FACTORS INFLUENCING STUDENTS' INTERACTIONS WITH ADVANCED CALCULATORS

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Abstract

There is an increasing use of and rapid advancements in technologies in education. In particular, there is a take-up of advanced calculators (graphing calculators and calculators with computer algebra system [CAS]) in senior secondary high-stakes examinations. Each year, tens of thousands of students in Australia, Singapore, and other regions, use advanced calculators in mathematics examinations that directly affect their entry into tertiary education. Thus, it was pertinent to investigate the ways in which students use these technologies when learning mathematics, and the factors that influenced them.

This study was built upon a bricolage of theories from various fields such as mathematics education, educational technology, learning theories, learning styles, and gender studies. From a review of the literature in the different fields, it was hypothesised that factors such as students' gender, beliefs about and attitudes toward mathematics and technology, approaches to studying mathematics, and learning preferences, influence their ways of using technology. A mixed methods research design was used, consisting of two parts: a quantitative large scale online survey of 964 Singaporean and 176 Victorian senior secondary mathematics students, and a qualitative small scale study of nine students in a Singaporean school.

There were several main results found in this study:

(i) How students interact with advanced calculators was influenced by their beliefs about and attitudes toward mathematics and their approaches to studying mathematics. Students' ways of knowing and learning mathematics best explained their ways of interacting with the calculator.

(ii) Students' learning preferences were situated, and the use of advanced calculators was associated with visual and kinesthetic modes and a preference to work cooperatively.

(iii) There were regional differences (in favour of Victorian students) in how students use the advanced calculators and their attitudes toward calculators.

(iv) There were gender differences (in favour of males) in students' attitudes toward mathematics and advanced calculators, and how they used the calculators. Although there were more student factors with gender differences in the Singaporean than the Victorian data, the effect sizes were larger in the Victorian sample.

The findings have implications for mathematics teaching practice, in that deep understanding, intrinsic interest, beliefs about the creative, inter-connectedness and contextual aspects of mathematics are associated with using calculators as a partner and collaborator for learning. Additionally, students tend to employ visual and kinaesthetic modes when learning how to use the calculators. Students were also found to have a preference for working on the calculator cooperatively with friends. Therefore, teachers can employ methods such as encouraging students to try out the calculator keys and to work cooperatively in groups when learning how to use the calculators.

Another significant contribution of this study was in the use of Facebook to recruit participants. More research can be done on the participation and response rates associated with this recruitment method. Further research can also be conducted to translate the implications of the study into practical classroom strategies and to investigate longitudinally the dynamic interplay between these factors and students' interaction with the advanced calculators.

Statement of originality

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university or other institution and to the best of my knowledge contains no material previously published or written by another person, except where due reference is made in the text of the thesis.

[redacted]

Hazel Tan

27 November 2012

Ethics Approvals

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Lastly I dedicate this thesis to my parents, Louis and Lily, and my siblings, Grace and Philip.

Chapter 1 Introduction and Research Questions

> The more students can do in and with information technology in mathematics, the greater is the need for their understanding, reflection, and critical analysis of what they are doing. So, in spite of what one might have expected because of the new opportunities offered by information technology, IT increases rather than decreases the demands on the teaching and learning of mathematics. (Niss, 1999, p. 20)

In recent decades the technological revolution in education has brought about many changes globally. Many countries have made huge investments in providing education technologies in schools (e.g., OECD, 1999). For mathematics education, reference to calculators and computers can also be found in many curriculum documents around the world (e.g., Drijvers, 1998; Monaghan, 2000; National Council of Teachers of Mathematics, 2000; Victorian Curriculum and Assessment Authority [VCAA], 2003; Wong, 2003).

While there is an urgent call for using education technologies in mathematics teaching and learning, it is the advanced handheld calculator, and not the computer, that leapfrogged its way in answering this call. For those countries or regions, such as Singapore and Victoria, Australia, that have mandated the use of graphing (or graphics or graphic or graphical) calculators (GC) or calculators with computer algebra system (CAS) in their national or regional examinations, this implies that a large number of students in the whole country or region will learn mathematics with hand-held technology *every year*. For example GCs have been allowed to be used by Singaporean students in the Year 12 national examinations starting from 2007; and in that year all of the 13,053 Year 12 students in Singapore who took mathematics had to undergo the new mathematics curriculum with the use of GCs (Ministry of Education Singapore, 2008, Mar 7). In Victoria, Australia, where graphing calculators (and more recently CAS calculators) have been allowed to be used in examinations for more than a decade, there are more than 15,000 Year 12 students each year taking examinations in mathematics subjects using advanced calculators (see e.g., VCAA, 2008, September 1). It is estimated that Texas Instruments, one of the giants of calculator companies, "…sells between 3 and 4 million graphing calculators per year and has nearly 13 million calculators of all kinds currently in use in schools…" (Trotter, 2007, p. 1) in the United States (US) and worldwide.

The enormous number of students affected by the advanced calculator policies warrants extensive research into the impact of these calculators on teaching and learning. Considering the large numbers of students that have been, and will be, using hand-held devices for mathematics education, and that these technologies impose increasing demands on teaching and learning (Niss, 1999), there is a strong impetus for greater understanding of the impact of these technologies on mathematics teaching and learning processes.

Many research studies have been conducted on students' use of technology in mathematics education, in particular, graphing and CAS calculators. However, most studies in which students' use of calculators has been investigated tend to be some form of evaluation of programs which equated effective student learning and achievement with their performance on particular types of assessment tasks (Penglase & Arnold, 1996). These studies generally assumed that the findings about calculator use were similar across the cohort of students rather than exploring possible differences between students with different learning characteristics. Studies which investigated student learning characteristics and how they use the advanced calculators were usually qualitative in nature (e.g., Guin & Trouche, 1999). In their review of 43 research studies on handheld graphing technology, one of the recommendations by Burrill et al. (2002) was that research is needed in the area of "student(s') beliefs, understandings, and characteristics" (p. ix).

Against this backdrop, student characteristics are the focus of this study to investigate how students use graphing and CAS calculators at the senior-secondary level (Years 11 and 12) in Singapore and Victoria, Australia. In the following sections, the background context and rationale for the research topic are discussed, and research aims and questions introduced.

Graphing and CAS Calculators in Mathematics Education

Graphing calculators, also called graphics or graphical calculators, have been around for less than three decades. The first graphing calculator was produced by Casio in 1985 (Green, 1998; Kissane, 1995). The graphing calculator can be seen as part of the evolution of technology - "a hierarchy of computational arithmetic and algebra systems running from the arithmetic calculator, by way of scientific, graphic and symbolic calculators, to the full-blown computer algebra system" (Ruthven, 1996, p. 439). In this thesis, the graphing calculator is abbreviated to "GC", and the symbolic calculator (calculator with computer algebra system) is abbreviated to "CAS calculator".

The introduction of GC in the mathematics curriculum began as early as 1986 in the United States, with the use of Casio fx-7000G (Waits & Demana, 1994). In the 1989 statement issued by the U.S. National Council of Teachers of Mathematics (NCTM) it was recommended that scientific calculators with graphing capabilities should be available to all students at all times.

Besides the United States and Europe, the advanced calculator like the GC has become prevalent in other countries, such as Australia and Singapore (Kissane, 2006a; Guin, Ruthven, & Trouche, 2005; Hoyles, & Lagrange, 2010; Ruthven, 1996). Details are discussed in the next section.

Graphing and CAS Calculator Policies

The following sections provide an introduction of the policies on senior secondary mathematics education, GC and CAS calculators in Australia, Victoria and in Singapore.

Australia and Victoria. In Australia there are general education guidelines at the federal government level, and the states vary in their education policies. At the time of the study, the Australian Curriculum, Assessment and Reporting Authority (ACARA) was in the process of developing The Australian Curriculum (http://www.australiancurriculum.edu.au/) which "sets out what all young people should be taught through the specification of curriculum content and the learning expected at points in their schooling through the specification of achievement standards" (ACARA, n.d., para. 4). The use of calculators for mathematics teaching and learning has been promoted since 1985, when the Australian Association of Mathematics Teachers (AAMT) published the *National statement on the use of calculators for mathematics in Australian schools*. As advances were made in the technology, the AAMT published the *Statement on the use of calculators and computers for mathematics in Australian schools* in 1996, recommending that the use of calculator and computer technologies for teaching and learning be "endorsed by all Australian education systems" (AAMT, 1996,

p. 2). In particular, the use of graphing calculators for use in the upper secondary level and beyond was given strong emphasis (e.g., AAMT, 2000). Victoria was the first state to implement the use of GCs in the final external examinations in 1997 (Routitsky & Tobin, 1998). In Victoria, there is a two-year, post-compulsory, senior secondary school program at Years 11 and 12, culminating in the Victorian Certificate of Education (VCE) examinations; VCE results are used for entry into tertiary education. There are a few schools which offer the International Baccalaureate (IB) and other equivalent qualifications, but these are not the mainstream pathways and have not been included in this study.

In Victoria, mathematics subjects are grouped into Units 1 & 2, usually taken by students at Year 11, and Units 3 & 4, usually taken at Year 12. Students take one or a combination of Units 1 & 2 mathematics subjects at Year 11, which serve as pre-requisites allowing them to take relevant Units 3 & 4 subjects at Year 12. In 2010, the mathematics subjects offered were: Foundation Mathematics Units 1 & 2, General Mathematics Units 1 & 2, Mathematical Methods (CAS) Units 1 & 2 and Units 3 & 4, Further Mathematics Units 3 & 4, and Specialist Mathematics Units 3 & 4. Units 1 & 2 subjects were internally assessed by schools, whereas Units 3 & 4 subjects were assessed through a combination of a school-based assessment, called School Assessed Coursework (SAC), and two written external examinations, Examination 1 and 2 (Victorian Curriculum and Assessment Authority [VCAA], 2010). CAS calculators were required in the SAC and Examination 2 assessment for both Mathematical Methods and Specialist Mathematics Units 3 & 4 subjects, but the written Examination 1 papers were technology free (VCAA, 2010). Prior to the adoption of CAS calculators, a pilot study was conducted from 2001 to 2003 on the use of CAS calculators in the Mathematical Methods subject. There was a transition period from 2004 to 2009 where the Mathematical Methods subject was offered in two parallel courses, one with GC and the other with CAS.

In summary, the use of technology in mathematics curriculum at the high-stakes VCE examinations in Victoria has evolved over the past decades. Leigh-Lancaster (2002) provided details of the evolution. His summary has been extended upon in Table 1.1 below:

Table 1.1

Overview of History of Technology Use in Victorian Year 12 Mathematics Examinations

Year	Technology use
1970	Slide rule and four figure mathematical tables.
1978	Scientific calculators.
1997/8	Approved GC permitted, but examinations had to be graphing calculator ‘neutral’, that is, all questions could be attempted and completed with or without the GC.
1999	“Assumed access” for GC in Mathematical Methods and Specialist Mathematics examinations, permitted for Further Mathematics examinations.
2000	“Assumed access” for GC in all mathematics examinations, examinations for revised VCE Mathematics study 2000-5 incorporating some graphing calculator ‘active’ questions, that is, questions that require the use of GC.
2001	Mathematical Methods (CAS) pilot study*, “assumed access” for approved CAS in pilot examinations.
2004	Inclusion of a technology-free paper for both Mathematical Methods and Mathematical Methods (CAS).
2010	“Assumed access” for CAS calculators in Mathematical Methods and Specialist Mathematics.

**Note.* For a discussion of the CAS introduction and use in Victoria, see Flynn (2007).

Singapore. Singapore’s general education system consists of six years of primary schooling and four or five years of secondary schooling. Post-secondary educational pathways include: two or three years of pre-university schooling at a junior college or centralised institute followed by university education, or tertiary education in a polytechnic or a vocational institution (Ministry of Education [MOE], 2006).

At the time of the study there were 17 Junior Colleges which ran two year courses (equivalent to Victoria’s Years 11 and 12), and one centralised institution, which ran a three year course. There were also two secondary schools with six-year integrated programs, all of which led to the General Certificate of Education “Advanced” Level (GCE A-Level) examination at the end of pre-university education. There were schools which also offered the IB and other equivalent qualifications; as for Victoria, these were also not the mainstream pathways and thus were not included in this study.

A review of the pre-university curriculum was undertaken in 2002 and the review committee recommended a new framework for the curriculum and education landscape to focus on thinking and communication skills and allow flexibility in the system (MOE, 2007). Under the revised "A" level curriculum, there were three levels of study for certain core subjects: Higher 1 (H1), Higher 2 (H2) and Higher 3 (H3). Graphing calculators (without CAS capacity) have been assumed in the H1, H2 and H3 GCE A-Level mathematics examinations since 2007. Students can choose to take either H1 or H2 Mathematics, and high ability students who took H2 Mathematics could also take H3 Mathematics, usually through invitations by their schools or recommendations by their teachers. H1 Mathematics was a pre-requisite for business, arts and accounting courses in Singaporean universities, and H2 Mathematics was a pre-requisite for science and engineering courses (MOE, 2007). The content, assessment and amount of curriculum time used at H1 level was half that of the H2 level.

The curriculum for H2 focuses on developing mathematical thinking and problem solving skills. The H2 mathematics A-level examination consists of two three-hour papers; the first paper contains questions from the pure mathematics section of the syllabus, and the second paper contains questions on both pure mathematics and statistics with a 40% and 60% weighting respectively (see http://www.seab.gov.sg/).

The main focus for H1 mathematics is on "the understanding and application of basic concepts and techniques of statistics" to "equip students with the skills to analyse and interpret data, and to make informed decisions" (Singapore Examination and Assessment Board [SEAB], n.d., H1 Mathematics Syllabus 2008, p. 1). The national examination consists of one three-hour paper containing questions on pure mathematics and statistics with a 40% and 60% weighting respectively. The use of graphing calculators (GC) is expected in all the mathematics examinations.

Based on the curriculum for the Advanced Level General Certificate of Education (GCE A-level), students take three H2 (Higher 2) level subjects and one H1 (Higher 1) level subject, in addition to language subjects and a unit of project work. Out of the four content area subjects, students have to take at least one from the Science and Mathematics domain, and one from the Arts and Humanities domain. For example if students have a preference for Arts and Humanities, they can take English literature, History and Economics at H2 level. These students usually take H1 mathematics rather than other H1 science subjects, since it is a pre-requisite for relevant university courses such as Business and Social Sciences. As a result, most students take a mathematics subject, either at the H2 level or at the H1 level.

Singaporean junior colleges usually run a lecture-tutorial system similar to that of universities, which is different from the general classroom teaching for Years 11 and 12 in Victorian schools. Singaporean students attend lectures for the various subjects in lecture theatres as a large group, as well as attend tutorials in classes of about 25 to 35. Since H1 and H2 mathematics are pre-requisites for a number of faculties in Singaporean universities, almost all students take either H1 or H2 mathematics; high ability students also take H3 mathematics. Also, there are no textbooks at pre-university level: students rely on lecture notes provided by teachers and reference books. In contrast, Years 11 and 12 Victorian students usually use a set of textbooks selected by the school.

Rationale for Research

As a Mathematics educator for more than 10 years in Singapore, I have taught in junior colleges and conducted research on the use of technology in schools (Forgasz, Griffith, & Tan, 2006; Forgasz & Tan, 2006; OECD, n.d.; Tan, 2005). I noted in my teaching that students' mathematics achievements appear to depend not only on their mathematical content knowledge, but also very much on their attitudes, studying strategies, and learning styles. For example, I found that some students do not take notes during mathematics lectures, and when questioned, they said that they were trying to understand and would remember the content after the lectures. This was contrary to what my colleagues and I taught them on good study practices and I felt frustrated that they did not follow our instructions on note-taking. It was after I read the book by Fleming (2006) on teaching and learning styles that I realized that these particular students may have had an aural preference and they had "become so engrossed in listening that their notes are scrappy and difficult to follow. They tune in, become engrossed in the rhetoric and stop taking notes because, they often say, '*It was all perfectly clear at the time*'" (Fleming, 2006, p. 115). For such students, Fleming suggested that they be advised to borrow notes from students with strong Read/Write preference "because these students usually caught most of the words of their teachers" (p. 115).

I taught the new “A” level curriculum (H1 and H2 mathematics) in its first two years of implementation to students. I felt that with the use of the new technology tool – the graphing calculator – issues of student differences (attitudes, studying strategies and learning styles) became even more prominent since the calculator not only affected their learning and understanding of mathematics, but also affected how students learn and interact with the technology. When I was teaching I assumed that students were technologically capable of learning to use the GC with step-by-step demonstrations and written instructions, and practising its use in solving mathematics problems. However, I realised later that there was much I did not know about how students learn mathematics through the use of advanced calculators. With the changes in curriculum and tools used, teaching has become more complex. Hence, it has become even more important for teachers to know the profiles of their students, so that they can design and customise their instruction and the classroom learning environment to create the best learning opportunities for their students.

Also, in my Masters in Education study, I realised that there were gender related differences associated with mathematics learning and technology use. Although the research studies I read about were not conducted in Singapore, I had found evidence of similarities in gender issues, for example a much higher proportion of male than female students in my Mathematics Honours university class. In addition, there is a social perception that males are better than females with technology, as evidenced by the very low proportion of females in the IT industry. My female cousin, who works as a software engineer in Singapore, once half-jokingly commented in her Facebook status that “it is only at an IT show (large scale trade exhibition) that there is no queue at the ladies’ toilet”. These past experiences aroused my interest in gender issues and I wanted to investigate if there are any gender differences in students’ attitude and use of advanced calculators.

This research study is timely because in the early years of policy implementation in Singapore, mathematics teachers tended to be grappling with learning how to use the technology. In my previous study conducted in 2004-2005, I found that both Singaporean and Victorian mathematics teachers considered familiarity with the tool (computer and graphing calculator) as one of the top three important factors in their use of technology for teaching mathematics (Tan, 2005). It is assumed that when teachers are developing familiarity with the technology, they are also developing their own ways of using the technology for teaching. Therefore a study focusing on student factors influencing their interactions with advanced calculators would be better conducted after teachers have become more familiar with the technology.

At the time of this study most teachers in Singapore had at least three years of teaching experience in the use of graphing calculators for mathematics. Some Victorian teachers would also have had the experience of transitioning from GC to CAS calculators. Hence, information about students' learning preferences, attitudes and beliefs, and factors affecting their ways of learning mathematics using advanced calculators would be timely and would provide valuable insights to assist teachers and educators in planning instruction, curriculum and assessment.

In Victoria, the use of CAS calculators was piloted beginning in 2001. Since 2010, the use of CAS calculators is required both in Mathematical Methods and Specialist Mathematics VCE examinations, phasing out the use of GC (VCAA, 2008, September 2). Hence, the CAS calculator is considered a new technology in the Victorian context, parallel in some aspects to the GC in the Singaporean context. Thus the cross regional comparison undertaken improved the validity and reliability of the data collection instruments, enriched the data, and enabled the transferability of the findings to be investigated.

As a teacher one of the main pedagogical principles I believe in is to know the profile of the students, in order to better tailor instruction to their learning. Therefore the focus of interest in this study is to investigate which student learning characteristics are influential in how students interact with the graphing calculators (GC) in Singapore, and the CAS calculators in Victoria.

Research Aims and Questions

Research aims. This study represents an exploration of the cognitive and affective influences on senior secondary students' learning of mathematics using GC and CAS calculators. The aim was to investigate the factors (learning preferences, attitudes and beliefs) and the relationships among the factors affecting students' learning of mathematics using the advanced calculators in senior secondary students in Singapore and Victoria, Australia.

Research questions. The research questions were:

1. What are Singaporean and Victorian students':
    (a) beliefs about and attitudes toward mathematics learning and advanced calculators;
    (b) learning preferences; and
    (c) ways of interacting with the advanced calculators?
2. Are there differences in the above for students in the two regions, Singapore and Victoria?
3. Are there gender differences within each region?
4. What are the relationships among students' gender, beliefs, attitudes, learning preferences, and ways of interacting with the calculators? Specifically:
    (a) What are the correlations between all the variables?
    (b) Which variable best explains students' ways of interacting with calculators?
    (c) How can these relationships be explained?
5. Are there other factors that affect the ways students interact with the graphing and CAS calculators for mathematics learning?

To answer these research questions, a mixed-methods approach was used. The study was conducted in two parts: a quantitative large scale survey for Singaporean and Victorian students, and a qualitative investigation of a small group of students from three classes in a Junior College in Singapore. In Part One of the study, due to a lack of responses from students in Victoria, an alternative method of recruiting student participants using Facebook advertisement was used. The survey data from both regions were analysed using descriptive and inferential statistics. The interview and qualitative data collected were coded and analysed to explain the correlations found in the quantitative analysis.

Outline of Thesis

In this chapter, the background context, rationale and research questions have been established. In the next chapter, relevant literature on students' calculator use, mathematics learning theories and learning styles theories will be discussed. In chapter

3, the mixed-method research design using the pragmatic paradigm will be detailed. The study has two parts, a quantitative large scale survey and a qualitative small scale investigation. The findings of Part One of the study are presented in chapter 4, and the findings of Part Two, in chapter 5. A discussion of the findings and implications can be found in the concluding chapter 6.

Chapter 2 Literature Review

> So if the machines can perform calculations, what is left of mathematics? Almost everything. Machines cannot do argumentations, reasoning, conjectures, proofs (not in the sense of automatic proof, but justifying the passages) and so on. (Ferrara, Pratt, & Robutti, 2006, p. 238)

English (2008), in her introduction to the second edition of the Handbook of International Research in Mathematics Education, highlighted the renewed interest in theory development in the mathematics research field and the need to draw upon theories from different fields in order to make sense of the complexity involved in today's research. In this research study the theoretical basis has been drawn from various disciplines: educational technology literature, learning style theories in psychology, and theories in mathematics education that focus on students' learning preferences and their learning of mathematics using graphing and CAS calculators. This chapter details these theories and relevant studies conducted in the various disciplines, in three main sections. First, students' use of GC and CAS calculators in general and in Australia and Singapore are presented. The review of studies includes several aspects of calculator use: mathematical content and skills learnt, technical demands of calculator use, achievement and performance of students, social interaction and communication, and comparison between GC and CAS calculators. General factors affecting the ways students interact with the calculators are gleaned from the review. This is followed by a section focusing on student factors affecting their engagement with the GC and CAS calculators, based on calculator literature, mathematics learning theories and related educational technology studies. The student factors discussed include epistemological beliefs about mathematics, attitudes and beliefs about mathematics and technology, gender, and individual differences. The second section concludes with a review on models relating to students' ways of interacting with technology. In the final section, relevant learning style theories and learning preferences are described, including approaches to learning, multiple representations and multimodal preferences, and social interaction for learning preferences.

How Students Engage with Calculators and Factors Influencing Them

With the use of GC and CAS calculators in the mathematics curriculum, many educators believe that there will be "less emphasis on student practice of routines and more emphasis on independent thinking, problem solving and mathematical investigation" (Kissane, 2006b, p. 7). There are several reviews and a meta-analysis on advanced calculators (graphing calculators in particular), including those by Dunham and Dick (1994), Penglase and Arnold (1996), Burrill et al. (2002), and Ellington (2006). There are also other reviews such as those by Sabra and Trouche (2008) on French calculator studies, and Forster, Flynn, Frid, and Sparrow (2004) on Australian calculator studies. Initial research focused more on the opportunities provided by the tools for students' learning, followed by a shift towards investigating students' development of concepts and changing epistemologies as they work with the handheld technologies (Trouche & Drijvers, 2010). The following subsections outline some of the main findings and focus areas in studies about students' calculator use, in terms of learning (learning mathematics content and skills, and technical demands and students' misconceptions and misuse), performance in assessment, instruction (social interaction and communication, and teacher factor), and comparison between GC and CAS calculators.

Mathematics learning and skills. Researchers have studied the use of GC and CAS calculators in the context of learning various mathematics content areas such as algebra (e.g., Artigue, 2002; Drijvers & Gravemeijer, 2005; Hong, Thomas, & Kwon, 2000; Pierce & Stacey, 2001; Slavit, 1998), calculus (e.g., delos Santos & Thomas, 2000; Ghosh, 2007; Hong, Thomas, & Kiernan, 2000; Kendal & Stacey, 1999), functions and graphs (e.g., Alexander, 1993; Asp, Dowsey, & Stacey, 1993; Ruthven, 1990), and more recently, statistics (e.g., Graham, Headlam, Honey, Sharp, & Smith 2003; Collins & Mittag, 2005) and mathematical modelling (e.g., Geiger, Faragher, Redmond, & Lowe, 2008; Greefrath, Siller, & Weitendorf, 2011).

Findings from some research studies suggest that the advanced calculators

(a) can facilitate the learning of functions and graphing concepts and the development of spatial visualisation skills;
(b) promote mathematical investigation and exploration; and
(c) encourage a shift in emphasis from algebraic manipulation and proof to graphical investigation and examination of relationship between graphical, algebraic and geometric representations (Penglase & Arnold, 1996, p. 58).

For example, Forster (2003) investigated how Year 12 Calculus students copy stored results and expressions on the graphing calculator, and their embedded mathematical conceptual understandings. She found that the use of the stored results, expressions and functions as letters on the GC facilitated algebraic generalisation, linking of multiple representations, understanding of function properties, and the distinction between parameters and variables.

In terms of mathematical and thinking skills, students were found to have reduced cognitive load and increased higher order and meta-cognitive thinking with the use of advanced calculators (Roschelle & Singleton, 2008; Nor'ain Mohd. Tajudin, Rohani Ahmad Tarmizi, Wan Zah Wan Ali, & Mohd. Majid Konting, 2011). However, Giamati (1990) had opposite findings in her comparison study of two experimental (work with GCs in pairs) and two control classes learning the family of equations and the transformation of graphs for a period of five and a half weeks. The control group performed better than the experimental group in the post-test (GC not allowed). She concluded that students who had partial or poor understanding of the relationship between graphs and equations were found to be cognitively distracted by also having to learn how to use the GC.

Besides investigating students' meta-cognitive skills, researchers also investigated students' learning outcomes in terms of their procedural or conceptual skills, as well as the types of multiple representations used in their solutions.

Procedural and conceptual skills. In a number of studies, procedural and conceptual skills associated with the use of advanced calculators were discussed. Results were varied, with benefits found either to both procedural and conceptual skills, or to one but not the other. Ellington (2006) performed a meta-analysis on comparison studies where students using graphing calculators were compared to those who did not. She analysed the studies according to procedural skills (test items involving application of an algorithm, rule or procedure), conceptual skills (items involving understanding and application of mathematical concepts) and overall achievement. She found that when GCs were used in instruction *and* assessment, there were significant gains in students' procedural skills, conceptual skills and overall achievement. And when GCs were used in instruction but not in assessment, there was significant gain in conceptual skills but not in procedural skills or in overall achievement. She concluded that using

GCs helps students in understanding concepts, even when they were not allowed in the assessment.

In a study of senior secondary students taking university entrance examinations by Hong, Thomas and Kiernan (2000), students in an experimental group underwent 4 one hour periods of intensive instruction on CAS calculators. The focus of the instruction was on how to use the CAS calculator for procedural computations, taught through teacher demonstration. Students then took a post-test in which having a CAS calculator was an advantage, where the tasks were "weighted heavily towards basic skill-type questions that the calculator handles very well" (Hong, Thomas, & Kiernan, 2000, p. 329). Their scores for the post-test and the university entrance examination (which was CAS neutral) were analysed. Students in the experimental group performed better than the control group in the post-test, but there was no significant difference between the scores of the experimental and control group in the university entrance examination. The researchers also divided students into lower and higher achieving based on their median scores on the pre-test. They found that the lower achieving students scored better on the post-test (CAS-advantaged) compared to the examination (CAS-neutral). There was no difference in performance for high achieving students. Nearly half of the students in the experimental group commented that the short sessions on using CAS helped them obtain correct answers and but did not help them in their conceptual understanding. The findings suggested that lower achieving students appeared to benefit more than higher achieving students when exposed to the use of CAS calculators; however, the benefit seemed to be limited to only procedural skills (Hong, Thomas, & Kiernan, 2000). It can be seen in Hong, Thomas, and Kiernan's (2000) study that various factors are implicated in the quality of students' mathematical learning outcomes: students' length of time with access to the calculators, how calculators were taught to students, the kinds of tasks in the assessment (CAS advantaged or CAS neutral), and the prior mathematical achievement level of students.

Students' use of multiple representations. As advanced calculators offer dynamic links between algebraic, numeric and symbolic representations, some researchers have focussed on students' use of multiple representations. Keller and Hirsch (1998) investigated students' preferences for particular representations (tables, equations, or graphs) when trying to solve mathematical problems. For the experimental and control groups of students after a 14 week Calculus course, they found that students' preferences were different for problems situated in contexts (contextualised) or purely abstract and mathematical (non-contextualised). For non-contextualised problems, most students preferred to use equations, while for the contextualised tasks, students preferred to use tables in the pre-test and to use graphs in the post-test. Students using GCs were more likely to have a graphical preference on both contextualised and non-contextualised problems compared to students not using GCs.

Hennessy, Fung and Scanlon (2001) surveyed students and tutors in an Open University mathematics course. They found that the majority of students and tutors believed the GC can encourage linking between multiple representations, through visualisation of functions, immediate feedback to changes, and automatic translation between representations. The researchers also noted from students' responses that the calculator books used in the course, with carefully structured GC activities, supported students' learning and calculator proficiency. On the other hand, in examining 37 representative examination scripts by students, Boers and Jones (1994) found that the GC was under-utilised by students in terms of both the amount of use and the way it was used. Analysis of the scripts revealed that "the majority of students treated questions as either essentially 'algebraic' or 'graphical'… the graphics calculator was only relied upon when a question specifically asked for graphical output." (p. 514). The authors concluded that students needed a certain depth of mathematical understanding and judgment to enable them to move back and forth between algebraic and graphical representations.

In a quasi-experimental study conducted by Merriweather and Tharp (1999), students used GC TI-82 for two weeks in two experimental classes. Both the control class and the two experimental classes were exposed to a variety of learning activities such as discovery learning to develop mathematics concepts. The students, aged 12-14, were described as having low to average mathematical aptitude. The researchers found that a majority of the students in the experimental classes were uncomfortable with the GCs and did not use them, preferring to solve the algebraic word problems symbolically; no students preferred to use a graphical method. Merriweather and Tharp (1999) concluded that two weeks was too short for students to observe and see how the mathematical processes worked using the calculators and that students needed more time to learn how to locate the GC functions and then use the GCs in applications.

In summary, students were found to have preferences for certain representations when trying to solve different types of tasks (Keller & Hirsch, 1998). However, their use of multiple representations might be influenced by other factors such as curriculum resources (Hennessy et al., 2001), time with calculators (Merriweather & Tharp, 1999), and students' depth of mathematical understanding of the relationship between algebraic and graphical representations (Boers & Jones, 1994).

Factors influencing students' interactions with calculators from research on mathematics learning and skills. Overall, findings indicate that extensive use of the technology does not necessarily interfere with students' acquisition of content knowledge and skills (Burrill et al., 2002). Students' learning with advanced calculators is a complex process. In these different studies, there was a mix of results (positive, negative, and no significant difference) in the student outcomes with and without advanced calculators. Hence, rather than looking at students' outcomes per se, the focus of the review is to surface the factors affecting the students' use and their learning outcomes with the use of calculators. Studies reviewed in this section suggest that various factors influence how students engage with the calculators, such as the level of integration of calculators into the curriculum, instruction, and assessment, type of assessment tasks, students' and teachers' beliefs about the technology and its perceived use, students' preferences for multiple representations, their depth of mathematical understanding, length of time with calculator access, and level of familiarity with the tool.

In the next subsection, the technical demands of calculator use, in terms of misconceptions and misuse of calculators, as well as the relationship between technical and mathematical demands, are described.

Technical demands of calculator use.

Misconceptions and misuse of calculators. There can also be some undesirable effects of calculator use. Some evidence suggests that the handheld calculator can be under-used, especially "when students are not sure how to use the technology as a tool in their work or when they are unsure how much written work is required” (Burrill et al., 2002, p. ii). With calculators, students employ more of what Ruthven (1996) called “*proximation strategies*” (p. 457), including *trialling*, where students are able to pursue superficial strategies such as trying out a large number of guesses more efficiently; and *stepping*, where “a repeated calculator action is coordinated with a mental count, or moderated by feedback from the machine” (p. 457) for example to find the intercept of a graph through repeated pressing of the cursor key to trace the coordinates along the graph. These pragmatic strategies can be seen as a way for students to overcome their lack of knowledge or skills to solve the problems using formal mathematics, but are usually seen as unintentional outcomes (Ruthven, 1996). Others have cautioned about students’ over-reliance on technology, and over-use of the calculator to the point that it is used “with little critical analysis of the [calculator] results” (Burrill et al., 2002, p. v).

Students can also have various misconceptions related to the use of GC such as greater confusion between rational and real numbers, acceptance of visual images without question, and lack of understanding of calculator limitations such as pixilation of the graphical screen or drawing of asymptotes (Burrill et al., 2002; Mitchelmore & Cavanagh, 2000). The lack of mental capacity to work with multiple representations (algebraic, symbolic and numeric) and the lack of technical understanding to deal with a) input of information, b) technical procedures and c) interpretation of outputs, are obstacles to students’ effective use of the calculators (Boers & Jones, 1994; Forster, 2006; Gratzer & Krishnan, 2008).

Also, as with the case of the GC, students have been found to exploit the ease of accessing different functions on the CAS calculator, such as fishing for answers, repeating the same calculator procedures, or trying out different commands after entering the data into the calculator (Trouche, 2005). Hong, Thomas and Kiernan (2000) found two main difficulties faced by students using CAS in their study: the problem of using an incorrect syntax for formula entry, leading to an incorrect answer; and the difficulties in remembering the correct sequences of key-strokes. As a result, some researchers (e.g., Forster, 2006; Giamati, 1990; Gratzer & Krishnan, 2008) believe that a balance between pen-paper analytic and calculator activities is important to maximise learning.

Relationship between technical and mathematical demands. Since the CAS calculator has all of the GC's functionalities and more, it possibly imposes a greater burden on students' technological understanding and corresponding mathematical mental schemes than the GC. For example students in Bostic and Pape's (2010) study who were proficient in using GC (TI 83+) found it difficult to learn how to use the CAS calculator (TI-Nspire). Guin and Trouche (1999) described three types of constraints of symbolic calculators: internal constraints related to "the internal representation of objects and their calculation processing" (p. 203), for example being able to give the exact value of cos π/8 but not cos π/16; command constraints related to the syntax control and commands to be understood and memorised; and organisation constraints related to the ways the commands are organised and accessed. In other words, students need to know the language of the technology (Heid, 2002) which is rigid and often specific to the brand and model of calculator.

Studies also suggest that there is an intimate and dialectic relationship between mathematical and technical demands in calculator use. Technical demands increase with the introduction of new mathematical concepts which require the learning of new commands. At the same time, a certain level of mathematical understanding is required in order to use the calculator effectively. Pierce and Stacey (2004) described the importance of having algebraic insight (having knowledge of algebra and ability to link representations) in deciding when to use CAS technologies and in entering expressions into CAS. In their study of students learning to use CAS calculators, Guin and Trouche (1999) found that students went through a discovery phase where they depended strongly on the tool and tried a variety of strategies and techniques, often without understanding. When they were able to associate commands with mathematical meaning, students moved to an organisation phase and restricted their calculator use to a limited number of commands as part of their problem solving strategies and techniques. Guin and Trouche (1999) further argued that the movement from first to second phase is determined by students' mathematical profiles such as having the mathematical knowledge to coordinate between multiple representations. They also observed that students became more engaged with the mathematics the more they mastered the calculator manipulations. Hence, overcoming the technical demand (i.e., having technical competency) supported mathematical learning, while having mathematical competency enabled effective use of the technology. This inter-relatedness between mathematical and technical knowledge has also been pointed out by other researchers. Burrill et al. (2002) believed that “in order to use the calculator successfully, students need to be familiar with the mathematics surrounding the task at hand and recognize how the limitations of the calculator can inhibit understanding of the mathematics" (p. 20). Dahland and Lingefjärd (1996) also espoused the importance of students having the “technical insight to be able to interpret the information given on a graphics screen, and... [they] must also have a sufficiently good mathematical understanding to realize the connection between the current problem and the possibilities given by the tool" (p. 31). Thus it is not surprising that high achievement in mathematics was found to be associated with high levels of mathematics and technology confidence and a strongly positive attitude towards learning mathematics with technology, whereas low achievement in mathematics was found to be associated with low levels of mathematics and technology confidence and a negative attitude towards learning mathematics with technology (Barkatsas, Kasimatis, & Gialamas, 2009).

So far in this section the review of literature has been about students’ use of advanced calculators with regard to students’ learning of mathematical content and skills, as well as the technical demands of calculator use. In the next subsections, students’ achievement and performance, their social interactions and communications, and comparisons between GC and CAS calculators are discussed.

Achievement and performance. From reviews of studies and meta-analyses of relevant research it was generally concluded that there were positive gains in achievement when advanced calculators are used (e.g., Ellington, 2006). Khoju, Jaciw, and Miller (2005) examined eight experimental graphing calculator studies for the impact of GC use on mathematics achievement. They compared the effect sizes and found that there is strong evidence that the use of GC is associated with better performance in algebra. However, there were also findings from analyses of examination scripts that revealed less positive outcomes for students using advanced calculators (e.g., Forster & Mueller, 2001a, b, 2002a). In the study described in an earlier section (p. 15), Hong, Thomas, and Kiernan (2000) studied students’ use of CAS calculators in a standard university entrance calculus examination in New Zealand. The students received four one-hour sessions on CAS calculator training focusing on calculator skills. It was found that the use of calculators advantaged lower achieving students (grouped based on median score on the pre-test) on the post-test, but only in terms of procedural skills. For the calculator-neutral section of the post-test, there was no significant difference in scores between the experimental group and the control group.

Some researchers included in their studies comparisons of calculator benefits to academically weaker or better students. Academically weaker students were found to have benefited more when advanced calculators were integrated into the curriculum for a substantial length of time (e.g., Harskamp, Suhre, & Van Streun, 2000; Kim & Lew, 2009; Ruthven, 1990). For example Kim and Lew (2009) studied 70 low achieving Year 10 students (bottom 20% out of 495 students) from a high school in Korea who had never used advanced calculators before. Both experimental and control groups were exposed to activities in which they solved algebraic problems using pen-and-paper and then reflected on their answers. The experimental group students compared their pen-and-paper solutions with the algebraic solutions obtained from a CAS calculator through operations performed on both sides of the equation (not using the SOLVE function), and the control group reflected on their answers with solutions given by the teacher. The activities were carried out 50 minutes daily for a month. Kim and Lew (2009) found that the experimental group improved more than the control group in the post-test, after taking into account their pre-test scores. They also found that the bottom scoring half of the experimental group improved significantly more than the top half. This gain in performance was consistent across the students in the bottom half of the experimental group, a pattern which was not seen in the control group. Harskamp et al. (2000) also found that lower achieving students seemed to benefit more from GC use, and suggested that the GC helped academically weaker students to transit from using tables and trial and error methods to using graphical representations, whereas the academically better students did not appear to need this support as they were conversant with graphical strategies. However, the benefits to low achieving students might not be actualised in cases where students are unable to overcome the technical demands, as described in a previous section. In such cases, academically weaker students “often give up the idea of understanding the [calculator] command’s meaning and what it does” (Guin & Trouche, 1999, p. 213) and resort to surface or ineffective strategies such as random trialling.

Social interaction and communication. Calculators, together with related technologies such as projectors and network connections, can also facilitate learning through the integration of individual inquiry and collective exploration in small groups and as a whole class (e.g., Goos, Galbraith, Renshaw, & Geiger, 2000, 2003; Hennessy et al., 2001). Goos et al. (2000, 2003) analysed data from a 3 year longitudinal study of five senior secondary mathematics classrooms using a socio-cultural perspective. They gave examples where technology was found to mediate mathematical discussion between peers, through deliberate orchestration by the teacher. In another report of the same study, Geiger (2006) reported on two classroom episodes where technology played the role of a partner to mediate student-student interactions. In the first episode, students' individual work with the calculator (writing a program to solve a mathematics task) was made public to the whole class through the use of calculator-associated presentation technologies. The class went through the cyclical process of discussing the student’s work, making suggestions to make the program work, and testing the program. Geiger (2006) proposed that the role of the technology in the vignette was as a partner who "offered to the group a skill or expertise that they lacked in order to get the job done" (p. 252). The functionality of the technology allowed students to build upon one another's ideas and progress the development of an individual student's work beyond his or her own capability. In the second vignette, a reluctant learner used the calculator to create a program to voice his dissent about the mathematics class. Due to positive reinforcement from teacher and peers, he was "slowly drawn into the ways of interacting with his learning community that he has previously shunned; initially when technology was involved and then, eventually, at other times" (p. 252). Geiger (2006) described the role of technology as a partner in crime for this student, and subsequently as a supportive go-between to connect the student with the learning community. In another study, Hennessy et al. (2001) looked at three pairs of adult students using the GC to solve problems in an Open University course and reported on one pair as a case study. The students used their own GCs to work on joint tasks and were instructed to talk aloud about their problem-solving strategies throughout the session. The researchers discovered that students’ thinking was influenced by the GC procedures and that the GC acted as a cognitive prop to mediate student-student interaction and collaborative problem solving. Most of the students’ verbalisation concerned “planning, executing and reporting calculator actions and strategies” (p. 275). The GC was found to act as an external reference that prompted students to make their thinking explicit, and it also was used as a basis for comparison allowing students to clarify and build upon each other's ideas.

However, there were also negative effects of calculator use on the social interaction for learning between students. Doerr and Zangor (2000) investigated two classes of students in a pre-calculus curriculum using GCs and associated measurement probes. Class activities alternated between small group investigation of mathematical modelling problems and whole class discussion of progress and results. One of the findings was that students tended to use the GC as a personal and private tool, which led to a breakdown of group interactions. This happened when two or more students in a group used their own GC for testing conjectures or computations, and then continued further on their own line of thinking without sharing with the rest of the group.

Overall, although the advanced calculators and associated handheld technologies have the potential to enhance the quality of the different types of student-peer-teacher interactions (such as collaboration, whole class discussions, see e.g., Guin & Trouche, 1999; Roschelle, Vahey, Tatar, Kaput, & Hegedus, 2003), there seemed to be a limited number of studies focusing on students' social interaction for learning when using advanced calculators. Studies suggest that while calculators can facilitate collective inquiry, they can also limit collaboration.

Comparisons between GC and CAS calculators. There are a few studies in which students' use of GC and CAS calculators are compared. Bostic and Pape (2010) compared a group of high school students using TI-Nspire CAS calculators for three weeks during Algebra II lessons, with a control group using TI 83+ GC. All the students were proficient in the TI 83+ GC before the experiment. They found that students using CAS calculators employed more graphical representations whereas the GC group used more symbolic solution strategies. The two groups did not perform significantly differently in the post-test. Responses from the student survey administered on the last day of the unit revealed that the user friendly split screen mode of the CAS calculator facilitated students' building of connections between multiple representations which could promote the use of non-traditional/symbolic strategies. However, some students also found the CAS calculator more difficult to use because of the new syntax and commands to be learnt. For younger students transiting from arithmetic to algebra, Zeller and Barzel (2010) found that using the TI-Nspire non-CAS GCs without algebraic manipulative functionality made it hard for some students to understand that "the same underlying rules and laws apply in both fields [arithmetic and algebra]" (p. 786). As a result, some students avoided algebraic approaches, preferring to use their GCs. The other group using TI-Nspire CAS calculators were motivated to think about the various algebraic operations by looking at the list of CAS commands, and they accepted algebraic results more easily than the GC group. The benefits of CAS calculators over GCs are also found in a third study. Herman and Milou (2003) compared students using TI 83 GCs and TI 89 CAS calculators in a university calculus course over a semester. Students had used GCs in previous units. They found that students having continuous personal access to the CAS calculator performed significantly better than the control group on three conceptual items and one procedural item, and there was no significant difference for the remaining items in a 13-item assessment held over the semester. They also found that some students seemed to become more interested in mathematics as they wanted to know how the CAS calculators obtained the results and compared the calculator workings with a by-hand method. This is consistent with Zeller and Barzel's (2010) suggestion that students valued algebraic work because of the perception of the CAS calculator (with its symbolic functionality) as a serious scientific tool.

A relationship was found between student's preferred ways of working with the GC and with the CAS calculators. Guin and Trouche (1999) found changes in senior secondary students' preferred work methods when they transited from using the TI 82 GCs to using TI 92 CAS calculators. Students who preferred a "rational work method" (working mainly within the traditional pen-paper environment, with reduced use of GC) seemed to prefer using the symbolic calculator, possibly due to its exact and formal calculations. They adapted quickly to the syntax and produced more conjectures and partial validations using CAS calculators than GCs. Students with a "resourceful work method" (using various resources - the GC, pen-paper, mathematical theories - in a variety of strategies) seemed to have more difficulty in meeting the CAS calculator's demands, especially regarding the syntax. Students with a "theoretical work method" (using mathematical reference as a systematic resource, rather than relying on the calculator) also had difficulty adjusting to the syntax of CAS because of their preference for the mathematical syntax. For students who preferred "random work method" (using trial and error procedures without verifying calculator results) or “mechanical work method” (using simple manipulations and relying on accumulation of calculator results), there were less favourable results when they used the CAS calculators, especially when they did not have the mathematical knowledge and skills to interpret the calculator output. Guin and Trouche (1999) recommended that students’ behaviour profiles and their mathematical competences be taken into account in order to integrate calculators successfully into classroom activities.

Geiger, Galbraith, Renshaw, and Goos (2003) studied secondary students’ selection of technology for modelling tasks, and found that students’ choices depended on factors such as the nature of the task, the familiarity with the tool, ability to see the input and output on the screen, similarity between the calculator and conventional syntax, and suitability of the tool to the mathematics of the model.

In summary, CAS calculators, having greater functionality than regular GCs, offer greater affordances in terms of their potential to enhance students’ conceptual and multiple representation development. However, their complexity can also hinder their adoption by students. Factors affecting students’ use of CAS and GCs seem similar: nature of tasks, instruction, familiarity with the tool, students’ preferences for solution strategies, and their perceptions of the tools.

The studies used in the meta-analyses and reviews in earlier sections were drawn from a variety of countries, such as the United States, United Kingdom, Australia and Europe. In the following sections, calculator studies conducted in Australia and Singapore are detailed.

Calculator studies in Australia. An early and well-known Australian study on the use of GC was conducted by Boers and Jones (1994). It involved students taking a traditional calculus test in the Swinburne University of Technology in Australia. A representative sample of 37 examination scripts of first semester students was analysed and responses showed that the GC was under-utilised by most students, “both in terms of the amount and the way in which it was used” (Boers & Jones, 1994, p. 491).

Analysing students’ scripts for the Year 12 Calculus Tertiary Entrance Examination (TEE) in Western Australia spanning 1998 to 2000, Forster and Mueller

(2001a, 2001b, 2002a) found that students' uses of the GC were similar to those reported by Boers and Jones (1994). There were difficulties for students in "interpreting graphics calculator outputs and knowing when use of graphics calculators is appropriate or possible" (Forster & Mueller, 2001b, p. 37). In particular, Forster and Mueller (2001a) claimed that "a balance between opportunities for visual, empirical approaches and analytic methods" (p. 35) needs to be taken into account in assessment and teaching.

Forster, Flynn, Frid, and Sparrow (2004) provided a comprehensive review of the research on GC and CAS calculator use in Australasia from 2000 to 2003. They classified the research into three areas: cognitive factors, pedagogic and social factors, and assessment. The section on cognitive factors dealt with findings relating to students' mathematical conceptions in various topics using GC. In the section on pedagogy and social factors, Forster et al. (2004) highlighted studies by Goos et al. (2000) and Lindsay (2002) on students' engagement and relationships with technology. Goos et al. (2000) developed four metaphors of technology use: technology as master, servant, partner and extension of self, to describe how students interacted with the advanced calculators and computers. Lindsay (2002, 2003a, 2003b) studied four low achieving undergraduate students using GCs, and expounded on three stages in the development of engagement with technology: (a) computational, (b) technician, (c) multi-representational, and discussed possible learning pathways for each stage. Forster et al. (2004) concluded that the findings complemented students' profiles and use of technology documented by Guin and Trouche (1999).

For the CAS calculator, Forster et al. (2004) reviewed the framework developed by Pierce and Stacey (2001) which describes the algebraic knowledge for effective use of CAS. There was evidence that "CAS allows alternative teaching approaches using multiple representations for concept development, which may result in students' making greater use of multiple representations and making connections between them in problem solutions" (Forster et al., 2002, p. 329). These findings echoed those by Burrill et al. (2002). Forster et al. (2004) concluded that "exposure does not guarantee students' uptake of CAS, and negative attitudes to CAS can mediate against its use" (p. 329).

Pierce, Stacey, and Barkatsas (2007) developed a scale to investigate students' attitudes towards mathematics and technology (computers and calculators). The

Mathematics and Technology Attitudes Scale includes five affective variables, and was tested with 350 years 8-10 students from six schools in Victoria. It was found that for boys, the attitude to learning mathematics with technology “is correlated only with confidence in using technology, but for girls the only relationship found was a negative correlation with mathematics confidence” (p. 285).

Studies on students’ social interaction and collaboration have been described earlier, and particularly the work done by Goos et al. (2000, 2003) and Geiger (2006) which involved Queensland students.

Teacher beliefs and instructional practices have also been found to have impact on students’ use of calculators. In their study of two teachers, Kendal and Stacey (2001) found that although having planned the lesson together, the teachers taught the lesson differently due to their “fundamentally different conceptions of mathematics with associated teaching practices, innate ‘privileging’ of representations, and of technology use” (p. 143). Other studies (e.g., Thomas & Hong, 2005) also found that teachers can have very different pedagogical approaches and preferences in using technology.

In summary, there is a significant body of research on the use of GC and CAS calculators in Australia. Studies have been on cognitive factors dealing with students’ mathematical conceptions in topics involving the use of calculators, on pedagogy and social factors, and on assessment. At the time of this study, there did not appear to be a cross-country study (involving Australia) focusing on affective factors, such as beliefs and attitudes, affecting students’ learning of mathematics when using the calculators.

Calculator studies in Singapore. Kaur (2004) provided a comprehensive overview of the Singaporean mathematics education system, the education policies that were prevalent, and the teaching context and culture from the perspectives of heads of department in eight secondary schools. Generally, Singaporean teachers "emphasize mastery of knowledge and skills, critical and creative thinking, communication and problem solving" (Kaur, 2004, p. 9), as voiced by the heads of department. Teachers have high expectations for their students and themselves. They expect students to be ready for lessons, to hand in homework punctually for grading, to correct any solutions graded incorrect by the teacher, to listen attentively and to be on task, either working alone or with their peers during class activities.

In terms of research on the use of technology in mathematics education, Ng and Leong (2009) provided a commentary and review of Singaporean studies. Most studies were on the affordances of technology in teaching and learning, as well as in relation to other factors in the instructional environment. The small scale and duration of these studies limited the generalisation of the findings (Ng & Leong, 2009).

The GC had only recently been introduced to the A-level examinations at the time of this study and there was a scarcity of research about their use by Singaporean teachers. Concerns by junior college mathematics teachers about the changes in the types of examination questions used and the impact of the GC on teaching and learning were reported by Lam and Kho (2002). Before the implementation of GCs into the Singaporean mainstream mathematics curriculum, Tan and Forgasz (2006) compared Singaporean and Victorian senior secondary teachers' views about GCs, and found that Singaporean teachers were less certain about the usefulness of the GC and indicated less GC proficiency than Victorian teachers. They speculated that the mandatory use of GCs in high-stakes examinations played a part in teachers' perceptions and use of the tool.

Ng (2003) reported findings from a quasi-experimental pilot study on the use of CAS calculators in Singapore with two classes of secondary three (Year 9) Additional Mathematics students. There were no significant achievement differences found between the experimental (CAS calculator users) and control groups (scientific calculator users). Internal validity was affected as the teacher who taught the control group conducted extra lessons between class tests and might have been trying to “counteract the effect of the intervention” (Ng, 2003, p. 242) by setting difficult questions which tended to advantage the non-CAS control group. While not generalisable, the findings revealed some beliefs and reservations that Singaporean teachers had with introducing new technology into the classroom. Survey feedback of the students’ attitudes suggested that students “generally found TI-92 more useful as a computational tool rather than a teaching tool for teachers” (p. 246). Access to the CAS calculator was highlighted as a critical aspect of its effective use.

Ng (2006) also conducted a study in 2003 on the use of the GC by junior college Further Mathematics students. Further Mathematics (FM) was a higher level mathematics subject aimed to prepare students for engineering and mathematics courses in university, and was removed when the new Advanced Level curriculum took effect in 2006. The GC was permitted in the FM year 12 examinations in 2001 and the questions were said to be GC-neutral. Ng surveyed 190 students on three occasions, and the results suggested that students using the GC performed better academically than those not using the GC. Ng (2006) contended that students’ competency with the GC could be influenced by other factors such as access to the calculator, familiarity with its functions, and the extent of exposure students have to its use, the latter being dependent on the teaching and learning environment.

A six-month CAS intervention programme was conducted in a junior college in 2004 where two classes of high achieving Year 11 students used TI Voyage 200 calculators in their mathematics lessons (Ng, Kwee, Lau, Koh, & Yap, 2005). Comparisons were made between the intervention group in 2004 and those from the previous year where TI 83 GC was used instead of the CAS calculator. There was no significant difference in achievement between the 2004 group and the 2003 group. Students’ attitudes towards CAS calculators (anxiety, confidence, liking and usefulness) were measured by a 40 item questionnaire, and were found to have improved significantly between pre and post treatment. The scores for the Usefulness and Liking subscales were highly correlated ($r = 0.826$), suggesting that the high achieving Singaporean students were practical, liking the tool more, the more it was perceived to be useful (Ng et al., 2005). Additionally it was observed that students’ initial enthusiasm with the CAS calculators diminished when they learnt that the calculators were not allowed in the examinations. Through analysis of students’ written journals, it was found that students were impressed by the symbolic, graphic and numeric capabilities of the CAS calculators and used them in a variety of ways, including checking answers, solving equations, proving identities, sketching graphs, and simplifying mathematical expressions. There was dissatisfaction with the limitations of the calculators, such as low screen resolution leading to distortion of graphs around asymptotes, inability to solve inequalities completely, calculator syntax different from conventional mathematics, and limitations with solving equations involving complex roots. Despite this, students also commented that the difficulties raised their awareness about writing mathematical expressions and about elements of graphing such as the domain of a function.

In summary, there have been many studies on students' use of GC and CAS calculators in Australia that have yielded rich theories about students' use of technology, and attitudes and beliefs about mathematics and calculators. In contrast, there is a scarcity of research on the GC in Singapore after its introduction into the mainstream senior secondary curriculum; thus an investigation of students' use of the GC is urgently needed.

So far the review of literature in this section was on students' use of GC and CAS calculators, looking at the mathematics content and skills learnt using calculators, the technical and mathematical demands required for effective use, achievement and performance for academically better and weaker students, students' social interaction and communication, comparison between GC and CAS calculators, and Australian and Singaporean calculator studies. Certain factors affecting the ways students interact with the calculators have consistently surfaced, such as the nature of task, instruction, and assessment; students' familiarity with and perceptions of the tool; and their personal preferences for representation and solution strategies. In addition, there has been a call for deeper reflection that "requires multidisciplinary research within the framework of cognitive sciences: psychology and cognitive ergonomics, communication, computing and informatics, sociology, and subject didactics" (Guin, Ruthven & Trouche, 2005, p. 301). Hence, in the next two sections, literature from broader and multiple disciplines: mathematics education, educational technology and learning styles are examined for potential student factors.

Student Factors Affecting Their Use of Calculators from Mathematics Education and Educational Technology Literature

While the research studies reviewed in the previous section focused on GC and CAS calculator use, studies in this section were from the broader fields of mathematics education and educational technology. Within these fields, there are many factors and issues relate to how students learn mathematics using technologies. This study (and this section) focuses on student factors, i.e. factors arising directly from the students themselves rather than other elements of the classroom such as the task, teacher, structure and nature of the lessons. First, studies on students' attitude and beliefs about mathematics and technology are reviewed, followed by a discussion of students' epistemological beliefs about the nature of mathematics, gender differences in technology use, and individual differences. Finally, some theories of phases or stages of technology use are presented.

Beliefs about and attitudes toward mathematics and technology. It is well known that students' beliefs and attitudes about themselves and their learning of mathematics affect their behaviour and performance (Cretchley, 2008; McLeod, 1992; Schoenfeld, 1989). However, there is a host of different definitions and terminologies used in describing beliefs and attitudes by various researchers which are not aligned (Cretchley, 2008; Hart, 1989).

Hart (1989) noted that mathematics educators and psychologists have different views of affective variables, and have established a distinction between the terms "beliefs, attitudes, and emotions". The term *belief* is used to reflect "a certain judgement about a set of concepts" (p. 44), *attitude* to refer to "emotional reactions to the object, behaviour toward the object, and beliefs about the object" (p. 44), and *emotions* to refer to "hot gut-level reaction(s)" (p. 44). In his review of research on affect in mathematics education, McLeod (1992) proposed that beliefs, attitude, and emotions, in order, are decreasing in stability and cognitive involvement, and increasing in emotional intensity. Different aspects of the affective variables were investigated in different contexts (e.g., problem solving, gender differences) in mathematics education (McLeod, 1992). For example Schoenfeld (1989), investigating beliefs of Grade 10 students enrolled in geometry courses, had focused on students' beliefs about mathematics as a discipline (e.g., nature of proofs, reasoning and geometrical constructions) and about mathematics learning (e.g., perceptions of mathematics and school practice); whilst Forgasz (1995), investigating gender differences in mathematics learning, had focused on students' beliefs about the mathematics learning (e.g. persistence at mathematics tasks, mathematics as a gendered domain, causal attributions of success or failure), value of mathematics (e.g., perceived usefulness of mathematics), students themselves as learners (e.g., confidence), and social context of learning (e.g., beliefs about significant others). Research on beliefs and attitudes usually go hand-in-hand, whereas research on emotions is scarce since researchers are more interested in "factors that are stable and can be measured by questionnaires" (McLeod, 1992, p. 582).

McLeod (1992) categorised beliefs in terms of the objects of beliefs: (1) about mathematics, (2) about self, (3) about mathematics teaching, and (4) about the social contexts in which mathematics learning occurs. Relating to the first category of beliefs about mathematics, he found that there have been few quantitative studies of beliefs about mathematics as a discipline. Since McLeod's (1992) review, mathematics education researchers have reconceptualised beliefs about mathematics as overlapping with epistemological beliefs about mathematics (Roesken, Pepin, & Toerner, 2010). This will be discussed further in the next section under the heading of students' ways of knowing and understanding mathematics.

Relating to the second category of beliefs about the self, McLeod (1992) pointed to affective variables such as confidence in learning mathematics, self-concept, and causal attributions of success and failure, and related these variables to the fields of student motivation, meta-cognition, and self-regulation. In their review of the literature on academic self-concept and self-efficacy, Bong and Skaalvik (2003) summarised work by other researchers such as Wigfield and Karpathian (1991), Parjares, Miller and Johnson (1999), Schunk (1991). Bong and Skaalvik (2003) described academic self-concept as referring to "individuals' knowledge and perceptions about themselves in achievement situations" (p. 6) and academic self-efficacy as referring to "individuals' convictions that they can successfully perform given academic tasks at designated levels" (p. 6). Although self-concept and self-efficacy are highly correlated, mathematics self-concept was found to be a better predictor (and mediator) for other affective variables such as interest and anxiety, while mathematics self-efficacy was a better predictor (and mediator) for mathematics achievement (Ferla, Valcke, & Cai, 2009).

Beliefs about mathematics teaching, the third category, were studied more by researchers investigating teachers' beliefs rather than students' belief, and beliefs about the social contexts, the fourth category, included those about social norms, classroom environment and cross-cultural contexts (McLeod, 1992).

There are many research studies about attitudes in mathematics education, and included are beliefs about mathematics and about the self; "it is difficult to separate research on attitudes from research on beliefs" (McLeod, 1992, p. 582). McLeod (1992) classified attitude as an "affective response that involve positive or negative feelings of moderate intensity and reasonable stability" (p. 581), that could be developed from a repeated emotional reaction to mathematics and transferred to a new task. The study of emotions in mathematics education was found to be sparse in McLeod's review (1992), but it was taken up more recently in studies of related fields such as those on self-regulation (De Corte, Depaepe, Op't Eynde, & Verschaffel, 2011).

In the area of technology in mathematics education, students' attitudes towards and beliefs about technology have been investigated. The importance of students' attitude towards technology and mathematics was noted by Lokan, Greenwood and Cresswell (2001), in their analysis of Australia's results in the Program for International Student Assessment (PISA) 2000 survey data. The researchers concluded that besides socioeconomic status, there were a number of factors significantly associated with mathematical literacy that were related to students' approaches to school and learning. These factors included "students' attitudes to computers, strategies used to control their learning processes, the use of memorisation in learning, and techniques of elaboration of existing knowledge to promote their learning" (p. 187).

In studies of students' use of technology in mathematics education, the affective variables being investigated were generally attitudinal in nature. For example Fogarty, Cretchley, Harman, Ellerton, and Konki (2001) measured students' mathematics confidence, computer confidence and attitudes towards technology for learning mathematics. Pierce, Stacey, and Barkatsas (2007) developed a scale to measure students' confidence in mathematics, technology and using technology in mathematics learning, as well as their affective engagement ("how students feel about the subject", p. 292) and behavioural engagement ("how they behave in learning the subject", p. 292).

Students' attitudes towards computers and handheld technologies have generally been positive (e.g., Ellington, 2006; Kahveci, 2010; Li, 2007), which can translate into greater engagement and enhanced performance (Reed, Drijvers, & Kirschner, 2010). In studies of students' attitude towards computers, mathematics, and using computers in mathematics learning, researchers found that students' attitude towards using technology in mathematics is more closely associated with the students' attitude towards technology, than their attitude towards mathematics (Galbraith & Haines, 1998; Forgasz, 2004a). However, there could be gender differences in the association: attitude towards learning mathematics with technology was found to correlate positively with confidence in technology for boys, and negatively with mathematics confidence for girls (Pierce et al., 2007, see later section on gender differences in p. 41).

There are different types of attitudinal measures used by researchers. For studies with quantitative components, students' confidence about mathematics and technology are usually investigated together with other factors such as perceptions about behaviour and engagement (self-concept and self-efficacy) and motivation to use technology in learning mathematics (such as enjoyment, interest and value) (e.g., Forgasz, 2004b; Galbraith, Goos, Renshaw, & Geiger, 2001; Galbraith & Haines, 1998; Pierce et al., 2007). In the qualitative component of studies, students' motivation (e.g., Ali & Kor, 2004), ways of working with the calculators to learn mathematics (e.g., Guin & Trouche, 1999; Herman, 2007), and self-concepts and beliefs about technology use in mathematics learning (e.g., Li, 2007) are usually investigated.

There is some evidence that students show more engagement and persistence and have more flexible approaches to problem solving when using advanced calculators (e.g., Dunham & Dick, 1994). Studies also show that students using calculators to learn mathematics have more positive attitudes towards mathematics and towards using calculators in mathematics than those not using calculators (Ellington, 2006). For example Hennessy et al. (2001) found that 85% of the 55 Open University students surveyed said their feelings changed during the year of GC use from 'apprehensive' towards being 'eager' (p. 271). Many students said their confidence increased with the use of GC, and that using the GC also improved their attitudes towards mathematics.

Additionally, 85% of the students said using GC made doing mathematics more enjoyable, and 78% reported that it made doing mathematics seem easier. However, there were mixed views about the GC's user-friendliness, with 80% of the students describing calculator features as easy to use, but 75% of them also raised the issue of difficult and counter-intuitive GC features.

Students generally indicated that they enjoyed using calculators because of the increased efficiency in calculations, but some were concerned about dependency on the technology and possible de-skilling effect (Groves & Obregon, 2001). However, positive improvement in student attitudes does not necessarily translate into an increase in mathematics performance or enhanced learning (Galbraith, 2006; Forgasz, 2004b; Penglase & Arnold, 1996). Researchers cautioned against neglecting the confounding effects of change in teaching approach which could produce positive attitudes with the use of new technology (Penglase & Arnold, 1996). Nonetheless, investigations of attitudes towards technology use, particularly advanced calculators, are pertinent in this study due to their potential influence on students’ performance in high-stakes examinations.

Next, the literature on students’ ways of knowing and understanding mathematics are discussed.

Ways of knowing and understanding mathematics. Closely linked to affective factors are students’ beliefs about the nature of mathematics, and of how they come to know and understand mathematics (epistemological beliefs). Although there are many studies on students’ epistemological beliefs in the field of psychology (see Hofer & Pintrich, 1997 for a review), studies suggested that “students’ beliefs about knowledge and knowing in a specific domain, i.e., classroom mathematics, are highly domain and context specific” (Op’t Eynde, De Corte, and Verschaffel, 2006, p. 68). Mathematics education researchers have generally investigated beliefs about mathematics as a construct in the affective domain (Muis, 2004), and in the last three decades research into students’ epistemological beliefs of mathematics has blossomed into a field encompassing a multitude of theories and views about the various aspects of beliefs and belief systems (Roesken, Pepin, & Toerner, 2011). In a review of mathematics education research on epistemological beliefs, Muis (2004) concluded that students at all levels tended to hold beliefs about mathematics that do not lead to positive learning outcomes. Students were generally found to believe that knowledge is unchanging, composed of various unrelated components, and handed down by some authority figure. They also held beliefs that the ability to do mathematics is innate, the goal of problem solving is to find the right answer, and the learning of mathematics should occur quickly, within 5 to 10 minutes (Muis, 2004).

A summary review of some of the literature on students' ways of knowing and understanding mathematics is shown in Table 2.1.

Table 2.1

Ways of Understanding and Knowing Mathematics

Author (year)	Conceptions used	Findings
Skemp (1976) proposed two types of understanding of mathematics.	Instrumental understanding –consists of "the learning of an increasing number of fixed plans, by which pupils can find their way from particular starting points (the data) to required finishing points (the answers to the questions)" (p. 25). Relational understanding - consists of "building up a conceptual structure (schema) from which its possessor can (in principle) produce an unlimited number of plans for getting from any starting point within his [sic] schema to any finishing point". (p. 25)	Skemp discussed the situations where each of instrumental understanding and relational understanding might have advantages, as well as problems of mismatching students' and teachers' expectations of what types of understanding were required during lessons.
Schoenfeld (1989) surveyed 230 high school students in New York about their mathematical beliefs and behaviour.	School mathematics – "the mathematics students know and experience in their classrooms" (p. 349). Abstract mathematics – "the discipline of creativity, problem solving, and discovery, about which students are told but which they have not experienced". (p. 349)	Students provide contradictory responses which indicated that there are two conceptions of mathematics as a discipline. For example, a majority of students stressed the importance of memorisation ("you must know certain rules, which are a part of all mathematics. Without knowing these rules, you cannot successfully solve a problem" (p. 344)), and yet agreed that mathematics is a creative discipline "in which one can

Author (year)	Conceptions used	Findings
		make discoveries, learn to be logical, and so on” (p. 346).
Becker (1995) transferred the Women’s ways of knowing model by Belenky et al. (1986) to mathematics and teaching.	Separate knowing – deals with “logic, rigour, abstraction, rationality, axiomatics, certainty, deduction, completeness, absolute truth, power and control, algorithmic approach, and structure and formality” (p. 167). Connected knowing – is related to “intuition, creativity, hypothesizing, conjecture, experience, relativism, induction, incompleteness, personal process tied to cultural environment, and contextual”. (p. 167)	Becker pushed for using connected teaching to “help students develop into constructed knowers” (p. 168). She gave a list of different examples of connected teaching in mathematics that deal with the issues of student voice, need for first-hand experience, confirmation of self as knower, problem-posing, believing versus doubting, support versus challenge, and structure versus freedom.
Lindsay (2003b) studied 10 low achieving students in their use of the GC for a year.	Procedural knowledge – “a sequence of actions, or steps, which allows mathematical tasks to be completed efficiently and with relatively little effort (Hiebert & Carpenter, 1992)” (p. 30). Conceptual knowledge – “knowledge which is rich in mathematical relationships”. (p. 30)	The two students discussed in the case studies made limited progress “via a ‘mix’ of pedagogies: procedural teaching that incorporated explicit instruction on pencil-and-paper skills, and conceptual teaching that included student-centred inquiry-based activities” (p. 35). Lindsay (2003b) argued that purely conceptual teaching strategies might suit only average and high-achievers; weaker students needed a balanced pedagogical approach that integrated procedural and conceptual knowledge.
Hoz and Weizman (2008) surveyed 176 Israeli high school mathematics teachers.	Static conception of mathematics – mathematics is a priori and infallible, a clear body of knowledge and techniques, a monolith, immutable product, static but unified body of certain rules that are to be discovered and not amenable to personal creation, is universal, absolute, and perfect. Dynamic conception of mathematics –	Hoz and Weizman measured teachers’ conceptions of mathematics and of mathematics teaching. They found that teachers “practise their profession without adhering to any official conception” (p. 905) – either their conceptions of mathematics do not match with that of their conceptions of teaching, or that they do not adhere to any

Author (year)	Conceptions used	Findings
	view of mathematics as changeable, developing continuously and dynamic, creative, heuristic, a social construction, a product of human invention, a process of enquiry. (adapted from Table 1 in p. 907)	conception. Only a quarter of them showed consistency in their conceptions of mathematics and of mathematics teaching.

Although there are other theories with more than two epistemological dimensions (e.g., Schommer, 1990), based on the review of literature as seen in Table 2.1, students' ways of knowing and understanding mathematics can be classified into two broad conceptions: (a) school mathematics, procedural knowledge, static conceptions of mathematics, separate knowing and instrumental understanding; and (b) abstract mathematics, conceptual knowledge, dynamic conceptions of mathematics, connected knowing, and relational understanding. Skemp (1976) and Becker (1995) pushed for teaching to cater for relational understanding and connected knowing respectively, whereas Lindsay (2003b) argued that for weaker students, a mixed teaching strategy would be more beneficial than focusing purely on conceptual teaching. Other researchers found that students (Schoenfeld, 1989) and teachers (Hoz & Weizmann, 2008) held conflicting conceptions within themselves. This suggests that the conceptions of mathematics are not bipolar but dichotomous, and are dependent on contextual factors such as students' mathematics background. Students and teachers can show contradictory conceptions, have one or both conceptions, or may even adhere to none.

Findings from other studies (e.g., Boaler, 2002; Norton, 2006; Ocean, 1998) have shown that ways of knowing and understanding mathematics might be gender-related. Girls, it seems, prefer authentic and contextual learning experiences. In her study of mathematics teaching and learning, Boaler (2002) studied two schools in England, one in which traditional approaches (expository teaching approach using textbooks) were used and the other where reform approaches involving project work and more student-centered learning were adopted. She found that both boys and girls taught using the traditional approach disliked it. The boys, however, adapted by viewing mathematics as a competitive game, whereas the girls were unable to adapt because they wanted to understand the mathematics. In competing with one another to see who had completed the most questions in the shortest time, the boys “came to regard mathematics as a system of rule following and rote learning” (Boaler, 2002, p. 140), whilst the girls became anxious and fell behind because they felt they could not understand mathematics. In the other school investigated by Boaler, a cooperative approach was used and there was no gender difference in the way the boys and girls perceived mathematics.

Norton (2006) carried out two interventions involving an integrated study of mathematics with design and technology in two schools in Brisbane (one co-educational and one girls’ school). The girls were in years 6 and 7. For both interventions, the results showed that there were no significant improvements in perceptions about the value of studying mathematics through technology practices. However, “when students were given explicit scaffolding in ‘within’ and ‘beyond’ the domain of mathematics integration as well as tasks that they considered authentic, student perceptions of mathematics study improved” (p. 69).

In investigating year 8 students’ use of GC and their preference for symbolic or numerical solution strategies, Merriweather and Tharp (1999) devised an attitude questionnaire to investigate if students are “rule-based” or not, based on responses to three questions: 1) Learning mathematics is mostly memorizing a set of facts and rules; 2) When doing mathematics it is only important to know how to do a process and not why it works; 3) Learning mathematics means exploring problems to discover patterns and make generalizations (p. 10). Although students’ short term use of GCs did not yield any significant improvements in achievement, researchers found that rule-based students tended to use equations (symbolic approach) to solve an algebraic word problem whereas non-rule based students tended to use numeric methods.

In summary, although researchers use a disparate set of terminologies describing students’ ways of knowing and understanding mathematics, there seem to be two common threads of conceptions underlying them. One thread refers to the immutable nature of mathematics as a logical set of rules to be followed, and students with such conceptions learn mathematics with a procedural, instrumental understanding. The other thread refers to the connected, creative nature of mathematics that is rich in relationships, and students holding such conceptions learn mathematics with conceptual, relational understanding. In the review of studies on students’ learning of mathematical skills using calculators, the focus of advanced calculator studies has been on the impact of calculator use on students' procedural and conceptual skills, as well as on students' representational preferences. There seemed to be an association between students' epistemological beliefs about mathematics and their representational preferences (Merriweather & Tharp, 1999). Hence, there is much potential for research on technology, and advanced calculators in particular, in which students' ways of knowing and understanding mathematics are investigated.

In the next section, findings on gender differences in the use of computers, graphing and CAS calculators, are discussed.

Gender differences in technology use. Gender differences in the learning of mathematics have been well studied (e.g., Fennema & Sherman, 1977, Leder, 1992, Vale & Bartholomew, 2008). Recent studies of gender differences in learning mathematics with technology have revealed differences in student participation, student engagement in mathematics, mathematics achievement, student attitudes, and student confidence (e.g., Barkatsas, Kasimatis, & Gialamas, 2009; Forgasz & Tan, 2010; Leder, Forgasz, & Taylor, 2006; Vale & Leder, 2004).

Pierce, Stacey and Barkatsas (2007) analysed data from the mathematics and technology attitudes scale (MTAS) survey of boys (N = 70) and girls (N = 71) in four co-educational secondary schools in Victoria. In their larger pilot study involving six schools (350 students), the word "technology" in the MTAS was replaced with "graphics calculators" for one of the six schools, but it was not clear whether the school was included when analysing for gender differences. Generally, they found that boys had statistically significantly higher scores than girls on four of the five subscales: affective engagement, mathematics confidence, confidence with technology, and attitude to learning mathematics with technology. There was high variability in the attitude towards learning mathematics with technology (MT) scores, which correlated positively with confidence in technology for boys, and negatively with mathematics confidence for girls. The authors found that girls with low mathematics confidence generally valued technology for learning, and that girls with high mathematics confidence exhibited a range of attitudes towards learning mathematics using technology. They concluded that "whereas boys may experience learning mathematics more positively simply because technology is present, some girls may value it when they feel it has the potential to compensate for self-perceived shortcomings" (p. 298).

Others have also found similar gender differences relating to the attitudes towards computers of middle secondary school students (e.g., Forgasz, 2004a; Vale & Leder, 2004). Vale and Leder (2004) studied two mathematics classes (year 8 and 9) in Melbourne. Girls were found more likely than boys to "express a view about computers that was related to success in mathematics rather than other themes in their responses to open-ended questions" (p. 298), whereas boys more often expressed pleasure, and commented more often than girls "about the relevance of using computers for learning computer skills that was useful for their future or other subjects" (p. 302). Boys were also found to be more positive than girls about computer-based mathematics, and that "students' attitudes to computer-based mathematics were more strongly associated with self-efficacy in computing …, and the desire to achieve at computing … than with their self-efficacy or aspiration for mathematics" (p. 306). Forgasz (2004a) surveyed 1613 Victorian students from years 7-10 and found a strong and significant correlation between attitudes to computers for learning mathematics and attitudes to computers, but not with attitudes to mathematics. Boys were found to score significantly higher than girls in their attitudes towards mathematics, computers, and using computers for learning mathematics. They also had significantly higher student computer ownership than girls. In another survey of two cohorts of Year 11 students, Forgasz (2004b) found that a significantly higher percentage of boys than girls in both cohorts believed that computers helped people learn mathematics better and helped students understand mathematics better. A significantly higher percentage of boys than girls in one of the two cohorts also believed that computers made mathematics more enjoyable, and that previous experiences with computers affected their decision to study mathematics at Year 11.

Overall, studies showed that the gender differences in attitudes towards computer use in learning mathematics generally seem to be in favour of boys. However, there are exceptions. Alkhateeb (2002) compared achievement, attitudes towards success in mathematics, and mathematics anxiety of college students taught calculus using GCs, with another group of students using CAS Maple e-textbook (50 males and 50 females in 3 classes). No significant difference was found between the groups.

Responses to pen-and-paper inventories of attitude and anxiety were in favour of students using computer rather than the GCs. Alkhateeb used two Fennema-Sherman Mathematics scales: Attitudes Towards Success in Mathematics and Mathematics Anxiety. There were no gender differences in student achievement and attitudes towards success in mathematics; however, women in the computer group were found to have improved significantly on the Maths Anxiety scale, compared to women using GCs. Based on students' comments, Alkhateeb (2002) suggested several factors that might have contributed to the lower anxiety of the women in the computer group: the Maple menu system on the computer seemed less tedious than the menu on the GC; Maple had symbolic algebra capability (which the GCs did not) which allowed students to focus on problem solving rather than on algebraic manipulations; the computers had bigger screens which allow students to see their work on one screen, compared to having to move from one screen to another using the GC; and students might have used computers in other subjects and in their daily lives and thus were more familiar with them than with GCs.

A well-known study on gender differences in calculator use, conducted by Dunham (1990), was aimed at determining if there were any gender differences in mathematical confidence and performance that could be related directly to the use of the GC. Confidence was measured by a 24-item scale developed by Dunham, with visual and algebraic subscales. Performance of the 213 college students was measured by pre- and post tests in the 10-week pre-calculus course taught with the aid of the GC. Dunham found that although males had superior performance on pre-test visual items, there were no performance differences on the post-test. There were no differences in confidence on the pre-test, but males showed higher confidence than females on post-test visual items. Additionally, Dunham (1990) interviewed eight high-confidence and eight low-confidence users, and found gender differences in solution choices on GC neutral items. Low-confidence females were found to rely more heavily on the GC and used algebraic approaches less frequently than any other group, while high-confidence females were more likely than any other group to choose an algebraic approach and less likely to use a graph to solve a problem. Low-confidence males also tended to use the GC more often than other males but did not rely upon them to the same extent to which low-confidence females did. High-confidence males used graphing and algebraic methods of solution almost equally, and were the most likely group to use a mix of both algebraic and graphing methods in a single solution. Dunham (1990) noted that a number of high-confidence females felt that they relied too much on what they thought were easy calculator solutions and expected to gain more from learning algebraic techniques.

In a comparison study of students using GCs and scientific calculators, Ruthven (1990) analysed students' performance in two types of questions, symbolisation (requiring algebraic description of graphs) and interpretation (extracting information from verbally contextualised graphs). He found that for symbolisation items, girls outperformed boys in the experimental group, but underperformed in the control group. However for interpretation items, boys outperformed girls in both groups. Ruthven pointed to past research findings that males are more confident, less anxious and exhibited better performance in visual-spatial tasks than females, and suggested that the regular use of GCs reduced anxiety and provided more opportunities and experiences with graphical images, which benefited female students more in solving symbolisation questions.

Examining the Australian Calculus Tertiary Entrance Examinations for 1995-2000, three years before and three years after the GC was introduced in Western Australia, Forster and Mueller (2002b) found that the performance of girls was higher than that of boys at the lower end of the achievement scale, while boys performed better at the top end of the scale. Girls seemed to perform better at questions requiring competence with analytic methods, whereas boys tended to fare better at questions where diagrams played a role in the solution. In the period of study, students' enrolments declined 3% for males and 22% for females, and technology use was implicated as one the main factors for the decline. In the Victorian context, a stronger trend of decline in enrolments for females than males was found for the intermediate and higher level mathematics subjects across the years in which the use of CAS calculators was phased into the high stakes examinations (Forgasz & Tan, 2010).

In summary, although there were similar gender-related patterns found in the use of technology for mathematics learning, the studies reviewed were generally either about technology in general or about computers. They were also more often conducted with students in the middle secondary years of schooling. There is also a dearth of gender related research on use of technology in mathematics education in Singapore.

There would appear to be a gap in the recent research investigating gender differences in students' use of the GC and CAS calculators in the final years of schooling, particularly in relation to senior secondary students' attitudes, learning preferences, confidence, and ways of using the calculators.

In the last subsection, theories and models relating to the ways students use technology are reviewed.

Ways of interacting with technology. While there have been several studies measuring students' attitudes towards and confidence in mathematics and technology use (e.g., Fogarty, Cretchley, Harman, Ellerton, & Konki, 2001), there are few studies in which the ways that students interact with technology, in particular the advanced calculators, have been measured. Table 2.2 shows a summary of some models of how students and teachers interact with technology in mathematics education.

Table 2.2

Models of How Students and Teachers Interact with Technology

Authors	Ways of interacting with technology in mathematics education
Doerr and Zangor (2000)	Found five patterns and modes of graphing calculator use: computational tool, transformational tool, data collection and analysis tool, visualizing tool, and checking tool. Results suggested "that nature of the mathematical tasks and the role, knowledge and beliefs of the teacher influenced the emergence of such rich usage of the graphing calculator" (p. 143).
Goos, Galbraith, Renshaw, and Geiger (2000)	Developed four metaphors to describe the roles of technology used by teachers and students: technology as Master, Servant, Partner, and Extension of Self. Geiger (2005) divided the metaphors into further sub-categories of students' use of technology.
Guin and Trouche (1999)	Described five work methods exhibited by students when using advanced calculators: 1) random work method where students use a trial and error approach, copy and paste strategies from previously memorised solutions; 2) mechanical work method where students rely on simple calculations and machine results, often avoiding mathematical references; 3) resourceful work method where students use a combination of calculator results, pen-paper work and knowledge of mathematical theories; 4) rational work method characterised by a preference for pen-paper rather than calculator, with a strong role of inference in their reasoning; and 5) theoretical work method where students rely on mathematical knowledge, "analogy and over-excessive interpretation of facts with average verifying procedures of machine

Authors	Ways of interacting with technology in mathematics education
	results.” (p. 216)
Kutzler (2003)	Developed a “two-level framework for understanding, categorizing, and planning the use of technology” (p. 53), particularly computer algebra systems (CAS). The first level is how CAS can support teaching and learning: automation (technology enabling computations in which the “user needs to know how to operate it and how to push the correct buttons” (p. 55) and compensation (technology helping mathematically challenged students to deal with advanced topics). The second level is pedagogical approaches: trivialisation (e.g. graphing becomes trivialised), experimentation (generating examples, observing them, and forming conjectures), visualization (“illustration of an object, fact or process with results that are graphic, numeric, or algebraic” (p. 62), and concentration (technology allowing mathematically challenged students to concentrate on learning new skills and not be hindered by weaknesses associated with old skills).
Lee and Hollebrands (2006)	Categorised features of a java applet into four sub-categories: “features over which user does not have any control and remain static, dynamic features that allow users to directly manipulate objects, dynamic features that update to provide feedback to users during problem solving, and features that activate parts of the applet” (p. 252). They investigated patterns in the features used to support the six problem solving goals: analysis, planning, implementation, assessment, verification, and organisation.

In summary, the models developed stemmed from the perspective of the tool (functional basis, e.g., Doerr & Zangor, 2000; Lee & Hollebrands, 2006), from the students’ perspective (sociocultural basis, e.g., Goos et al., 2000; Guin & Trouche, 1999), or from the teachers’ perspective (pedagogical basis, e.g., Kutzler, 2003). There are other models, such as those developed from the roles played by the GC or CAS calculators in the mathematics topic (e.g., Brown, 2005, on affordances that technology provides when students learn functions). However, since this PhD research study focuses on the general use of technology in mathematics, rather than on particular mathematics topics, they are not discussed here.

Overall, there is already a significant body of research on the use of graphic and CAS calculators by students, and the effects of students’ use are found to be dependent on various factors such as the availability of the tool, students’ mathematical conceptions and technological expertise, the teacher’s role, and “the possible variation in students’ behaviour, according to gender (Penglase & Arnold, 1996) or work method" (Trouche, 2005, p. 16-17). So far in this section literature from mathematics education and educational technology fields have been reviewed, with the focus on possible student factors influencing technology use. These factors are students' attitudes towards and beliefs about mathematics and technology, gender, ways of knowing and understanding mathematics, and ways of interacting with technology.

The literature on the factors affecting students' use of advanced calculators stemming from the learning styles literature is discussed next.

Student Factors Affecting Their Use of Calculators from the Learning Styles Literature

In the following subsections, relevant literature on general learning style theories, students' approaches to learning, multiple representations and multimodal preferences, and social instructional preferences are discussed.

Learning style theories. The study of learning styles has been one that is both intriguing and perplexing, due to much complexity and controversy, and unresolved issues (Cassidy, 2004; Curry, 1983; Riding & Rayner, 1998; Rushby, 2007; Zhang & Sternberg, 2005). The literature refers to Allport's (1937) early work on individual traits, that "…behind all confusion of terms, behind the disagreement of judges, and apart from errors and failures of empirical observation, there are none the less *bona fide* mental structures in each personality that account for the consistency of its behavior." (p. 289). There was a gain in prominence of learning styles and theories particularly from the 1960s to 1990s. A review of post-16 (post-secondary) learning styles research by Coffield, Moseley, Hall, and Ecclestone (2004) yielded a database of over 800 references and papers, out of which about 350 texts referred to 13 major theories out of 71 theories identified. In the last decade, however, discussion of "learning styles" seems to be more subdued and subsumed under "personalisation of learning" and "individual differences" (e.g., Coates, 2005).

One of the most fundamental issues of contention is that there are many definitions of the term *learning style* according to the context used and the people defining it. The notion of "style" as a construct in psychology "has been developed in a number of different areas such as: personality, cognition, communication, motivation, perception, learning and behaviour" (Riding & Rayner, 1998, p. 6). Generally, the term "style" "describes the way in which a person habitually approaches or responds to the learning task" (Riding & Rayner, 1998, p. 7). In the field, *learning styles* have been broadly related to cognitive styles, learning strategies, intellectual styles, learning approaches, and thinking styles.

There have been many attempts to map the various learning style constructs and models (e.g., Cassidy, 2004; Coffield et al., 2004; Curry, 1983; Desmedt & Valcke, 2004; Riding & Cheema, 1991). Curry (1983) proposed that different learning styles can be organized into "strata resembling layers of an onion" (p. 7). The innermost stratum is composed of a person's cognitive personality dimensions which fundamentally control the learning behaviour. This behavioural intention is then translated through the middle stratum, the information processing dimensions, and interacts with the person's environmental dimensions. Hence, the three layers of the onion describe three levels of preferences: cognitive personality preferences, information processing preferences, and instructional preferences. As the layers progress from inside out, the stability of the preferences decreases. This parallels the concepts of state versus trait in psychology (Curry, 1983). Curry's onion model remains one important landmark in the field that academics allude to in later works (see for example, Riding & Raynor, 1998; Zhang & Sternberg, 2006).

Similarly, Coffield et al. (2004) grouped learning styles into five families: 1) styles and preferences which are largely constitutionally based (e.g. Dunn and Dunn's model of learning styles); 2) styles that reflect deep-seated features of cognitive structure, including patterns of ability (e.g., Riding's Cognitive Styles Analysis); 3) styles being one component of a relatively stable personality type (e.g., Myers-Briggs Type Indicator); 4) styles which are flexible stable learning preferences (e.g., Kolb's Learning Style Inventory; Honey & Mumford's Learning Styles Questionnaire); and 5) moving on from learning styles to learning approaches, strategies, orientations, and conceptions of learning (e.g., Entwistle's Approaches and Study Skills Inventory for Students). These five families lie on a continuum, at one end are those "with strong beliefs about the influence of genetics on fixed, inherited traits and about the interaction of personality and cognition" (p. 20), whereas at the other end are models which emphasise "personal factors such as motivation and environmental factors like cooperative or individual learning" (p. 20), including effects of instruction, curriculum, assessment on students' choice or avoidance of particular learning strategies.

In another review, Riding and Cheema (1991) found at least 30 different labels of style, and categorised them into two principal cognitive styles and a family of learning strategies. They distinguished between cognitive style and learning style, with the former being of a bipolar dimension and a fairly fixed individual characteristic, and the latter having multiple dimensions and describing the ways that an individual may prefer to use to cope with learning situations and tasks. The two cognitive style families are: the Wholist-Analytic style describing the tendency of an individual to process information in wholes or in parts; and the Verbalizer-Imager style describing the tendency for an individual to represent information during thinking either verbally or in images. The two styles are considered to be independent of one another.

Despite the many different labels and types of learning styles used in the general psychology literature, there have been relatively few studies conducted in mathematics education and with the use of technology. The next two subsections cover the literature on learning styles and mathematics education, and learning styles and technology use in mathematics education.

Learning styles and mathematics education. Some years ago, Head (1981) exposited that there was scant attention given to investigating personality characteristics and mathematics learning, and found only a few studies directly using psychometric tests of personality with mathematics students. He also reviewed the literature indirectly through studies on attitudes and sex differences. In examining studies on the influences of personality on cognitive bias such as verbal, visual and spatial modes of working, and on cognitive styles such as field independence or dependence (see Witkin, Moore, Goodenough, & Cox, 1977), Head (1981) summarised the work of various researchers that "certain personality characteristics are associated with a liking or an ability in mathematics" (p. 347). Students who had strong verbal skills and weak in mathematics skills tended to be warm, friendly, responsive to people rather than be interested in physical things, whilst students who were weak in verbal skills and strong in mathematics skills tended to be more interested in things rather than people. Students who liked mathematics also tended to have a preference for symbolic rather than verbal modes of communication. High field-dependence (having a perception of an entity that is strongly influenced by its surroundings) was found to inhibit high mathematical attainment. From the gender and mathematics learning literature, high spatial ability was associated with masculine and withdrawn personality characteristics.

Head (1981) cautioned against the simplistic view that a particular cognitive bias or style could lead to "successful mastery of mathematics" (p. 344), since different tasks necessarily impose different demands on the learner and there could be a variety of successful strategies to solve a problem. He suggested that flexibility in thinking, of being able to switch strategies if one did not work, was a key factor, and cautioned that the traditional mathematics education system of providing students with rules and having them work through many problems using these rules, might stifle students' flexibility. He called for more systematic studies using formal models of personality development in childhood and adolescence.

Since Head's (1981) review, there have not been many studies in mathematics education focusing on learning styles. Pitney (1996) studied pre-calculus students' preferences for simultaneous and sequential information processing modes when using a video-based homework system to learn about absolute functions and graphs. Students were assigned randomly into three groups: using geometric-based materials, using algebraic-based materials, and a control group using lectures. Immediate and delayed post-tests were given after treatment. Pitney found that students high in simultaneous processing ability (above the median score) performed better in the geometric group than the other two groups. In another study, Hong, Sas and Sas (2006) explored, through interviews, test preparation and test-taking strategies of 61 high school students taking an algebra course. Two groups – high achieving students with strong interest in mathematics, and low achieving students with low or no interest in mathematics – were identified using Milgram and Hong's (2002) "Activities and Accomplishment Inventory: Math" and their strategies compared. It was found that high achievers tended to use cognitive strategies, such as reviewing study materials and solving practice problems from at least one source, in test-preparation more frequently than low achievers. There were some frequently used cognitive strategies that were common to both groups, such as checking answers and processes, and repeating (redoing problems over and over). High achievers also tended to manage their surrounding environment, organised study time, and sought assistance from teachers and peers significantly more than low achievers. For test-taking strategies, significantly more high than low achievers said they were concerned about the structural organisation of the test problems, such as estimating the difficulty of the questions and re-sequencing the items. Also, significantly more high achievers checked the correctness of their test answers than low achievers.

Generally, studies in mathematics education have involved the calculated use of learning styles theories which were aligned to the mathematical skills and concepts in question. These styles seemed to deal with symbolic, verbal, images, graphical, or geometric representations of information, or with sequential versus holistic, field independence versus field dependence modes of thinking, or with other learning strategies such as test-preparation and test-taking strategies. In the next section, studies on learning styles and technology use in mathematics teaching and learning are identified and summarised.

Learning styles and technology use in mathematics education. There is renewed interest in learning styles with the use of information and communication technology in education, for example with regard to use of hypermedia and learner comprehension, control and style (Dillon & Gabbard, 1998), the instructional design of e-learning modules (Wang & Kang, 2006), and learner characteristics in web-based classrooms (Hartley & Bendixen, 2001). In this subsection, literature relating to learning styles and technology use in mathematics education, including calculators, is reviewed.

Gasiorowski (1998) examined the relationship between student characteristics (using Kolb’s Learning Style Inventory) and mathematics performance in basic statistics and data analysis. She compared two groups of year 7 students (N = 114), one experiencing standard instruction and the other using computer spreadsheets. Kolb’s Learning Style Inventory (Kolb, 1985) was used to measure students’ learning strength along two dimensions: 1) Concrete - Abstract scale, with the learner relying more on personal feelings and experiences at the concrete end of the continuum and relying more on logic and ideas to understand problems and situations at the abstract end of the scale;

2) Active - Reflective scale, where the learner experiments with changing situations and is involved actively in the doing, versus relying on objectivity, careful judgement, observation and reflection. Gasiorowski (1998) found that traditional instruction appeared to favour students at the Abstract end of the Concrete-Abstract scale, and those in upper socioeconomic groups, while computer-based instruction favoured students at the Active end of the Active-Reflective scale, and seemed to "equalize socioeconomic factors" (p. ii). She suggested that a technology-enriched learning environment could be particularly helpful to students with an Active learning strength and a lower socioeconomic status.

There were a few learning style studies where students used advanced calculators in their mathematics learning. In her Ph.D. study, Treacy (1996) surveyed 377 year 8 to 12 students who had completed at least one mathematics course at a private school. She used the Learning Style Inventory by Dunn, Dunn, and Price (1989), and three other attitudinal surveys on technology (scientific calculators, graphing calculators, and computers) based on Carruther's (1990) Attitude Toward Computers Scale. Students' final course grades were compared to investigate relationships between mathematics achievement and learning style, and feelings and beliefs about technology. Treacy found that there were significant correlations between students' learning style preferences and their feelings and beliefs about technology, and that certain learning style preferences such as motivation, persistence, and auditory preferences influenced mathematics achievement significantly. Additionally, feelings, rather than beliefs about technology, were more important in predicting achievement; and positive feelings and beliefs about computers and graphing calculators, rather than scientific calculators, were associated with achievement.

Alfonso and Long (2005) studied rural (N = 75) and non-rural (N = 55) high school students learning algebra with GCs, and their learning styles (using Myers-Briggs Type Indicator [MBTI], Myers, McCauley, Quenk, & Hammer, 1998). The MBTI measures personality traits along four dichotomous scales: Extroversion (E) – Introversion (I) (energised by the outside world or the inner world), Sensing (S) - Intuition (N) (preference for taking in information from specific to general, or from general to specific), Thinking (T) - Feeling (F) (preference for making decisions through logic and scientific methods or through personal values and feelings), and

Perceiving (P) - Judging (J) (preference to keep things open or move towards closure). A survey about how comfortable students feel about working with the GCs was also administered. The researchers found no significant differences between the rural and non-rural students in terms of comfort with GC use, and with their MBTI style types. The ENFP type occurred the most frequently among both non-rural (52.7%) and rural (33.3%) students. As well, no significant difference was found in academic achievements among students in both groups.

Investigating the association between brain hemisphericity, learning styles, and confidence in using CAS calculators, Ali and Kor (2007) administered three instruments to 44 undergraduate mathematics students in a Malaysian university: the Brain-Dominance Questionnaire (Mariani, 1996), Index of Learning Style Inventory (Felder & Solomon, 2001) and Confidence in Using GC to Learn Mathematics Questionnaire (Ali & Kor, 2004). The learning styles investigated consisted of four domains: active – reflective, sensing – intuitive, visual – verbal, and sequential – global (Felder & Solomon, 2001). Although the researchers did not find any significant differences between calculator confidence and learning styles, nor between calculator confidence and brain hemisphericity, there were significant associations between learning styles and brain dominance. Most of the participants (71%) were left brain dominant, and they tended to be sensing and sequential learners. There were also no significant differences in brain dominance by gender or race.

In summary, disparate research goals and learning styles were investigated in these studies, which led to fragmented information about the links between learning styles and technology use in mathematics education. Technology use seemed to benefit students with certain learning preferences (Gasiorowski, 1998), and feelings about technology and learning styles seemed to influence students' achievement (Treacy, 1996). There appear to be equivocal findings relating to learning styles and technology attitudes, with Treacy (1996) finding correlations between learning styles and technology beliefs and feelings, and Alfonso and Long (2005) and Ali and Kor (2007) finding no significant differences between learning styles and technology confidence. Since different models of learning styles were used and the sample sizes for some studies were small, no clear conclusions can be drawn. More research is thus needed in this area. In the next two subsections, three frameworks and models from the learning styles literature that have the potential to influence students’ advanced calculator use are reviewed. These are: students’ approaches to learning, multimodal preferences, and social interaction for learning preferences.

Students’ approaches to learning. It has been proposed that students’ study behaviours mediate the relationship between cognitive style and student performance (e.g., Biggs, 1987a). There is a branch of research in this area developed in the 1970s and 1980s which investigated what is known as students’ approaches to learning (SAL) (Beattie, Collins, & McInnes, 1997).

The SAL literature pointed to early work by two Swedish researchers, Marton and Säljö (1976a, 1976b), who studied university students’ learning processes using naturalistic experiments such as reading and interpreting texts, and in-depth interviews about how they tackled the reading task. Differences were found in the outcomes of learning which were associated with “qualitative differences in the process of learning” (Marton & Säljö, 1997, p. 47), described as surface levels and deep levels of processing, depending on whether students search for meaning and understanding within the text, or just try to memorise parts of the text. Students’ learning intentions were found to affect their learning outcomes (Marton & Säljö, 1976a, 1976b), and their approaches to learning were situated in both the content and the context of learning (Entwistle & Ramsden, 1983). Since then, research has branched into two directions, one using the qualitative approach, later called phenomenography, adopted by Marton and Säljö in their original work (Marton & Säljö, 1997), and the other using quantitative methods (self-report surveys and questionnaires). The latter direction was taken up by Biggs in Australia and Entwistle in the United Kingdom (see reviews e.g., Beattie et al., 1997; Biggs, 1993a; Watkins, 2001).

Stemming from his work on tertiary students’ study processes since the 1960s, Biggs (1993) commented that his original 10-scale instrument (Biggs, 1976) had “too many scales to be useful” (Biggs, 1993, p. 4) to inform classroom practice. Influenced by Marton and Säljö, further work led him to conceptualise a “student approaches to learning” (SAL) framework that describes student learning approaches as being made up of a combination of motive and strategy.

A *surface* approach:

> arises from an intention to get the task out of the way with minimum trouble, while appearing to meet course requirements. Low cognitive-level activities are used, when higher level activities are required to do the task properly. (Biggs & Tang, 2007, p. 22)

This could mean using rote learning and memorising when understanding is required, and having extrinsic motivation. A *deep* approach, in contrast “arises from a felt need to engage the task appropriately and meaningfully, so the student tries to use the most appropriate cognitive activities handling it” (Biggs & Tang, 2007, p. 24), such as focusing on underlying meanings, main ideas, and having intrinsic motivation in learning. Biggs also conceptualised an additional *achieving* approach which was dropped in later shorter revisions of the instruments (Kember, Biggs, & Leung, 2004).

The instruments used by Biggs and colleagues were the Student Process Questionnaire (SPQ; Biggs, 1987b) for university students and the Learning Process Questionnaire (LPQ; Biggs, 1987c) for secondary school students. Research studies have investigated the psychometric properties of the instruments (e.g., Fox, Manus, & Winder, 2001; Kember, Biggs, & Leung, 2004) and related students’ approaches to their preferences for assessment methods (Furnham, Batey, & Martin, 2011), to learners’ self-concepts (Burnett, Pillay, & Dart, 2003), to student outcomes (e.g., SOLO taxonomy by Biggs & Collins, 1982), and to other psychological constructs (e.g., to personality traits by Zhang, 2003; to career personality types by Zhang, 2004).

Parallel work was done by Entwistle and colleagues (Entwistle & Ramsden, 1983) who drew on the work of others like Marton and Säljö (1976a, 1976b), Pask (1976) and Perry (1970) to investigate the attributes of university students that influence academic success. Their inventory, although developed independently, had similar factors (and items) as Biggs’ instrument, and was further refined to the Approaches to Study Inventory (ASI; Entwistle & Ramsden, 1983) measuring four orientations to studying: Meaning, Reproducing, Achieving, and Non-academic. The first three orientations were similar to Biggs’ Deep, Surface, and Achieving approaches respectively (Entwistle & Ramsden, 1983). However, as mentioned by the researchers about their studies: “two main orientations were clear-cut and identifiable in every discipline, being meaning orientation and reproducing orientation” (Entwistle &

Ramsden, 1983, p. 51). In summarising the field, the defining features of SAL are found in Table 2.3 as described by Entwistle (2001).

Table 2.3

Defining Features of SAL (Entwistle, 2001, p. 596)

Approach	Intention	Methods
Deep (transforming)	To understand ideas for yourself	Relating ideas to previous knowledge and experience Looking for patterns and underlying principles Checking evidence and relating to conclusions Examining logic and argument cautiously and critically Becoming actively interested in the course content
Surface (reproducing)	To cope with course requirements	Studying without reflecting on either purpose or strategy Treating the course as unrelated bits of knowledge Memorising facts and procedures routinely Finding difficulty in making sense of new ideas presented Feeling undue pressure and worry about work

There is a body of work with the SAL instruments, particularly in the higher education sector. Students' approaches to learning were found to be related to their perceptions of the quality of teaching, assessment, and course content and structure (Ramsden, 1997; Trigwell, Prosser, & Waterhouse, 1999), coping strategies used when studying for examinations (Moneta, Spada, & Rost, 2007), and learning outcomes (Chamorro-Premuzic & Furnham, 2008; Trigwell & Prosser, 1991). Trigwell, Prosser and Waterhouse (1999), for example, found that students in classes where their teachers described their teaching approach as focusing on transmitting knowledge were more likely to adopt a surface approach to learning the subject. Conversely, where their teachers reported a student-centred teaching focus, students adopted a significantly deeper approach to learning. In another study on 158 first year undergraduate students (~70% females) from University College London, Chamorro-Premuzic and Furnham (2008) measured students' approaches to learning (using SPQ), personality traits, and intellectual ability, and compared their psychometric scores with academic ability (measured by the mean score of six essay-based examinations) after a year. It was found that academic performance correlated with ability, achieving and deep learning approaches, and openness to experience and conscientious personality traits. These variables together explained 40% of the variance in academic performance (AP), suggesting that the different student factors operate independently to lead to different student outcomes. The researchers also noted that a “deep learning approach contributed to the prediction of AP beyond personality and intelligence” (Chamorro-Premuzic & Furnham, 2008, p. 1602). However, Duff, Boyle, Dunleavy, and Ferguson (2004), studying 146 social science undergraduates, found that the three approaches to learning (deep, surface and achieving approaches) were related to some personality traits but were poor predictors of academic performance. They used a different set of instruments from Chamorro-Premuzic and Furnham (2008) to measure SAL, a revised version of the ASI developed by Entwistle, and personality traits.

In relation to mathematics education, Crawford, Gordon, Nicholas, and Prosser (1994, 1995, 1998) investigated the relationships between students’ conceptions of mathematics, their approaches to learning mathematics, and their academic performance. Using a phenomenographic approach (Crawford et al., 1994), they found that there were two types of students’ conceptions of mathematics: fragmented (mathematics as number, rules and formula, with applications to problems) and cohesive (mathematics as a way of thinking for complex problem solving and providing new insights for understanding the world). Surveying about 300 first year mathematics students in an Australian university using a modified version of Bigg’s SPQ, the researchers found over 75% of the students held fragmented conceptions of mathematics and over 90% of these students learnt it using surface approaches (Crawford et al., 1994). Quantitative analysis revealed that the fragmented conception was significantly correlated to the surface approach subscales ($r = 0.36$), and the cohesive conception was significantly correlated to the deep approach subscales ($r = 0.43$). They also investigated students’ perceptions of aspects of the course: workload, assessment, teaching, goals of the subject, and freedom in learning, using a modified version of the Course Experience Questionnaire (Ramsden, 1990). A surface approach was associated with inappropriate (high) workload and assessment measuring reproduction of knowledge, and a deep approach was associated with good teaching, freedom in learning and clear goals (Crawford et al., 1995). Cluster analysis of the data revealed two groups of students, a group with fragmented conceptions of mathematics, used surface approaches to learning mathematics, perceived the course as having high workload and reproduction type of assessment, and achieved relatively low marks on the final examinations. The second group had cohesive conceptions of mathematics, used deep approaches to learning mathematics, perceived the course as having clear goals, good teaching and freedom to learn, and achieved at a higher level in the final examinations (Crawford et al., 1998). The researchers concluded that students' conceptions of mathematics were related to their approaches to learning mathematics and their perceptions about the learning environment.

In a separate study on 279 second year psychology students learning statistics, Gordon (1997) also found qualitatively different orientations to, and outcomes of, learning statistics. She found four clusters of students:

1) a group of 47 high achievers adopting a deep approach to learning statistics; 54% of students in this group expressed willingness to learn statistics, and 53.5% perceived statistics as a tool that is applicable in real life;
2) a group of 61 high achievers adopting a surface approach, but 77% of students in this group reported reluctance to study statistics. Most of them either perceived statistics as mechanical techniques or algorithms (39%) or as information to be accumulated and stored to meet assessment demands (32%);
3) a group of 42 relatively low achievers adopting a deep approach, with an average score in the final examinations of 52%, compared to 77% and 70% for groups 1 and 2, and 38% for group 4; and
4) a group of 61 low achievers adopting a surface approach; 93% of them reporting reluctance to learn statistics, and 55% perceived statistics as about mastery of statistical ideas and skills.

Even though nearly 75% of the participants were females (203 out of 279), there were gender differences in the clustering, with 38% and 30% of the males falling into groups 2 and 1 respectively, and 33% and 26% of the females falling into groups 4 and 2 respectively. Generally, males in the study "tended to see the statistics in terms of academic exercises" (Gordon, 1997, p. 194) compared to females. For example 10% of males viewed statistics as having No Meaning (imposed and irrelevant, "you tell me, I just learn", p. 194) compared to 3% of females; and 14% of the males viewed statistics as a Tool, compared to 33% of the females. In the final examinations, however, males outperformed females significantly, (mean scores: male = 63.9%, females = 56.6%, $t = 2.58$, $p < .05$). Females were found to score significantly higher than males on the surface approach subscale, and there was no gender difference in deep approach scores. Gordon (1997) concluded that a majority of the psychology students were unwilling to learn statistics, saw the subject as an accumulation of knowledge to satisfy assessment requirements, and used surface approaches to learn it. She called for a need to take a more systematic view of the learning environment and consider not only the subject content and delivery of lessons, but also students' perceptions of the subject and its learning context.

Overall, researchers pointed to the close relationship between students' approaches to learning and their perceptions of the learning context (e.g., Beattie et al., 1997; Biggs, 1993; Crawford et al., 1998; Entwistle & Ramsden, 1983; Gordon, 1997). Culture might be a factor of consideration because in certain cultures such as Chinese and Japanese cultures, there are beliefs that "understanding may come through memorisation... and as the intention here is clearly to deepen understanding, a memorisation strategy in this case becomes part of a deep approach" (Biggs, 1993, p. 7; also see Fan, Wong, Cai, & Li, 2004). However, in comparing the SAL of 63 matched-pairs of local Australians and South-east Asian students before and after their first semester in an Australian university, Volet, Renshaw, and Tietzel (1994) found that South-east Asian students had consistently higher surface approach scores than Australian students, and that the two groups showed similar patterns of change in their SAL. The researchers also concluded that South-east Asian students adapted to the local teaching and learning context and became more similar to their Australian counterparts, which showed that SAL was influenced by students' perceptions of the learning environment "rather than determined by stable personal characteristics or cultural differences" (p. 301). Furthermore, in a number of validation studies of inventories such as the LPQ and SPQ in different cultures, confirmatory factor analysis yielded two factors corresponding to surface and deep approaches (e.g., Kember & Leung, 1998, on tertiary and secondary students in Hong Kong; Deo & Phan, 2006, on students from Fiji and other Pacific Islands). Bernardo (2003) used Bigg's LPQ to assess Filipino college students' approaches to learning, and found that it was valid for non-low-achieving students, with deep and achieving approaches relating significantly to academic achievement. This relationship was generally similar for both boys and girls.

There seems to be a general consistency in the findings across students of different year levels. Burnett and Proctor (2002) used the LPQ with 580 elementary students (years 6-7) in Brisbane schools. They investigated the relationship between SAL and students' self-concepts of school, reading, mathematics, and learning. They found that strong mathematics and reading self-concepts were significantly correlated with deep approaches to learning. For the middle years, Burnett, Pillay, and Dart (2003) surveyed 355 students between Years 8 to 12 in Australia, and found that students using a deep approach liked learning new things and viewed learning as a personal development, whereas students using a surface approach reported that they were not good at learning and also adopted an achieving approach. Using structural equation modelling, they found that students' self-concepts mediated their conceptions of meaning and approaches to learning.

Gender differences in approaches to learning were also investigated in some studies, such as Gordon (1997) and Bernardo (2003) cited earlier. Duff (2002) reviewed previous studies using the ASI (Entwistle & Ramsden, 1983) and its revised versions, and found that most studies (11 out of 13) reported no gender differences. One study reported that males scored higher than females on reproducing (surface) and achieving orientations (Gledhill & van Der Merwe, 1989), and another reported that males scored higher on deep approaches and females scored higher on surface approaches (Sadler-Smith, 1996). Duff's (2002) own study on 308 undergraduates and graduates of a business and management course found some gender differences: the three-factor model fitted better to females than males; and the factor loadings, error variances and factor covariances were different. He suggested that the constructs "might be differentially indicated across groups" (p. 997), but that the instrument did not seem "sufficiently sensitive to measure gender differences" (p. 1008) since it did not contain certain types of constructs known to have gender differences, such as females' preference for interaction during learning and for relating subject-matter to personal experience. Furthermore, since students' approaches to learning depended on their perceptions of the learning context, content, and assessment, and gender studies had shown some differences in these perceptions by males and females, therefore "gender differences in approaches to learning could emerge in particular academic contexts, or via specific forms of academic assessments" (Duff, 2002, p. 1007).

A final point to note about SAL is that "it is unrealistic to assume that a deep approach to learning is universally desirable" (Beattie et al., 1997, p. 1), instead "it is important to have the right balance: you need surface to have deep; and you need to have surface and deep knowledge *and* understanding in a context or set of domain knowledge" (Hattie, 2009, p. 29). Hence, a mix of approaches to learning is possible (Beattie et al., 1997) and even desirable (Hattie, 2009).

Overall, SAL is shown to be related to students' conceptions about mathematics, their self-concepts, and perceptions about the learning environment. There does not seem to be a study involving students' use of technology and SAL. Given that technology use changes the learning context and environment, perhaps even more so for the case where advanced calculators are being used in high-stakes examinations, such a study seems urgently needed.

Multiple representations and multimodal preferences. Noss (2001) argued that technology and multiple representations change the way we come to know things. With the use of advanced calculators in the curriculum, there is an increased emphasis on visualisation of relationships through graphs, and the relationships between symbolic and graphic representations (Ruthven, 1996).

Since the GC and CAS calculators offer what Kaput (1998) called the "Big Three" representations – "numerical, graphical and character-string" (p. 272), researchers have been interested in the roles that multiple representations play in students' mathematical learning (e.g., Dunham & Dick, 1994; Kendal & Stacey, 2003; Kieran, 2007; Ruthven, 1990). Recently, researchers have also investigated other modes of representation such as verbal and kinesthetic (see Ferrara, Pratt, & Robutti, 2006).

In the research literature, there is an assumption that representational fluency promotes mathematical understanding, and is one of the affordances of technology (e.g., Brenner, Herman, Ho, & Zimmer, 1999; Kieran, 2007). Zbiek, Heid, Blume, and Dick (2007) described representational fluency as

> the interaction between student and representation, … includes the ability to translate across representations, the ability to draw meaning about a mathematical entity from different

> representations of that mathematical entity, and the ability to generalize across the different representations. (p. 1192)

However, researchers have also found that there are students who seemed to prefer one type of representation over others. Ruthven (1990), for example, studied upper secondary students in England and their use of the GC for solving questions involving algebraic descriptions of graphs (symbolisation). He found the following different approaches used by students:

- *analytic-construction* approach, where "the student attempts to exploit mathematical knowledge, particularly of links between graphic and symbolic forms, to construct a precise symbolisation from the information available in the given graph" (p. 439)
- *graphic-trial* approach, for which the student "uses the graphing facility of a calculator to repeatedly modify a symbolic expression in the light of information gained by comparing successive expression graphs with the given graph" (p. 440)
- *numeric-trial* approach, where "a symbolic conjecture is formulated, often guided by the numeric pattern of a small number of coordinates from the graph as well as graphic form, and modified in the light of the information gained by comparing calculated values of the expression with corresponding values on the given graph" (p. 441-443)

Herman (2007) studied the strategies chosen by students when solving algebra problems using the GC. She found that even when students were proficient in using GCs for both graphical and tabular approaches to problems, they tended to choose symbolic approaches as their primary solution strategy.

Villarreal (2000) studied three pairs of women (first year biology students) learning applied mathematics using *Derive* software. She observed two general styles or approaches used by the students: algebraic and visual, which are not mutually exclusive but complementary (see Table 2.4).

Table 2.4

Algebraic and Visual Approaches (adapted from Villarreal, 2000, pp. 4-5)

Approach	Description
Algebraic approach	a preference for analytic solutions when graphic solutions are also possible; difficulty in establishing graphic interpretations of analytic solutions; when a graphic solution is requested, a brief run through the analytic one is needed; facility with formulating conjectures and refutations or generating explanations based on formulas or equations.
Visual approach	use of graphic information to solve mathematical questions that could also be approached algebraically; difficulty in establishing algebraic interpretations of graphic solutions; when graphic solutions are requested, there is no need to run through algebra first; facility in formulating conjectures and refutations or giving explanations using graphic information.

Students might work with an algebraic or visual approach or use both approaches depending on the situation. An example given by Villarreal (2000) was when a pair of students had to determine if a line tangent to a point on a parabola touches the parabola at another point. Visually on the computer, the tangent line appeared to touch the parabola at more than one point, even after zooming in (visual strategy). An algebraic strategy was then used to solve the problem. One issue that Villarreal (2000) pointed out was that students preferring algebraic approaches “can experience difficulties or discomfort in the computer environment” (p. 7). In another study of tertiary students studying abstract algebra, Zazkis, Dubinsky, and Dautermann (1996) also found that most students used some combination of visual and analytic approaches, rather than distinctly preferring one or the other. They concluded that the conventional analyser/visualiser dichotomy was not appropriate for describing the learning process and proposed an alternative model where visualisation and analysis were mutually dependent in problem solving.

The idea of students’ preferences was supported by others. Presmeg (2006), for example, added that “the claim that students are reluctant to visualize was complex and should not be interpreted simplistically to mean that students do not use this mode of mathematical thinking” (p. 215). She cited other factors, such as the problem task, the task instructions, and sociocultural factors, which affected students’ preferences for certain approaches. Herman (2007) described other factors that influenced students’ approaches including their perception of what is mathematically proper, their teachers’ beliefs about the value of the different approaches, their exposure to uses of representations modelled by their teachers, and their perceptions of the efficiency in which a particular representation can be used to solve the given problem. Kendal and Stacey (2001) also found teacher privileging, that is, “a teacher’s individual way of teaching and includes decisions about what is taught and how it is taught” (p. 145), to be a critical factor.

Culture might be a factor that affects students’ preferences for different representations. Brenner et al. (1999) investigated the test responses of 895 sixth-grade students from four nations (China, Taiwan, Japan, and United States). It was found that all Asian students scored significantly higher on visual representation of fractions compared to American students; Chinese students had the highest scores. Interestingly, Cai and Lester (2005) compared U.S. and Chinese teachers’ use of representations when teaching (pedagogical representations) and their grade 6 students’ use of symbolic, verbal (written) or pictorial (visual drawings) representations. The four U.S. and five Chinese teachers were video-taped in their lessons and their use of representations in five common types of instructional tasks were coded and analysed. Students’ representations were measured through their solutions to 12 open-ended assessment tasks. The researchers found that U.S. students (N = 232) had significantly higher representational mean scores than Chinese students (N = 310) in using written words and visual drawings, whereas Chinese students had significantly higher representational mean scores than U.S. students in using mathematical symbols. The use of symbolic representations in both samples correlated with performance in the assessment tasks. Additionally, Cai and Lester (2005) found that Chinese teachers “overwhelmingly used symbolic representations for solutions to instructional tasks, whereas U.S. teachers relied almost exclusively on verbal explanations and pictorial representations” (p. 235); these were indicative of the social and cultural differences in pedagogical practice.

There is some parallel between the representational preferences discussed above and the learning preferences found in cognitive psychology. Keller and Hirsch (1998) described two directions taken by research on students’ preference for representations, the first attempting “to determine students’ preferences by the representation *used* to perform tasks” (p. 2). They described, as an example, Dreyfus and Eisenberg’s (1992) study on students’ intuitions on function concepts presented in diagram, graph, and table settings, and found that high ability students preferred graphical settings throughout, whereas students with low ability preferred the table settings. The other direction of research is “oriented more towards learning or cognitive styles” (Keller & Hirsch, 1998, p. 3). Students’ cognitive preferences for certain representations might be constrained by their perceptions of the type of task given, learning environment, and their own mathematical abilities. Keller and Hirsch (1998) argued that technology could remove some of the constraints by making certain representations more accessible to students. In their own study, described earlier in this chapter, they found that students did have preferences for certain representations (graphs, equations or tables), which were different for contextualised and non-contextualised problem tasks. Also, students in the experimental group who were using GCs were more likely than those not using GCs to prefer graphs on both types of tasks. The researchers believed that using GCs “diminished differences in preferences of students between contextualized and non-contextualized situations by removing constraints perceived by students on the ease with which various representations could be manipulated” (p. 14).

In the learning styles literature, the different modalities in which individuals prefer to perceive and process information were investigated. In reviewing the literature on individual perceptual preferences for the instructional design of audiovisual materials, Jaspers (1992) clarified that the term “preferences” can be understood in two ways: *subjective* preference, where there is “a tendency for learners to prefer one modality rather than another” (p. 236); and *objective* preference, where the modality chosen is the more or most effective one, and is different for different individuals. In the second instance, a student might choose a particular modality because it is the most effective. An example can be seen in Keller and Hirsch’s (1998) study; two students interviewed said they were dyslexic and preferred graphical methods due to difficulty in reading symbols. According to Jaspers (1992), studies often did not differentiate between the two types of preferences and, overall, the theoretical basis for different types of modalities such as video or audio, verbal or visual, was still incomplete.

One of the earlier works in education on perception modalities including visual, auditory, tactile, and kinesthetic was by Barbe and Milton (1980, 1981), who referred to the channels through which perceptions occurred as “modalities”. They distinguished between modality strengths and modality preferences. The former refers to the most efficient channels for processing information (objective preference) as measured by some kind of task, and the latter being a subjective preference as measured by self-reports in questionnaires like the Learning Style Inventory by Dunn, Dunn and Price (1975).

Fleming (2006) developed the VARK framework – Visual, Aural, Read/Write, and Kinesthetic – of modal preferences that individuals have in receiving and transmitting information (see Table 2.5). Although influenced by prior research on visual, aural and kinesthetic sensory approaches (VAK) in neuro-linguistic programming (Fleming & Mills, 1992), as well as Dunn and Dunn’s learning styles model (Dunn, 1984), Flemings’ emphasis is on the “pragmatic part, of the complex set of attributes that make up a learning style” (p. 46), since “students and teachers can do something about learning when they know their modality preference” (p. 46).

Table 2.5

VARK Framework (Fleming, 2006, pp. 1-2)

Preference	Description
Visual (V)	This preference includes the depiction of information in charts, graphs, flow charts, and all the symbolic arrows, circles, hierarchies and other devices that teachers use to represent what might have been presented in words. Layout, whitespace, headings, patterns, designs and colour are important in establishing meaning. These students are more aware of their immediate environment and their place in space. It does not include pictures, movies, videos and animated websites (simulation) that belong with Kinesthetic below.
Aural (A)	This perceptual mode describes a preference for information that is spoken or heard. Students with this modality report that they learn best from discussion, oral feedback, email, cellphone chat, discussion boards, oral presentations, classes, tutorials, and talking with other students and teachers.
Read/Write (R)	This preference is for information displayed as words either read or written. Not surprisingly, many academics and high-achieving students have a strong preference for this modality. These learners place importance on the precision in language and are keen to use quotes, lists, texts, books and manuals. They have a strong reverence for words.

Preference	Description
Kinesthetic (K)	By definition, this modality refers to the “perceptual preference related to the use of experience and practice (simulated or real).” Although such an experience may invoke other modalities, the key is that the student is connected to reality, “either through experience, example, practice or simulation”. It is often referred to as “learning by doing” but that is an oversimplification, especially for college and university learning which is often abstract but can still be made accessible for those students with a Kinesthetic preference. This mode is where students use many senses (sight, touch, taste and smell) to take in their environment to experience and learn new things. Some theorists believe that movement is important for this mode but it is the reality of a situation that appeals the most.

Although Fleming’s model is not specific to mathematics (it does not have numeric or symbolic modes which might be subsumed under Read/Write preferences), it appears to be a useful model that covers aspects of students’ representational preferences that would be relevant to mathematics learning with technology use, compared to other learning style measures such as the more established “Verbal-Imagery style dimension” which was developed by Rayner and Riding (1997) from a meta-analysis of other cognitive and learning style constructs. Even within the different types of visualiser-verbaliser measures, the Verbal and Imagery measures in the Cognitive Styles Analysis instrument by Riding (1991) did not correlate with other similar measures and did not seem to “measure what other instrument designers think of as cognitive style or learning preference” (Mayer & Massa, 2003, p. 838).

Fleming’s (2006) model also takes into account multimodal preferences, of which there are two types: an individual can select different modes according to the learning situation, or might assimilate the same input via different modes in order to learn. This is consistent with the literature on mathematics education where students can have multiple approaches or preferences. Additionally, Fleming also described the difference between a modality preference (subjective preference) and the strength of the preference (efficiency of the preference) and suggested strategies to students to reinforce or expand their preferences. In contrast to other VAK learning style models which are popular in schools, but noted for their lack of research scholarship (see Sharp, Bowker, & Byrne, 2008), the VARK learning styles inventory has been found to have some validity (Leite, Svinicki, & Shi, 2010), and has been used in research studies (e.g., French, Cosgriff, & Brown, 2007, linking VARK to Kolb's Learning Styles; Rogers, 2009, on using VARK to customise a university course; Dobson, 2010, comparing perceived and assessed VARK preferences by gender and course performance).

In summary, there is a body of research into students' preferences for mathematical representations, and the use of technology such as advanced calculators has provided cognitive support in terms of ease of converting between representations. However, there appears to be no study investigating students' preferences for *learning how to use* the calculators, a context which might play an important part in their representational preferences when using the calculators to solve problems. In the learning styles literature, preferences for perceptual and sensory modalities such as visual, aural, read/write, and kinesthetic modalities seem to have some parallel features relating to how students learn to use the GC and CAS calculators: visual – graphs on the calculator screen and screenshots; aural – teacher instruction and peer discussions; read/write – text, symbols and written instructions; and kinesthetic – solving contextual problems, actual pressing of the calculator buttons and working with the calculator. As such there is a potential to investigate these modality preferences with calculator use.

Social interaction for learning preferences. Learning can also be seen as "a social as well as an individual activity" (Jarvis, Holford, & Griffin, 2003, p. 42). As discussed in the reviews of calculator studies relating to social interaction and communication earlier this Chapter, it can be seen that advanced calculators have the potential to enhance the quality of student-peer-teacher interactions, yet they can also limit collaboration. Also, there seems to be a limited number of studies in this area.

In the learning styles literature, there are different style models with varied views of social interaction in learning, in terms of stability of the preference and theoretical basis of the quality of interaction. The Dunn and Dunn model (Dunn, Dunn, & Price, 1975), for example, was categorised by Coffield et al. (2004) as constitutionally-based, with the theoretical belief that the styles were biologically imposed and relatively fixed and thus teaching should be customised to accommodate them. In contrast, the Grasha-Riechmann model (Riechmann & Grasha, 1974) was categorised by both Coffield et al. (2004) and Curry (1983) as belonging to the family of instructional approaches, strategies, orientations, and preferences, and being influenced by person-environment interactions. Some of the style models are described below.

Dunn and Dunn model. One of the more famous learning style models is Dunn and Dunn's model of learning style preferences (Dunn & Dunn, 1978). It contains different elements that affect learning: environmental, emotional, sociological, and physical. Under the sociological element, Dunn and Dunn proposed that students can learn in a variety of ways: "working alone, with one or two friends, with a small group or as part of a team, with adults, or, for some, in any variation thereof" (Dunn & Dunn, 1978, p. 12). Unfortunately, there are critiques about the validity and reliability of studies involving Dunn and Dunn's model (e.g., Coffield et al., 2004; Kavale & LeFever, 2007). In a systematic and critical review of learning styles models by Coffield et al. (2004), the authors highlighted "serious concerns about the [Dunn and Dunn] model, its application and the quality of the answers it purports to offer about how to improve learning" (p. 33). The Dunn and Dunn model assumed that preferences are relatively fixed, which is in contrast to other learning style models that are based on approaches and strategies that are context-specific and amenable to change. Moreover, the large number of empirical studies reviewed "evaluated only one preference (within an element) in a test or a short intervention" (p. 33), and the studies

> appear to have chosen that element in advance of testing the preferences of the experimental population and sometimes only include students with strong preferences. In addition, the studies often test one preference and then combine results from single studies to claim overall validity (p. 32).

The studies that supported the Dunn and Dunn model are generally associated with St. John's University, in which "Dunn heads the Center for the Study of Learning and Teaching Styles" (Kavale & LeFever, 2007, p. 98), and there is "little independent evaluation of their model" (Coffield et al., 2004, p. 28).

Grasha-Riechmann model. The Grasha-Riechmann Student Learning Style Scales (GRSLSS) was developed "based on the types of learning styles students demonstrate in the classroom" (Riechmann & Grasha, 1974, p. 214). From the perspective of three classroom dimensions of student attitudes towards learning, views of teachers and/or peers, and reactions to classroom procedures, the researchers classified six general styles:

> Independent – prefer to think for themselves, work on their own, and learn content they feel is important;
>
> Dependent – show little intellectual curiosity, learn only what is required, see teachers and peers as sources of structure and support, want to be told what to do;
>
> Collaborative – feel that they can learn the most by sharing their ideas and talents, cooperate with teachers and peers and likes to work with others, see classroom as a place for social interaction and content learning;
>
> Competitive – learn material in order to perform better than others in the class, compete with other students in the class for grades or teachers' attention, view classroom as a win-lose situation where they must win;
>
> Participant – want to learn the course content and like to go to class, take responsibility for getting the most out of class and participate with others when told to do so;
>
> Avoidant – not interested in learning course content in the traditional classroom, do not participate with students and teachers, uninterested or overwhelmed by what goes on in the classes. (adapted from Riechmann & Grasha, 1974, pp. 221-222).

Although Curry (1983) found some reliability and internal consistency in the GRLSS, Ferrari, Wesley, Wolfe, Erwin, Bamonto, and Beck (1996) administered GRLSS to 870 students and found that there was acceptable internal consistency for the Participative, Avoidant, and Collaborative scales, but not for the Dependent, Independent, and Competitive scales. Factor analyses of the items and scales did not produce a satisfactory solution or a factor structure which was aligned to the theoretical model.

Owens and colleagues. Similar to Grasha and Riechmann's (1974) styles, but influenced by goal theory in the study of motivation in educational psychology (see e.g., Ames, 1984; Deutsch, 1949; Johnson & Johnson, 1974), Owens and colleagues (Owens & Barnes, 1982; Owens & Straton, 1980) described three learning preferences: *cooperative*, *competitive*, and *individualised*. The preference for different modes of learning "is a basic part of the 'mental set' by which a learner perceives dimensions of classroom atmosphere or climate" (Owens & Barnes, 1982, p. 183). The different types of modes or goal structures described by Owens and Straton (1980) are:

(a) cooperative - where "students can achieve their own individual goals only by working conjointly with others as they achieve their goals (e.g., a large task accomplished by division of labour" (p. 147);
(b) competitive - where "students can achieve their own individual goals only when others fail to achieve their goals (e.g., coming first in a test or a race)" (p. 148);
(c) individualistic – where "students can achieve their own individual goals no matter what others have chosen to do (e.g., completing an individually-assigned library research assignment)" (p. 148).

Through surveys of large samples of Australian, American, and English schoolchildren, it was found that the three preferences were independent. Owens (1993) also surveyed teachers in Sydney (Australia), Minneapolis (United States of America), and the Midlands (England). He found that there were significant differences in competitive learning preferences between male and female teachers in Sydney and Minneapolis, with males more inclined to competitiveness than females. He also found that "in all three locations, the learning preferences of Mathematics teachers were strongly oriented to competitive learning" (p. 461).

Other studies. Emanuel and Potter (1992) adapted a questionnaire from various sources such as Riechmann and Grasha, and Owens and Barnes, to survey high school and college students about their learning styles. They distinguished between six types of styles similar to that by Riechmann and Grasha: Dependent, Independent, Participative, Avoidant, Collaborative, and Competitive. In an analysis of the 327 high school students (years 8-12) and 235 college students (different majors), it was found that, overall, females were more likely to be Participative and less likely to be Independent than males. Compared to high school students, college students scored significantly higher in Participative, Competitive styles, and significantly lower in Dependent, Collaborative, and Independent styles. These differences for Dependent, Collaborative, and Competitive styles were more pronounced for females than males. There were also differences across year levels, “generally increasing preference for Dependent and Participative styles as grade level increases” (p. 408), as well as across different study majors. The researchers did not discuss gender differences, but suggested that high school students might be socialised into enjoying the participation in scholastic activities and became more dependent on the teacher over time. They claimed that the differences between college and high school students could be due to the differences in expectations (e.g., taking responsibility for own learning), or to other factors such as composition of the students surveyed.

As reviewed in an earlier section of this chapter (p. 39), Boaler (2002) found that in the school with traditional mathematics teaching, both boys and girls expressed dislike of textbook lessons; yet boys and girls gave different reasons for their preferences. Boaler (2002) generalised the boys’ reasons as “playing a kind of school mathematics game” (p. 139) and the girls’ reasons as “a quest for understanding” (p. 139). The boys competed with one another in the “game”, whereas the girls became disaffected in relation to mathematics. For the girls, the reasons they gave for preferring to work cooperatively in groups, or for working at their own pace, were to provide a greater depth of understanding. Boys said they enjoyed individualised work because it enabled them to “tear ahead and complete as many books as possible” (p. 143). Here it would seem that the preferences for working competitively, individually and cooperatively were influenced by gender and the learning environment.

Ingram (2008) investigated the effects of seating arrangements in the social interactions and social identities of 31 students during mathematics classes in an urban coeducational school in New Zealand. She found that in self-choice seating and in assigned seating, “seating arrangements were successful when two conditions operated: *other students’ behaviour did not negatively affect the student* and the student *liked and felt comfortable with the others they were sitting with*” (p. 283). Ingram also said that if the seating arrangement was unsatisfactory (i.e., a student was distracted or disrupted by others sitting around him/her), then the impact might be greater if the student had a verbal learning preference. Ingram quoted one student: “In maths, it’s a subject where talking helps you…talking to the people beside you helps… so if you're silent, you don't learn as much" (p. 284). However, Ingram added that the social element and identity became stronger when the students became more confident with members of the opposite sex and there was a tension between their social and mathematical identities. Overall, she recommended that teachers be aware and harness social aspects through sensitive seating plans to improve student learning.

In summary, these studies reveal the complex nature of social interactions for learning. Findings from the learning styles literature showed that students and teachers can have particular social instructional preferences, and that their preferences and the classroom environment interact to affect students' learning. This interaction may be different by gender, year level, subject discipline, and possibly between traditional and technology-rich classroom environments. GC and CAS calculators, as handheld technologies, are personal devices. As remarked by Trouche and Drijvers (2010), on the one hand having ownership could facilitate students to explore freely and make errors (Ruthven, 1990) and on the other hand "this privacy might hinder students from sharing their results, and questions, with peers and their teacher (Doerr & Zangor, 2000)" (Trouche & Drijvers, 2010, p. 669). Hence, an important aspect to study is to investigate students' social interaction for learning preferences in the context of GC and CAS calculator use.

Summary

In this chapter, the general literature relating to students' use of GC and CAS calculators in mathematics education, and several student factors relating to learning preferences identified to be relevant to this study, have been discussed. In particular, the factors discussed were: students' attitudes towards using calculators to learn mathematics, ways of knowing and understanding mathematics, modal preferences and multiple representations, and social interaction for learning preferences. The findings show that these factors impact the way students learn mathematics using technology tools like the advanced calculators. There are also gender related differences found in students' attitudes, ways of knowing and understanding mathematics, and social interaction for learning preferences. However, there is no one study in which all of these factors and the relationships between the factors are investigated. To do so is the aim of this research study. In the next chapter, the research design and methodology for the study are discussed.

Chapter 3 Methodology

> A *bricoleur* is a handyman who invents pragmatic solutions in practical situations and is adept at using whatever is available. Similarly, I suggest, ..., that rather than adhering to one particular theoretical perspective, we act as *bricoleurs* by adapting ideas from a range of theoretical sources to suit our goals – goals that should aim not only to deepen our fundamental understanding of mathematics learning and teaching, but also to aid us in providing practical wisdom about problems practitioners care about. (Lester, 2005, p. 177)

The aim of this research study was to investigate the relationships between the factors affecting students' learning of mathematics using graphing calculators (GC) or calculators with computer algebra system (CAS calculators), in order to inform teaching and learning practices. Relevant literature on these factors was reviewed in the previous chapter, including research studies conducted in Singapore and Australia. This chapter outlines the research methodology used for the study: design of instruments and methods of data collection and data analyses.

The motivation for the study stemmed from the researcher's own teaching experience (Chapter 1, p. 7). Hence, the intention to benefit teaching practices through research was a pragmatic one. According to Creswell (2009), researchers with a *pragmatic worldview* "look to the *what* and *how* to research, based on intended consequences – where they want to go with it" (p. 11). In a pragmatic paradigm, research always occurs in social, historical, political, and other contexts, and the researchers make decisions being aware of their own values, personal history, social background and cultural assumptions (Morgan, 2007). Pragmatic researchers believe "in an external world independent of the mind as well as that lodged in the mind" (Creswell, 2009, p. 11), and use various different methods, assumptions, forms of data collection, and analysis (Johnson, Onwuegbuzie, & Turner, 2007). These elements of the pragmatic paradigm—pluralistic epistemologies and methodologies, and recognition of the contextual nature of knowledge claims (Howe, 1988; Creswell, 2009)—were the basis for the decisions to draw upon theories from various fields, investigate students from two different countries (educational contexts), and employ mixed methods for the study.

The pragmatic worldview is a relatively new methodological approach, arising from the need to move beyond the "forced choice" (Howe, 1998, p. 14) between positivist/empiricist and constructivist/ interpretivist/ phenomenological approaches (see e.g., Creswell, 2009; Johnson, Onwuegbuzie, & Turner, 2007; Tashakkori & Teddlie, 1998). Morgan (2007) argued that debates between positivist and constructivist paradigms emphasised a "top-down" (p. 57) approach where the ontological assumptions about the nature of reality restricted epistemological assumptions about the nature of knowledge and what could be known, and in turn affected the methodology and methods used.

> In contrast, a pragmatic approach would treat issues related to research itself as the principal "line of action" that methodologists should study, with equal attention to both the epistemological and technical "warrants" that influence how we conduct our research. (Morgan, 2007, p. 68)

In attending to methodological issues as the crux, the pragmatist:

a) uses *abductive* reasoning, which is the "uncovering and relying on the best of a set of explanations for understanding one's results" (Johnson & Onwuegbuzie, 2004, p. 17) through a process of moving "back and forth between induction and deduction" (Morgan, 2007, p. 71) to connect theory and data;
b) relates to the research process through *intersubjectivity* to work between objective and subjective frames of reference (Morgan, 2007, Tashakkori & Teddlie, 1998); and
c) infers *transferability* of findings from the data through the investigation of factors that affect whether the knowledge gained can be transferred to other contexts (Morgan, 2007).

Following from the pragmatic paradigm, consideration was given during the research design to allow for a rich multi-faceted investigation of students' learning of mathematics using calculators through the use of a mixed methods approach. Based on the classic typology of purposes for using mixed methods by Greene, Caracelli, and Graham (1989), the study design is one that seeks to achieve multiple purposes of expansion, triangulation, and complementarity elements. The three mixed-method purposes of this study, using the descriptions by Greene, Caracelli, and Graham (1989), are found in Table 3.1.

Using quantitative and qualitative methods to extend the scope and range of inquiry, the findings from both methods can be triangulated. A quantitative large scale study using survey instruments has strength in numbers. Inferential statistical analyses can be performed to provide information about the population. Comparisons of quantitative data from two regions—in this study, Singapore and Victoria—can enhance the reliability of findings, as well as highlight cross-cultural differences. However, the limitation of a survey instrument is that it can be focused too narrowly on existing factors and items. Therefore the quantitative data were complemented by qualitative data (interviews and classroom observation) which, although with limited generalisability, provide richer descriptions about the factors, and uncover relationships that are specific to the cultural and education contexts.

Table 3.1

Description of Three Mixed-Method Purposes of This Study

Purpose	Description adapted from Greene, Caracelli, & Graham (1989)
Expansion	To extend the scope, breadth, and range of inquiry by using different methods for different inquiry components. A higher order expansion design (e.g., using combinations of qualitative and quantitative methods to assess students' attitudes, learning preferences, and ways of using calculators in this study) can incorporate elements of triangulation and complementarity, becoming a multipurpose study.
Triangulation	The quantitative and qualitative methods used must be different from one another with respect to their strengths and limitations/biases, and both method types must be used to assess the same phenomenon.
Complementarity	Qualitative and quantitative methods are used to measure overlapping and different facets of a particular phenomenon, yielding an enriched, elaborated understanding of that phenomenon.

The study was originally designed to be sequential explanatory (see Creswell, 2009, chapter 10 for a discussion of mixed methods procedures), so that the findings from the large scale survey would inform the selection of participants and interview protocols for the fieldwork in classrooms. It is acknowledged that this mixed methods strategy "often appeals to researchers with strong quantitative leanings" (Creswell, 2009, p. 211). The strength of this strategy is in its straightforward nature of design and clear separate stages. However, as mentioned by Creswell (2009), the weakness is in the length of time required. In the actual conduct of the study, the issue of having to fit the timing of data collection into the school academic year, and to abide by schools' decisions about when to collect the data, made it impossible to conduct the two parts in sequence as was intended.

Hence, the resultant methodology involved two parts conducted concurrently, but the quantitative and qualitative data were analysed sequentially.

Part 1 of the study was a large scale survey conducted from February to November 2009 for Singaporean students and from January to July 2010 for Victorian (Australian) students. A survey instrument with closed- and open-ended questions to gauge the various factors was used. A pilot study was conducted in a Singaporean school to establish the validity and reliability of the items and instruments selected, as well as to refine any ambiguous survey items.

Part 2 of the study involved student and teacher interviews and classroom observations and was conducted from September to October 2009 in a Singaporean school. It is to be noted that in both parts of the study, the data collected were in English. The language of instruction in both regions is English, thus no translation is necessary. Details of the two parts of the study are described in the following sections.

Part 1: Large Scale Survey

In Part 1, a quantitative large scale survey was used. The aims were:

- to find the significant factors associated with students' learning of mathematics using the advanced calculators;
- to explore the relationships among the factors;
- to determine if there were differences among the students from the two regions: Singapore and Victoria; and
- to determine if there were gender differences.

The factors identified based on the literature were: students' attitudes towards mathematics and calculators, their beliefs about the nature of mathematics, their learning approaches towards mathematics, their learning styles and preferences, as well as their ways of using the calculators.

An outline of the data collection and analysis methods for Part 1 is shown in Table 3.2. In the next sections, the theoretical frameworks and instruments used will be presented, followed by a discussion of the refinement of the instruments derived from the results of the pilot study (details of the analysis are presented in Appendix A).

Table 3.2

Data Collection and Analysis Methods for Part 1 of the Study

Data collection methods	Data analysis methods
1. A pilot study was conducted in Singapore using an online survey instrument. (October 2008 to February 2009)	1. Descriptive statistics were used to find measures of the factors. 2. For various learning preference instruments, an iterative process of factor analyses and reliability testing was used to eliminate poor performing items and refine the instruments. 3. Open-ended responses were examined for difficulties or ambiguities in understanding the survey.
2. Schools in Singapore and Victoria were invited to participate in the main study. Year 11 and 12 students were surveyed anonymously through an online survey. (Singapore: February 2009 to November 2009; Victoria: January 2010 to July 2010)	1. Descriptive statistics were used to find measures of the factors. 2. Statistical analyses including Pearson bi-variate correlations, chi-square tests, t-tests, ANOVAs, and factor analysis were used to explore the relationships between the factors and examine for differences. 3. Open-ended responses were coded and analysed using thematic analysis.

Theoretical framework of the study and instrument design. Rather than seeking to analyse students' uses of the GCs and CAS calculators in mathematics education using one particular construct and theory of learning styles, the approach taken was to build a bridge linking theories in various domains within mathematics education (e.g., learning theories, technology use, gender issues) and the learning styles literature from the psychology field (see Chapter 2). The findings from the study using a *bricolage* of theories from different fields serve to enrich pre-existing theories in mathematics education and inform the teaching practice (Lester, 2005).

From the GC and CAS calculator literature, studies on multiple representations—visual, symbolic and numeric modes—were identified. This body of research could be connected with the communication modes in the VARK (Visual, Aural, Read/Write, & Kinesthetic) framework (Fleming, 2006). Affective theories have been found in the mathematics, technology, gender, and learning style fields. The SAL (Students' Approaches to Learning, Biggs, 1993) has been used by some researchers to investigate mathematics learners' motivations and learning strategies (e.g. Crawford et al., 1994, 1995, 1998).

An overview of the student factors of interest in this study, and the instruments used, are presented in Table 3.3. Selection of the instruments was based on several factors:

- relevance and applicability of the instrument to investigate students' use of technology (including advanced calculators) in learning mathematics;
- suitable length of instrument – must be short and simple enough to be incorporated together with other instruments; and
- validation and use in other studies.

Details about the instruments associated with each factor follow.

Table 3.3

Student Factors and Instruments Chosen

Factor	Instrument chosen	Reasons
Ways of knowing and understanding mathematics: Separate or connected knowing (Belenky, Clinchy, Goldberger, & Tarule, 1986; Becker, 1995)	Researcher developed instrument adapted from Ocean's (1998) survey.	Although there are other instruments such as the Knowing Styles Inventory (Knight, Elfenbein, & Messina, 1995), and the Attitudes Toward Thinking and Learning Survey (Galotti, Clinchy, Ainsworth, Lavin, & Mansfield, 1999), they are too general and not as applicable to mathematics education as Ocean's survey.

Factor	Instrument chosen	Reasons
Approaches to learning: Surface and Deep Approaches to learning (Biggs, 1993)	Learning Process Questionnaire (Kember, Biggs, & Leung, 2004)	The instrument measures students' motives and strategies towards learning, and has been used with Hong Kong secondary school students (Kember, Biggs, & Leung, 2004).
Self-ratings of mathematics and calculator competencies	Researcher developed items.	One item each for mathematics and calculator competencies was used.
Learning styles modality preference (multiple representation and multi-modal preferences): Visual, Aural, Read/Write, & Kinesthetic preference (VARK)	VARK learning styles inventory for High School Students (Fleming, 2006, 2007)	There is no instrument that relates multiple representations in mathematics to visual, verbal, and kinesthetic learning style modes. VARK was chosen for its pragmatic theoretical framework because the preferences can be strengthened and developed (with appropriate teaching and learning strategies), and because the use of advanced calculators incorporates Visual, Read/Write, and Kinesthetic modes.
Social interaction for learning preference: Individual, cooperative or competitive (Owens & Barnes, 1992)	Researcher developed instrument based on the Learning Preference Scales for Students (LPSS) (Owens & Barnes, 1992). The LPSS was too long (36 items), and a shortened version based on its theoretical framework was developed.	Other instruments evaluated were Dunn and Dunn's model (Dunn & Dunn, 1978) and Grasha and Riechmann's Student Learning Style Scales (GRSLSS) (Riechmann & Grasha, 1974). Both models were developed in the 1970s and received criticism in terms of their validity (see, Chapter 2 and Ferrari et al., 1996, for critique of Dunn and Dunn's model and GRSLSS).
Ways of using the GC: Master/ servant/ partner/ extension of self (Goos et al., 2000; Geiger, 2005)	Researcher developed instrument, by adapting from students' responses found and reported by Geiger (2005).	Geiger's model provides a general framework for measuring students' ways of using technology. Since the items were adapted from students' responses, they have some construct and content validity. A paper was written on the development of this instrument (see Tan, 2009, Appendix F).

Ways of knowing mathematics. In the review of literature on students' ways of knowing and understanding mathematics (see Chapter 2), two broad conceptions of mathematics were identified. The separate and connected knowing conceptions from the Women's Ways of Knowing by Belenky et al. (1986) were adopted because: (a) they were closely related to the two broad conceptions of mathematics identified in the mathematics education literature; (b) the model took into consideration gender differences, which could potentially relate to the gender issues of technology use. In Table 3.4, the notions of separate and connected knowing in mathematics, adapted from Becker (1995) and Belenky et al. (1986), are described.

The items used were modified from Ocean's (1998) survey questions that measured a person's separate (SK) or connected (CK) ways of knowing mathematics. As can be seen from Table 3.4:

> the model of Separate Knowing closely reflects the individualist and competitive values of traditional mathematics education, while Connected Knowing is more representative of a style that places emphasis on cooperation, discussion, and group work (Ocean 1998, p. 429).

Table 3.4

Separate and Connected Knowing in Mathematics

Separate Knowing (SK)	Connected Knowing (CK)
Involves facts, formulae, and known procedures	Involves personal experience and process tied to cultural environment
Reliance on memory	Reliance on conceptual understanding
Axiomatic and algorithmic approach	Creative and heuristic approach
Deals with logic, rigour, abstraction, and deduction	Deals with hypothesising, conjecture, and intuition
Certainty (right versus wrong)	Complexity, incompleteness
No acceptance of alternative methods for solution	Acceptance of alternative methods for solution
Mathematics is an absolute and finite body of knowledge	Mathematics is dynamic, contextual, and a body of inter-related ideas

There are other instruments used to measure SK and CK, such as the Attitudes Toward Thinking and Learning Survey (ATTLS) developed by Galotti, Clinchy, Ainsworth, Lavin, and Mansfield (1999), and the Knowing Styles Inventory (KSI) by Knight, Elfenbein, and Messina (1995). However, in these inventories, the items are more about general thinking and learning situations and not easily adapted for mathematics (e.g., an item in KSI "As soon as someone tells me her or his point of view, I immediately start arguing in my head the opposite point of view"). Thus, it was decided to adapt Ocean's items despite their lack of rigour — small sample size, unbalanced number of items, no statistical reliability reported — because they were specific to mathematics education. Duplicated items in Ocean's questionnaire were removed and new items added to balance the number of SK and CK items. The scoring system used was different from Ocean's original scoring regime because findings from other studies (e.g., Galotti, et al., 1999; Knight, Elfenbein, & Messina, 1995) suggested that SK and CK are not bipolar (i.e. not "Separate" at one end and "Connected" at the other). Rather, they are considered to be two independent dimensions, that is, a person can show both separate and connected ways of knowing, possibly depending on contexts. Ocean scored each item as "Undecided", "Separate (S)" or "Connected (C)", and assumed bipolarity. If a participant disagreed with a separate knowing item it would be scored "C". In the modified instrument designed for this study, there were five SK and five CK items, and the scoring was done separately for each subscale using a 5-point Likert scale. The list of ten items, codes for SK and CK, and source of items are shown in Appendix A1, Table A1. After the first trial of the pilot study, the list was reduced to eight items, and after the second trial, to six items (see Appendix A1, Table A2). The final list of three CK and three SK items are shown in Table 3.5.

Approaches to learning. The Learning Process Questionnaire (LPQ), developed by Biggs in 1987 for use in school contexts, is based on the 'Student Approaches to Learning' (SAL) framework (Kember, Biggs, & Leung, 2004; see Chapter 2). Under this framework, students employing a "surface approach" base their intentions to study on "a guiding principle or intention that is *extrinsic to the real purpose of the task*" (Biggs, 1993, p. 6, original emphasis). The strategy undertaken is intended to minimize the time and effort needed to meet assessment requirements, such as through rote learning of selected content, without understanding. Conversely, students employing a "deep approach" have an *intrinsic interest* to study. Their strategy is to maximise understanding, “to *engage the task properly*, in its own terms” (Biggs, 1993, p. 7, original emphasis). Originally a third approach was conceptualised – the “achieving approach”, whereby students use a combination of deep and surface learning strategies in order to maximise achievement. In 2004, the LPQ questionnaire was revised and shortened to 22 items to reflect two approaches to learning – surface and deep approaches (Kember, Biggs, & Leung, 2004). For each approach – surface and deep – the items are categorised into motive and strategy subscales.

What distinguishes Biggs’ (1993) LPQ from other similar instruments is that it is a short questionnaire that has been tested in the Asian context with Hong Kong students (see Entwistle & McCune, 2004). The issue of context was raised by Richardson (2004) in his review of instruments on students’ learning. The critique is that most studies are conducted in the Western context, and hence the instruments might not be suitable for Asian students. One of the objectives of this study was to compare the factors identified as associated with how Australian and Singaporean students learn to use the calculators. Hence, Biggs’ LPQ, which was developed using both Western and Asian students in his original and revised versions respectively, was selected. For this study, minor modifications were made to the items to focus on approaches to learning mathematics rather than general studies (see Appendix A2, Table A3). For example, the item “I am discouraged by a poor mark on a test and worry about how I will do on the next test” was modified to “When I score poorly on a maths test, I worry a lot about how I will do on the next one”.

The original responses in LPQ—“A- this item is *never* or *only rarely* true of me; B- this item is *sometimes* true of me; C- this item is true of me about *half the time*; D- this item is *frequently* true of me; E- this item is *always* or *almost always* true of me” (Kember, Biggs, & Leung, 2004, p. 277) — were changed to a 5-point Likert type response format (Strongly Disagree to Strongly Agree) to match the rest of the survey questionnaire used in this study so that it was easier for participants to answer. Mean subscale scores were computed and reduced to the range 1 to 5 for ease of interpretation.

Combined ways of knowing and learning mathematics. It was found from literature (Crawford et al., 1994, 1995, 1998) that students’ conceptions about mathematics were associated with their approaches to learning (SAL). In reviewing the literature from both fields (beliefs about mathematics and SAL), it was noted that there were some similarities between students' ways of knowing mathematics (Separate and Connected Knowing, see Table 3.4), and their approaches to learning mathematics (Surface and Deep Approaches).

Separate knowing (SK) emphasises mathematical procedures and reliance on memory, which embodies some similarity to the rote-learning strategies taken by students using a surface approach (SA). Connected knowing (CK) emphasises conceptual understanding, interconnectedness of ideas and contexts. Students with connected knowing are likely to be also using a deep approach (DA): strategies to maximise understanding and fulfilling their intrinsic interest in the subject. Hence, based on the analysis of the pilot study, the final items from the two instruments were pooled to form a new combined instrument, *Ways of Knowing and Learning Mathematics*. Principal components analysis of the pooled items yielded two components, with SK and SA items as one component and CK and DA items as the other. The final instrument has 22 items, half of them measuring Separate Knowing – Surface Approach (SK-SA) and the other half measuring Connected Knowing – Deep Approach (CK-DA) (see Table 3.5). Details of the pilot study, the instrument and analyses are reported in Appendix A3.

Table 3.5

Items in 'Ways of Knowing and Learning Mathematics' Instrument by Construct

Connected Knowing and Deep Approach (CK-DA)	Separate Knowing and Surface Approach (SK-SA)
CK	SK
Maths makes you think creatively.	In maths, something is either right or it is wrong.
Good maths teachers show students several different ways to look at the same question.	To solve maths problems you have to be taught the right procedure or you can't do anything.
In maths you can be creative and discover things for yourself.	When I solve maths problems, I'm often stuck if I can't remember the next step.
DA	SA
I try to relate what I have learned in maths to what I learn in other subjects.	When I score poorly on a maths test, I worry a lot about how I will do on the next one.
I work hard at my studies because I find mathematics interesting.	I see no point in learning material which is not likely to be in the examination.

As I am reading, I try to relate new concepts and ideas to what I already know about that topic.	Even when I have studied hard for a maths test, I worry that I may not be able to do well in it.
I frequently think about how to solve maths problems even while on the bus or lying on my bed.	I learn maths formulas by heart even if I don't understand them.

Self-ratings of mathematics and calculator competencies. Students' competency components of their self-concepts (Bong & Skaalvick, 2003) relating to mathematics and calculator were measured. Since the study is not specific to any particular mathematics topics or tasks, students' self-concepts (typically measured at a general level) rather than self-efficacies (measured at task level) are measured (Ferla, Valcke, & Cai, 2009). Two items were used to elicit students' self-ratings of their mathematics and calculator competencies:

Currently for Maths I consider myself

Excellent ☐ Good ☐ Average ☐ Below Average ☐ Weak ☐

In terms of GC/CAS calculator skills, I consider myself

Excellent ☐ Good ☐ Average ☐ Below Average ☐ Weak ☐

In his synthesis of meta-analyses, Hattie (2009) found that students' self-estimates of their own performance were found to be ranked first among the various student factors influencing their achievement, with a large effect size of *d* = 1.44 (p. 44). Hence, it can be assumed that "students have reasonably accurate understandings of their own achievement" (Hattie, 2009, p. 43).

Learning styles modality preferences. The model adopted in this study was Fleming's (2006) Visual, Aural, Read/Write, and Kinesthetic (VARK) modes of taking in and processing information (see Chapter 2 for discussion). The VARK learning styles inventory was selected because the scoring allows for multiple preference modes. Although the items on the VARK instrument are phrased in a general format, rather than specifically for mathematics learning, the literature suggests that the way an individual perceives and processes information is relatively stable across contexts (Curry, 1983). Fleming's (2006) 13-item high school version of the questionnaire (pp. 127-128) was used in the pilot study (see Appendix A8).

In the first trial of the pilot study, the original set of 13 items for VARK was used. Two items (Q12 and Q13, Appendix A4, Table A8) were modified: in one question that asked about a mathematics-related project rather than about an English project; and in the other question, "teacher" was changed to "mathematics teacher" to make the context more specific to mathematics teaching and learning. Based on the data analysis from the first trial of the pilot study (46 students), the seven best performing items out of the 13 items on the instrument were selected for the main study. The selection was based on a comparison of the students' responses and their computed VARK preferences (see Appendix A4). Since some accuracy would be lost by removing items, in the main study only the highest scoring VARK preference(s) for each respondent (rather than a multitude of VARK preferences in order of strength) was identified and used. The wording of the instrument was further refined after it was trialled a second time.

In an independent study by Leite, Svinicki, and Shi (2010) on the validation of the scores of the VARK learning styles inventory, the researchers found preliminary support for the validity of the VARK scores, but raised issues with the item wording and the scoring algorithm of the scale. The scoring algorithm was complicated and classified respondents "into having very strong, strong, or mild single learning style preferences or any combination of two, three, or four learning style preferences" (Leite, Svinicki, & Shi, 2010, p. 336). For this current study, the instrument was shortened, items reworded, and scoring simplified. This avoided some of the issues described by Leite et al. (2010). However, it should be noted that a limitation of the instrument is the scarcity of literature on the psychometric testing of its validity and reliability.

In addition to the VARK items (henceforth referred to as *general VARK* items), there were four items investigating the VARK modes specific to learning how to use calculators (henceforth referred to as *calculator VARK* items). The first item asked students to indicate which method(s), out of a list of 10 methods, their teachers used when teaching them how to use the calculators. In the second item, students indicated for each method whether they believed it would help or would not help them learn how to use the calculator to solve mathematics problems. The last two items asked for students' most preferred and least preferred methods. The items are reproduced below:

8. Which one or more of the following ways has your teacher used when teaching how to use the graphing/CAS calculator? [Please tick where appropriate]

☐ provide a demonstration.
☐ let students demonstrate to the whole class.
☐ refer to the calculator screen captures shown in notes or textbooks or manual.
☐ let students discuss answers with one another.
☐ explain the steps and concepts clearly and thoroughly.
☐ read out the steps given in notes, textbooks or manual.
☐ write out the steps on the board.
☐ ask you to make your own notes.
☐ during a demonstration ask you to follow the steps as shown.
☐ encourage you to play around with the calculator.
☐ OTHERS (Please describe what activities your mathematics teacher does in your class)

____

9. For each of the following, indicate if it helps you learn how to use graphing/CAS calculator to solve maths problems.

	Yes, it definitely helps	No, it doesn't really help
a. see my teacher's demonstration in class.	☐	☐
b. see the steps my friends show me on their calculators.	☐	☐
c. look at the calculator screen captures in notes, textbooks or manual.	☐	☐
d. discuss answers with my friends.	☐	☐
e. listen to a teacher who explains the steps and concepts clearly and thoroughly.	☐	☐
f. listen to a teacher who reads out the steps given in notes, textbooks or manual.	☐	☐
g. copy down the steps my teacher writes on the board.	☐	☐
h. make my own notes.	☐	☐
i. try out the steps on the calculator at the same time I see a demonstration or hear an explanation or read the instructions.	☐	☐
j. try the buttons out and play around with the calculator.	☐	☐

10. Which one of the above a) – j) is your most preferred way of learning to use the calculator to solve maths problems?
    If not any of the above a)-j), please specify your most preferred way. ☐
    ____

11. Which one of the above a) – j) is your least preferred way? ☐

The ten methods were developed by the researcher based on prior experiences teaching with advanced calculators, teaching methods described in research studies, and descriptions of how students learn using different modes by Fleming (2006). A summary of the description of the teaching and learning method statements and their VARK categories can be found in Table 3.6 below. Additional remarks were provided where there were possible ambiguities.

Table 3.6

Teaching and Learning Methods on How to Use the Calculator and Their VARK Categories

	Teaching method statements	Learning method statements	VARK category	Additional remarks
a)	Provide a demonstration	See my teacher's demonstration in class	Visual	Although Fleming (2006) categorised "demonstrations" as kinesthetic rather than visual due to "extraneous Aural, Kinesthetic, and Read/write material" (p. 119), the predominant mode in this context is considered as Visual rather than Kinesthetic because students can see how the calculator is being used. Teachers usually demonstrate through showing what buttons to press using a picture or a software simulation of the calculator.
b)	Let students demonstrate to the whole class	See the steps my friends show me on their calculator	Visual	The learning method could include pair-work or group-work contexts, besides the whole class context described in the teaching method.

	Teaching method statements	Learning method statements	VARK category	Additional remarks
c)	Refer to the calculator screen captures shown in notes or textbooks or manual	Look at the calculator screen captures in notes, textbooks or manual	Visual	Screen captures are diagrams that show the output of the calculator screen, hence is considered as a visual data.
d)	Let students discuss with one another	Discuss answers with my friends	Aural	
e)	Explain the steps and concepts clearly and thoroughly	Listen to a teacher who explains the steps and concepts clearly and thoroughly	Aural	
f)	Read out the steps given in notes, textbook or manual	Listen to a teacher who reads out the steps given in notes, textbooks or manual	Aural	The teacher reading aloud is considered as Aural rather than Read/Write because it involves students listening as the mode of communication.
g)	Write out the steps on the board	Copy down the steps my teacher writes on the board	Read/ Write	
h)	Ask you to make your own notes	Make my own notes	Read/ Write	
i)	During a demonstration ask you to follow the steps as shown	Try out the steps on the calculator at the same time I see a demonstration or hear an explanation or read the instructions	Kinesthetic	It may also be considered as multimodal since students see a demonstration, listen to an explanation or read the instructions at the same time.
j)	Encourage you to play around with the calculator	Try the buttons out and play around with the calculator	Kinesthetic	This method may include trial and error of the calculator procedures.

Social interaction for learning preferences. As presented in Table 3.3, the instrument employed as a reference for the social interaction for learning preference was the “Learning Preference Scales for Students” (LPSS) by Owens and Barnes (1992). In order to reduce the length of the survey, open-ended questions relating to students’ mathematics and calculator learning preferences were used instead of the full 36-item

LPSS questionnaire. The LPSS was considered but not used because of the overall length of the survey and the many categories for each mode of preference. There were 12 categories in LPSS relating to different aspects such as beliefs about “what ‘other students’ prefer, based on psychoanalytic concept of projection” (Owens & Barnes, 1992, p. 16), the quality of outcomes and ideas, and the stress due to working using a particular mode. Instead, one set of items was created for studying mathematics and a similar set for working with calculators, both with open-ended response formats to allow students to explain their preferences for individual, cooperative, or competitive learning. For these two sets of items, the aim was to find the overall preference for a particular learning mode in each of the two contexts (studying mathematics and working with calculators). The item used to identify students’ social interaction for learning preferences for studying mathematics is shown below. The other item used to find students’ preferences when working with calculators was similar, but with the words “study maths” replaced with “work with calculators”.

How do you study maths / work with calculators? Indicate whether or not you like each of the following.

I like to	I don’t like to	
☐	☐	study individually on my own.
☐	☐	cooperate with friends.
☐	☐	compete with friends.

Which of the above do you **most** prefer? _____________________

Please explain why.____

The open-ended responses were coded according to categories designed to capture the dominant themes described by students, and were analysed using thematic analysis (Braun & Clarke, 2006).

Ways of interacting with technology. The four metaphors framework developed by Goos, Galbraith, Renshaw, and Geiger (2000) was chosen to be adapted into an instrument to measure students’ ways of using calculators for several reasons. First, the theoretical orientation of the framework lends itself to the development of a large scale survey instrument for students. Goos et al. (2000) addressed “technology usage as an integral component of the learning environment” (p. 306) rather than investigating “the effects of different instructional strategies (both with and without technology) and teacher attitudes towards technology" (pp. 305-306). Second, the metaphors cover the roles of technology in a broad and logical manner. The model is not topic specific and adequately covers various uses of the calculator. Although the metaphors represent increasing levels of sophistication, this does not mean that once attained, students will always use the higher levels for all tasks. Rather, a higher level of sophistication of use indicates an "expansion of a technological repertoire where an individual has a wider range of modes of operation available to engage with a specific task" (Goos et al., 2000, p. 370). Hence, students' responses to items based on the four metaphors are likely to give an indication of the extent of use represented by each metaphor and provide a rich description of student use. Third, since the metaphors and sub-categories were grounded in students' responses (Geiger, 2005), it was relatively easy to transform them into items to include in an instrument. Fourteen items were created based on the sub-categories of Geiger's (2005) four metaphors of technology use; they were reduced to 12 items after the pilot study analyses (Tan, 2009). Consistent with the other instruments described earlier, a 5-point Likert scale was used for students to indicate the extent of their agreement with each of the items. The descriptions and sample items for each metaphor are found in Table 3.7. In the actual survey, it was indicated that the word "calculator" referred to the GC for the Singaporean version and the CAS calculator for the Victorian version.

Table 3.7

Four Metaphors of Technology Use by Students (Adapted from Geiger, 2005, p. 371)

Metaphor	Description and Sample Item
Technology as Master	The student is subservient to the technology- a relationship induced by technological or mathematical dependence. If the complexity of usage is high, student activity will be confined to those limited operations over which they have competence. If mathematical understanding is absent, the student is reduced to blind consumption of whatever output is generated, irrespective of its accuracy or worth. Sub-categories: lack of technological skills, mathematical dependence, unfamiliar conventions. Sample item: (M1) I do not know why sometimes the calculator does not give me the answer that I want.
Technology as Servant	Here technology is used as a reliable timesaving replacement for mental, or pen and paper computations. The tasks of the mathematics classroom remain essentially the same- but now they are facilitated by a fast mechanical aid. The user "instructs" the

Metaphor	Description and Sample Item
	technology as an obedient but “dumb” assistant in which s/he has confidence. Sub-categories: looking after large calculation and tedious repetitive methods, performs calculation more quickly and efficiently, reduces errors in calculation, presentation, checking answers. Sample item: (S3) I use the calculator to look after large calculations and tedious repetitive methods.
Technology as Partner	Here rapport has developed between the user and the technology, which is used creatively to increase the power that students have over their learning. Students often appear to interact directly with the technology (e.g., graphical calculator), treating it almost as a human partner that responds to their commands- for example, with error messages that demand investigation. The calculator acts as a surrogate partner as students verbalise their thinking in the process of locating and correcting such errors. Calculator or computer output also provides a stimulus for peer discussion as students cluster together to compare their screens, often holding up graphical calculators side by side or passing them back and forth to neighbours to emphasise a point or compare their working. Sub-categories: for exploration and different perspectives, looking after cognitive load, facilitating understanding e.g., via visualisation, scaffolding. Sample item: (P4) The calculator helps me understand concepts better.
Technology as Extension of Self	The highest level of functioning, where users incorporate technological expertise as an integral part of their mathematical repertoire. The partnership between student and technology merges to a single identity so that, rather than existing as a third party, technology is used to support mathematical argumentation as naturally as intellectual resources. Students working together may initiate and incorporate a variety of technological resources in the pursuit of the solution to a mathematical problem. Sub-categories: mind expander, freedom. Sample item: (E2) The calculator allows me to expand my ideas and to do the work my own way.

In addition to the 12 items based on Geiger’s (2005) metaphors, students were asked three items about their self-perceived calculator competency, enjoyment, and confidence:

In terms of GC* skills, I consider myself

Excellent ☐ Good ☐ Average ☐ Below Average ☐ Weak ☐

	Strongly Agree	**Agree**	**Neutral**	**Disagree**	**Strongly Disagree**
I enjoy using GC* to learn maths.	☐	☐	☐	☐	☐
I feel confident doing maths using GC*.	☐	☐	☐	☐	☐

* "GC" was replaced with "CAS calculator" for Australian students.

Table 3.8 provides a summary of the sections of the survey instrument and learning style components that were investigated. The full copy of the survey can be found in the end of Appendix B.

Table 3.8

Summary of Sections of Survey and Factors being Investigated

Section of the survey	Factors investigated	Sample Items
Section 1: About You	Profile of students: gender; year level; ethnic group; mathematics subject taken; calculator models owned/used; past mathematics grades; and self-perceived mathematics and calculator abilities.	Currently for maths I consider myself: (a) Excellent (b) Good (c) Average (d) Below Average (e) Weak
Section 2: About Your Learning Preferences	General Visual, Aural, Read/Write, and Kinesthetic (VARK) preferences;	I prefer a maths teacher who likes to use: (a) textbooks or handouts or notes (b) diagrams or graphs or pictures (c) hands-on activities or outdoor maths investigations (d) class discussions or online discussions.
	Calculator VARK preferences.	For each of the following, indicate if it helps you learn how to use the calculator* to solve maths problems.

Section of the survey	Factors investigated	Sample Items
		(a) see my teacher's demonstration in class (Yes, it definitely helps/ No, it doesn't really help)
Section 3: Your Views about Maths and Studying Maths	Separate (SK) and connected knowing (CK) preferences;	CK: Maths makes you think creatively. (Strongly disagree to strongly agree)
	Deep (DA) and surface (SA) learning approaches;	SA: I learn maths formulas by heart even if I don't understand them. (Strongly disagree to strongly agree)
	Social interaction for learning preferences for maths: Individual/cooperative/competitive.	How do you study maths? Indicate whether or not you like each of the following: I like to/ don't like to study individually on my own.
Section 4: Your Preferences about Using Advanced Calculators	Ways of Interacting with Technology: Master/ servant/ partner/ extension of self;	I use the calculator for basic calculations because it is more accurate than working by hand. (Strongly disagree to strongly agree)
	Attitude towards using the calculator (enjoyment and confidence);	I enjoy using the calculator to learn maths. (Strongly disagree to strongly agree)
	Social interaction for learning preferences when working with calculators: Individual/cooperative /competitive.	How do you work with the calculator? Indicate whether or not you like each of the following: I like to/ don't like to work with the calculator individually on my own.

* "Calculator" referred to GC in the Singaporean survey and CAS calculator in the Victorian survey.

Descriptions of the theoretical frameworks and instruments used for Part 1 in this study have been presented. In the next sections, the details about the data collection and analysis methods are outlined.

The pilot study. The pilot study was conducted in three phases from October 2008 to January 2009 in two Singaporean schools (junior colleges). The questionnaire initially developed was reviewed by a panel of three teachers and seven students from Singapore who commented on phrasing ambiguities and appropriateness of the items. After modification of the items based on comments received, the questionnaire was trialled in two schools in separate phases, using an anonymous online survey in one school (N = 49), and pen-and-paper survey in the other (N = 189).

Based on the trial in the first school (N = 49), changes to the wordings were made for the items relating to VARK, Ways of Knowing Mathematics, and Ways of Interacting with Technology. Two poor performing items from the 10-item Ways of Knowing Mathematics (one each for Separate Knowing [SK] and Connected Knowing [CK]) instrument were removed. The VARK instrument was also shortened from 13 to 7 items.

The revised survey was then trialled in the second school (N = 189). It was noted that there were moderate to strong positive correlations between the CK and DA scores ($r = 0.606$) and between SK and SA scores ($r = 0.401$). Exploratory factor analysis of the pooled items from the Ways of Knowing Mathematics (8 items) and the Approaches to Learning Mathematics (22 items) instruments resulted in two components corresponding to Connected Knowing – Deep Approach (CK-DA) and Separate Knowing – Surface Approach (SK-SA). The combined 32-item instrument had higher reliability ($\alpha_{\text{CK-DA}} = 0.859$; $\alpha_{\text{SK-SA}} = 0.662$) than the separate instruments ($\alpha_{\text{CK}} = 0.669$; $\alpha_{\text{SK}} = 0.551$; $\alpha_{\text{DA}} = 0.833$; $\alpha_{\text{SA}} = 0.521$). Hence, a decision was made to combine the instruments into a single Ways of Knowing and Learning Mathematics instrument. An iterative process of factor analysis and reliability testing was carried out to remove poor-performing items, and the instrument was shortened from 32 to 14 items (see Table 3.5, p. 85), with final Cronbach-α reliability measures ($\alpha_{\text{CK-DA}} = 0.792$; $\alpha_{\text{SK-SA}} = 0.683$) still within acceptable limits (Pallant, 2007).

Exploratory factor analysis was also conducted for Ways of Interacting with Technology instrument. Three components were found, corresponding to items from i) Master, ii) Servant, iii) Partner and Extension of Self. The items for Technology as Partner and as Extension of Self loaded on one factor, which was called Technology as

Collaborator. Further analysis was conducted to remove poor performing items, and the instrument was shortened from 14 to 12 items. The Cronbach–α values for the three subscales were 0.542 (Technology as Master), 0.664 (Technology as Servant), and 0.788 (Technology as Collaborator). More details of the collapsing of the Partner and Extension of Self subscales into one category can be found in Tan (2009).

T-tests were used to compare the data from the first trial using online survey and data from the second trial using pen-paper survey. No significant differences were found in the scores of most of the interval variables (e.g., CK-DA, SK-SA, Master, Servant, Collaborator) between the two schools, with the exception of one item. The mean score of calculator competency self-rating for the first school (N = 49; $\bar{x}$ = 3.04) was significantly higher than the second (N = 189; $\bar{x}$ = 2.64). It was noted that the school with the higher calculator competency mean score was considered above average amongst the 17 junior colleges in Singapore, whereas the other school was considered below average. Since there were no significant differences in the mean scores between pen-and-paper and online versions of the survey for most of the instruments, the anonymous online survey was used for the main study.

In addition, minor changes were made to the survey to accommodate the different regional educational contexts. For example, in the Singapore version, “graphing calculator” was used, whilst in the Victorian version, “CAS calculator” was used. The demographic questions were also modified as appropriate for both contexts. As mentioned earlier, the Singaporean version was reviewed by a panel of teachers and students before piloting in two schools. After the pilot study, the Victorian version was reviewed by one student and one teacher. No issues were raised regarding the wording and appropriateness of the questionnaire.

The main study. In order to capture a snapshot of the factors influencing students' learning of mathematics using the GC and CAS calculators, a cross-sectional sampling method was used (Creswell, 2009). An online survey was created using SurveyMonkey.com. Permission was sought through schools and from the Singaporean Ministry of Education (MOE), and Victorian Department of Education and Early Childhood Development (DEECD) and Catholic Education Office (CEO).

Six Singaporean junior colleges (JC) were invited to participate in the study, out of 17 JCs in Singapore. Four schools agreed to participate. From February to November 2009, JC Years 1 and 2 students studying Higher 1 or Higher 2 Mathematics in Singapore were surveyed. Heads of the Mathematics Departments in the schools sent invitation emails, with the explanatory statement and link to the online survey, to students. The four schools varied in their decisions about which groups of students to survey (e.g., one school chose to survey only their Year 11 students), and about the timing of the survey (e.g., after Year 11 examinations at the end of the academic year).

The target population was Years 11 and 12 students, some of whom might be younger than 18 years old. The study was approved by the Monash University Human Research Ethics Committee (MUHREC) based on the argument that senior secondary students "are mature enough to understand and consent, and are not vulnerable through immaturity in ways that warrant additional consent from a parent or guardian" (from *National Statement on Ethical Conduct* by National Health and Medical Research Council, Australian Research Council, & Australian Vice-Chancellors' Committee, 2007, p. 55), and that submission of an anonymous online survey indicated consent. However, the Victorian Department of Education and Early Childhood Development (DEECD) required stricter rules that demanded written parental consent for students less than 18 years of age. The additional administrative procedures resulted in having zero response from Victorian government schools, despite some showing interest in the initial round of email invitations in December 2009. Follow-up telephone conversations with two mathematics coordinators in government schools revealed that the reason for their non-participation was the additional administrative procedure, i.e. obtaining parental consent. It was then decided to focus on independent schools as they are not bound by DEECD rules and the additional procedure for parental consent was not required. Simultaneously, the use of Facebook (http://www.facebook.com) as a recruitment platform was explored and carried out in July 2010 after consulting with the MUHREC and obtaining the ethical clearance. The necessary funding for advertising through Facebook was obtained from the Faculty of Education, Monash University. More details on the process, issues and challenges of using Facebook to recruit participants for this study have been reported (see Tan, 2010).

Data analysis procedures. Both quantitative and qualitative data were collected using the survey questionnaire. The quantitative measures of the various students' learning preferences were analysed using descriptive and inferential statistics:

- For categorical data such as students' VARK and social interaction for learning preferences, the frequency and percentages were computed.
- For interval data such as mathematics and calculator competencies, Ways of Knowing and Studying Mathematics (CK-DA, SK-SA), Ways of Using Calculators (Master, Servant, & Collaborator), missing data and normality inspections were carried out.
- For construct validity and reliability of variable scales (CK-DA, SK-SA, Technology as Master, Servant, and Collaborator), factor analyses and the calculation of reliability coefficients were conducted.

To answer the research questions about the relationships between students' gender, learning preferences, beliefs, and ways of interacting with advanced calculators, a variety of statistical analyses – scatter plots, analyses of variance (ANOVAs), t-tests, Pearson bi-variate correlations, point bi-serial correlations, and multiple regression – were used when appropriate (Tabachnick & Fidell, 2001). The list of statistics and tests used to answer each research question is summarised in Table 3.9.

Table 3.9

Students' Learning Preferences and Factors Examined, and the Types of Statistics Used

Research question	Learning preferences and factors examined	Statistics
1. What are students' beliefs and attitudes, learning preferences, & ways of interacting with calculators?	Mathematics competency self-rating (MSR)	Mean scores
	Calculator competency self-rating (CalSR)	Mean scores
	Ways of knowing and studying mathematics (CK-DA, SK-SA)	Mean scores, scatterplot of CK-DA versus SK-SA
	General VARK, calculator VARK	Mode, percentages, bar-graphs

Research question	Learning preferences and factors examined	Statistics
	Social interaction for learning preferences (Individualised, cooperative, competitive)	Mode, percentages
	Calculator enjoyment (Cal_Enj) and calculator confidence (Cal_Conf)	Mean scores
	Ways of interacting with technology (calculator as Master, Cal_Ma; as Servant, Cal_Se; and as Collaborator, Cal_Co)	Mean scores
2. Are there any differences between Singapore and Victoria?	Interval data: MSR, CalSR, CK-DA, SK-SA, Cal_Enj, Cal_Conf, Cal_Ma, Cal_Se, & Cal_Co	t-tests
	Categorical data: VARK, Social interaction for learning preferences	Chi-square (χ^2) tests
3. Are there any gender differences within each region?	Gender differences in students' beliefs, attitudes, learning preferences and ways of interacting with calculators.	Comparison of effect sizes of significant gender differences between the two regions
	Interval data: MSR, CalSR, CK-DA, SK-SA, Cal_Enj, Cal_Conf, Cal_Ma, Cal_Se, & Cal_Co	t-tests and Mann-Whitney U tests (small number of males in Victorian data)
	Categorical data: VARK, Social interaction for learning preferences	Chi-square (χ^2) tests
4. What are the relationships among the learning preferences, attitudes and beliefs, and ways of using GC?	Between variables with interval data (MSR, CalSR, CK-DA, SK-SA, Cal_Enj, & Cal_Conf), and ways of interacting with calculators (Cal_Ma, Cal_Se, & Cal_Co)	Pearson bi-variate correlation coefficients
4 (a) what are the correlations between all the variables?	Between variables with categorical data (gender, VARK, Social interaction for learning preferences) and ways of interacting with calculators (Cal_Ma, Cal_Se, & Cal_Co)	Point bi-serial correlation coefficients (for dichotomous data), ANOVAs, means plots
4 (b) Which variable best explains students' ways of interacting with calculators?	Independent variables: Gender, learning preferences, beliefs and attitude Dependent variables: Cal_Ma, Cal_Se, Cal_Co	Multiple linear regression

Qualitative data were obtained about students' reasons for their social interaction for learning preference. Thematic analysis, a widely used qualitative analysis method, was used because it is accessible to both positivists and constructivists and "works to both reflect reality and to unpick or unravel the surface of 'reality'" (Braun & Clarke, 2006, p. 81). The analysis process was a recursive one which followed the following phases described by Braun and Clarke (2006): 1) familiarisation with the data – reading and re-reading the data; 2) generating initial codes – coding interesting features of the data in a systematic manner; 3) searching for themes – collating codes into potential themes; 4) reviewing themes – checking if themes work for the coded instances across the data set; 5) defining and naming themes – analysing and refining specifics of each theme; 6) producing the report – relating analysis back to research and literature.

Coffey and Atkinson (1996) described the process of coding as non-mechanistic, and decisions were made by the researcher on "what aspects of the data to tag with codes" and "what levels of generality or detail to go into" (p. 37). They referred to Strauss' (1987) distinction between sociologically constructed codes and in vivo codes. In vivo codes are derived from the words and terms used by the participants, as opposed to existing terms and phrases derived from past research. In this context, in vivo codes were used in the initial coding process. After coding, the codes were re-examined for themes based on the theoretical underpinnings of the study. All the responses were recoded after two weeks, and intra-coder reliability was more than 80% for most categories except those which were refined after aggregating the themes. This percentage is considered acceptable as an initial reliability check (Miles & Huberman, 1994).

It is acknowledged that the process of code and theme generation was an abductive one informed by the researcher's own background experiences, knowledge, and values. Existing literature was reviewed for possible ways of categorising the codes into themes. However, existing theories (learning styles inventories by Riechmann & Grasha, 1974 and Owens & Barnes, 1992) perused did not fit the codes for students' reasons for preferring to study and work with calculators individually, cooperatively, or competitively. For example, students in the current study provided affective reasons for their social interaction preferences, such as "fun and motivating". They also provided details about how they cooperate with their peers. This was not found in the theoretical frameworks of the learning styles inventories reviewed. The inventories were inadequate in providing a working model in which the codes in this study could be anchored. Consequently, the themes or categories were developed from the data based on an iterative, abductive process: themes were generated inductively by organising similar codes and then tested deductively by reviewing if the themes described all the coded instances adequately and that there were no major overlaps between the themes (Braun & Clarke, 2006).

The frequency of the codes for each category was tallied using an Excel spreadsheet, and analysed to provide indications of the major reasons students gave for choosing a particular learning preference (individual, cooperative, competitive).

There were some questions asked in the survey that were not analysed in the main study because they were found to be irrelevant in answering the research questions. For example, Singaporean students were asked to indicate their Year 10 national examination results. However, there was no equivalence for Victorian students since they do not have a common Year 10 examination, so the analysis of the main study focused on comparing students' self-ratings of their mathematics competency. There were open-ended questions at the end of the survey about what students liked and disliked about using calculators in the classroom. These were either not answered, or reasons cited that were similar to the use of calculators as Master (e.g. "It is sometimes confusing if I don't understand the answers the calculator is giving me."), Servant (e.g. "It's surprisingly convenient and you don't have to work out all the tedious steps by hand.") or Collaborator (e.g. "it gives me a quicker way to solve problems and also helps me understand complex maths calculations."). Hence, students' responses to these open-ended questions were not analysed.

The results for Part 1 of the study are reported in Chapters 4 and 5.

Part 2: Small Scale Study

In Part Two, using a qualitative small scale study, the aim was to better understand and find explanations for the relationships between students' beliefs, attitudes, and learning preferences found in Part 1 of the study. This provides a qualitative perspective of these student factors to complement the large scale quantitative data. In other words, the answer to research question 4(c) is investigated in the small scale study.

Research question 4: What are the relationships among students' gender, beliefs, attitudes, learning preferences, and ways of interacting with the calculators? Specifically:

(a) what are the correlations between all the variables?
(b) which variable best explains students' ways of interacting with calculators?
(c) how can these relationships be explained?

As mentioned earlier in this chapter, Part 2 was conducted concurrently with Part 1 although originally conceptualised to be sequential. The small scale study results were used to investigate further the factors found in Part 1 and the relationships between the factors within one localised learning context, in particular that of one Singaporean Junior College.

The qualitative methods used were interviews and classroom observations, together with participating students' responses to the same quantitative survey used in Part 1 of the study. The rich data gathered from the qualitative approach were used to describe and explain the relationships found (e.g., correlations between learning preferences and ways of using calculators) in Part 1, as well as to uncover any new factors that influence how students interact with and learn to use the calculators. Table 3.10 shows an outline of the data collection and analysis methods for Part 2 of the study.

Table 3.10

Data Collection and Analysis Methods for Part 2 of the Study

Data collection methods	Data analysis methods
1. Invited 3 Singaporean teachers and 9 of their students to participate. The school was different from those that participated in the large scale survey study to avoid survey fatigue and to triangulate the findings.	1. Interviews were recorded and later transcribed; observations notes were taken.
2. Students who agreed to participate completed the same questionnaire as in Part 1 of the study.	2. Transcripts, observation notes, and survey responses were coded based on the theoretical frameworks used in the study.
3. Classroom observations (2 lectures, and 3 classroom tutorials per teacher); student and	3. Instances of codes and quantitative survey data were analysed to investigate the relationships between learning preferences, beliefs, attitudes, and students' ways of interacting with calculators.

Data collection methods	Data analysis methods
teacher interviews were conducted.	4. The findings from the small scale and large scale studies were compared to extend and enrich the overall findings.

Selection and recruitment process. Two Singaporean schools were approached, and one agreed to participate. After a briefing by the researcher during a staff meeting, the mathematics teachers in the school were invited to participate. Three teachers agreed to have one of their mathematics classes observed. The researcher introduced herself to the participating classes during the first classroom observation and invited students to be interviewed. Interested students were asked to approach the researcher at a specified venue in the school during break-time. However, initially there were no volunteers. It took about a week of observing each class (three tutorial lessons) for students to get to know the researcher. After another round of invitations, two to four students (nine in total) from each class agreed to be interviewed. After being interviewed, students completed the surveys, and teachers completed a similar survey with items reworded in terms of the teaching rather than the learning perspective (see Appendix B3).

When the teachers and students are not comfortable in lectures and tutorials because they are being observed, their behaviour and responses may be contrived (Creswell, 2009). When students are uncomfortable during interviews, there might be differences between what they say and what they actually do during lessons. To counter these possible threats to the validity and reliability of the study, the researcher encouraged the teachers and students to be comfortable by talking to them before the interviews and observations, reassuring the students and teachers that their privacy would be respected, and ensured that they were not being coerced into participation.

Generally Singaporean junior colleges run a lecture and tutorial system much like universities. In this study, two mathematics lectures were also observed, and these were conducted by one of the participating teachers. Overall, the school visits lasted about three weeks. Explanatory statements and consent forms were given to participating students and teachers to comply with ethical requirements. Details of the school and participants are discussed in Chapter 5.

Interview protocols. Since Part 2 of the study was conducted concurrently with Part 1, the interview protocol was designed to capture students' learning preferences and attitudes toward and beliefs about mathematics and calculators in general, rather than focusing on specific relationships between these factors. Semi-structured interviews were used. A series of pre-determined questions served as a guide and the interviewer followed up based on the responses given by students. This interviewing technique is flexible, "suitable for gathering information and opinions and exploring people's thinking and motivations; yields rich information" (Drever, 1995, p. 8) and provides good coverage of data when used in conjunction with surveys and classroom observations (Drever, 1995).

The pre-determined set of interview questions, prompts and the student factors examined were:

1. How do you find mathematics as a subject? (*Attitude towards Mathematics, Connected and Separate Knowing*)
    - (a) Can you use three adjectives to describe mathematics? Tell me more about one of them.

2. How do you find using graphing calculators (GCs) in mathematics? (*Attitude towards GC, Calculator as Master, Servant, Collaborator*)
    - (a) Can you use three adjectives to describe how you use the GC? Tell me more about one of them.

3. Can you tell me how you study mathematics? (*Deep and Surface Approaches, VARK, Social interaction for learning preference*)
    - (a) How do you prepare for mathematics tests and examinations?
    - (b) What are the most difficult and the easiest things for you in mathematics classes?
    - (c) Do you study mathematics with your friends?

4. How do you study a topic that needs the use of GC (e.g., graphs and functions)? What about a topic that does not use the GC as much (e.g., differentiation and vectors)? (*VARK, Social interaction for learning preference, Calculator as Master, Servant, Collaborator*)

5. How do you prefer your teacher to teach when you want to learn how to use the calculator to solve mathematics problems? (*VARK, Social interaction for learning preferences, Calculator as Master, Servant, Collaborator*)
    - (a) How do you learn best?
    - (b) Is there anything that you wish your teacher would do?
    - (c) What do you like or dislike about your mathematics class?

Data analysis procedures. The data were analysed qualitatively using thematic analysis (Braun & Clarke, 2006). The observation notes, interview transcripts, and students' and teachers' surveys were coded, reviewed, and organised into categories or themes that cut across all the data sources. Three themes, based on the results of the correlational analysis in Part 1 (see Chapter 4), were: (a) students' beliefs about mathematics (including Connected Knowing-Deep Approach, Separate Knowing-Surface Approach, mathematics competency), (b) calculator attitudes (calculator competency, enjoyment and confidence) and (c) ways of using calculators (calculator as Master, Servant, Collaborator). A sample extract of a student interview and the codes are shown in Table 3.11.

Table 3.11

Extract of Hajah's Interview and Codes

Data extract	Sub-themes and Codes
Interviewer: ok. Hajah can you tell me three words to describe mathematics? Like what does mathematics mean to you?	
Hajah: I'd say maths would be rather… it's interesting, because basically we tend to, though certain things (you) may not be (able to) apply in future, we get to actually know things that will, that might or might not help us, so it's kind of new to us you see, every… when we graduate from primary school to secondary school it changes, it's kind of new to us, every time we learn a new maths topic, so it's kind of interesting to be looking forward to something new, so I'm… I find it quite interesting. Another thing would be sometimes it might get complicated. Maths being a rather tough subject, because we know that some people might not be able to do maths as well as others, but I'm rather ok with it, because maths has always been, had had been a weak point in my life, but once I had actually gone for this primary school tuition I kinda got a lot of confidence from it, then I'm, now I'm very, I'm very, trying to enjoy maths as much as I can, so I find maths very interesting too, complicated sometimes…	Deep Approach: Intrinsic interest - New things to look forward to. Connected Knowing: Complexity – it is complicated Separate Knowing: Certainty – some people might not be able to do maths as well as others Attitude: Confidence and enjoyment

Analyses of the themes and codes were conducted to seek explanations for the significant correlations between students' learning preferences and ways of using calculator found in Part 1 of the study. First, the learning preferences, beliefs, and attitudes from students' survey responses were examined to see if there were any similar patterns of association. Students' interviews relating to the learning preferences, beliefs and attitudes, and ways of interacting with calculators were compared and contrasted with their survey responses, teachers' interviews, and classroom observation field notes. The possible relationships and explanations generated were compared across students to see if there were similarities or differences. This was to see if the explanations generated were idiosyncratic or generalisable. The process was recursive and the resulting explanations were reviewed and refined. Finally, the findings were compared with the existing literature, and are reported in Chapter 5.

In the conclusion chapter (Chapter 6), the combined findings of Parts 1 and 2 of the study are compared to enrich the answers to the research questions.

Validity and Reliability of the Study

According to Creswell (2009), validity of both the quantitative data and the accuracy of the qualitative findings can be checked using the methods from the respective approaches. For Part 1 of the study, statistical procedures such as factor analysis and reliability tests were used to check the validity and reliability of the instruments used. For Part 2, some validity strategies recommended by Creswell (2009) were used: (a) triangulating different data sources of information (interviews, survey, classroom observations); (b) using rich, thick description to convey the findings; and (c) presenting negative or discrepant information that runs counter to the themes. Reliability procedures involved checking the transcripts to correct any errors made during transcription, and "constantly comparing data with the codes and by writing memos about the codes and their definitions" (Creswell, 2009, p. 190).

Besides validity pertaining to individual parts, pragmatic researchers describe the need to establish validity specific to mixed methods research (see e.g., Creswell, Plano, & Clark, 2007; Onwuegbuzie & Johnson, 2006; Tashakkori & Teddlie, 2003). Two issues of validity related to mixed methods are described in the literature: the extent to which the overall findings are representative of the population, and the extent to which both quantitative and qualitative findings are integrated.

In terms of the first issue, it is acknowledged that a limitation of the study is that in Part 2 of the study, only Singaporean students were interviewed, rather than students from both regions. The decision to carry out the qualitative study in Singapore was influenced by two considerations: (a) the researcher has relevant insider knowledge and background about Singaporean schools; (b) there was a large sample from Singapore in Part 1 of the study to enhance rigor and validity in the analysis and interpretation. In terms of the sampling, representativeness of Singaporean data to the student population could be assumed; the quantitative data were from four out of 17 junior colleges in Singapore, and the qualitative data were from three Singaporean classes with various subject combinations, taught by different teachers. For the Victorian data, although only non-government schools agreed to participate in the study, responses were obtained from students in government schools through recruitment from Facebook.

Relating to the second issue of the integration between the two methods, Creswell (2009) noted that the mixing of qualitative and quantitative data can occur at different stages: “the data collection, the data analysis, interpretation, or at all three phases” (p. 207). During the data collection phase of this study, although both qualitative and quantitative data were collected, Part 1 of the study was predominantly quantitative in nature and Part 2, predominantly qualitative in nature. During the analysis and interpretation phase, the analysis of data from the small scale study (Part 2) was conducted based on the findings of the large scale study (Part 1). Thus, the overall conclusions and interpretations of the study were derived as a result of integrating both qualitative and quantitative data, ensuring validity within the framework of mixed methods approach.

Conclusion

A concurrent mixed methods research design was used in this study, with the purpose of wanting “to both generalize the findings to a population as well as develop a detailed view of the meaning of a phenomenon or concept for individuals” (Creswell, 2009, p. 18). The study has two parts, a large scale survey study (quantitative) and a small scale study (quantitative and qualitative). The findings from Part 1 of the study, presented in Chapter 4, were used in analysing the data from Part 2. Findings from Part 2 of the study are presented in Chapter 5. The integration and interpretation of the overall results follow in Chapter 6.

Chapter 4 Results and Analysis of Part 1 of Study

Introduction

In this chapter, the results and analysis of the quantitative survey data for Singaporean and Victorian (Australia) students are presented. They answer the research questions 1, 2, 3, 4a and 4b below:

1) What are Singaporean and Victorian students':
    a. beliefs about and attitudes toward mathematics learning and advanced calculators,
    b. learning preferences, and
    c. ways of interacting with the advanced calculators (GC for Singapore, CAS calculators for Victoria)?
2) Are there differences in the above for students in the two regions, Singapore and Victoria?
3) Are there gender differences within each region?
4) What are the relationships among students' gender, beliefs and attitudes, learning preferences, and ways of interacting with the calculators? Specifically:
    a. what are the correlations between the variables?
    b. which variable best explains students' ways of interacting with calculators?
    c. how can the relationships be explained?
5) Are there other factors that affect the ways students interact with the calculators for mathematics learning?

To answer questions 4c and 5, a small scale qualitative study was conducted. The findings are reported in Chapter 5.

In the following sections, the pre-analysis checking of the data is presented, followed by the general profile of the Singaporean students in the sample and the results and analysis of the first research question relating to their beliefs about and attitudes and learning preferences toward mathematics learning, graphing calculators and their use. The results and findings for the Victorian students are then presented, together with the comparison between the Victorian and Singaporean data, answering research question 2. This is followed by the investigation of gender differences and the discussion of results to answer research question 3. Finally, the results for the correlational analysis and multiple regressions used to answer research questions 4(a) and 4(b) respectively are presented. Answers to research question 4(c) and 5 are presented Chapter 5, in which Part 2 of the study is described.

Pre-analysis Checking of Data

The responses from the complete surveys using the various instruments discussed in the previous chapter were coded and entered into SPSS, version 17.0. A list of the codes and abbreviations used for the different instruments can be found in Appendix C.

The data were downloaded from the SurveyMonkey online survey platform in Excel format. Closed-ended responses were then coded and imported into SPSS. Following the recommendations by Tabachnick and Fidell (2007) and Pallant (2007), pre-analysis checking of data was performed in three steps: 1) checks for accuracy of data input, 2) investigation of the pattern of missing data, and 3) checking for normality and outliers of interval data.

In the first step, data screening of the closed-ended responses for errors was conducted, following the steps outlined by Pallant (2007). Minimum and maximum values of the data were tabulated and checked for any errors in the range. The frequencies of the categorical data and the means and standard deviations of the interval data were examined to identify if there were any gross errors or out of range values. No errors were detected for categorical and interval data. There were 10 items with open-ended responses, and these responses were examined in Excel. Meaningless responses such as ":D", "-", or "~" were deleted. Visual checks of the overall set of data in Excel indicated that although there were cases of students who responded with the same answers (e.g. agree) for a whole section of Likert type items, their responses to other types of questions (e.g., with categorical responses and open-ended format) for the rest of the survey suggested that, overall, their responses appeared genuine. Hence, their responses were kept as they were in all the analyses conducted.

In the second step, missing data analyses were performed since in typical statistical procedures missing cases are discarded from the analyses (i.e. casewise deletion or listwise deletion), and unbiased analyses depend on the assumption that "the pattern of missing values does not depend on the data values" (SPSS Inc, n.d., p. 4).

According to Tabachnick and Fidell (2007), missing data can be classified into three types: missing completely at random (MCAR) in which the distribution of missing data is unpredictable; “ignorable nonresponse” (p. 62) or missing at random (MAR) in which the “pattern of missing data is predictable from other variables in the data set” (p. 63); and missing not at random or non-ignorable (MNAR) in which the pattern of missing data is related to the dependent variable and hence cannot be ignored. For MCAR, Tabachnick and Fidell (2007) recommended the missing cases be dropped in the analysis, which is the default option in SPSS. For missing data that are MAR or MNAR, imputation or estimation of the missing data might be considered.

For the variables with interval data used in the instrument, the Little’s MCAR test using Expectation Maximisation (EM) estimation (SPSS Inc, n.d.) was used to test whether the data were missing completely at random (MCAR). The EM method

> forms a missing data correlation (or covariance) matrix by assuming the shape of a distribution (such as normal) for the partially missing data and basing inferences about missing values on the likelihood under that distribution. (Tabachnick & Fidell, 2007, p. 68)

Roderick J. A. Little’s chi-square statistic was used to test whether the values were MCAR (SPSS Inc, n.d.). Results showed that for the Singaporean and Victorian data, the null hypothesis that the missing data are MCAR was not rejected since the p-values > 0.05 (Spore: $\chi^2 = 1001.28$, df = 950, $p = 0.12$; Vic: $\chi^2 = 302.30$, df = 276, $p = 0.133$). Since MCAR can be inferred, the SPSS default option of dropping the missing cases can be used in analysis (Tabachnick & Fidell, 2007).

For the Singaporean dataset, all the interval variables had fewer than 5% of missing values, and there were up to 11% of missing values for a few categorical variables. For the Victorian dataset, there were a few interval variables with up to 32% of missing values, and a few categorical variables with up to 39% of missing values. Although the percentages were more than the 5% ‘safe’ range, there are no empirical guidelines on what counts as excessive missing values, Fox-Wasylyshyn and El-Masri (2005) cited a range of propositions from 10% by Cohen and Cohen (1983) to 40% by Raymond and Roberts (1987). Tabachnick and Fidell (2007) recommend further investigation of the pattern for randomness rather than relying on the extent of the missing data. Investigation of the patterns of missing values following the method outlined in the SPSS missing values users' guide (SPSS Inc., n.d.) showed that the cases were due to students dropping out of the survey along the way, rather than purposefully skipping through certain items. The missing values were not imputated since they were MCAR. Also, no prior assumptions can be made about the variables and relationships between the variables, so using imputation methods such as mean substitution or regression might introduce bias to the data (Tabachnick & Fidell, 2007) and create problems in the analysis.

In the final step, all interval data were examined for normality and univariate outliers. Normality of the variables with interval data could be assessed by either graphical or statistical methods. For large sample sizes, statistical tests such as the Kolmogorov-Smirnov test would yield significant results from small deviations from normality (Field, 2005), and "a significant test doesn't necessary tell us whether the deviation from normality is enough to bias any statistical procedures that we apply to the data" (Field, 2005, p. 93). Instead of using formal inference tests, Tabachnick and Fidell (2007) recommended examining the shape of the distribution, since for a large data set "a variable with statistically significant skewness often does not deviate enough from normality to make a substantive difference in analysis" (p. 80) and "the impact of departure from zero kurtosis also diminishes" (p. 80). Visual examinations of the histograms indicated that the data were fairly normally distributed. Also, the means and 5% trimmed means were similar, so no outliers were removed. Based on these results, all the interval data were retained in subsequent analyses and inferential statistical tests were then performed.

Reliability Analyses of Instruments Used

In this section, the reliability analyses of the instruments used for the *Ways of Knowing* (Connected and Separate Knowing), *Approaches to Learning Mathematics* (Deep and Surface Approaches), and *Ways of Interacting with Technology* (calculator as Master, Servant and Collaborator) are reported.

Ways of knowing and learning mathematics. As reported in the previous chapter, students' conceptions of mathematics and their intentions and strategies to study mathematics have been found to be related (see Crawford, Gordon, Nicholas, and

Prosser, 1994, 1995, 1998). There are theoretical similarities between the Connected Knowing (CK) and Deep Approach (DA) in that both emphasised deep relational understanding and connection of mathematical ideas and concepts. There are also similarities between the Separate Knowing (SK) and Surface Approach (SA) in that both emphasised procedural understanding and an algorithmic, rote approach towards studying mathematics. From the pilot study, it was found that the items from the *Ways of Knowing* and *Approaches to Learning Mathematics* instruments can be pooled with improved reliability. Factor analysis of the pooled instrument revealed two factors. The items hypothesised as reflecting CK and DA loaded on one factor; and the other factor was comprised of items hypothesised as reflecting SK and SA (see Appendix A3, Table A6).

For the main study, the two instruments for CK, SK, DA, and SA were again combined and the pooled items were subjected to Factor Analysis and reliability analysis. The findings were consistent with those from the pilot study: the items split into two factors, with those hypothesised as reflecting CK and DA as one component and those hypothesised as reflecting SK and SA as the other (see Appendix D1 Table D3). The resultant 14-item instrument also has increased reliability with higher Cronbach-alphas, compared to that of the individual instruments. The Cronbach-alphas can be found in Table 4.1. Note that S'pore and Vic are used henceforth as abbreviations for Singapore and Victoria respectively.

Table 4.1

Cronbach-α for Individual CK, SK, DA, SA, and Combined CK-DA and SK-SA Measures

Cronbach-α	Connected Knowing [CK]	Separate Knowing [SK]	Deep Approach [DA]	Surface Approach [SA]	Connected Knowing and Deep Approach [CK-DA]	Separate Knowing and Surface Approach [SK-SA]
S'pore*	0.66	0.46	0.68	0.62	0.78	0.70
Vic	0.62	0.33	0.75	0.53	0.80	0.64

As can be seen in Table 4.1, the combined instrument has higher Cronbach-alphas. Additionally, all the items also load onto two factors (CK-DA and SK-SA) in the factor analysis. Hence, the combined instrument was used in the main analyses, called *Ways of Knowing and Learning Mathematics,* comprising Connected Knowing and Deep Approach (CK-DA), and Separate Knowing and Surface Approach (SK-SA).

Ways of interacting with calculators. The instrument for measuring how students engage with the graphing and CAS (computer algebra system) calculators was developed based on work done by Goos at al. (2000) and Geiger (2005), as presented in Chapter 3. Their framework consists of four metaphors of the role of technology, that is, how people engage with technology as they learn mathematics: technology as Master, Servant, Partner and Extension of Self. In the present study, the GC or the CAS calculator was the technology and the items comprising the instrument were derived from representative student responses for each metaphor as described by Geiger (2005). The instrument was piloted with 178 Singaporean senior secondary mathematics students (Tan, 2009) with GC as the technology. Based on a factor analysis of the responses, it was found that there were three factors and not the four anticipated (see Tan, 2009). Calculator as Master and as Servant were identified clearly. However, the items representing Calculator as Partner and as Extension of Self loaded onto a single factor. The factor was named Calculator as Collaborator.

For the main study, results from the factor analysis of the instrument were consistent with the findings from the pilot study. Again, three factors were found instead of four, with the same items loading on the GC as Master, Servant and Collaborator factors in the pilot study (see Appendix D2, Table D4). In Table 4.2, the reliability measures for the subscales of the instrument that were used in all subsequent analyses are shown. The calculated Cronbach-alphas seen on Table 4.2 indicate that each of the reliability coefficients was close to the acceptable value of 0.70 or higher (Pallant, 2007).

Table 4.2

Cronbach-alphas and Sample Items for Scales Used

Scale	Cronbach's alpha (S'pore)	Cronbach's alpha (Vic)
Connected Knowing and Deep Approach [CK-DA]	0.78	0.80
Separate Knowing and Surface Approach [SK-SA]	0.70	0.64
Calculator as Master [Cal_Ma]	0.71	0.69
Calculator as Servant [Cal_Se]	0.70	0.70
Calculator as Collaborator [Cal_Co]	0.82	0.74

For each measure, the mean score for all the items in the subscale was calculated to give the score for the measure, which was used in all subsequent analyses. The mean scores of items in the instruments from a large data set were used. Therefore, based on the Central Limit Theorem, "the sampling distributions of means are normally distributed regardless of the distributions of the variables" (Tabachnick & Fidell, 2007, p. 78). Hence, the normality of the measures was assumed in subsequent analyses.

In the next section, results and findings from the Singaporean survey are presented to answer research question 1, followed by the results from the Victorian survey to answer research questions 1 and 2.

The Main Study: Singaporean Students' Survey

Singaporean students' profile. The sample comprised 964 students (606 F = 62.9%, 358 M = 37.1%) from four junior colleges in Singapore. The population from which this sample was drawn was the 32,110 students enrolled in pre-university courses in 2009 (Singapore Department of Statistics, 2010). Background data were gathered on the Singaporean students' gender, school, year level of study, mathematics subject taken, their ethnicity, and their ownership of GC. A summary of the sample characteristics is shown in Table 4.3.

Table 4.3

Sample Profile: Singaporean Students (N = 964)

Gender	Number (%)	School	Number (%)
M	358 (37.1%)	1	11 (1.1%)
F	606 (62.9%)	2	179 (18.6%)
Year level	Number (%)	3	570 (59.1%)
10 (IP)*	38 (3.9%)	4	204 (21.2%)
11	517 (53.6%)	Ethnicity	Number (%)
12	409 (42.4%)	Chinese	867 (89.9%)
Math subjects	Number (%)	Malay	23 (2.4%)
H1**	16 (1.7%)	Indian	39 (4.0%)
H2	932 (96.7%)	Other	31 (3.2%)
Missing	16 (1.7%)	Missing	4 (0.1%)
No. of GC owned	Number (%)	GC model owned	Number (%)***
1	922 (95.6%)	TI 83+	53 (5.5%)
2 or more	40 (4.1%)	TI 84+****	905 (93.9%)
Missing	2 (0.2%)	Casio FX9860G	9 (0.9%)

* Integrated Programme, where the pre-universities offer Year 7 – 12 or 9 – 12 programmes to students without them having to go through the Year 10 national examinations.

** H1: Higher 1 mathematics, for entry into business, arts and humanities university courses; H2: Higher 2 mathematics, for entry into mathematics and science university courses.

*** includes students who said they owned two or more GCs

**** includes TI 84+ silver edition

From Table 4.3 it can be seen that there was a higher percentage of female (N = 606, 62.9%) students than male (N = 358, 37.1%) students. This is consistent with previous literature that females tended to have higher response rates compared to males for web and paper surveys (Porter & Umbach, 2006; Sax, Gilmartin, & Bryant, 2003).

There were an uneven number of responses among the schools: 11 from School 1 (1.1%), 179 from School 2 (18.6%), 570 from School 3 (59.1%), and 204 from School 4 (21.2%). These responses reflected different school contexts. School 2 had 175 responses from Year 11 students and 4 responses from Year 12. The head of the mathematics department in School 2 had given the survey to only their Year 11 students because the school did not want their Year 12 students to participate in the survey as they were preparing to take the A-levels examinations at the end of the academic year. School 1had a very small number of responses overall. When informed of this, the head of the mathematics department said that they had poor responses even for their internal school surveys of their mathematics programme. In contrast, School 3 had 253 Year 11 and 317 Year 12 student responses. Their head of mathematics department was enthusiastic about the study and was interested in knowing more about the *VARK* learning preferences. In School 4, the head of the mathematics department had given the survey to some classes for each year level from Year 10 to Year 12, resulting in 38 responses from Year 10 (IP), 82 responses from Year 11, and 84 responses from Year 12 students.

At the time the data were gathered, Schools 1 and 4 offered Integrated Programmes (IP) that start at various entry points at the secondary level (e.g. Year 7 or 9 equivalent) and continue till the Advanced level (Ministry of Education Singapore, 2010). The 38 Year 10 (IP) students (3.9%) in this study were from these two schools, and were also using graphing calculators. Overall, there were roughly equal percentages of Year 11 (N = 517, 53.6%) and Year 12 (N = 409, 42.4%) students.

The majority of students (N = 932, 98.3%) said they were taking the mainstream mathematics subject, H2 mathematics, which was meant for students intending to take tertiary level science and engineering related courses, and 16 (1.7%) said that they were taking the H1 mathematics subject, which was meant for students intending to take tertiary level arts and business related fields.

In terms of ethnicity, the sample comprised 867 Chinese (89.9%), 23 Malay (2.4%), 39 Indian (4.0%), 31 others (3.2%) and 4 missing responses (0.1%). The sample’s ethnic composition appeared to be different from the total Singaporean residents’ population of 74.2% Chinese, 13.4% Malay, 9.2% Indian and 3.2% others (Singapore Department of Statistics, 2010), with a higher percentage of Chinese compared to Malay and Indian students. This could be because there were more Chinese students in pre-universities than students from other ethnicities. There were no data available at the time of writing on the ethnic composition of students in pre-universities.

However, the information can be inferred from the percentages, within ethnic groups, of students who possess the minimum requirements to enter pre-universities. Based on the performance data by ethnic groups of the 2007 and 2008 year 10 national examinations shown (the O-level examinations) in Table 4.4, it can be seen that Chinese students had the highest percentage of students within ethnic group to have at least 5 O-level passes, compared to other ethnic groups. Since entrance into pre-university courses requires a minimum of 5 O-level passes, this means that more Chinese students qualify to enter pre-universities, and could explain why there was a higher proportion of Chinese students in the sample than in the general population. Another possible reason could be differences in response rates among ethnic groups. For example, Sax, Gilmartin, and Bryant (2003) found that in the sample 4416 American first year college students surveyed, there were different response rates by ethnicity, with Asian American having the highest rate of 30.8% and African American students having the lowest (15.4%). It could be that the Chinese students in the Singaporean data had a higher response rate than students of other ethnicity.

Table 4.4

Year 10 Performance of Students with at least 5 O-level Passes, within Ethnic Groups

Ethnic group	2007	2008
Chinese	85.4%	86.2%
Malay	59.4%	59.3%
Indian	72.6%	73.0%
Others	81.3%	79.7%

(Data extracted from Ministry of Education, Singapore, 22 Dec 2009.)

The majority of students in the sample (N = 922, 95.6%) indicated that they owned one GC, and 40 (4.1%) students had two or more GCs, with one missing response. Almost all students used Texas Instruments GCs: 53 students (5.5%) owned TI 83+; 905 students (93.9%) owned TI 84+ or TI 84+ silver edition; and only 9 students (0.9%) owned Casio FX9860G calculators. The percentages add up to more than 100% because some students who said that they owned two or more GCs indicated which two types they used.

In summary the sample was composed of:

- more female (N = 606, 62.9%) than male (N = 358, 37.1%) students,
- similar proportions of Year 11 (N = 517, 53.6%) and Year 12 (N = 409, 42.4%) students, and
- a majority of students with Chinese ethnicity (N = 867, 89.9%), taking H2 mathematics (N = 932, 96.7%) and owning a TI 84+ or TI 84+ calculator (N = 905, 93.9%).

Research Question 1

What are students' beliefs about and attitudes and learning preferences toward mathematics learning and advanced calculators, and their ways of interacting with advanced calculators?

A range of categorical and interval data were collected to find out students' beliefs about and attitudes and learning preferences toward mathematics learning and about the advanced calculators, and about how they interact with the calculators. A summary of the instruments used in the questionnaire is shown in Table 3.8 (p. 97-98) and the full instrument can be found in the Appendix B. The interval data were collected on:

- mathematics competency self-rating (MSR);
- calculator competency self-rating (CalSR);
- separate knowing-surface approach (SK-SA) and connected knowing-deep approach (CK-DA);
- ways of interacting with calculators – calculators as Master (Cal_Ma), Servant (Cal_Se), and Collaborator (Cal_Co); and
- attitudes towards calculators – enjoyment (Cal_Enj) and confidence (Cal_Conf).

Categorical data were collected on:

- general Visual, Aural, Read/Write, and Kinesthetic preferences (V, A, R, & K);
- calculator VARK preferences – students' preferences for different learning methods (e.g., watching a teacher demonstration) when learning how to use the calculators, their most preferred and least preferred methods;
- social interaction for learning preferences for studying mathematics – whether students preferred to study individually (Ma_Indv), cooperatively (Ma_Coop),

and competitively (Ma_Comp), and their most preferred mode of social interaction (Ma_Social); and

- social interaction for learning preferences for working with calculators – whether students preferred to work with calculators individually (Cal_Indv), cooperatively (Cal_Coop), or competitively (Cal_Comp), and their most preferred mode (Cal_Social).

Qualitative data were collected on:

- social interaction for learning preferences for studying mathematics and working with calculators – reasons for most preferring a particular mode of social interaction.

In the following subsections, students' characteristics for each of the instrument and measures are described. For the variables with interval data, the mean scores and standard deviations are presented. The mean scores were used, which ranged from 1 (Strongly Disagree) to 5 (Strongly Agree). One sample t-tests were conducted for each of these variables, with the null hypothesis that the mean score is the mid-value 3, to investigate if the means were significantly different from 3, using a p-value of 0.05. For the variables with categorical data, the frequencies and valid percentages are presented. For the open responses, the content were examined and categorised. The categories are then presented along with their frequency of occurrence.

Mathematics competency and GC competency self-ratings. In Singapore there are no common Year 11 and 12 assessments across schools other than the A-level examinations at the end of Year 12. Since actual measures of students' mathematical competence could not be obtained, and there are no measures of GC competencies, items tapping students' self-perceptions of their mathematics and GC competencies were used. Past research studies have found that there was a high correlation between students' self-reports of competency and their actual achievement (Hattie, 2009). In this study, the Likert-type response format was scored in ascending order as follows: 1 = "Weak", 2 = "Below Average", 3 = "Average", 4 = "Above Average", 5 = "Excellent". Following Gray, Williamson, Karp, and Dalphin (2007), the data were treated as interval data enabling means and standard deviations to be calculated. The item statements, mean scores, standard deviations and one sample t-tests results for the two items are found in Table 4.5.

It can be seen in Table 4.5 that the Singaporean students generally rated themselves as below average in both mathematics ($\bar{x}$ = 2.90) and in calculator ($\bar{x}$ = 2.94) competencies, since t-tests revealed that the values were significantly below the average “3”.

Table 4.5

Items, Mean Scores, Standard Deviations and Frequencies of Responses to MSR and CalSR

Instrument	Item	$\bar{x}$	S.D.	N
Mathematics competency self-rating (MSR)	Currently for Maths I consider myself ___.	2.90*	1.10	963
Calculator competency self-rating (CalSR)	In terms of GC skills, I consider myself ___.	2.94*	0.86	962

* Mean score significantly different from 3 (p < .05) using one sample t-tests.

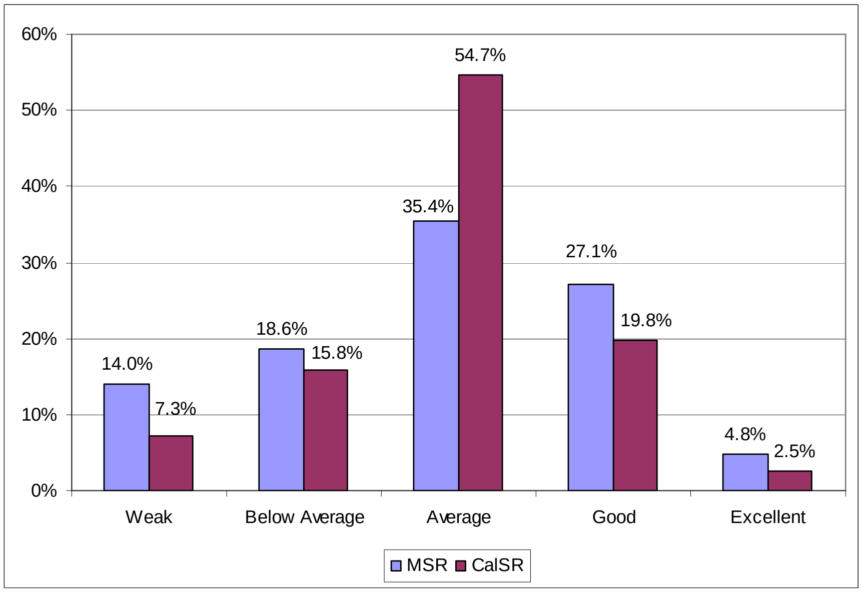

Figure 4.1. Percentages of MSR and CalSR responses.

In Figure 4.1, the percentages of the students who reported the various levels of self-ratings for mathematics (MSR) and graphing calculator (CalSR) competencies are shown. It can be seen that a higher percentage of students rated themselves as average in CalSR (N = 526, 54.7%) compared to those that rated themselves as average in MSR (N = 341, 35.4%). This could be because students were new to GC; most students were introduced to GC only during their first year of pre-university. A paired t- test performed on MSR and CalSR found that there was no significant difference between the means of the two distributions (t = -1.277, df = 961, *p* = 0.202).

General Visual, Aural, Read/write, and Kinesthetic learning preferences. The instrument used was modified from Fleming (2006)'s *VARK* for students, and piloted with 178 students from a Singaporean junior college different from the schools used in the main study. Based on the pilot study, a shortened version of the instrument comprising seven items was used (see Appendix A4 for details of the findings from the pilot study leading to the shortened version). A sample item with the responses corresponding to different VARK modes (in brackets) is shown below. Students were asked to select those response(s) which best explained their preference.

I like websites that have

☐	interesting design and visual effects. (Visual)
☐	interesting written information and articles. (Read/Write)
☐	audio channels for music, chat and discussion. (Aural)
☐	things I can click on and do. (Kinesthetic)

For the seven multiple response questions for *Visual*, *Aural*, *Read/Write*, and *Kinesthetic* learning preferences, the number of times each preference was selected by a student was added to give a score for that preference. So, for example, if a student selected the visual mode in 5 out of the 7 questions, then the *V-score* was 5. Although there were cases for which students did not select any of the four *VARK* responses on one or two of the questions, there were no cases for which a student left three or more questions blank. Hence, it was assumed that students' non-selection of the responses indicated that they did not prefer any of the modes, and not that they did not answer the question, that is, blank responses were not considered missing data. Besides the score for each of the *VARK* preferences, each student's most preferred mode was calculated based on the highest score among the *VARK* scores. In some cases, students had more than one most preferred mode, for example, if a student had a *V-score* = 2, *A-score* = 1, *R-score* = 1, *K-score* = 2, then the most preferred mode was coded as "*VK*". Hence, the most preferred mode can be any combination of *V*, *A*, *R*, and *K*, with a total of $\sum_{r=1}^{4} {}^{4}C_{r} = 15$ possible combinations. The percentages of students for the 15 possible most preferred *VARK* modes are presented in Figure 4.2, in descending order.

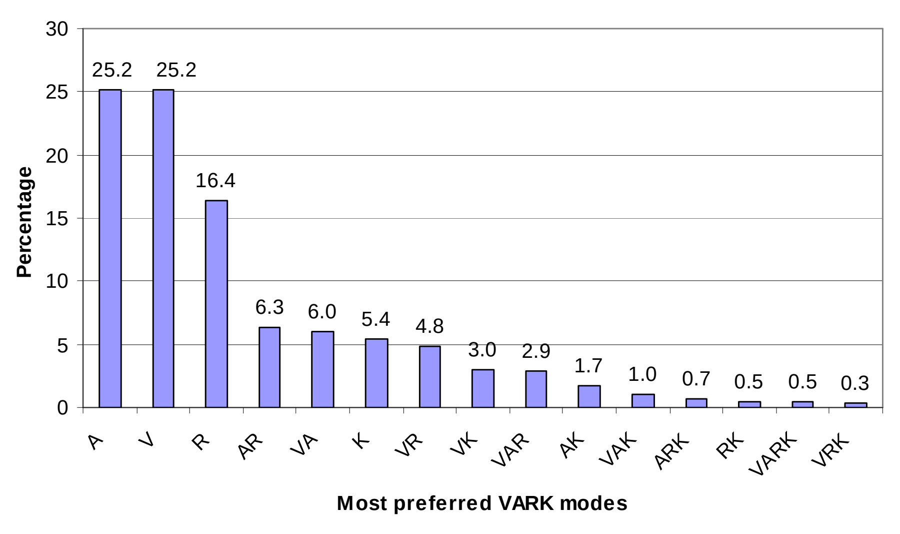

Figure 4.2. Percentages of students' most preferred VARK mode in descending order (N = 964).

From Figure 4.2, the most preferred mode with the highest percentages were *Aural* only (N = 243, 25.2%) and *Visual* only (N = 243, 25.2%) preferences, followed by *Read/Write* only (N = 158, 16.4%). There were fewer students (N = 52, 5.4%) with *Kinesthetic* only as the most preferred mode. The remaining 268 (27.8%) students were considered multimodal: they had two or more modalities as their strongest preferences. This pattern is markedly different from the data collected over the *VARK* website (http://www.vark-learn.com) by Fleming (2006), which had 62.7% multimodal, and 37.3% single preferences (*V* = 3.4%, *A* = 7.5%, *R* = 14.6%, and *K* = 11.8%). There could be many reasons for the differences between Singaporean data and Fleming's data, with the two main ones being the different populations of participants (Singaporean senior secondary students versus Fleming's data collected over the *VARK* website, which had students from various age groups from different parts of the world), and a different set of instruments and scoring systems used. The Singaporean instrument was a shortened and modified version of Fleming's original instrument, and the scoring system was also modified to accommodate the shortened instrument. The scoring process used in Fleming's original instrument was a complex one involving the calculation of the differences between the *V*, *A*, *R*, and *K* scores, from highest score to the lowest score, to find out if the respondent had a single or multiple preference(s). Based on the differences between the scores, the system also measured the strength of the preference in terms of mild, strong, and very strong (Fleming, 2006). In this study, only the highest score was used to measure the most preferred VARK mode. This could explain why there were fewer multimodal preferences found in the Singaporean sample compared to Fleming's data.

Next, the *V-scores, A-scores, R-scores,* and *K-scores* of the Singaporean data were examined. Table 4.6 below shows the means and standard deviations of the *VARK* scores, and Figure 4.3 shows the percentages of students having *V*, *A*, *R* or *K* as (one of) their strongest preference(s).

Table 4.6

Means and Standard Deviations for V-score, A-score, R-score, K-score, Out of Seven Questions

	$\bar{x}$	S.D.
V-score	3.16	1.70
A-score	3.18	1.59
R-score	2.79	1.61
K-score	1.95	1.43

The mean values shown in Table 4.6 indicate that in answering the seven multiple response questions, Singaporean students, on average, selected just over 3 *Visual* and 3 *Aural* items, nearly 3 *Read/Write* items, and around 2 *Kinesthetic* items. It should be remembered that they were able to select more than one of the *VARK* responses to any particular question. The findings suggest that students have stronger *Visual* and *Aural* preferences than *Read/Write* preferences, and that *Kinesthetic* preferences are their least favourite.

The interpretation of the mean scores in Table 4.6 is confirmed by the data in Figure 4.3. Illustrated in Figure 4.3 are the percentages of students having *V, A, R*, or *K* as one of their most preferred VARK mode. Percentages do not sum to 100% because some students had more than a single most preferred mode. It can be seen that a slightly higher percentage of students had *Aural* (N = 428, 44.4%) than *Visual* (N = 422, 43.8%) as one of their most preferred modes. About a third of the students had *Read/Write* (N = 313, 32.5%), and only 127 (13.2%) students had *Kinesthetic* as one of their most preferred modes. This is also consistent with the data shown in Figure 4.2.

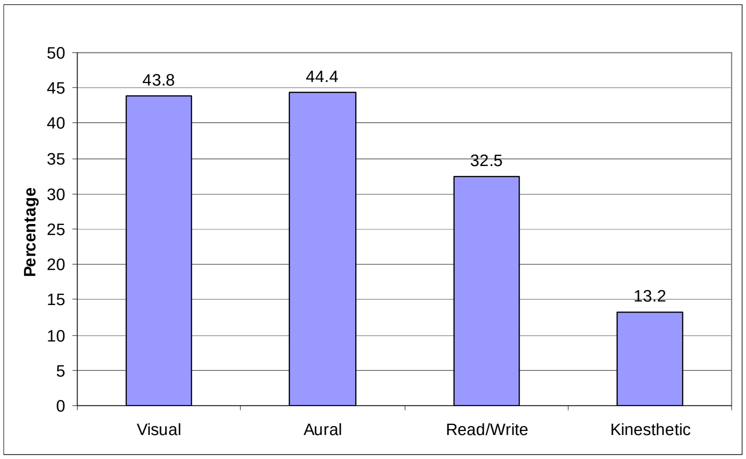

Figure 4.3. Percentages of students with *V, A, R,* or *K* as their most preferred mode.

These results were also markedly different from those reported by Fleming (2006). In his data collected from October 2006 (N = 10791), Fleming found that there were 16.1% students with Visual, 24.5% with Aural, 29.7% with Read/Write and 29.7% with Kinesthetic as either their single preference, or one of their multimodal preferences. Again, the reasons could be that they were data from different populations, and also that the instruments and scoring systems were different.

VARK preferences for learning how to use the calculator. The previous subsection described the general *VARK* preferences of the students. Next, the *VARK* preferences for learning how to use the advanced calculator to solve mathematics problems are described in terms of:

1) what methods their teachers used;
2) for each method, whether students find it helpful;

3) students’ most preferred method;
4) students’ least preferred method.

The set of 10 methods for teaching students how to use the calculator, and the corresponding learning methods used by students were categorised into *VARK* modes that most fit the activities. The descriptions of the methods and their categories are found in Table 3.6 (p. 88). Students were given the option of writing down additional teaching and learning methods that were not found in the list provided.

In the survey, Singaporean students were given 10 methods and asked to select those that their teachers used when teaching them how to use the GC to solve mathematics problems. There were two students who did not select any of the methods. These were treated as missing data and not reported in the subsequent analysis. For the rest of the 962 students who selected at least one method from the list, non-selection of the rest of the methods were treated as the response that their teachers did not use those methods.

Students were then asked whether they found each method helpful (“Yes, it definitely helps” or “No it doesn’t really help”). The methods were rephrased from teaching to learning strategies, as described in Table 4.7. There were between 4 to 24 missing responses across the different method items and the valid percentages of students who replied “Yes, it definitely helps” were calculated. The combined data showing the percentages of students who said their teachers used particular teaching methods, and the percentages of students who said that a particular method was useful, can be found in Table 4.7. Note that even when students did not indicate in the first question that their teacher used a particular teaching method, they still responded to the second question on whether the corresponding learning method was useful.

Table 4.7

Percentages of Students Who (1) Said Their Teacher Used the Teaching Method, and (2) Found the Learning Method Useful, in a Set of Ten Teaching and Learning Methods.

	Teaching methods	% of students who said their teacher used this method	Learning methods	% of students who said they found this method helpful	*VARK*
(a)	Provide a demonstration	92.0%	See my teacher's demonstration in class	95.1%	Visual
(b)	Let students demonstrate to the whole class	8.0%	See the steps my friends show me on their GC	89.5%	Visual
(c)	Refer to the GC screen captures shown in notes or textbooks or manual	78.7%	Look at the GC screen captures in notes, textbooks or manual	77.3%	Visual
(d)	Let students discuss with one another	27.7%	Discuss answers with my friends	74.8%	Aural
(e)	Explain the steps and concepts clearly and thoroughly	63.5%	Listen to a teacher who explains the steps and concepts clearly and thoroughly	88.2%	Aural
(f)	Read out the steps given in notes, textbook or manual	43.8%	Listen to a teacher who reads out the steps given in notes, textbooks or manual	47.2%	Aural
(g)	Write out the steps on the board	40.3%	Copy down the steps my teacher writes on the board	56.6%	Read/ Write
(h)	Ask you to make your own notes	8.8%	Make my own notes	65.6%	Read/ Write
(i)	During a demonstration ask you to follow the steps as shown	72.1%	Try out the steps on the GC at the same time I see a demonstration or hear an explanation or read the instructions	94.7%	Kinesthetic

	Teaching methods	% of students who said their teacher used this method	Learning methods	% of students who said they found this method helpful	*VARK*
(j)	Encourage you to play around with the GC	51.9%	Try the buttons out and play around with the GC	75.7%	Kinesthetic

(1) Teaching methods. It can be seen in Table 4.7 that the most frequently cited methods used by teachers were:

- (a) providing demonstrations (Visual, N = 885, 92.0%);
- (c) referring to GC screen captures shown in lecture notes or textbooks or manual (Visual, N = 757, 78.7%);
- (i) asking students to follow the steps during demonstrations (Kinesthetic, N = 694, 72.1%);
- (e) explaining the steps and concepts clearly and thoroughly (Aural, N = 611, 63.5%); and
- (j) encouraging students to play around with the GC (Kinesthetic, N = 499, 51.9%).

Very few students said that their teachers (b) let students demonstrate to the class (Visual, N = 77, 8.0%), (h) asked students to make their own notes (Kinesthetic, N = 85, 8.8%), or (d) let students to discuss answers with one another (Aural, N = 266, 27.7%).

As can be seen from the data, more students said their teachers used Visual and Kinesthetic methods, compared to Aural and Read/Write methods. The top three most cited methods used by teachers were methods with Visual (method (a): 92.0% and method (c): 78.7%) and Kinesthetic (method (i): 72.1%) modalities. This suggests that the GC might lend itself to Visual and Kinesthetic approaches of teaching and learning. Also, given that there are equally high percentages of students with strong Visual (43.8%) and Aural (44.4%) modalities as their general VARK preferences (see Figure 4.3), teachers' teaching methods may be privileging students with Visual preferences and not sufficiently catering to students with Aural preferences.

There was an option where students could add a method that their teachers used which was not found in the list given. There were eight responses to this open-ended item, with their *VARK* modalities placed in brackets where categorising was possible:

- He would ask us to insert the numbers for e.g. (using the) simultaneous equation solver (function in the GC) to solve vectors questions and (then to) discuss and explain the figures that we get from the screen. [Aural]
- No demonstrations are used (by the teacher). Self-learned (I learnt how to use the GC on my own).
- Ask your friends! (It) saves time.
- Using the Computer GC (computer software emulator)
- Compete against each other to come up with the answer within the shortest time
- Let us figure it out ourselves
- Use the visualiser (a device that projects what was put on it onto the projector screen) and show the whole class how to use the GC [Visual]

For most of the responses, it was not possible to categorise these responses according to *VARK* modalities because there were ambiguities as to which modes were engaged. For example, students' self-learning or figuring it out by themselves suggests that students find their own ways of learning, which might be undertaken in a variety of modalities (e.g., reading the notes, textbooks or manuals, or discussing with their friends, or playing around with the GC, or looking at the steps their friends show them on the GC screen).

(2) Learning methods. It can be seen in Table 4.7 that students generally agreed that the methods were helpful to their learning of GC skills (range between (f) 47.2% and (a) 95.1%). The three methods with the lowest percentage of students who found them helpful involved Aural and Read/Write modalities:

- (f) listen to a teacher who reads out the steps given in notes, textbooks or manual (N = 444, 47.2%);
- (g) copy down the steps my teacher writes on the board (N = 532, 56.6%); and
- (h) make my own notes (N = 617, 65.6%).

There were similarities and differences between what methods students said their teachers used, and what they said helped them learn. For the following methods involving Visual and Aural modalities the two percentages were similar:

- (a) teacher demonstration (Visual, teacher used = 92.0%, students found helpful = 95.1%);
- (c) referring to GC screen captures (Visual, teacher used = 78.8%, students found helpful = 77.3%); and
- (f) reading out steps given in notes, textbooks or manual (Aural, teacher used = 43.8%, students found helpful = 47.2%).

In contrast, for the following Visual, Aural, and Read/Write methods there was a wide gap (the difference in percentages was more than 50%):

- (b) letting students demonstrate to the whole class (teacher used = 8.0%) / seeing the steps students' friends show on their GC (students found helpful = 89.5%);
- (d) letting students discuss answers with friends (teacher used = 27.7%, students found helpful = 74.8%); and
- (h) getting students to write their own notes (teacher used = 8.8%, students found helpful = 65.6%).

For each of these methods, there was a much higher percentage of students who said it helped them learn ((b) 89.5%; (d) 74.8%; and (h) 65.6%), compared to the percentages who said that their teachers used the method ((b) 8.0%; 27.7%; and (h) 8.8%). It is noted that for method (b), the wide gap could be due to the fact that the teaching method did not completely correspond to the learning method. A teacher could also encourage students to work together and share their answers on the GC screens with one another. Nevertheless, even though there was a high percentage of students saying that their teachers provided demonstrations (92.0%), there was a very low percentage that indicated that their teachers let students demonstrate to the class (8.0%). An implication of the findings is that teachers should, perhaps, employ more of the methods (b), (d), and (h) that students said helped them learn how to use GC. It is also interesting to note that methods (b), (d), and (h) seemed to be consistent with a socio-constructivist approach where students learn through making meaning from discussions, and take charge of their own learning by making their own notes.

(3) Most preferred method, and (4) least preferred method. The next two questionnaire items asked students to choose which learning method they most and least prefer when learning how to use GC to solve mathematics problems[1]. The valid percentages of students who selected each of the methods as their most and least preferred are shown in Figure 4.4.

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[1] There was an open-ended response option for students to add their own most preferred method when learning how to use the GC. There were seven open-ended responses:

1. actually i think and (sic) b) and i) are both almost equally applicable to me, and a) as well if i were paying attention during lessons.
2. see teacher's demonstration & follow the demonstration on my own gc at the same time
3. h and i
4. a) see my teacher's demonstration in class.
5. all are equally effective for me to use the GC
6. using catalog help (:
7. to try it out on my own after a demo.

For responses #1 and #6, the students selected (b) and (j) respectively as their most preferred method of learning how to use the GC, which were coded. Response #2 was coded as (i) and response 4 coded as (a). Responses #3, #5 and #7 were not coded.

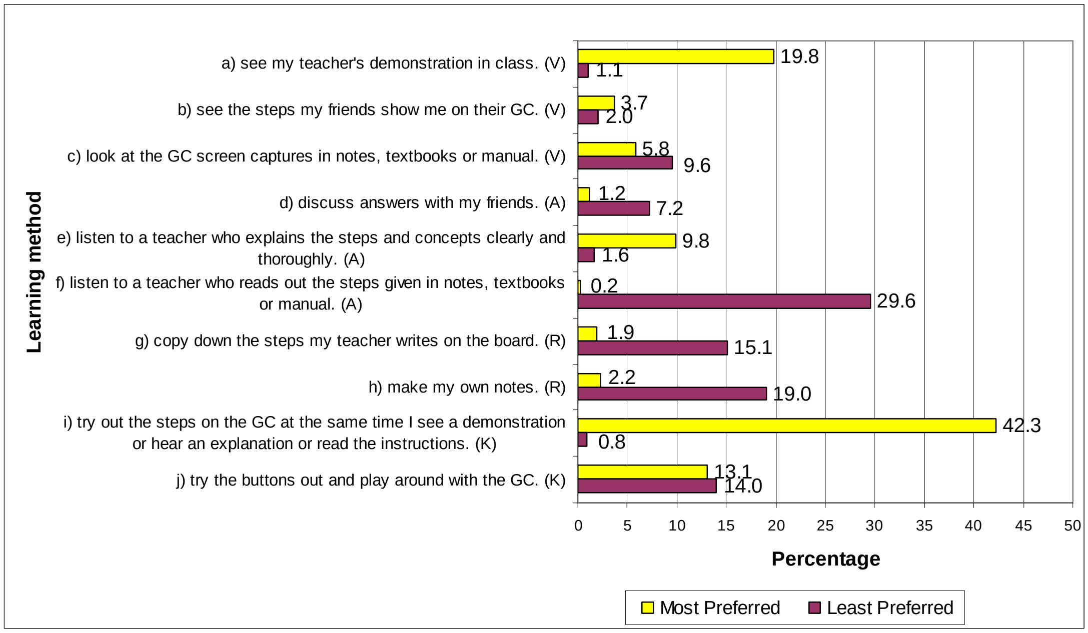

Figure 4.4. Percentages of students' most and least preferred methods when learning how to use the GC.

As can be seen in Figure 4.4, the most preferred methods in descending order were:

- (i) when students try out the steps on the GC at the same time they watch a demonstration or hear an explanation or read the instructions (Kinesthetic, N = 400, 42.3%);
- (a) seeing their teacher's demonstration in class (Visual, N = 187, 19.8%);
- (j) trying the buttons out and playing around with the GC (Kinesthetic, N = 124, 13.1%).

This most preferred pattern of Kinesthetic and Visual preferences relating to learning how to use the GC is markedly different from the previous general *VARK* items that showed high percentages of Visual and Aural preferences (Figure 4.3). The pattern is also markedly different from the percentages of students who said that the methods were helpful (Table 4.7). Among those methods which students found helpful (Table 4.7), it was the Kinesthetic method (i) that had the highest percentage (42.2%) as the most preferred method, compared to other Visual or Aural methods. This suggests that the GC, being a tool for graphing, lends itself more to learning in Kinesthetic and Visual modes. It may also be that students adapt or select their learning preferences according to the situation, and learning how to use the GC warranted Kinesthetic and Visual modes. The Kinesthetic method (i) may be favoured by more students because it also involves other modalities at the same time. From the literature on technology use in mathematics education, teacher privileging can be a factor that influences students' preferences (Kendal & Stacey, 2001). However, this was not evident from comparison of teacher methods and students' preferences in this data. Although high percentages of students said their teachers used methods (a) (92.0%) and (i) (72.1%), which were most preferred by a high percentage of students; a much lower percentage of students (51.9%) said their teacher "(j) encouraged them to try out the GC buttons and play around with the GC", even though method (j) was also one of the top three most preferred methods. Conversely, a high percentage of students said their teachers used method (c) (78.7%), but only 5.8% of students most preferred this method to learn how to use the GC. It seemed that teacher privileging particular methods did not necessarily influence students to prefer using the methods to learn.

Also from Figure 4.4, the least preferred methods with percentages in descending order were:

- (f) listen to a teacher who reads out the steps given in notes, textbooks or manual (Aural, N = 279, 29.6%),
- (h) make their own notes (Read/Write, N = 179, 19.0%),
- (g) copy down the steps their teacher wrote on the board (Read/Write, N = 142, 15.1%), and
- (j) try the buttons out and play around with the GC (Kinesthetic, N = 132, 14.0%).

It is interesting to note that most of the Visual methods had lower percentages of students that least preferred them, and that the least preferred method is of Aural modality (f). Method (f) was the one with the lowest percentage of students who found it helpful (47.2%), although it was a method that 43.8% of the students said their teacher used (see Table 4.7).

Further investigation of the pattern of most preferred method of learning how to use the GC, with respect to students' general VARK preferences was conducted and the results reported in the next subsection.

Are students' general VARK preferences related to their calculator VARK preferences? To investigate whether students' general VARK preferences were related to their most preferred methods to learn how to use the GC (i.e., calculator VARK preferences), the students were categorised into five groups based on their general *VARK* preferences:

- students with only Visual mode (V) as their most preferred mode (N = 243),
- students with only Aural mode (A) as their most preferred mode (N = 243),
- students with only Read/Write (R) mode as their most preferred mode (N = 158),
- students with only Kinesthetic (K) mode as their most preferred mode (N = 52), and
- those who were multimodal for their most preferred mode (VA, VR, VK, etc.) (N = 268).

The most preferred methods to learn how to use the GC for these groups of students were tabulated and the percentages within group calculated. The bar-charts of the groups are shown in Figure 4.5. As seen in Figure 4.5, the patterns of percentages among the five groups were very similar despite the differences in their *VARK* preferences, supporting the argument that Singaporean senior secondary students most prefer to employ Visual and Kinesthetic modes when learning how to use the GC, regardless of their general *VARK* preferences.

As seen in Figure 4.5, the highest percentages of students in the five groups responded that they most preferred method (i): try out the steps at the same time they see a demonstration, hear an explanation or read the instructions (Visual: 41.8%, Aural: 47.1%, Read/Write: 37.7%; Kinesthetic: 36.5%; Multimodal: 42.2%). This suggests that students tended to prefer to engage with the calculator kinesthetically, while at the same time receiving input via their preferred modes such as Visual or Aural or Read/Write.

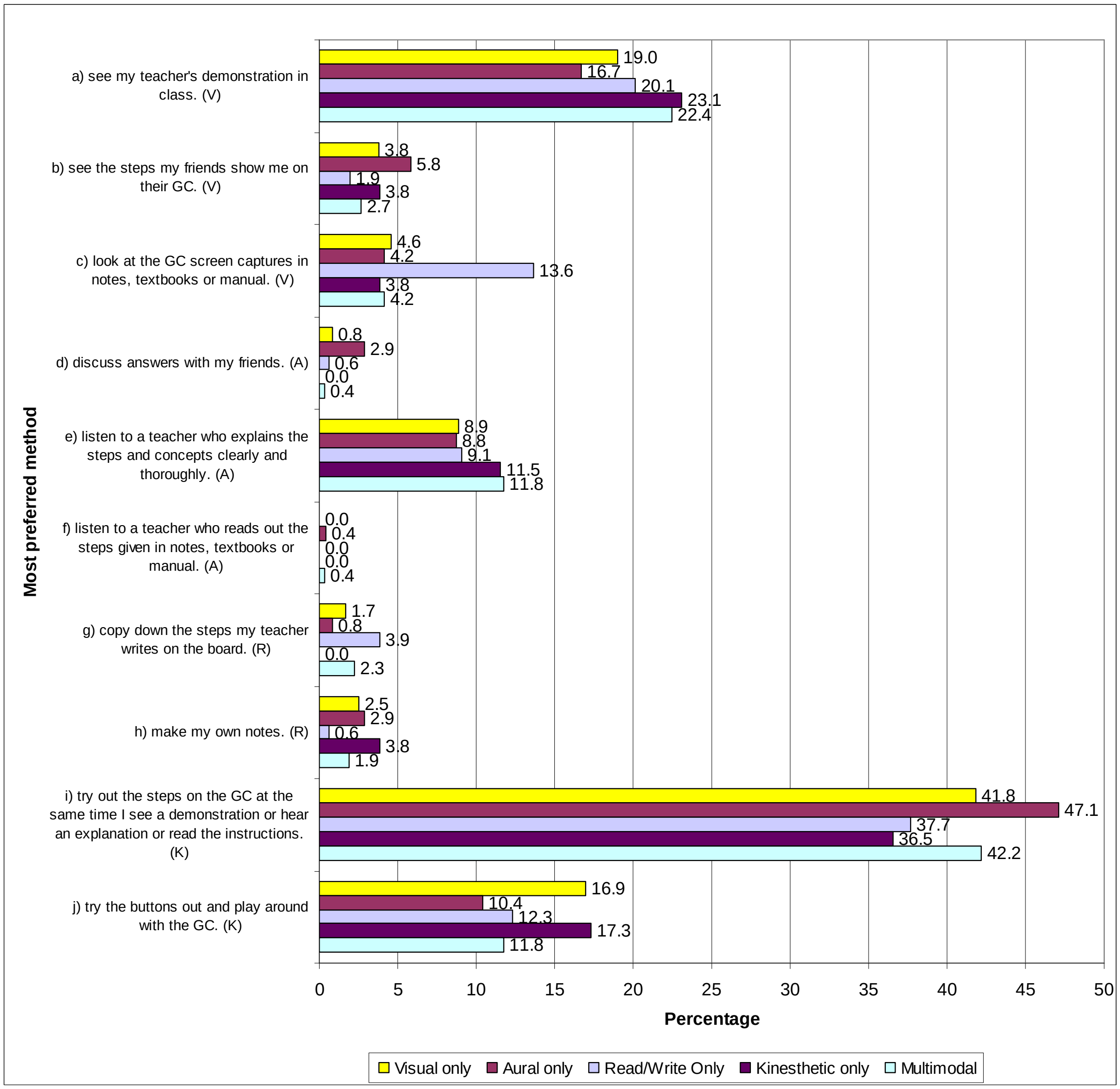

Figure 4.5. Comparisons of most preferred methods between students who were Visual, Aural, Read/Write, Kinesthetic and Multimodal.

As seen in Figure 4.5, there were relationships between students' general VARK preferences and their most preferred method to learn how to use the GC. A higher percentage of students with Read/Write preference (N = 21, 13.6%) most preferred method (c): "look at the GC screen captures in notes, textbooks or manual", compared to the percentages of students with other modal preferences. One reason could be that students with Read/Write preference would prefer to read the notes, textbooks or handout when learning how to use the GC, and therefore method (c) is a related learning activity. Perhaps for future studies another method could be added to the list: reading from notes, textbooks and manual as a method for students with Read/Write preference. There were also higher percentages of students with Visual (16.9%) and Kinesthetic

(17.3%) preferences who most preferred method (j) (of Kinesthetic modality), than students with Aural (10.4%), Read/Write (12.3%) or multimodal preferences (11.8%). This implies that students with general Visual and Kinesthetic preferences had a higher tendency to prefer learning by playing around with the GC on their own than students with other modality preferences. Overall, however, the pattern of most preferred methods (calculator VARK preferences) were similar across groups of students with different general VARK preferences.

Summary of students' general and calculator VARK preferences. In summary, for general *VARK* preferences, there were higher percentages of Singaporean senior secondary students who had Visual (N = 422, 43.8%) and Aural (N = 428, 44.4%) modes as their most preferred mode than those with Read/Write (N = 313, 32.5%) and Kinesthetic (N = 127, 13.2%) as their most preferred mode (see Table 4.3, p. 120). Note that the percentages do not add up to 100 because there were multimodal preferences (e.g., having VAK as the most preferred mode). When students' multimodal preferences were taken into account, about three-quarters of the students (N = 749, 77.7%) of the students had an Aural and/or a Visual preference as (one of) their most preferred mode(s).

Most students said that their teachers used some methods with Visual and Kinesthetic modalities when teaching students how to use the GC to solve mathematics problems: (a) providing demonstrations (N = 885, 92.0%); (c) referring to GC screen captures shown in lecture notes or textbooks or manual (N = 757, 78.7%); (i) asking students to follow the steps during demonstrations (N = 694, 72.1%). There were other methods with Visual and Kinesthetic modalities that very few students said their teachers employed, such as (b) letting students demonstrate to the class (8.0%) and (h) asking students to make their own notes (8.8%), which could be linked to socio-constructivist teaching and learning approaches.

Students generally found the methods helpful in their learning of GC skills. More than 70% of the students found the range of methods with Visual, Aural and Kinesthetic modalities helpful (see Table 4.7, p. 132). The three methods with the lowest percentage of students who found them helpful involved Aural and Read/Write modalities:

- (f) listen to a teacher who reads out the steps given in notes, textbooks or manual (N = 444, 47.2%, Aural)
- (g) copy down the steps my teacher writes on the board (N = 532, 56.6%, Read/Write)
- (h) make my own notes (N = 617, 65.6%, Read/Write)

When learning how to use the GC, out of the list of ten methods, a high percentage of Singaporean students (N = 400, 42.3%) said they most preferred to (i) try out the steps at the same time they see a demonstration, listen to explanation, or read the instructions. It was found that generally students' most preferred general VARK modes (Visual, Aural, Read/Write, Kinesthetic) did not correspond with their calculator VARK preferences (see Figure 4.6). This implies that calculator VARK preferences did not seem to be related to students' general VARK preferences, and that the GC seemed to lend itself to methods with visual and kinesthetic modalities. In addition, the kinesthetic method that also engages students' other modes (i.e. (i) trying out the steps at the same time as watch a demonstration, listening to an explanation or reading the instructions) is the most successful approach when teaching students how to use the GC to solve mathematics problems. This difference found between general VARK and calculator VARK preferences might also be one between a *subjective* and an *objective* preference (Jaspers, 1992), as mentioned in Chapter 2. It could be that the general VARK instrument measured students' personal subjective preference for a particular modality, whilst the calculator VARK instrument measured what students perceive as the most effective modality for learning how to use calculators.

Connected knowing-deep approach and separate knowing-surface approach. In this subsection, the data and results of the combined 14-item instrument of Connected and Separate Knowing (CK, SK), and Deep and Surface Approaches (DA, SA) to mathematics learning are presented. As discussed in Chapter 3, two components were found from the factor analysis of the pooled CK, SK, DA, and SA items using principal components analysis with varimax rotation. One component was CK-DA with the seven CK and DA items, and the other was SK-SA with the seven SK and SA items. The combined CK-DA and SK-SA subscales produced better Cronbach-alphas than the CK, DA, SK, and SA subscales separately (see Table 4.1). The seven items for each subscale were worded positively, and the responses were coded from Likert type response formats of 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, and 5 = strongly agree. Since a 7-item subscale would produce a range of scores from 7 to 35, for ease of interpretation the mean score is used instead to represent the subscale score. The mean score would have similar interpretation as an individual item: ranging from 1 (strongly disagree) to 5 (strongly agree). Hence, the mean value of 3.28 for the CK-DA subscale implies that students agreed slightly to the items on the Connected Knowing-Deep Approach subscale.

Table 4.8

Mean and Standard Deviations for CK-DA and SK-SA Subscales

Subscales	N	Mean**	S.D.
Connected Knowing and Deep Approach (CK-DA): 7 items	928	3.28*	0.67
Separate Knowing and Surface Approach (SK-SA): 7 items	933	3.47*	0.69

* Significantly different from mid-point 3, using one sample t-test, p < .01

** Paired sample t-test shows significant difference between the means CK-DA and SK-SA, t(921) = -5.36, p < .01

In Table 4.8, the number of valid responses, means and standard deviations for the two subscales are shown. It can be seen from Table 4.8 that Singaporean students scored significantly higher for SK-SA (= 3.47) than for CK-DA (= 3.28) (paired t-test, t(921) = -5.362, *p* < .01). This implies that students agree more strongly to using separate knowing-surface approaches than to using connected knowing-deep approaches. To further investigate the relationship between CK-DA and SK-SA, students' CK-DA scores were plotted against their SK-SA scores using a scatterplot (see Figure 4.6).

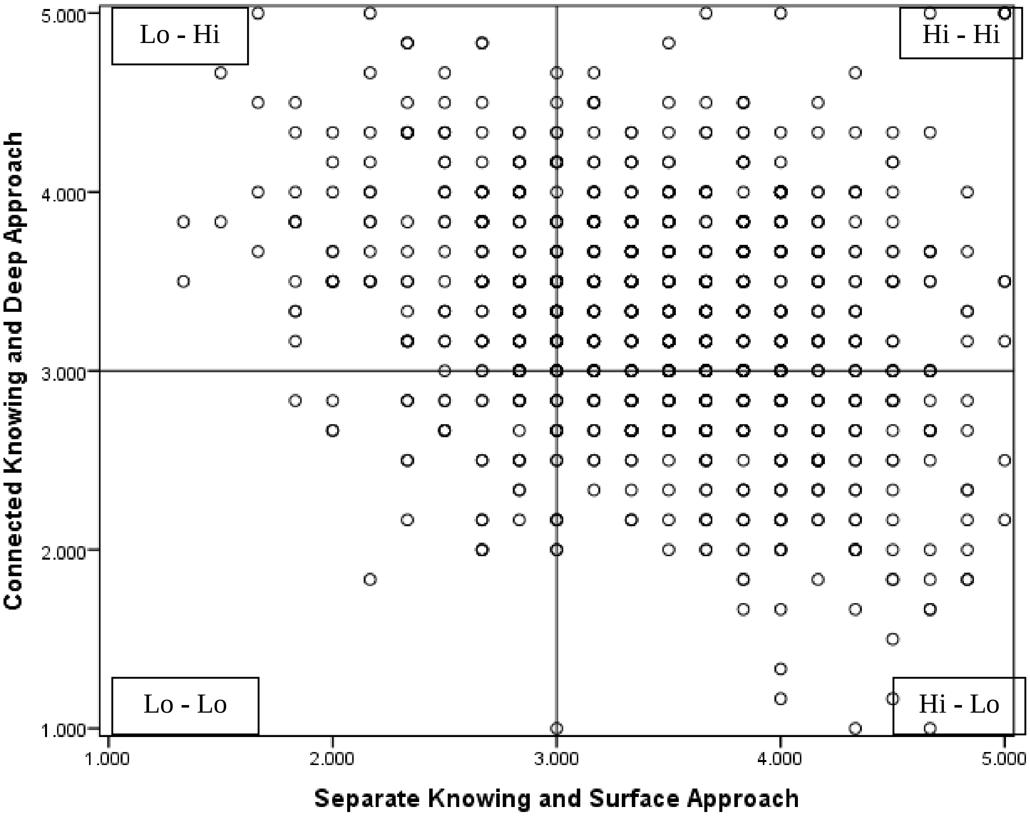

Figure 4.6. Scatterplot of SK-SA against CK-DA for all Singaporean students.

It can be seen in Figure 4.6 that most of the scores were either higher (>3) in both CK-DA and SK-SA (in the Hi-Hi quadrant), or higher (>3) in one and lower (<3) in the other (in the Lo-Hi and Hi-Lo quadrants). There were few students who were in the Lo-Lo quadrant, and no students had both CK-DA and SK-SA scores below 2.

Using Pearson product moment correlation, a weak negative correlation between Connected Knowing-Deep Approach and Separate Knowing-Surface Approach (r = -0.26, p < .01) was obtained. With their original two factor deep-surface approaches instrument, Kember, Biggs, and Leung (2004) found a modest positive correlation between deep and surface approaches (r = 0.33) from the data based on 841 students in Hong Kong secondary schools. They found that the Surface Motive subscale (with two subcomponents: fear of failure and aim for qualification) correlated positively to Deep Motive and Deep Strategy subscales. The researchers described the surface motive subscale as a multidimensional construct. The weak correlation between CK-DA and SK-SA (r = -0.26, p < .01) found in this study is consistent with the assumption of the orthogonality of components found through factor analysis.

In this study, the sample comprised senior secondary students in pre-university courses, considered to be academically able and focussed on gaining entrance into university. Hence, students with high scores on both CK-DA and SK-SA might be considered as employing both surface and deep approaches, with the intention of achieving high scores in examinations. Also, a possible reason why there were few students in the Lo-Lo quadrant in the scatterplot (Figure 4.6) could be that students with low scores on both might be disengaged in learning. In the Singapore context, only few of such students probably would be able to qualify for pre-university courses and hence appear in the sampling frame.

Social interaction for learning preferences when studying mathematics and working with calculators. There were five types of questions with regard to social interaction for learning preferences (individual, cooperative, and competitive) that were found in the survey:

(1) For each mode, students indicate if they prefer or do not prefer the mode of social interaction preference to study mathematics.

(2) For each mode, students indicate if they prefer or do not prefer the mode of social interaction preference when working with advanced calculators.

(3) Students indicate which of the three modes they most prefer when studying mathematics.

(4) Students indicate which of the three modes they most prefer when working with advanced calculators.

(5) Open-ended responses for students to explain their choice of most preferred modes for questions (3) and (4).

Preference for each mode and most preferred mode. The findings for (1) – (4) are presented in Figures 4.7 and 4.8.

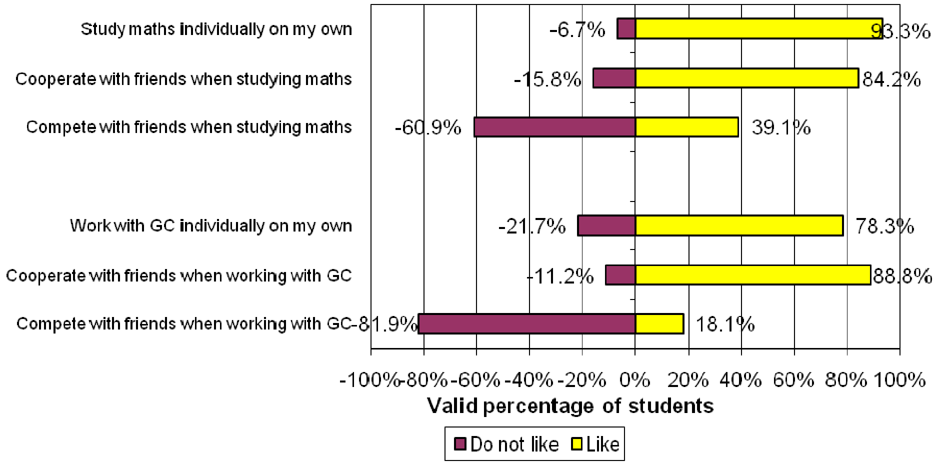

Figure 4.7. Valid percentages of students who liked or disliked each social interaction for learning preference.

In Figure 4.7, it can be seen that there were similar patterns between students' social interaction for learning preferences for studying mathematics and working with GC. A majority of the students liked to study mathematics individually (93.3%) and cooperatively (84.2%), and to work with GC individually (78.3%) and cooperatively (88.8%). Fewer students liked to compete with friends when studying mathematics (39.1%) and when working with GC (18.1%).

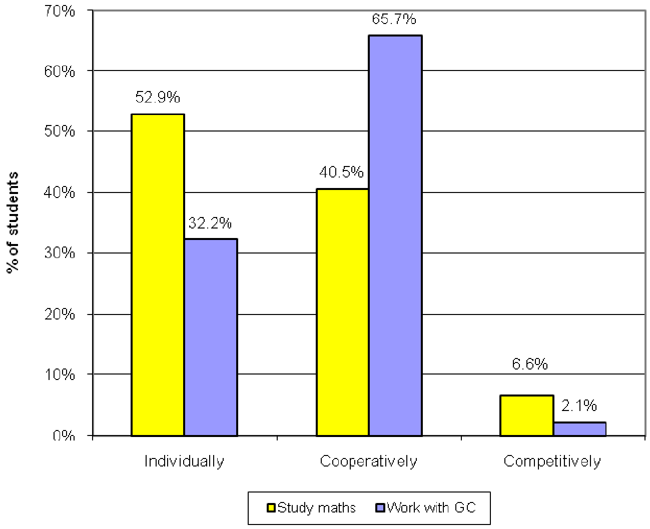

Figure 4.8. Comparison of students' most preferred social interaction modes, between studying mathematics and working with GC.

In Figure 4.8, it can be seen that the patterns for the most preferred social interaction for learning preference were different for studying mathematics and for working with GC. A Chi-square test indicated that the differences were significant, $\chi^2(4, N = 896) = 109.7, p < .001$, with more than 80% of the expected cell frequencies greater than five (Pallant, 2001, p. 259). For working with GC, there was a much higher percentage of students who indicated that they most preferred to cooperate with their friends (65.7%), compared to working individually (32.2%). For studying mathematics, a higher percentage of students said they most preferred to study individually (52.9%), compared to studying cooperatively (40.5%). Although the percentages were small for the competitive preference, a slightly higher percentage of students most preferred to compete with friends when studying mathematics (6.6%), compared to working with GC competitively (2.1%). The finding that students most preferred to study mathematics individually is consistent with the finding by McKinnon, Nolan, and Owens (1992) that students' preference for cooperation decreased with increased year level. The finding that a higher percentage of students most preferred to cooperate with friends when working with GC, compared to when studying mathematics, is consistent with some of the past research that technology promotes collaborative learning (see e.g., Geiger, 1998, 2006).

Explanations for the most preferred mode. Students were asked to explain their choice of most preferred social preference for both studying mathematics and working with calculators, in the form of open-ended comments. The open-ended responses were coded and analysed using thematic analysis (Braun & Clarke, 2006). The codes were analysed and aggregated into categories. The frequency of responses for each category was tabulated in order to get a sense of the prevalence of the types of reasons given by students for their social interaction for learning preferences. Many comments included statements related to one or more of the identified subcategories and categories. Multiple categorisations resulted and consequently, the percentages do not sum to 100%.

Theory underpinning the coding process. In chapter 3, justification of the use of items for social interaction for learning preferences was presented. In the thematic analysis of students' explanations for their most preferred mode of social interaction, six major categories or themes were derived from the categories used in past studies (illustrated in Table 4.9), from an iterative inductive-deductive process where categories were generated and tested against all the coded responses, and based on “researcher judgement” (Braun & Clarke, 2006, p. 82). An additional seventh category specific to technology emerged. Students’ responses were coded into subcategories, which were based on the words and terms used by participants, and classified into the following categories:

1. learning outcomes - good or bad qualities related to learning mathematics concepts and problem solving;

2. learning performance - related to students’ performance and achievement in assessment;

3. learning process - related to how students learn, such as rate of progress;

4. learning environment - related to the physical environment in which students learn, such as a quiet environment;

5. attitudes - related to the emotions students feel about the learning preference, such as tension and stress, motivation and satisfaction; and

6. peer interaction - related to how students work with one another, such as friends helping them, or peer tutoring.

Table 4.9

Categories of Reasons for Students’ Most Preferred Mode of Social Interaction for Learning, and Categories Used by Pre-existing Inventories

Categories used in this study	Categories used by	
	Owens & Barnes (1992)	Riechmann & Grasha (1974)
Learning outcomes	Positive and negative work outcomes	Reactions to classroom procedures
Learning performance	The future	
Learning process	Rate of progress	
Learning environment	Individual differences	

Categories used in this study	Categories used by	
	Owens & Barnes (1992)	Riechmann & Grasha (1974)
Attitudes	Global preference Global dislike Tension Self-sufficiency	Students' attitudes towards learning
Peer interactions	Global projection Altruism	View of teachers and/or peers

An example of multiple categorisations. A student who most preferred to study mathematics individually gave the following reason:

> "I will be able to study at my own pace and to be able to realise the mistake myself instead of always relying on my friends" (student #839).

The comment was coded into three subcategories, two of which were grouped into the same category:

Quote	Subcategory	Category
study at my own pace	work at own pace	learning process
able to realise the mistake myself	doing it myself, learn and explore maths on my own	learning process
instead of always relying on my friends	do not want to be over reliant on friends	peer interactions

A summary of the percentages of responses in each category within the social interaction modes, for both studying mathematics and working with GC are found in Table 4.10. For each category, the subcategory with the highest frequency is reported in brackets (Table 4.10). Details of the list of subcategories for each category and their corresponding examples can be found in Appendix D3, Tables D7 and D9 (for studying mathematics) and Tables D8 and D10 (for working with GC).

i) social interaction for learning preferences when studying mathematics. There were 491 students who most preferred to study mathematics individually, but only 361 students explained the reasons for their choice. The corresponding numbers for the other two modes were: cooperatively (376 most preferred, 304 explained why) and competitively (61 most preferred, 48 explained why). It can be seen in Table 4.10 that 60.4% of the 361 students who most preferred to study mathematics individually cited reasons pertaining to learning outcomes, such as being able to concentrate better. In addition, students most preferring to study mathematics cooperatively with friends tended to cite reasons pertaining to peer interaction, such as friends helping them (72.0%), and those most preferring to study mathematics competitively tended to cite attitudinal reasons such as motivation and fun (62.5%). Students most preferring to study mathematics cooperatively or competitively did not mention any reasons pertaining to the learning environment, which are shown on Table 4.10 as zero percent.

ii) social interaction for learning preferences when working with GC. There were 292 students who most preferred to work with the GC individually, but only 200 students gave explanations. The corresponding numbers for the other two modes were: cooperatively (595 most preferred, 452 explained why) and competitively (19 most preferred, 13 explained why).

It can also be seen in Table 4.10 that 31.5% of the 200 students who most preferred to work with the GC individually cited reasons pertaining to learning outcomes, such as being able to concentrate better. In addition, students most preferring to work with GC cooperatively with friends tended to cite reasons pertaining to peer interaction, such as friends helping them (68.1%), and those most preferring to study mathematics competitively tended to cite reasons pertaining to improved attitudes (46.2%) and the learning process (46.2%). Further discussions of the results follow Table 4.10, to compare the patterns of student explanations for studying mathematics and when working with GC.

Table 4.10

Summary of Percentages of Categories within Each Social Interaction Mode for Studying Mathematics and for Working with GC

	Studying Mathematics			Working with GC		
	Individually (N = 361)	Cooperatively (N = 304)	Competitively (N = 48)	Individually (N = 200)	Cooperatively (N = 452)	Competitively (N = 12)
Learning outcomes	60.4% (concentrate better*)	41.8% (deepen understanding)	6.3% (think, concentrate better)	31.5% (concentrate better)	36.7% (check answers, GC steps)	8.3% (think, concentrate better)
Learning performance	2.8% (compete with self)	8.9% (I am weaker than peers)	12.5% (brings out the best)	4.5% (prepare for assessment)	7.1% (I am weaker than peers)	0.0%
Learning process	33.5% (own pace)	29.3% (share answers)	50.0% (study harder)	23.5% (explore on my own)	21.9% (share knowledge)	50.0% (study harder)
Learning environment	36.6% (no distractions)	0%	0%	9.5% (no distractions)	0%	0%
Attitudes	13.9% (social pressure when studying with friends)	15.5% (fun, motivating)	62.5% (fun, motivating)	10.0% (I like it)	12.4% (fun, motivating)	50.0% (fun, motivating)
Peer Interaction	17.5% (seek help from friends or teacher if needed)	72.0% (friends help, peer tutoring)	6.3% (compare with those better)	12.5% (friends are of no help)	68.1% (get help from friends)	0%
Technology				22.5% (GC is a personal device)	29.9% (learn from friends how to use GC)	0%

* The subcategory with a majority of the percentage within the category (see Appendix D3, Tables D7 to D10).

Comparisons between explanations of social interaction preferences for studying mathematics and working with GC. There are two main findings which can be seen in Table 4.10:

- There are differences in the distribution of categories of explanations among the different social interaction modes (individual, cooperative, competitive).
- The patterns of distribution of categories are generally similar when studying mathematics and when working with GC.

The following are descriptions of the distribution patterns of explanations:

(i) individual mode of social interaction preference

- Learning outcomes had the highest percentages within mode for both studying mathematics (60.4%) and working with GC (31.5%).
- Learning environment was not as frequently mentioned in students' reasons for working individually with GC (9.5%), compared to studying mathematics individually (36.6%).
- About a quarter of the students who gave reasons for preferring the individual mode of working with the GC (22.5%) referred to the technology as a tool, mainly about the GC as a personal device. This supports Doerr and Zangor's (2000) findings that the handheld calculator, when viewed as a personal device, could lead to breakdown in small group collaborations. In this study, the reason "GC was a personal device" was given by only students who most preferred to work with GC individually, and not those who most preferred to work with GC cooperatively or competitively.

(ii) cooperative mode of social interaction preference

- The peer interaction category had the highest percentages for both studying mathematics (72.0%) and working with GC (68.1%). Students cited friends' helping them or mutual help as their reasons for choosing to cooperate with friends. There were some overlaps between the peer interaction category (GC: 68.1%) and the technology category (GC: 29.9%), for example when students said they learnt from friends how to use the GC functions or explore the GC together.

- Another common category of reasons given was improved learning outcomes (maths: 41.8%; GC: 38.7%). In particular, clearing doubts and misconceptions, checking answers and GC steps were mentioned.

- Students also referred to learning processes (maths: 29.3%; GC: 21.9%) such as the ability to share knowledge and ideas as a reason for cooperation.

(iii) competitive mode of social interaction preference

- The two categories - attitudes (maths: 62.5%; GC: 50.0%) and learning process (maths: 50.0%; GC: 50.0%), were cited by high percentages of students. These students found it fun and motivating to compete and competition motivated them to study harder.

The differences in the patterns of explanations for the different social interaction modes were consistent with past research on students' motivation and perceptions in individualistic, cooperative and competitive classroom environments (Ames, 1984). Students with individualistic motivation were focused on mastery of learning; consequently the individual's past performance, the effort put in, and opportunities for self-improvement were viewed as important factors for them (Ames, 1984). In this study, the Singaporean students who most preferred to study individually were focused on improving their own individual effort in learning. They monitored their own learning process and controlled their learning environment to optimise their learning (e.g., "No distractions, allow me to think clearly and at my own pace.", student #917) Also, eight students (2.2%) who most preferred to study mathematics individually explicitly wrote that they preferred to compete with themselves, aiming at self-improvement. About a fifth (22.5%) of the students who most preferred to work with the calculator individually either referred to calculators as a personal device or referred to the difficulties in using GCs collaboratively, consistent with the findings by Doerr and Zangor (2000).

In contrast, according to Ames (1984), students with cooperative motivation systems prefer to work towards a common shared goal, and that "students helping one another is a motivational component of cooperative structures and mediates achievement and learning" (p. 194). The concepts of shared effort and positive interdependence contributing to improved outcomes can be observed in this study, exemplified by the following student response:

> Studying with others helps clear doubts and common misunderstandings of the subject. Plus if I don't know, I can seek help. And if I help others, the method and concept will be instilled more strongly in my head so it'll be easier for me to do it again next time. (student #74)

Students in Geiger's (1998) study said that they tended to seek help from peers when they were stuck on problems, rather than sharing mathematical discoveries. The help seeking could be for both technical and mathematical assistance. This is consistent with the high percentages of help seeking-related explanations ("friends help, peer tutoring") given by students for most preferring to cooperate with friends (38.5% of students for studying mathematics; 40.0% of students for working with GC, see Appendix D3). Also, 28.5% of students who most preferred to work with GC cooperatively with friends said they learnt how to use the GC from their friends (see Appendix D3, Table D8, under main category of "Technology").

A competitive classroom structure promotes "an egoistic or social comparative orientation" (Ames, 1984, p. 189) where "winning is 'everything'" (p. 190). In a meritocratic society like Singapore, students often have report cards on which, besides their grades for each subject, their rank in class, or rank as a percentile of the entire school cohort is found. Due to the exaggeration of the value of winning in a competitive environment, "self-perceptions of ability are easily aggrandized by the occurrence of success and self-worth is enhanced" (Ames, 1984, p. 192). The concept of enhancing self-worth is consistent with the findings here in that a much higher percentage of Singaporean students mentioned motivation (62.5% of students for studying mathematics, 50.0% of students for working with GC) as a reason for most preferring to compete with friends, compared to the other social interaction preferences (see Table 4.10). For example:

> Personally, competition motivates me to study harder and to push myself so that I can win my friends and makes me feel a sense of accomplishment satisfied with myself, unlike studying individually which doesn't gives me the same sense. (student #124)

However, Singaporean students seemed to attribute the success in learning more to effort ("study harder", "push me to the limits") than to ability, as mentioned by Ames (1984). This could also be related to the socio-cultural context since there is an attribution of success to effort (Fan, Wong, Cai, & Li, 2004) in Confucius-heritage cultures like Singapore.

Conversely, according to Ames (1984), students who performed poorly would have negative self-perceptions and self-esteem in a competitive environment. Since there can only be one or few winners and many losers, the negative affective aspect associated with losing might put a majority of students off the competitive mode of learning, seen in the following quote.

> Study individually enables me to set my own pace so that I will find it comfortable. Competing with friends may provide a sense of motivation but at the same time, it can ruin friendships or even transforming to a stress that "I am incompetent". Cooperating with friends would provide a collection of ideas, but I would like to discover those ideas myself instead of playing the 'spoon-feeding' game. (student #146)

This may partially explain why there was only a small percentage of students who most preferred to study mathematics (6.6%) and work with GC (2.1%) competitively (see Figure 4.8).

There were also a small percentage of students (12.5%, N = 6) who said that competition made mathematics interesting and meaningful for them (see category and sample response in Table 4.11). This may be a similar type of student learning strategy as found in Boaler's (2002) study in which the boys who were disinterested in mathematics in a traditional mathematics environment competed with one another to finish as many problems as possible. However, in this instance, the responses were made by girls with average and below average mathematics competency self-ratings, and boys with average and good mathematics competency self-ratings, suggesting that motivations were similar for both genders when their most preferred mode of learning was to compete. Results and discussions of gender differences are reported later in the section on Research Question 3.

In summary, the open-ended responses for students' choice of most preferred social interaction preference, when studying mathematics and working with GC, revealed that the reasons for preferring to study or work individually were related to improving individual learning outcomes through self-monitoring and control of learning processes and environment. Students' reasons for preferring to cooperate with friends were related to cooperative helping strategies to achieve shared learning outcomes. More than a third of the students said they received help from their friends; about a quarter said they help or teach each other. Reasons for preferring to compete were linked to positive attitudes towards competition and increase in effort for learning.

The main difference in the patterns of students' responses lie with the different social interaction preferences (individually, cooperatively, competitively), rather than between studying mathematics and working with GC. There was a higher percentage of students who most preferred to work with GC cooperatively (65.7%), compared to studying mathematics cooperatively (40.5%). This, taken together with their reasons for most preferring to work with GC cooperatively, suggests that students value peer interaction and support more when working with GC (e.g., getting help from friends) than when generally doing mathematics. Furthermore, this could be due to their unfamiliarity with the technology as most of the Singaporean students only started learning how to use the GC in Year 11 (comparisons were made between Singaporean and Victorian students' calculator competency, see the results of the next research question, p. 154). Also, some students who most preferred to cooperate when using the GC mentioned checking answers and steps with friends after initially working out the mathematical solution on their own. For these cases the GC also provided support and functioned as "the physical facility necessary to present the findings in a more public forum" (Geiger, 2009, p. 206). In contrast, some students viewed GC as a personal device and most preferred to work individually with the GC rather than cooperatively or competitively.

Despite differences in the frequency distribution of students' most preferred social interaction modes (individual, cooperative, competitive) for studying mathematics and working with GC (see Figure 4.8), the frequency distributions of the categories of explanations for each mode were similar for studying mathematics and working with GC (see Table 4.10). This implies that students' reasons or motivations behind their preferences for certain modes generally follow a pattern, e.g., those who preferred to work individually (on mathematics or with GC) tended to cite increased learning outcomes such as "concentrate better" as the reason. The reasons are consistent with the theory on students' motivation systems in different classroom goal structure (individualistic, cooperative, or competitive) by Ames (1984).

Attitudes towards calculators: enjoyment and confidence. Singaporean students were asked to indicate their agreement with two statements: "I enjoy using GC to learn maths." and "I feel confident doing maths with GC." using 5-point Likert response format. Table 4.11 shows the mean scores and standard deviations for both items. It can be seen that the Singaporean students generally agreed that they enjoyed using the GC to learn mathematics ($\bar{x} = 3.36$), and slightly agreed that they were confident in using the GC ($\bar{x} = 3.20$). The Cal_Enj mean score was found to be significantly higher than the Cal_Conf mean score ($t\,(936) = 6.39$, $p < .001$), implying that Singaporean students agreed more strongly to enjoying calculator use than to being confident about using the calculators.

Table 4.11

Mean and Standard Deviations for Cal_Enj and Cal_Conf

Items	N	Mean	S.D.
Calculator enjoyment (Cal_Enj)	938	3.36**	0.95
Calculator confidence (Cal_Conf)	937	3.20**	1.00

** Significantly different from mid-point 3, using one-sample t-test, p < .01

How students use graphing calculators: calculator as Master, Servant and Collaborator. As described in Chapter 3 and earlier in this chapter, a 12 item instrument (Tan, 2009) comprised of three subscales was developed and used to measure how students use calculators: calculator as Master (Cal_Ma), as Servant (Cal_Se), and as Collaborator (Cal_Co). The mean scores and standard deviations for the three subscales are shown in Table 4.12.

Table 4.12

Mean Scores and Standard Deviations for GC as Master, Servant and Collaborator

Ways of interacting with calculators	N	Mean	S.D.
Cal_Ma	932	3.19**	0.80
Cal_Se	934	3.78**	0.66
Cal_Co	920	3.03	0.73

** Significantly different from mid-point 3, using one-sample t-test, p < .01

Since "3" is the mid-point neutral value of the 5-point scales used, it can be seen in Table 4.12 that on average, students agreed slightly that they used Calculator as Master ($\bar{x} = 3.19$) and were neutral about using Calculator as Collaborator ($\bar{x} = 3.03$). However, they tended to agree more strongly to using Calculator as Servant ($\bar{x} = 3.78$). T-tests conducted for Year 11 and 12 students found that Year 11 students had significantly higher Calculator as Master score than Year 12 ($\bar{x}_{Yr11} = 3.27$, $\bar{x}_{Yr12} = 3.11$, $t(894) = 2.97$, $p < .01$), and there were no significant differences on the mean scores for the other two subscales. Since Year 11 students have used GC for a shorter period of time compared to Year 12, this result is consistent with the findings from past research (see Chapter 2) that length of time using the advanced calculators affects the quality students' mathematics outcomes. Since the data are cross-sectional, a longitudinal study would be better suited to confirm this hypothesis. The high Calculator as Servant score in both Year 11 and 12 ($\bar{x}_{Yr11} = 3.73$, $\bar{x}_{Yr12} = 3.79$) and the neutral Calculator as Collaborator score could reflect a strong focus on computation in the curriculum, instruction and assessment. The results of the further investigations between the ways of using calculators and the other factors are explored in the section on Research Question 4 (p. 171).

In summary, Singaporean students' beliefs, attitudes, learning preferences and ways of interacting with advanced calculators (GC) have been presented in this section to answer Research Question 1. Generally, Singaporean students rated themselves below average in both mathematics and calculator competencies. They tended to have general Visual and/or Aural modality preferences, and Kinesthetic and/or Visual preferences when learning how to use the GC. A majority of them most preferred to study mathematics individually and to work with GC cooperatively. They also used both connected knowing-deep approach and separate knowing-surface approach when learning mathematics. In terms of GC, Singaporean students agreed with enjoying GC use and with being confident in using GC. They also slightly agreed to using GC as Master, strongly agreed to using GC as Servant, and were neutral to using GC as Collaborator.

In the next section, Victorian students' data are presented together with comparisons with the Singaporean data. This answers both Research Question 1 about Victorian students' profiles, and Research Question 2 about comparison of profiles between regions.

Research Question 2

Are there differences in students' attitudes, beliefs, learning preferences, and ways of interacting with calculators for students in Singapore and Victoria?

In this section, Victorian students' beliefs, attitudes, learning preferences, and ways of interacting with calculators are presented together with comparisons with the Singaporean data.

Profile of Victorian students and regional differences. There were 176 Victorian students who responded to the survey. As mentioned in the methodology chapter, due to difficulties in getting responses from government schools, the data collection was carried out in three phases (invitation through government, Catholic and Independent schools; re-invitation sent to independent schools; and direct recruitment of students through Facebook). The final sample was not representative of the student profile in Victoria because there were more students from non-government schools than government schools who participated in the online survey. The demographics of students are compared and shown in Table 4.13.

Table 4.13

Demographics of Singaporean and Victorian Students Surveyed

Singapore (N = 964)		Victoria (N = 176)	
Gender	Number (Percentage)	Gender	Number (Percentage)
M	358 (37.1%)	M	55 (31.3%)
F	606 (62.9%)	F	121 (68.8%)
Year level	Number (Percentage)	Year level	Number (Valid Percentage)
10	38 (3.9%)	Missing	1
11	517 (53.6%)	11	116 (66.3%)
12	409 (42.4%)	12	59 (33.7%)
School type	Number (Percentage)	School type	Number (Percentage)
Government	204 (21.2%)	Government	34 (19.3%)
Government-aided	749 (77.7%)	Catholic	12 (6.8%)
Independent	11 (1.1%)	Independent	130 (73.9%)

From Table 4.13 it can be seen that there was a higher percentage of Year 11 (66.3%) than Year 12 (33.7%) Victorian students, compared to the almost equal percentages of Year 11 (53.6%) and 12 (42.4%) Singaporean students. Also, the online survey garnered about two-thirds female and one-third male responses in both regions. For the Victorian data, the high female to male ratio was not reflective of the student population enrolled in the Mathematical Methods (CAS) subject. In 2010 when the survey was conducted in Victoria there were 8833 males and 6958 females enrolled in the Unit 4 of the Mathematical Methods (CAS) subject.

One reason explaining the high Victorian female to male ratio is that more girls' schools (n = 6) than boys' schools (n = 3) from the independent sector were invited to participate in the study as there were more independent girls' (24) than boys' (14) secondary schools in Victoria at the time of the study (http://www.independentschools.vic.edu.au/). Similar numbers of female (29) and male (30) Victorian students responded through Facebook. In contrast, all four participating Singaporean schools were co-educational. In 2009, when the survey was conducted in Singapore, there were more female (55.5%) than male senior secondary students in Singaporean junior colleges (Ministry of Education, 2010). This gender proportion was likely replicated among the participating schools. Research also indicates that girls are more likely than boys to respond to invitations issued via schools (e.g., Porter & Whitcomb, 2005). Facebook statistics also show that there are more females than males (F = 54%, M = 46%) using Facebook in Australia (http://www.socialbakers.com/facebook-statistics/australia, accessed 2011 May 14).

Overall, it must be noted that the small sample size of Victorian data (< 300) and the high percentage of Independent school students (73.9%) limit the generalisability of the Victorian findings, and although large, there is an over-representation of students from government-aided schools in the Singaporean sample.

Regional differences for students' beliefs about and attitudes toward mathematics and calculators, and their ways of interacting with calculators. To investigate regional differences between students' beliefs about and attitudes toward mathematics and calculators, and their ways of interacting with calculators, t-tests were used. A summary of the t-test results is shown in Table 4.14. Effect sizes were calculated as a measure of the magnitude of the differences in mean.

It can be seen in Table 4.14 that there are statistically significant regional differences on a number of variables. The effect sizes are generally small, except for calculator competency (CalSR; $r = 0.52$), for which 26.7% (r^2) of the total variance can be explained by region.

Table 4.14

Summary of T-test Results for Student Competencies, Beliefs, Attitudes, and Ways of Interacting with Calculators, by Region

		Region	N	Mean	t-statistic	Effect size r [1]
MSR	Vic > S’pore	Singapore	963	2.90	-7.35***	0.21
		Victoria	166	3.57		
CalSR	Vic > S’pore	Singapore	962	2.94	-9.05***	0.52
		Victoria	166	3.60		
CK-DA		Singapore	928	3.28	NS	
		Victoria	125	3.34		
SK-SA		Singapore	933	3.47	NS	
		Victoria	124	3.50		
Cal_Enj		Singapore	938	3.36	NS	
		Victoria	122	3.39		
Cal_Conf	Vic > S’pore	Singapore	937	3.20	-4.15***	0.14
		Victoria	122	3.63		
Cal_Ma	S’pore > Vic	Singapore	932	3.19	5.34***	0.16
		Victoria	121	2.77		
Cal_Se	S‘pore > Vic	Singapore	934	3.78	2.79**	0.23
		Victoria	120	3.56		
Cal_Co		Singapore	920	3.03	NS	
		Victoria	121	3.06		

[1] Effect size $r = \sqrt{\frac{t^2}{t^2 + df}}$ (Field, 2005, p. 302)

* $p < .05$ ** $p < .01$ *** $p < .001$

Victorian students had significantly higher mean scores than Singaporean students in mathematics competency (MSR; $\bar{x}_{\text{Vic}} = 3.57$, $\bar{x}_{\text{S'pore}} = 2.90$) and calculator competency (CalSR; $\bar{x}_{\text{Vic}} = 3.60$, $\bar{x}_{\text{S'pore}} = 2.94$). There are various possible partial explanations for these differences, such as cultural differences between students in the two countries. Elliott, Hufton, Willis, and Illushin (2005), from reviews of studies conducted on TIMSS data, argued that American, English and Scottish students have higher self-perceptions of their mathematics competency than students from Asian countries like Singapore, Japan and Korea, and some European countries like France and Germany. As can be seen in Table 4.14, Singaporean students generally rated themselves below average for both mathematics and calculator competencies ($\bar{x}_{\text{MSR}} = 2.90$, $\bar{x}_{\text{CalSR}} = 2.94$ [one-sample t-tests showed mean scores were significantly less than 3 – see Table 4.5]) whereas Victorian students rated themselves above average for both competencies ($\bar{x}_{\text{MSR}} = 3.57$, $\bar{x}_{\text{CalSR}} = 3.60$). Another reason for the regional differences in MSR and CalSR could be due to socio-economic differences suggested by the high percentage of Independent school students in the Victorian sample. School-sector differences in student performances have been reported in Australia (e.g., Marks, 2009). Yet a third possible partial explanation for Victorian students' higher self-rating of calculator competency is their familiarity with advanced calculators, since there are some Victorian students who used GC and CAS technologies at lower year levels (Years 7 to 10; see e.g., Pierce & Ball, 2010). Singaporean junior colleges are generally only for Years 11 and 12; consequently students are typically not exposed to the GC in secondary schools and only came to use the GC at Year 11. However, this explanation does not account for the higher mathematics competency self-rating of Victorian than Singaporean students.

Interestingly, there were no significant differences in the connected knowing-deep approach [CK-DA] and separate knowing-surface approach [SK-SA] scores of students in the two regions. However, the mean scores for SK-SA were higher than that for CK-DA for both regions, with the difference being significant only for Singaporeans ($t(921) = -5.36$, $p < .001$). This finding of high SK-SA scores is consistent with Kılıç and Sağlam's (2010) conclusion, from a research study of Turkish students from different school types, that schools with an extreme emphasis on academic performance and examination success are associated with a tendency for a surface learning approach.

There are significant differences in students' responses to some of the items in the CK-DA and SK-SA instrument, as shown in Table 4.15. The Singaporeans agreed more strongly than Victorians that mathematics is associated with creativity (items CK1 and CK4). However, Singaporeans also agreed more strongly than Victorians to learning mathematics formulae by heart even if they did not understand them (SS5), and disagreed more strongly to thinking about solving mathematics problems frequently even while on the bus or lying on their beds (DM6). These suggest that there may be contextual and cultural differences in the conceptions of mathematics (enabling creativity) and in approaches to studying mathematics (learning formulae by heart and thinking frequently about solving).

Table 4.15

Differences in Connected Knowing-Deep Approach and Separate Knowing-Surface Approach Items between Students in the Two Regions

Items		Region	N	Mean	t	Effect size r^1
CK1 Maths makes you think creatively.	S'pore > Vic	Singapore	944	3.58	5.31***	0.40
		Victoria	128	3.02		
CK4 In maths you can be creative and discover things for yourself.	S'pore > Vic	Singapore	939	3.54	2.73**	0.22
		Victoria	128	3.24		
SS5 I learn maths formulas by heart even if I don't understand them.	S'pore > Vic	Singapore	940	3.29	2.50*	0.08
		Victoria	127	3.02		
DM6 I frequently think about how to solve maths problems even while on the bus or lying on my bed.	Vic > S'pore	Singapore	938	2.54	-2.50*	0.08
		Victoria	126	2.80		

[1]Effect size $r = \sqrt{\dfrac{t^2}{t^2 + df}}$ (Field, 2005, p. 302)

* $p < .05$ ** $p < .01$ *** $p < .001$

There was a significant difference in the calculator confidence (Cal_Conf) of students in the two regions (see Table 4.14); Victorians were more confident than Singaporeans ($\bar{x}_{\text{Vic}} = 3.63$, $\bar{x}_{\text{Spore}} = 3.20$). This is consistent with the finding that Victorians rated themselves higher in calculator competency than Singaporeans. However, there was no significant difference in calculator enjoyment; both Victorian and Singaporean students agreed moderately to enjoying calculator use ($\bar{x}_{\text{Vic}}$ = 3.39, $\bar{x}_{\text{Spore}}$ = 3.36).

There were significant differences in the ways Singaporean and Victorian students interacted with their calculators. Singaporean students had significantly higher mean scores than Victorian students for calculator as Master (Cal_Ma; $\bar{x}_{\text{Spore}}$ = 3.19, $\bar{x}_{\text{Vic}}$ = 2.77) and calculator as Servant (Cal_Se; $\bar{x}_{\text{Spore}}$ = 3.78, $\bar{x}_{\text{Vic}}$ = 3.56). There was no significant difference in the calculator as Collaborator (Cal_Co) scores.

Overall, the findings show that, compared to Victorian students, Singaporean students indicated lower competency, less confidence and less fluency in calculator use. Besides the previously mentioned socio-cultural factors (different culture and school type), differences in the school systems in the two regions could be due to additional factors:

- With the use of GC allowed in the VCE since 1997, Victorian mathematics teachers may have more experience with teaching the use of programmable calculators and might be better able to mediate students' learning with CAS calculators than Singaporean teachers with GCs.

- Most Victorian senior secondary students learn in a classroom structure using published textbooks with calculator instructions. Most Singaporean senior secondary students, however, learn in a lecture-tutorial structure, relying mainly on lecture notes with calculator instructions provided by their teachers.

- Victorian secondary schools usually encompass Years 7-12, whereas most Singaporean senior secondary schools consist of Years 11-12 only (Tan & Forgasz, 2011).

In summary, compared to Singaporean students, Victorian students might be exposed to better quality calculator-integrated learning environments (e.g. teaching and textbooks) or provided with more opportunities to use programmable calculators (e.g. at grade levels earlier than Year 11). Additionally, since CAS calculators and GCs share a number of similar functionalities and syntax, Victorian teachers may be more familiar with the CAS calculators than Singaporean teachers with GCs. These factors might be why Victorians had higher self-ratings of calculator competency with the CAS calculators than Singaporeans with the GC, and less likely to use their CAS calculators at the Master level than Singaporean students use their GCs.

Singaporean students also agreed more strongly than Victorian students to using calculators as Servant (Cal_Se) to replace pen-and-paper computation. This may be due to the presence of a technology-free examination in Victoria where students are not allowed to use their calculators and have to rely on pen-and-paper calculations. In Singapore, GC use is allowed and expected in all the mathematics examinations.

For using calculators as Collaborator (Cal_Co), both Singaporean and Victorian students had mean scores not significantly different from the neutral value 3 as shown by one-sample t-tests (S'pore: $t(919) = 1.39$, $p>0.05$; Vic: $t(120) = 0.83$, $p>0.05$). This indicates that students, on average, neither agreed nor disagreed with using calculators at the highest level of sophistication. Perhaps they had insufficient years of experience with the calculators to agree with using calculators at the highest level, or there might be other factors which directly affect Cal_Co, such as instruction, curriculum and assessment. Further studies are needed.

To summarise the findings, compared to Singaporean students, Victorian students rated themselves higher in mathematics and calculator competencies, and had higher confidence and greater fluency in using calculators. There were no significant differences in their connected knowing-deep approach and separate knowing-surface approach scores, but differences in certain items of the instrument might reflect contextual and cultural differences.

Regional differences for students' learning preferences.

(i) Most preferred general VARK styles. Since the data on students' learning preferences is categorical, chi-square tests were used to determine if there were any regional differences. As described in the previous section on research question 1 (p. 117-120), students' most preferred VARK mode was measured using seven items with multiple responses. The scores for Visual, Aural, Read/Write, and Kinesthetic were compared and the highest scoring mode was the most preferred mode. Hence, the most preferred VARK mode could be multimodal if there were two or more modes with equal highest scores. The distributions of Singaporean and Victorian students' most preferred general VARK modes are shown in Table 4.16.

Table 4.16

Percentages of Students' Most Preferred General VARK Modes by Region

Mode	Singapore (N = 964)	Victoria (N = 143)
Single		
V	25.2%	7.7%
A	25.2%	17.5%
R	16.4%	42.7%
K	5.4%	0.7%
Multimodal	27.8%	31.5%

It can be seen that Singaporean and Victorian students had different distribution patterns for the most preferred VARK modes, particularly for the single modes. Both these patterns are also markedly different from the data collected over the *VARK* website by Fleming (2006), which had 62.7% multimodal, and 37.3% single preferences ($V = 3.4\%$, $A = 7.5\%$, $R = 14.6\%$, and $K = 11.8\%$). This may be due to the modifications to the original instrument and the scoring system used in the present study. To further investigate regional differences, the individual modes (V, A, R, and K) were examined in relation to students' most preferred mode. That is, students with multimodal preferences such as VA were considered twice, under the individual modes V and A.

It was found that there were significant differences in the distributions of most preferred general VARK modes between Singaporean and Victorian students for Visual, Read/Write and Kinesthetic styles ($\chi^2_{\text{Visual}}(1, 1106) = 17.3$, $p < .001$; $\chi^2_{\text{Read/Write}}(1,1106) = 70.8$, $p < .001$; $\chi^2_{\text{Kinesthetic}}(1,1106) = 4.29$, $p < .05$) but not for Aural ($\chi^2_{\text{Aural}}(1, 1106) = 1.62$, $p = 0.204$). The percentages of most preferred VARK mode within each region are shown in Figure 4.9. The percentages add up to more than 100% due to the presence of multimodal preferences. It can be seen that a significantly higher percentage of Singaporean students had Visual as their most preferred VARK mode (S'pore = 43.8%, Vic = 25.4%), whereas a much higher percentage of Victorian students had Read/Write (Vic = 69.0%, S'pore = 32.5%) as their most preferred VARK mode. There was also a significantly higher percentage of Singaporean than Victorian students with Kinesthetic as their most preferred VARK style (S'pore = 13.2%, Vic = 7.0%, $p < .05$).

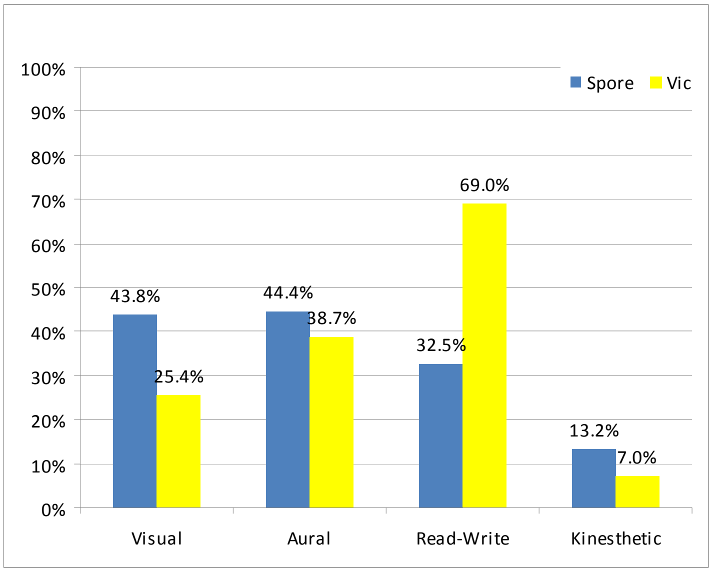

Figure 4.9. Percentages of students by region with most preferred VARK styles.

These findings suggest that there are regional differences in VARK preferences: Singaporean students have a stronger preference for Visual modes of input, and Victorian students have a stronger preference for Read/Write modes. This may be due to differences in the senior secondary classroom structure (lecture-tutorial system in Singapore versus classroom teaching in Victoria), or in socio-cultural contexts. As one who has been to both regions, I found that the city state Singapore, being the second most densely populated country in the world with 7,257 people per square kilometre (Department of Statistics Singapore, 2011), has more visual elements in public spaces to communicate information such as signage, advertisements, and banners, compared to Victoria. Although Victoria is the second most populated state in Australia, its population density is only 24 people per square kilometre (Australian Bureau of Statistics, 4 November, 2011). Comparatively the visual elements are sparser. It is hypothesised that there is a higher need to process the greater visual input (for example looking and recognising people, signage, advertisements) in Singapore, resulting in greater Visual preference. Correspondingly, a lower population density could imply less visual elements and greater travelling distances, which could promote more text-based activities, for example students might read more on trains or buses while travelling. The explanations for this difference are worthy of further investigation.

(ii) Most preferred calculator VARK styles. There were similarities and differences by region in students' most preferred method of learning how to use the calculator, shown in Table 4.17. It can be seen in Table 4.17 that the top three most preferred methods of learning how to use the calculators were the same:

- (i) trying out the calculator steps at the same time they see/listen/read the instructions (Kinesthetic; Vic = 37.0%, S'pore = 42.3%);
- (a) watching the teacher's demonstration (Visual: Vic = 22.5%, S'pore = 19.8%); and
- (j) trying the buttons out and playing around with the calculator (Kinestheic; Vic = 17.5%, S'pore = 13.1%).

This consistency of finding across two regions with different general VARK profiles further supports the implication that the calculator lends itself to kinesthetic and visual methods rather than aural and read/write methods.

It can also be seen in Table 4.17 that for most methods the percentages are similar for both regions, except for methods (g) and (i) where there were differences greater than 5%. A higher percentage of Victorian than Singaporean students most preferred to (g) copy down the steps their teachers wrote on the board (Vic = 10.1%, S'pore = 1.9%), whereas a higher percentage of Singaporean than Victorian students most preferred to (i) try out the calculator steps at the same time they see a demonstration or listen to an explanation or read the instructions (S'pore = 42.3%, Vic = 37.0%). This seems consistent with students' general VARK preferences since method (g) can be classified as using a Read/Write style preferred by more Victorian students, and method (i) as using a Kinesthetic style while engaging multiple modes preferred by more Singaporean students.

Table 4.17

Frequencies and Percentages of Singaporean and Victorian Students Who Selected (a) – (j) as Their Most Preferred Method of Learning How to Use the Calculator.

	Region						Diff in % within region
	Singapore			Victoria			
	Count	Expected Count	% within Region	Count	Expected Count	% within Region	(S % - V %)
a) see my teacher's demonstration in class.	187	190.2	19.8%	31	27.8	22.5%	-2.7%
b) see the steps my friends show me on their calculator.	35	35.8	3.7%	6	5.2	4.3%	-0.6%
c) look at the calculator screen captures in notes, textbooks or manual.	55	51.5	5.8%	4	7.5	2.9%	2.9%
d) discuss answers with my friends.	11	12.2	1.2%	3	1.8	2.2%	-1.0%
e) listen to a teacher who explains the steps and concepts clearly and thoroughly.	93	89.9	9.8%	10	13.1	7.2%	2.6%
f) listen to a teacher who reads out the steps given in notes, textbooks or manual.	2	2.6	.2%	1	.4	.7%	-0.5%
g) copy down the steps my teacher writes on the board.	18	27.9	1.9%	14	4.1	10.1%	-8.2%
h) make my own notes.	21	18.3	2.2%	0	2.7	.0%	2.2%
i) try out the steps on the calculator at the same time I see a demonstration or hear an explanation or read the instructions.	400	393.6	42.3%	51	57.4	37.0%	5.3%
j) try the buttons out and play around with the calculator.	124	123.9	13.1%	18	13.0	17.5%	-4.4%
Total	597	597.0	100.0%	349	349.0	100.0%	

(iii) Social interaction for learning preferences. Students were asked to indicate (a) whether or not they *prefer* to study mathematics or work with calculators individually/cooperatively/competitively; and (b) which they *most prefer* (individually/cooperatively/competitively). In Figure 4.10, the percentages of students in Singapore and in Victoria who indicated that they preferred each social interaction mode are shown. The percentages of students for their most preferred social interaction mode for studying mathematics and working with calculators are illustrated in Figure 4.11. Chi-square tests were used to investigate if there were any differences between students in the two regions.

It can be seen from Figures 4.10 and 4.11 that:

- A higher percentage of Singaporean than Victorian students *preferred* to study mathematics individually (S’pore = 93.3%, Vic = 88.2%, $\chi^{2 =}$ 4.34, $p < .05$)

- A higher percentage of Victorian than Singaporean students *preferred* to work with calculators competitively (S’pore = 18.1%, Vic = 25.9%, $\chi^{2 =}$ 4.00, $p < .05$)

- There were differences in the percentages of the students from the two regions who *most preferred* to work with calculators individually, cooperatively, and competitively ($\chi^2(2, 1024) = 7.94$, $p < .05$). Higher percentages of Victorian than Singaporean students most preferred to work with calculators individually (Vic = 44.1%, S’pore = 32.3%), whereas higher percentages of Singaporean than Victorian students most preferred to work with calculators cooperatively (S’pore = 65.7%, Vic = 52.5%). A slightly higher percentage of Victorian than Singaporean students most preferred to compete with friends when working with calculators (Vic = 3.4%, S’pore = 2.1%).

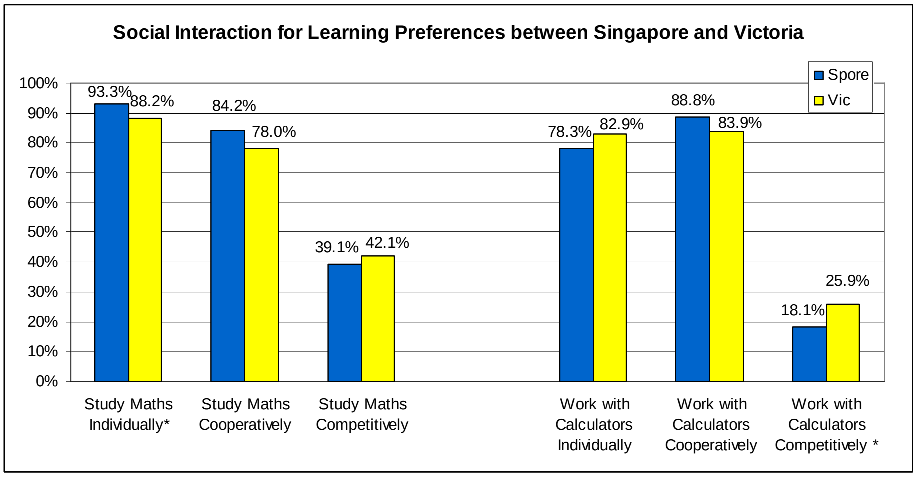

Figure 4.10. Percentages of students *preferring* each social interaction (those with * are significantly different using chi-square tests).

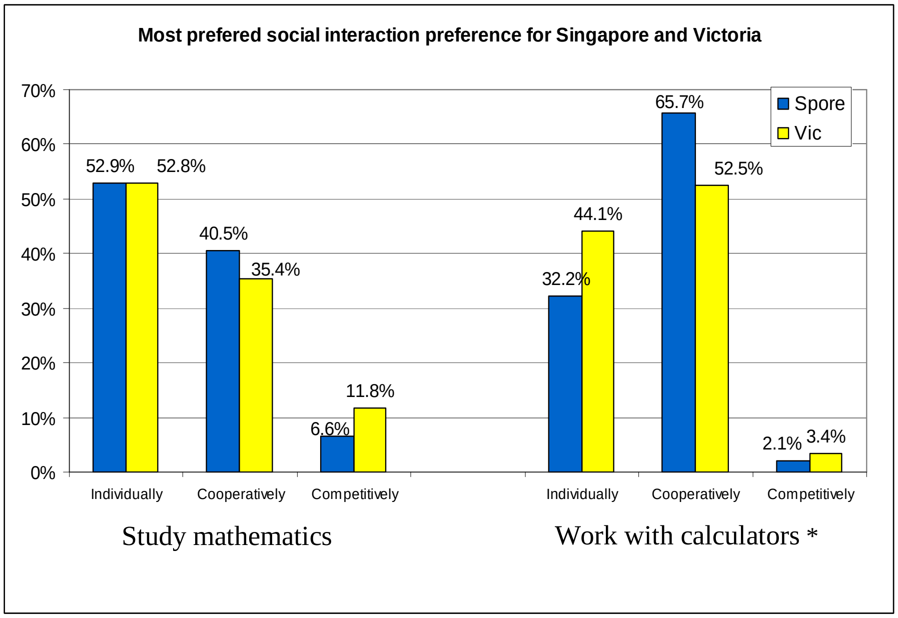

Figure 4.11. Percentages of students' *most preferred* social interaction mode by region.

It was reported in an earlier subsection that Singaporean students were less confident and fluent with using calculators than Victorians (see Table 4.14). The lack of calculator confidence and competency in Singaporean students might lead students to seek help from their friends, and hence indicate that they most preferred to cooperate with friends (see Singaporean students' responses to why they most preferred to cooperate with friends, Table 4.10).

(iv) Explanations of social interaction preferences. Students' explanations for their most preferred social interaction for learning preferences were coded and categorised (see p. 99 for discussion of theoretical underpinnings of the analysis). Each open-ended response was coded into one or more categories, depending on the number of ideas and reasons mentioned. Using thematic analysis, six categories were found: Learning outcomes, learning performance, learning process, learning environment, attitudes, and peer interaction. Additionally, students' references to calculator functions and characteristics were coded as the sixth category: technology. The summaries of the percentages of Singaporean and Victorian students' responses for each category, along with its subcategory with the highest frequency (i.e., most commonly cited reason within the category), are presented in Table 4.18 (for studying mathematics), and Table 4.19 (for working with calculators).

It has been discussed earlier, from the analysis of the Singaporean data, that there were differences in the distributions of categories among the different social interaction modes (individual, cooperative, and competitive). In addition, the patterns of distribution were generally similar when studying mathematics and when working with calculators. It can be seen from the comparisons between the Singaporean and Victorian results found in Tables 4.18 and 4.19, that:

- the patterns of distribution of categories of explanations among the individual and cooperative social interaction preferences are similar for the Singaporean and Victorian samples;

- the subcategory with the highest frequency within each category was similar across the Singaporean and Victorian samples, for individual and cooperative social preferences and when studying mathematics and working with calculators; and

- there were slight differences in the distributions of categories (and subcategories) in the explanations for the competitive preference between Singaporean and Victorian students.

Table 4.18

Students' Reasons for Their Most Preferred Social Interaction Preference when Studying Mathematics: Summary of Percentages within Regions and Most Common Reasons within Categories

	Individually		Cooperatively		Competitively	
	S'pore N = 361	Vic N = 48	S'pore N = 304	Vic N = 48	S'pore N = 48	Vic N = 13
Learning outcomes	60.4%	54.2%	41.8%	38.9%	6.3%	23.1%
	(concentrate better*)		(deepen understanding)		(think, concentrate better)	(learn best this way)
Learning performance	2.8%	2.1%	8.9%	2.8%	12.5%	15.4%
	(compete with self)		(I am weaker than peers)		(brings out the best)	
Learning process	33.5%	33.3%	29.3%	30.6%	50.0%	7.7%
	(own pace)		(share answers)		(study harder)	(do maths quickly)
Learning environment	36.6%	45.8%	0.0%	0.0%	0.0%	0.0%
	(no distractions)					
Attitudes	13.9%	16.7%	15.5%	16.7%	62.5%	61.5%
	(social pressure when studying with friends)		(fun, motivating)		(fun, motivating)	
Peer Interaction	17.5%	10.4%	72.0%	69.4%	6.3%	15.4%
	(seek help from friends or teacher if needed)		(friends help, peer tutoring)		(compare with those better)	(help one another)

* The subcategory most frequently cited within the category (see Appendix D3, Tables D7 and D9). Most subcategories were common across regions; those that were not common are listed separately.

Table 4.19

Students' Reasons for Their Most Preferred Social Interaction Preference when Working with Calculators: Summary of Percentages within Regions and Most Common Reasons within Categories

	Individually		Cooperatively		Competitively	
	S'pore N = 200	Vic N = 36	S'pore N = 452	Vic N = 46	S'pore N = 12	Vic N = 2
Learning outcomes	31.5% (concentrate better)	47.2%	36.7% (check answers, calculator steps)	45.7%	8.3% (concentrate better)	0.0%
Learning performance	4.5% (prepare for assessment)	0.0%	7.1% (I am weaker than peers)	2.2%	0.0%	0.0%
Learning process	23.5% (explore on my own)	22.5% (work at own pace)	21.9% (share knowledge)	37.0%	50.0% (study harder)	0.0%
Learning environment	9.5% (no distractions)	13.5%	0.0%	0.0%	0.0%	0.0%
Attitudes	10.0% (I like it)	11.1% (satisfying and fun)	12.4% (fun, motivating)	15.2% (easier to cooperate)	50.0% (fun, motivating)	100% (fun, motivating, I always win)
Peer Interaction	12.5% (friends are of no help)	19.4% (ask teachers if I don't understand)	68.1% (get help from friends)	67.4%	0.0%	0.0%
Technology	22.5% (Calculator is a personal device)	13.9%	29.9% (learn from friends how to use GC)	32.6%	0.0%	0.0%

* The subcategory most frequently cited within the category (see Appendix D3, Tables D8 and D10). Most subcategories were common across regions; those that were not common are listed separately

The following are descriptions and discussions of the distribution patterns for the explanations:

(i) individual mode of social interaction preference

- Learning outcomes had the highest percentages within mode for both studying mathematics (S’pore = 60.4%, Vic = 54.2%) and working with calculators (S’pore = 31.5%, Vic = 54.2%). The most common explanation relating to learning outcomes was that students could concentrate better when studying (“Able to concentrate and focus better.” S’pore student #83) or working with calculators individually (“Much easier because I can focus better.” S’pore student #360).

When students explained their preference for working with calculators individually, some students referred to the technology as a tool (S’pore = 22.5%, Vic = 13.9%) and, in particular, the calculator as a personal device. For example, “Only one person can really use a calculator at a time” (Vic student #10); and “GC is a PERSONAL calculating device. It is irritating to discuss with friends about how to use a GC” (S’pore student #551). This suggests that there is a group of students who most preferred to work with calculators individually, and might not support collaborative activities involving shared use of calculators (Doerr and Zangor, 2000).

(ii) cooperative mode of social interaction preference

- The peer interaction category had the highest percentages of explanations for both studying mathematics (S’pore = 72.0%, Vic = 69.4%) and working with calculators (S’pore = 68.1%, Vic = 67.4%). Students cited friends’ helping them or mutual help as their reasons for choosing to cooperate with friends. There were some overlaps between the peer interaction category and the technology category (S’pore = 29.9%, Vic = 32.6%). For example, when students said they learnt from friends how to use the calculator functions or explore calculator use together (“If there is a concept on the calculator that we don't understand we can work together to find the answer.” Vic student #102), it was coded under both categories.

- A high percentage of students who most preferred to cooperate with friends cited reasons pertaining to learning outcome, when studying mathematics (S’pore = 41.8%, Vic = 33.3%) and when working with calculators (S’pore = 36.7%, Vic = 45.7%). However, the subcategories with the highest frequencies within the “learning outcomes” category were different: for studying mathematics, it was to deepen understanding (S’pore = 13.5%, Vic = 13.9%, see Appendix D3, Tables D7 and D9), and for working with calculators, it was to clear doubts, check answers and calculator steps (S’pore = 20.1%, Vic = 21.7%, see Appendix D3, Tables D8 and D10). For example:

> I find that it really helps me understand things, and help others understand them. Ideas can be communicated in a much more... well, understandable way by my peers rather than my teacher. (Vic student #11, most prefer to study mathematics cooperatively)
>
> I might have missed out certain steps and my friends can identify them for me. (S’pore student # 433, most prefer to work with calculators cooperatively)

These findings suggest that when using advanced calculators, students who cooperate with their friends tend to check answers and calculator steps with their friends, rather than seeking to deepen understanding of mathematics. This is consistent with Geiger’s (1998) findings that students tended to seek help when they were stuck rather than sharing mathematical discoveries. From Figure 4.11, it can be seen that a higher percentage of students most preferred to cooperate with friends when working with calculators, compared to when studying mathematics. Taken together, this suggests that although the use of advanced calculators might promote student cooperation, some of the student interactions might be limited to discussing calculator procedures rather than mathematical ideas.

(iii) competitive mode of social interaction preference

- There were small numbers of students who most preferred to compete with friends for both studying mathematics (S’pore = 48, Vic = 13) and working with calculators (S’pore = 13, Vic = 2). Since the numbers are small the findings are not generalisable. Nonetheless, a general pattern can be seen in that the highest percentages of students in both regions cited attitudinal reasons (fun, motivating) among all other reasons as the reason why they most preferred to compete. This pattern is consistent for both studying mathematics (S'pore = 62.5%, Vic = 53.8%) and working with calculators (S'pore = 46.2%, Vic = 100%), and is consistent with the Ames' (1984) theory that winning in a competitive classroom structure enhanced students' self-worth.

- However, there was a slight difference in students' explanations among the categories for Singaporean and Victorian students. A high percentage of Singaporean students mentioned that competition motivated them to study harder (learning process), for studying mathematics (50.0%) and working with calculators (46.2%); while a high percentage of Victorian students (23.1%) said that they learnt best through competing (learning outcomes) when studying mathematics. This difference might be related to the socio-cultural context since effort is seen as important to success by students in a Confucius-heritage culture (Fan et al., 2004).

Overall, the similarity in the patterns of distributions of students' explanations across the Singaporean and Victorian samples, and across learning situations (studying mathematics and working with calculators) suggests that the students' social interaction for learning preferences and their reasons for choosing a particular mode of interaction (individually, cooperatively and competitively) may be relatively stable and consistent with the theory on classroom goal structures (Ames, 1984). When working with calculators, there were two main groups of students: those who most preferred to work individually and those who most preferred to work cooperatively. The former group tended to view calculators as a personal device, and the latter group tended to seek help or give help when cooperating with friends. This result explains the variation of findings from other studies by Doerr and Zangor (2000), where the calculator was viewed by some students as personal devices and led to breakdown in small group collaborations, and by Geiger (1998), where students tended to seek help from peers. The implication for teachers when developing learning activities for students is to be sensitive to the needs of both groups of students, as well as to the quality of discussions in student collaborations to promote mathematical thinking rather than calculator procedures.

Summary. Research question 2 compared Victorian and Singaporean students' beliefs, attitudes, learning preferences, and ways of interacting with calculators:

- Singaporean students, compared to Victorian students, scored significantly lower in self-rating of mathematics and calculator competencies. They also had significantly lower confidence in using calculators, and agreed more strongly to using calculators as Master and as Servant.

- There were no significant differences between Singaporean and Victorian students in connected knowing-deep approach and separate knowing-surface approach. However there were differences in the levels of agreement to the items relating to mathematics as being creative (S'pore > Vic), learning mathematics formulae by heart even if students do not understand them (S'pore > Vic), and thinking about mathematics even on the bus or lying on the bed (Vic > S'pore).

- Higher percentages of Singaporean than Victorian students had Visual, Aural and Kinesthetic as their most preferred VARK preference, whereas a higher percentage of Victorian students had Read/Write as their most preferred VARK preference. Correspondingly for learning the use of calculators, a higher percentage of Singaporean than Victorian students most preferred the Kinesthetic mode of trying out the steps on the calculator at the same time they see a demonstration, hear an explanation or read the instructions, whereas a higher percentage of Victorian than Singaporean students most preferred the Read/Write mode of copying down the steps their teacher wrote on the board.

- A higher percentage of Singaporean than Victorian students most preferred to study mathematics cooperatively and a higher percentage of Victorian than Singaporean students most preferred to study mathematics competitively. The trend was similar for working with calculators: higher percentages of Victorian than Singaporean students most preferred to work with calculators individually and competitively, and a higher percentage of Singaporean than Victorian students most preferred to work with calculators cooperatively.

- The distribution patterns of the categories of students' reasons for most preferring individual and cooperative modes were similar for the Singaporean and Victorian samples. There were slight differences in the pattern for competitive modes (higher percentages of Singaporeans than Victorians said competition made them work harder on mathematics and calculator use), which could be due to socio-cultural contexts or the small sample sizes.

In this section, the findings and results for research question 2 have been discussed. Generally Singaporean and Victorian students' beliefs about and attitudes toward mathematics and social interaction for learning preferences were similar. However, Victorian students were found to be more confident and more fluent in using calculators than Singaporean students. There were also differences in students' general and calculator VARK preferences. In the next section, gender differences in students' beliefs, attitudes, learning preferences and ways of interacting with calculators are presented for each region.

Research Question 3

Are there any gender differences in the students' profiles?

In order to investigate if there are any gender differences in the students' beliefs, attitudes, learning preferences and ways of interacting with calculators, t-tests and chi-square tests were used.

Gender differences for students' beliefs, attitudes and ways of interacting with calculators.

Due to the small number of Victorian male students, Mann-Whitney U tests were performed on the interval variables to investigate gender differences. Comparisons of the gender differences for students' beliefs, attitudes, and ways of interacting with calculators (interval variables) including the effect sizes (calculated based on Field, 2005), are shown in Table 4.20.

Table 4.20

Comparisons of Gender Differences for Interval Variables for Singapore and Victoria

		Singapore				Victoria			
	Gender	N	Mean	t	Effect size r[1]	N	Mean	z (Mann-Whitney U test)	Effect size r[1]
MSR (M>F)	Female	605	2.79	-4.01***	0.13	118	3.53	NS	
	Male	358	**3.08**[2]			48	**3.67**		
CalSR (M>F)	Female	604	2.87	-3.59***	0.12	118	3.53	NS	
	Male	358	**3.07**			48	**3.79**		
CK-DA (M>F)	Female	586	3.21	-3.67***	0.15	100	3.27	2.04*	0.18
	Male	342	**3.39**			25	**3.61**		
SK-SA (F>M)	Female	587	**3.51**	2.46*	0.08	100	**3.55**	-2.29*	0.21
	Male	346	3.40			24	3.28		
Cal_Ma (F>M)	Female	586	**3.23**	2.31*	0.08	98	**2.87**	-2.51*	0.23
	Male	346	3.11			23	2.34		
Cal_Se	Female	585	3.75	NS		98	**3.62**	-2.27*	0.21
	Male	349	**3.82**			22	3.28		
Cal_Co (M>F)	Female	579	2.96	-3.66***	0.14	99	3.02	NS	
	Male	341	**3.15**			22	**3.21**		
Cal_Enj (M>F)	Female	589	3.28	-3.39**	0.11	99	3.33	NS	
	Male	349	**3.49**			23	**3.65**		
Cal_Conf (M>F)	Female	588	3.08	-4.64***	0.18	99	3.49	3.07**	0.28
	Male	349	**3.40**			23	**4.22**		

[1] Effect size for t-test $r = \sqrt{\frac{t^2}{t^2 + df}}$, for Mann-Whitney U test $r = \frac{z}{\sqrt{N}}$ (Field, 2005)

[2] The higher of the male and female mean scores is in bold.

* $p < .05$ ** $p < .01$ *** $p < .001$

It can be seen in Table 4.20 that:

- There were statistically significant gender differences common across regions for

  - Connected Knowing-Deep Approach (CK-DA; Males > Females);
  - Separate Knowing-Surface Approach (SK-SA; Females > Males);
  - Calculator as Master (Cal_Ma; Females > Males); and
  - Calculator confidence (Cal_Conf; Males > Females) scores.

- Although statistically significant for the Singaporean sample but not for the Victorian sample, males also had higher mean scores than females for

  - Mathematics competency self-rating (MSR);
  - Calculator competency self-rating (CalSR);
  - Calculator as Collaborator (Cal_Co); and
  - Calculator enjoyment (Cal_Enj).

- There were a greater number of variables with statistically significant gender differences for the Singaporean data than for the Victorian data, indicating that gender differences are more prevalent in Singapore than in Victoria.

- Where there were common gender differences in the two regions, the effect sizes were larger for the Victorian data than for the Singaporean data. This indicates that where gender differences exist, the gender gap is wider in Victoria than in Singapore. For the Singaporean sample, although significant, the effect sizes were considered small and gender explained between 0.56% for SK-SA ($r^2 = 0.075^2 = 0.56\%$) and 3.06% for Cal_Conf ($r^2 = 0.175^2 = 3.06\%$) of the total variance (Field, 2005). For the Victorian sample, the effect sizes were slightly larger and gender explained between 3.31% for CK-DA ($r^2 = 0.182^2 = 3.31\%$) and 7.67% for Cal_Conf ($r^2 = 0.277^2 = 7.67\%$) of the total variance in the scores.

Overall, these findings imply that:

- compared to females, males tend to be more likely to use connected knowing-deep approaches, and to be more confident using calculators, and

- compared to males, females tend to be more likely to use separate knowing-surface approaches and to be more likely to use calculators as Master.

As can be seen in Table 4.20, Singaporean females had significantly lower scores than males in mathematics competency (MSR; $\bar{x}_{F} = 2.79$, $\bar{x}_{M} = 3.08$), calculator competency (CalSR; $\bar{x}_{F} = 2.87$, $\bar{x}_{M} = 3.07$), calculator enjoyment (Cal_Enj; $\bar{x}_{F} = 3.28$, $\bar{x}_{M} = 3.49$) and calculator confidence (Cal_Conf; $\bar{x}_{F} = 3.08$, $\bar{x}_{M} = 3.40$), compared to males. This is consistent with findings from past research on students' confidence and attitudes towards mathematics (e.g., Lim, 2010) and using technology (e.g., Barkatsas, Kasimatis, & Gialamas, 2009). However, there were no significant gender differences in Victorian students' self-ratings of mathematics and calculator competencies. In Australia, Vale (2008) reported that gender differences in achievement were found in more recent studies (e.g., PISA 2006) favouring males. In the earlier studies (2000-2004) Vale reviewed there were no significant gender differences found in achievement, though "males were more likely to record higher mean scores" (Vale, 2008, p. 2). Australian male students were also found to have more positive attitudes towards technology than females (Vale, 2008). The findings of the current study are consistent with those of past research. Additionally, there was no gender difference in Victorian students' enjoyment of calculators, even though males exhibited a much higher level of confidence in using calculators than females ($\bar{x}_{F} = 3.49$, $\bar{x}_{M} = 4.22$).

In both regions females had a lower mean score for CK-DA (S'pore: $\bar{x}_{F} = 3.21$, $\bar{x}_{M} = 3.39$; Vic: $\bar{x}_{F} = 3.27$, $\bar{x}_{M} = 3.61$) and a higher SK-SA mean score (S'pore: $\bar{x}_{F} = 3.51$, $\bar{x}_{M} = 3.39$, Vic: $\bar{x}_{F} = 3.55$, $\bar{x}_{M} = 3.28$) than males, suggesting that they were more likely than males to employ a surface approach rather than a deep approach towards studying mathematics. Although this is consistent with the pilot study finding, related research literature has shown ambivalent findings:

- at elementary level with general learning (no specific subject discipline), grades 6-7 male students in Brisbane (Australia) were found to score higher than females on Surface approach to learning, and females scored higher than males on Deep approach to learning (Burnett & Proctor, 2002);

- at secondary level with general learning, Turkish female high school students had a stronger meaningful learning orientation (using deep approaches) than males, and there were no significant gender difference in surface orientation (Kılıç & Sağlam, 2010);

- at university level with statistics learning, no gender differences were found for a group of first year psychology students (Wilson, Smart, & Watson, 1996). However, in another study on second year psychology students at the University of Sydney, females scored higher than males in surface approach when learning statistics and there were no gender difference for deep approach (Gordon, 1997). Males outperformed females in the statistics course.

Although the scales used were somewhat different for the different studies, the underlying theoretical constructs of deep and surface approaches to learning were similar. Kılıç & Sağlam (2010) suggested that cultural factors may influence the findings on gender differences. The subject disciplines, school contexts, participants' age and year levels might also play a part in the variation of findings.

In both regions, female students had higher calculator as Master mean scores (S'pore: $\bar{x}_{F} = 3.23$, $\bar{x}_{M} = 3.11$, Vic: $\bar{x}_{F} = 2.87$, $\bar{x}_{M} = 2.34$), suggesting that they might be using advanced calculators at a lower level of sophistication than male students. Additionally Singaporean females had a lower calculator as Collaborator mean score ($\bar{x}_{F} = 2.96$, $\bar{x}_{M} = 3.15$) than males; and although a similar trend can be seen in the Victorian sample ($\bar{x}_{F} = 3.02$, $\bar{x}_{M} = 3.21$), the difference was not statistically significant.

It is interesting to note that for calculator as Servant (Cal_Se) scores, there was a gender difference for Victorians ($\bar{x}_{F} = 3.62$, $\bar{x}_{M} = 3.28$) but not for Singaporeans. Victorian males agreed less strongly than females about using calculators as Servant to replace pen-and-paper computations. Since there is a technology-free examination in the VCE Mathematical Methods (CAS) subject, and higher percentages of males than females scored top grades in the examinations for the subject (Forgasz & Tan, 2010), this suggests there may be a relationship between Cal_Se and mathematics achievement in the Victorian context. The boxplots of Victorian students' Cal_Se scores against their mathematics competency self-rating (MSR) in Figure 4.12 show that students with higher MSR tended to have lower Cal_Se scores. Males tend to have lower Cal_Se scores than females, regardless of their MSR.

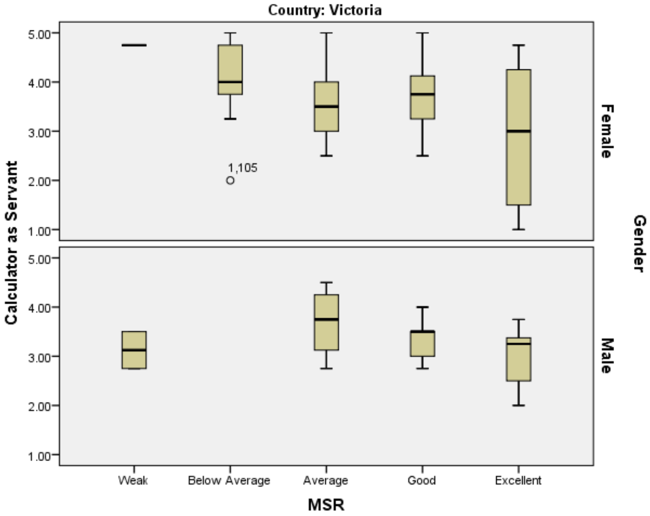

Figure 4.12. Boxplots of calculator as Servant by MSR for Victorian females and males.

In the next two subsections, gender differences for categorical data (VARK and social interaction for learning preferences) are reported.

Gender differences for students' learning preferences.

(i) General and calculator VARK preferences. For categorical data, chi-square tests were used. It was found that there were no significant gender differences in the distribution of most preferred general VARK styles for students in both regions (see Appendix D4 Tables D15 and D16 for cross tabulation and chi-square test results). However, there were gender differences in the most preferred learning method on how to use the advanced calculators (calculator VARK). As described previously, students selected their most preferred method of learning how to use the calculators, out of a list of ten methods. The percentages of Singaporean and Victorian female and male students who selected each of the calculator VARK methods (a)-(j) as their most preferred method of learning how to use the calculators are shown in Tables 4.21 and 4.22.

It can be seen in Tables 4.21 and 4.22 that with the exception of a few methods, there was little gender difference in the percentages of most methods. For the Singaporean sample (Table 4.21), there was at least a 5% difference in the percentages of females and males most preferring three of the methods: (a), (i) and (j). A chi-square test conducted on the three methods revealed that there were significant gender differences for these three methods ($\chi^2(2,711) = 17.84$, $p < .001$).

- Higher percentages of males than females who most preferred to (a) watch their teachers demonstrate in class (M = 22.9%, F = 17.9%) and (j) try the buttons out and play around with the GC (M = 17.5%, F = 10.6%).

- Higher percentage of females than males most preferred to (i) try out the GC steps at the same time as they watch a demonstration, hear an explanation, or read instructions (F = 46.6%, M = 35.0%).

Table 4.21

Frequencies and Percentages of Singaporean Females and Males who Selected (a) – (j) as Their Most Preferred Method of Learning How to Use the GC

	Gender						Diff in % within gender
	Female			Male			
	Count	Expected Count	% within Gender	Count	Expected Count	% within Gender	(F% - M%)
a) see my teacher's demonstration in class.	107	118.0	17.9%	80	69.0	22.9%	-5.0%
b) see the steps my friends show me on their calculator.	23	22.1	3.9%	12	12.9	3.4%	0.5%
c) look at the calculator screen captures in notes, textbooks or manual.	34	34.7	5.7%	21	20.3	6.0%	-0.3%
d) discuss answers with my friends.	5	6.9	.8%	6	4.1	1.7%	-0.5%
e) listen to a teacher who explains the steps and concepts clearly and thoroughly.	58	58.7	9.7%	35	34.3	10.0%	-0.3%
f) listen to a teacher who reads out the steps given in notes, textbooks or manual.	1	1.3	.2%	1	.7	.3%	-0.1%
g) copy down the steps my teacher writes on the board.	14	11.4	2.3%	4	6.6	1.1%	1.2%
h) make my own notes.	14	13.3	2.3%	7	7.7	2.0%	0.3%
i) try out the steps on the calculator at the same time I see a demonstration or hear an explanation or read the instructions.	278	252.4	46.6%	122	147.6	35.0%	11.0%
j) try the buttons out and play around with the calculator.	63	78.3	10.6%	61	45.7	17.5%	-6.9%
Total	597	597.0	100.0%	349	349.0	100.0%	

Table 4.22

Frequencies and Percentages of Victorian Females and Males who Selected (a) – (j) as Their Most Preferred Method of Learning How to Use the CAS Calculators

	Gender						Diff in % within gender
	Female			Male			
	Count	Expected Count	% within Gender	Count	Expected Count	% within Gender	(F% - M%)
a) see my teacher's demonstration in class.	24	24.3	22.2%	7	6.7	23.3%	-1.1%
b) see the steps my friends show me on their calculators.	5	4.7	3.6%	1	1.3	3.3%	0.3%
c) look at the calculator screen captures in notes, textbooks or manual.	3	3.1	2.8%	1	0.9	3.3%	-0.5%
d) discuss answers with my friends.	2	2.3	1.9%	1	0.7	3.3%	-1.4%
e) listen to a teacher who explains the steps and concepts clearly and thoroughly.	9	7.8	8.3%	1	2.2	3.3%	5.0%
f) listen to a teacher who reads out the steps given in notes, textbooks or manual.	0	0.8	0.0%	1	0.2	3.3%	-3.3%
g) copy down the steps my teacher writes on the board.	13	11.0	12.0%	1	3.0	3.3%	8.7%
h) make my own notes.	-	-	-	-	-	-	-
i) try out the steps on the calculator at the same time I see a demonstration or hear an explanation or read the instructions.	43	39.9	39.8%	8	11.1	26.7%	13.1%
j) try the buttons out and play around with the calculator.	9	14.1	8.3%	9	3.9	30.0%	-21.7%
Total	597	597.0	100.0%	349	349.0	100.0%	

The pattern of gender differences was similar for the Victorian sample. There was at least 5% difference in the percentages of females and males most preferring three of the methods: (e), (i) and (j). A chi-square test conducted on the three methods revealed that there were significant gender differences for these methods ($\chi^2(2,79) = 9.97$, $p < .01$).

- Higher percentage of males than females who most preferred to (j) try the buttons out and play around with the CAS calculator (M = 30.0%, F = 8.3%).

- Higher percentages of females than males most preferred to (e) listen to a teacher who explains the steps and concepts (F = 8.3%, M = 3.3%), and (i) try out the CAS calculator steps at the same time as they watch a demonstration, hear an explanation, or read instructions (F = 39.8%, M = 26.7%).

Overall, it can be seen that there were gender differences that were common across the two regions. Higher percentages of males than females preferred the trial and error approach of (j) trying out the buttons and playing around with the calculator. This is consistent with findings reported in the gender literature that males were more confident with using technology (e.g., Vale, 2008) and more likely to take risks (Gallagher & Kaufman, 2005). When using new technologies such as computers and internet, males were also found to gain enthusiasm quickly and be more self-assured, whereas females needed more time to appreciate the new technology (Broos, 2005). In contrast, higher percentages of females than males most preferred (i) to try out the steps on the calculator at the same time they see a demonstration or listen to an explanation or read the instructions. It could be argued that because females were less confident in using calculators, they needed more support, such as watching a demonstration or listening to the explanation or reading the instructions, when trying out the buttons of the calculators. Further research is needed to investigate this hypothesis.

(ii) Social interaction for learning preferences. Chi-square tests were also used to investigate if there were any gender differences in students' social interaction for learning preferences. Recall that students were asked two types of questions about their preferences for studying mathematics and working with advanced calculators: whether they liked or did not like individual, cooperative or competitive modes, and the mode which they most preferred. The percentages by gender for each of these questions, and the results of the chi-square tests, by region, are found in Table 4.23.

Table 4.23

Percentages within Gender of Social Interaction for Learning Preferences and Results of Chi-square Tests, by Regions

	Singapore			Victoria		
	% Females	% Males	Chi-square statistics	% Females	% Males	Chi-square statistics
(a) Like to study maths						
Individually	**94.4%***	91.5%	NS**	**90.2%***	80.0%	NS
Cooperatively	**85.7%**	81.7%	NS	77.5%	**80.0%**	NS
Competitively	31.8%	**51.3%**	$\chi^2(1,931) = 34.57$, $p < .001$	35.6%	**68.0%**	$\chi^2(1,126) = 8.61$, $p < .01$
(b) Like to work with calculators						
Individually	77.7%	**79.5%**	NS	82.5%	**85.0%**	NS
Cooperatively	**90.2%**	86.5%	NS	**85.4%**	77.3%	NS
Competitively	14.0%	**25.0%**	$\chi^2(1,862) = 16.36$, $p < .001$	22.1%	**42.9%**	$\chi^2(1,116) = 3.86$, $p < .05$
(c) Most prefer to study maths						
Individually	**54.5%*****	50.1%	$\chi^2(2,928) = 13.70$, $p < .001$	**59.8%**	24.0%	$\chi^2(2,127) = 16.27$, $p < .001$
Cooperatively	**41.2%**	39.4%		33.3%	**44.0%**	
Competitively	4.3%	**10.5%**		6.9%	**32.0%**	
(d) Most prefer to work with calculators						
Individually	29.3%	**37.2%**	$\chi^2(2,906) = 7.54$, $p < .05$	**45.8**%	36.4**%**	NS
Cooperatively	**68.9%**	60.1%		51.0**%**	**59.1**%	
Competitively	1.7%	**2.7%**		3.1%	**4.5%**	

* The higher of the male or female percentage is bolded.

** Not significant (NS).

*** The preference (individually, cooperatively, or competitively) with the highest percentage of students, within gender, is highlighted.

It can be seen in Table 4.23 that:

- For parts (a) and (b) on whether students like or do not like each mode, there were significant gender differences in the competitive social interaction modes for both studying mathematics (S’pore: F = 31.8%, M = 51.3%; Vic: F = 35.6%, M = 68.0%) and working with calculators (S’pore: F = 14.0%, M = 25.0%; Vic: F = 22.1%, M = 42.9%), with higher percentages of males than females preferring to compete with friends.

- For parts (c) and (d) on students’ most preferred social interaction mode for studying mathematics and working with calculators, there were statistically significant gender differences.

- For studying mathematics (c), a higher percentage of males than females most preferred to compete (S’pore: M = 10.5%, F = 4.3%; Vic: M = 32.0%, F = 6.9%) with friends, whereas a higher percentage of females than males most preferred the individual (S’pore: F = 54.5%, M = 50.1%; Vic: F = 59.8%, M = 24.0%) mode. For the cooperative mode the finding is mixed, with a higher percentage of Singaporean females than males, and a higher percentage of Victorian males than females most preferring to cooperate with friends (S’pore: F = 41.2%, M = 39.4%; Vic: F = 33.3%, M = 44.0%). There is a statistically significant gender difference in the pattern of most preferred mode of studying mathematics in Victoria, with females most preferring to study mathematics individually (59.8%) and males most preferring to study mathematics cooperatively (44.0%).

- For working with calculators (d), significant gender differences were found only in the Singaporean sample. A higher percentage of males than females most preferred individual (M = 37.2%, F = 29.3%) and competitive (M = 2.7%, F = 1.7%) modes, and a higher percentage of females than males most preferred the cooperative (F = 68.9%, M = 60.1%) mode.

The finding that higher percentages of males than females preferred competitive modes of social interaction for learning (in (a), (b), (c) and (d)) is consistent with past research (e.g., Boaler, 2002; Owens 1993). However, it is interesting that in this study, Singaporean and Victorian students had slightly different patterns with regard to their most preferred social interaction for learning preferences. Singaporean male and female students had similar patterns of most preferred modes for (c) studying mathematics and (d) working with calculators:

- in (c) more than half of the students within each gender most preferred to study mathematics individually (F = 54.5%, M = 50.1%); and
- in (d) a majority of the students most preferred to work with calculators cooperatively (F = 68.9%, M = 60.1%).

For Victorian students, the pattern was slightly different between males and females:

- in (c) a majority of females most preferred to study mathematics individually (F = 59.8%), whereas the highest percentage of males most preferred to study mathematics cooperatively (M = 44.0%). Also, about a third of the males (32.0%) most preferred the competitive mode.
- in (d) more than half of the males and the females most preferred to work with calculators cooperatively (F = 51.0%, M = 59.1%).

When working with advanced calculators, both Singaporean and Victorian males and females tended to most prefer cooperating with their friends. This suggests that using calculators may promote collaboration, which is consistent with past research (see e.g., Geiger, 1998, 2006).

(iii) Explanations of most preferred social interaction for learning preference. As described earlier, students' explanations for their most preferred social interaction for learning preferences were categorised into five categories: learning outcomes, learning performance, learning process, learning environment, and attitudes. The frequency distributions of the categories of explanations for males and females were found to be generally similar (see Appendix D3 for analyses of the Singaporean and Victorian samples). The main reason for students most preferring to study mathematics individually was related to learning outcomes (e.g., concentrate better). The main reason given by students for most preferring to study mathematics cooperatively was peer interaction (e.g., friends help), and the main reason for most preferring to compete was related to attitude (e.g., motivation). There were some differences in the percentages between females and males; these differences were smaller for Singaporean than for Victorian students. This suggests that Singaporean females and males were more similar in their patterns of explanations than Victorian students, which is consistent with their smaller effect sizes of the other variables measured that had gender differences. The larger gender difference found in the Victorian data may also be due to the small number of Victorian students sampled, which could result in higher variability and limited generalisability of the data.

Summary. In summary, there were common gender differences, in favour of males, found for most of the variables related to studying mathematics and calculator use:

- Male students had a greater tendency to have a connected knowing-deep approach rather than a separate knowing-surface approach, expressed higher confidence with the calculator, and had lower agreement with using calculators as Master, compared to females. For these common gender differences found in the two regions, the effect sizes of the Victorian sample were larger than that of the Singaporean sample.

- When learning how to use the calculator, higher percentages of males than females most preferred to try the buttons out and play around with the calculators. Female students had a higher tendency than males to try out the calculator buttons at the same time as they watch a demonstration, listen to an explanation, or read the instructions when they learning how to use the calculators.

- There were no gender differences in students’ general VARK preferences.

- Male students had higher tendencies than females to prefer to compete with friends when studying mathematics and working with calculators. There were similar patterns of students’ most preferred mode when working with advanced calculators in both regions – both males and females most preferred to cooperate with friends rather than working with the GC individually or competitively.

In the next section, the discussion of findings for research question 4 is presented.

Research Question 4

What are the relationships among students' gender, beliefs, attitudes, learning preferences, and ways of interacting with the calculator?

There were three subsidiary questions:

a. What are the correlations between all the variables?
b. Which variable best explains students' ways of interacting with calculators?
c. How can these relationships be explained?

Parts (a) and (b) are associated with Part 1 of the study using the data from the large scale surveys, and are presented in the following section. Part (c) is associated with Part 2 of the study – a small scale investigation of a group of Singaporean students. Results and findings of Part 2 of the study are presented in the next chapter (Chapter 5).

(a) What are the correlations between all the variables? Pearson bi-variate correlations were calculated between the variables with interval data. Variables with a dichotomous response format were included since the point bi-serial correlations involved the same calculations (Field, 2005). The correlation coefficients between variables for both Singaporean and Victorian data are shown in Table 4.24. VARK preferences were not included since the variables had weak ($r = 0.1$ or lower) or non-significant correlations with the other variables (see Appendix D5, Table D17), with one exception, the correlation between the Read/Write preference and the preference for studying mathematics individually ($r = 0.29$) for Victorian students. The social interaction for learning preferences, that is, preferences to study mathematics individually (Ma_Indv), cooperatively (Ma_Coop), and competitively (Ma_Comp), and preferences to work with calculators individually (Cal_Indv), cooperatively (Cal_Coop), and competitively (Cal_Comp), correlated with one another, but not with the other variables (see Appendix D6, Table D18). The only exceptions were Cal_Indv with Cal_Enj ($r = 0.33$) for Singaporeans, and with Cal_Conf ($r = 0.31$) for Victorians. Since the set of social interaction preferences correlated mainly with one another rather than the other variables, they were also not included in the analyses of the patterns of correlations.

Table 4.24

Correlations between Interval and Dichotomous Variables: Singapore and Victoria

		MSR	CalSR	CK-DA	SK-SA	Cal_ Enj	Cal_ Conf	Cal _ Ma	Cal _ Se	Cal _Co
Gender#	S'pore	.13**	.12**	.13**	-.08*	.11**	.15**	-.08*	.05	.12**
	Vic	.07	.14	.19*	-.17	.12	.26**	-.24**	-.16	.10
MSR	S'pore		.43**	.43**	-.40**	.11**	.18**	-.15**	-.11**	.24**
	Vic		.36**	.33**	-.21*	-.10	.04	-.35**	-.25**	.07
CalSR	S'pore			.21**	-.15**	.40**	.52**	-.35**	.11**	.43**
	Vic			.19*	-.31**	.26**	.38**	-.40**	-.14	.36**
CK-DA	S'pore				-.26**	.20**	.19**	-.07*	-.09**	.41**
	Vic				-.18*	.13	.27**	-.23*	-.11	.41**
SK-SA	S'pore					-.03	-.06	.36**	.21**	-.10**
	Vic					.08	.11	.52**	.34**	.01
Cal_Enj	S'pore						.69**	-.31**	.26**	.55**
	Vic						.58**	-.12	.31**	.50**
Cal_Conf	S'pore							-.37**	.24**	.53**
	Vic							-.19*	.28**	.52**
Cal_ Ma	S'pore								.04	-.23**
	Vic								.30**	-.19*
Cal_Se	S'pore									.21**
	Vic									.27**

* $p < .05$ ** $p < .01$

#Point bi-serial correlations

Note: statistically significant correlations are highlighted according to strength: weak (0.1 to 0.3) = blue, moderate (0.3 to 0.5) = yellow, and strong (> 0.5) = green) based on Cohen's (1977) definition of small ($r = 0.1$), medium ($r = 0.3$) and large ($r = 0.5$) size of correlational effects.

In Table 4.24, the coefficients were colour-coded by strength based on Cohen's (1977) criteria of r = 0.1 (weak), 0.3 (medium) and 0.5 (strong). The pattern of medium to strong correlations common to both regions (Singapore and Victoria) is illustrated in Figure 4.13. It can be seen in Figure 4.13 that the variables can be classified into three groups:

(i) ways of using calculators (calculator as master, servant, collaborator);

(ii) beliefs about mathematics and mathematics learning (connected knowing-deep approach, separate knowing-surface approach, mathematics competency self-rating); and

(iii) calculator attitudes (calculator competency self-rating, calculator enjoyment, calculator confidence).

Common pattern of correlation among variables.

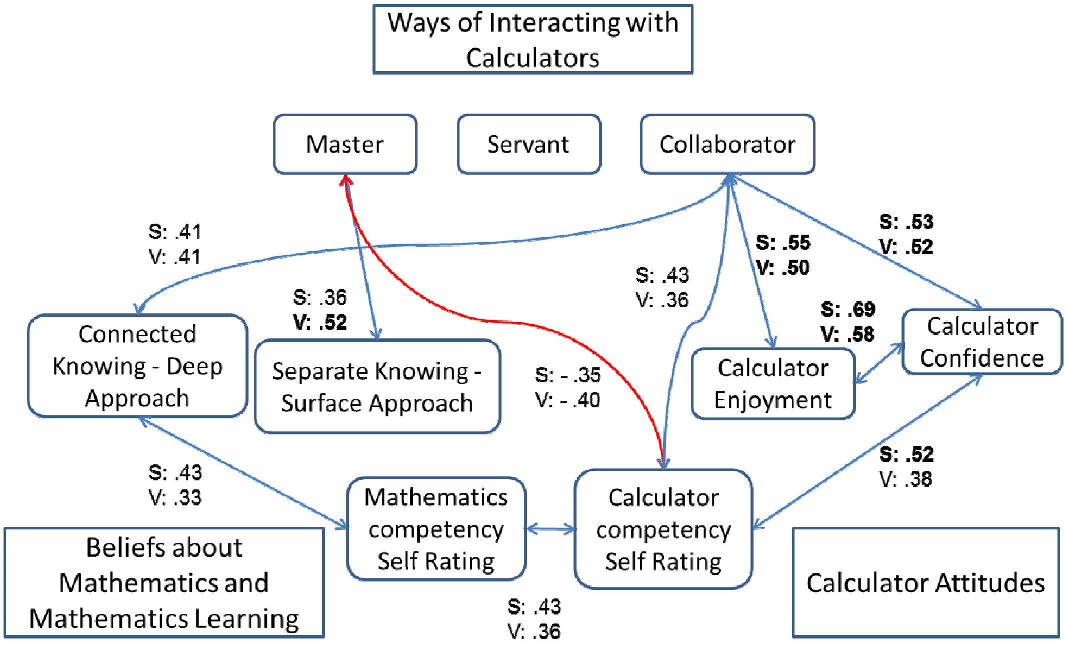

Figure 4.13. Common pattern of moderate to strong correlations (r > 0.3) between the variables, for both Singaporean and Victorian students. Red indicates negative correlation; blue indicates positive correlations.

It can be seen in Figure 4.13 that:

- Using calculator as Master (Cal_Ma) i.e., being subservient to the technology, is associated with having a Separate Knowing and Surface Approach towards mathematics learning. That is, students who learn mathematics by memorising the steps without real understanding also tend to use the calculators in the same way. They also tend to have low calculator competency self-ratings. This is consistent with the MSPE theory that students using calculator as Master have a technological or mathematical dependence on the calculators.

- Using calculator as Collaborator (Cal_Co) i.e., engaging with calculator as a Partner and as an Extension of Self, is associated with having a Connected Knowing and Deep Approach towards mathematics learning. That is, students who learn mathematics through intrinsic interest and seeking deep understanding tend to use the calculators for problem solving and mathematical exploration. Students who employ Connected Knowing-Deep Approach to learning tend to "maximise understanding" (Biggs, 1993, p. 6) and "engage the task properly" (Biggs, 1993, p. 7) with deep understanding. They also use the calculators "creatively to increase the power that students have over their learning" (Geiger, 2005, p. 371) and "incorporate technological expertise as an integral part of their mathematical repertoire" (Geiger, 2005, p. 371).These students also tend to have high levels of calculator competency, calculator enjoyment and calculator confidence. This suggests that students need to have sufficient competency and confidence with the calculator in order to enjoy using it, and to be able to engage with the tool at the highest level of sophistication.

- Calculator competency was related to calculator confidence, but the association between calculator competency with enjoyment was only present for the Singaporean data (see next section). Calculator competency was also negatively related to Cal_Ma and positively related to Cal_Co. Students who agree with engaging with calculator as Collaborator are likely to have higher calculator competency and higher levels of enjoyment and confidence compared to those who disagree. In contrast, students who agree with engaging with the calculator as Master are likely to have lower calculator competency and lower levels of enjoyment and confidence compared to those who disagree.

It is interesting to note that there was no strong correlation between mathematics competency and calculator as Master or as Collaborator. This suggests that the ways in which students use their calculators are consistent with their approaches to knowing and studying mathematics, and associated only weakly with their self-perceptions of mathematics competency.

- In both Singaporean and Victorian students mathematics competency (MSR) is associated with Connected Knowing – Deep Approach (CK-DA). However, MSR is associated with Separate Knowing – Surface Approach (SK-SA) in the Singaporean data but not in the Victorian data (see Table 4.24). The finding for Australian students is consistent with findings from Burnett and Proctor (2002) where elementary Australian students' mathematics self-concepts correlated moderately with Deep Approach, but not with Surface Approach. Kılıç and Sağlam (2010) found significant differences in rote learning orientation (similar to surface approach) scores between Turkish secondary students from different school types, and no differences in meaningful learning orientation (similar to deep approach). They suggested that the school contexts – curriculum content, learning tasks, assessment, etc. – could have affected students' learning orientations. As can be seen in the next section, there are differences in the correlation patterns between SK-SA and other variables for Singaporean and Victorian students, which could be due to the different educational contexts.

Overall, students' ways of interacting with calculators were associated with their beliefs about mathematics and mathematics learning, as well as their calculator attitudes. Use of calculators as Master (being subservient to technology) was associated with high Separate Knowing-Surface Approach and low calculator competency, and use of calculators as Collaborator (high level of sophistication) was associated with high Connected Knowing-Deep Approach, calculator competency, calculator enjoyment and calculator confidence.

Correlation pattern among variables for Singaporean data. Figure 4.14 contains the common pattern seen in Figure 4.13 (solid lines), and additional correlations specific to the Singaporean data (dashed lines).

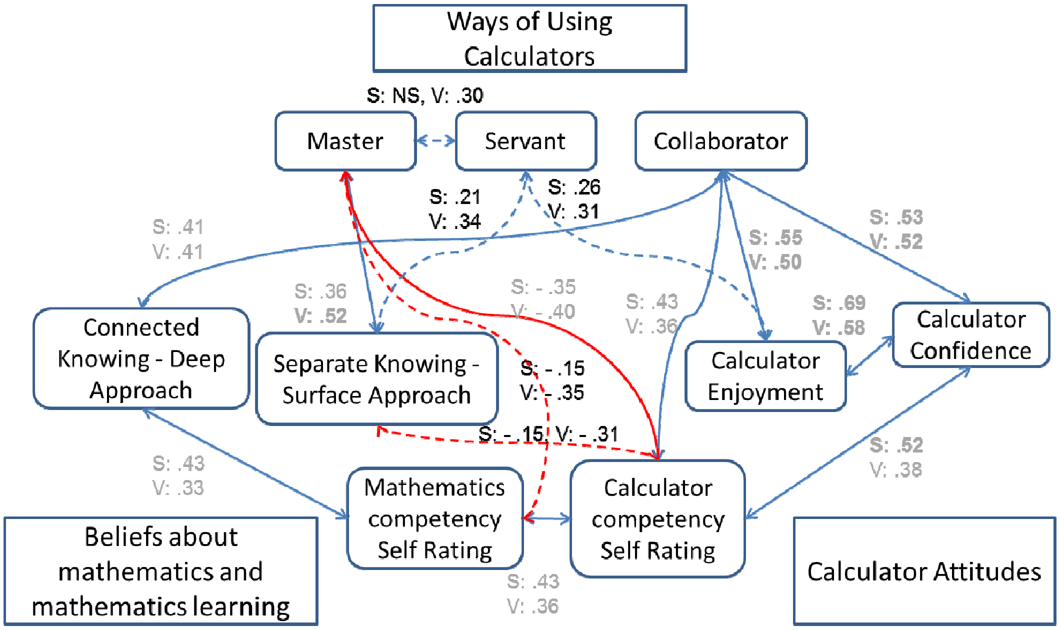

Figure 4.14. Pattern of moderate to strong correlations ($r > 0.3$) for Singaporean students. Dotted lines indicate correlations that are unique for Singaporean students. Red indicates negative correlations; blue indicates positive correlations.

It can be seen in Figure 4.14 that Calculator as Master is associated negatively (red) with calculator enjoyment ($r = –0.31$, see Table 4.24) and confidence ($r = –0.37$). These associations were not found in the Victorian data.

The box-plots of the calculator as Master scores for different levels of calculator enjoyment and confidence are shown in Figures 4.15 and 4.16 respectively. It can be seen that for Singaporean students, calculator as master scores tended to decrease (i.e. students become less subservient to the technology) as calculator enjoyment and confidence increased. The pattern was similar for Victorian students with one exception. Victorian students who strongly disagreed with enjoying calculator use (N = 9) and having confidence in using calculators (N = 5) were found to have the lowest median calculator as Master scores (i.e. more fluent with calculators) compared to the rest of the Victorian students. This suggests that there was a small group of Victorian students in the sample who were fluent in using CAS calculators but did not enjoy and were not confident in using them. Further investigation confirmed the hypothesis. There were four Victorians (all females) who strongly disagreed to both enjoying and being confident in using calculators. Out of the four students, two scored the lowest 1.0 for calculator as master, one scored 1.7, and one had the neutral score of 3.0. The three students with the low scores (1.0 and 1.7) for calculator as master disagreed to being subservient to the calculator and can be assumed to be fluent.

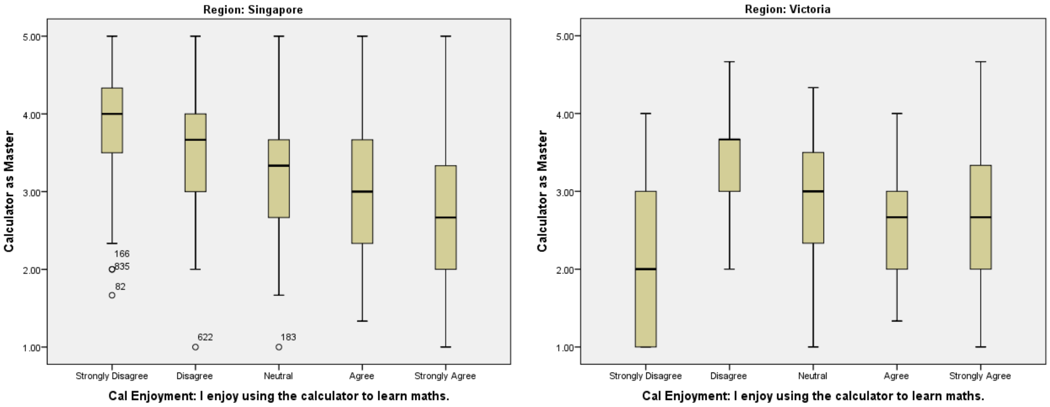

Figure 4.15. Box-plots of calculator as Master scores for different levels of calculator enjoyment.

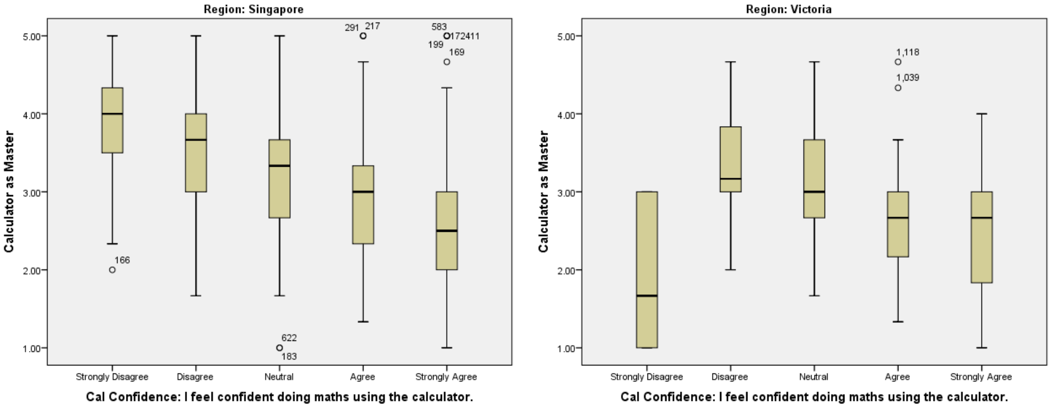

Figure 4.16. Box-plots of calculator as Master for different levels of calculator confidence.

It can also be seen in Figure 4.14 that Separate Knowing – Surface Approach is associated negatively with mathematics competency ($r = -0.40$, see Table 4.24). From the box-plots shown in Figure 4.17, the trend is generally similar for both regions.

However, the correlation between SK-SA and MSR is weak in the Victorian data (*r* = –0.21, see Table 4.24), which could be due to a small group (N = 3) of Victorian students who rated themselves weak in mathematics competency and yet had lower median score for separate knowing and surface approach, compared to students who rated themselves better in mathematics.

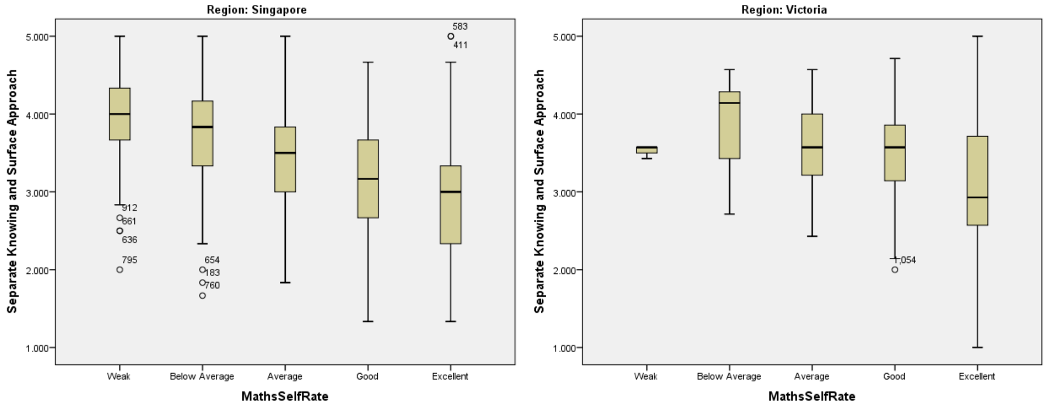

Figure 4.17. Box-plots of Separate Knowing-Surface Approach for different levels of mathematics competencies.

Correlation pattern among variables for Victorian data. Figure 4.18 contains the common pattern (solid lines) seen in Figure 4.13, and additional correlations specific to the Victorian data (dashed lines).

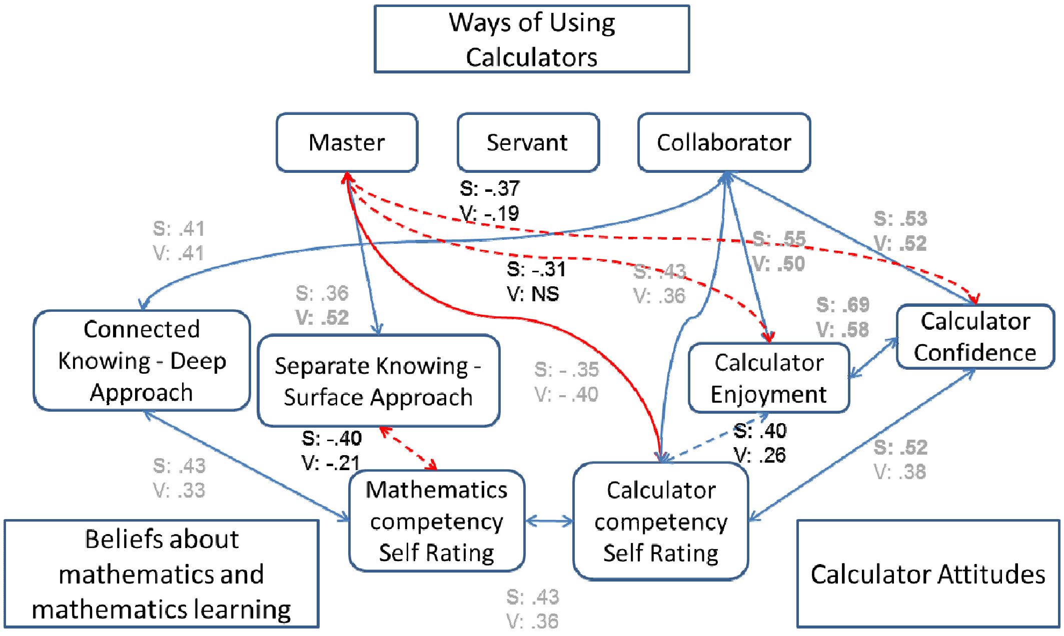

Figure 4.18. Pattern of moderate to strong correlations ($r > 0.3$) for Victorian students. Dotted lines indicate correlations that are unique for Victorian students. Red indicates negative correlations; blue indicates positive correlations.

It can be seen in Figure 4.18 that Calculator as Master correlates positively with calculator as Servant ($r = 0.30$, see Table 4.24). This is different from Singaporean data where there was a very weak non-significant correlation. For both regions, the scatter-plots of the calculator as Servant versus calculator as Master, together with the linear regression lines, are shown in Figure 4.19. It can be seen that the values for calculator as Servant were generally lower in Victoria than Singapore, suggesting that Victorian students had engaged less with calculator as Servant than Singaporean students (S'pore: $\bar{x}_{Cal\_Se} = 3.78$; Vic: $\bar{x}_{Cal\_Se} = 3.56$, see research question 2). Since the slope of the regression line for the Victorian scatter-plot is positive, higher calculator as Master scores are associated with higher calculator as Servant scores, suggesting that students who were more fluent with calculator (i.e. had lower calculator as Master scores) also tend to engage with the calculator less as Servant. It could be because of the technology-free component of the VCE mathematics examinations that Victorian students who were more fluent with calculators tended to rely less on them as replacements for pen-and-paper computation. In contrast, Singaporean students appear to use calculators as servant regardless of their fluency with calculators. All Singaporean mathematics examinations require the use of the graphing calculators (GC), that is, there are no calculator free examinations.

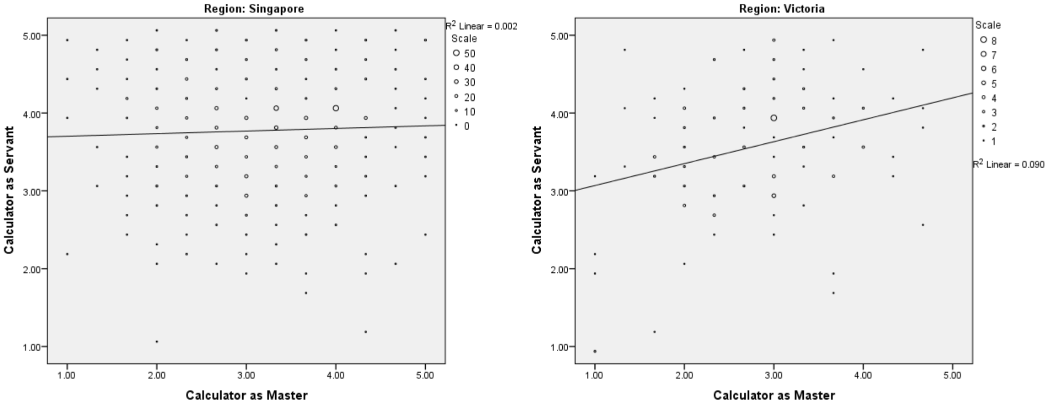

Figure 4.19. Scatter-plots with regression lines of calculator as Master against calculator as Servants for both regions.

It can also be seen in Figure 4.18 that Mathematics competency self-ratings correlated moderately with calculator as Master (*r* = –0.35, see Table 4.24), in the negative direction, for Victorians but only weakly for Singaporeans (*r* = –0.15, also see box-plots in Figure 4.20). The findings suggest that basic mastery of using the CAS calculator might be related to both calculator competency and mathematics competency, consistent with Geiger’s (2005) description of the use of technology as Master as a relationship “induced by technological or mathematical dependence” (p. 371). With the additional computer algebra system in the calculator, using the CAS calculator seems to be more mathematically demanding compared to using the GC. This is also consistent with the findings in the literature reviewed (e.g., Guin & Trouche, 1999; Pierce & Stacey, 2004) described in the Chapter 2 section on technical and mathematical demands.

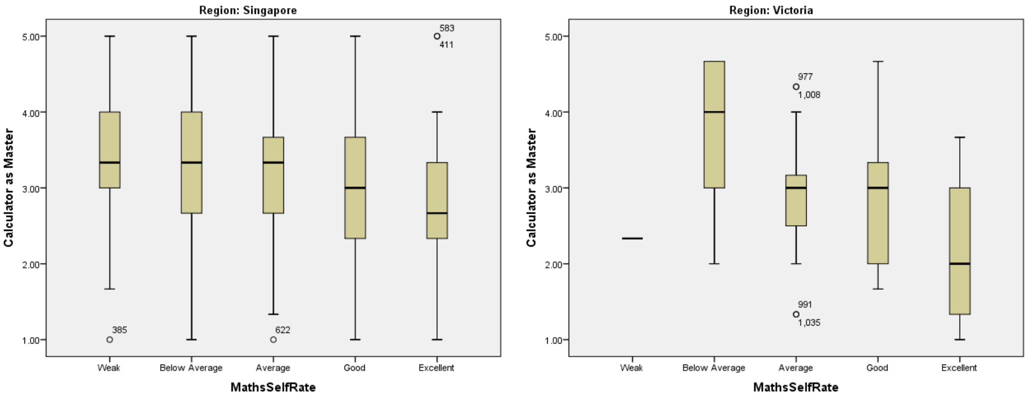

Figure 4.20. Box-plots of calculator as master scores for different levels of mathematics competency self-ratings.

Furthermore, it can be seen in Figure 4.18 that Calculator as Servant seems to have characteristics which are a mix between calculator as Master and as Collaborator, associating with SK-SA on one hand (similar to calculator as Master), and Cal_Enj on the other (similar to calculator as Collaborator). It was seen earlier (Table 4.14) that Singaporean students had significantly higher scores on calculator as Servant (mean = 3.78) compared to Victorians students (mean = 3.56). Although there seemed to be a similar trend of increasing calculator as Servant median scores as enjoyment increases (see boxplots in Figure 4.21), the trend is clearer among Victorian students than for Singaporean students. Similarly in the scatterplots of Separate Knowing-Surface Approach against calculator as Servant (Figure 4.22), the correlation is stronger (data-points closer to regression line) and the regression line is steeper for Victorian students than for Singaporean students.

There was a moderate negative correlation between Separate Knowing–Surface Approach and calculator competency found for Victorian students (r = –0.31) compared to weak correlation for Singaporean students (r = –0.15). However, from the box-plots in Figure 4.23, the trend was reversed for the small number of Victorian students who rated themselves weak (N = 2) or below average (N = 8) in calculator competency. Most of the Victorian students (N = 153) reported average, good or excellent calculator competencies, and for these students the trend can be seen that the median scores of SK-SA decreased as calculator competencies increased.

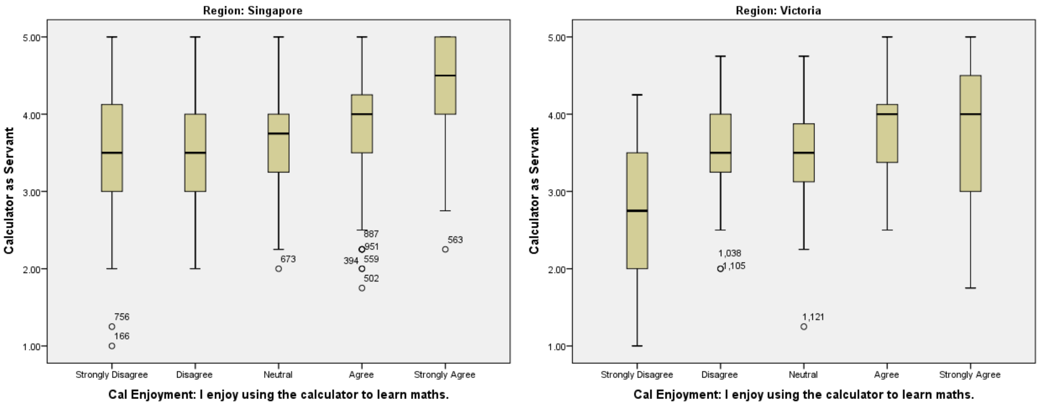

Figure 4.21. Box-plots of calculator as Servant scores for different levels of calculator enjoyment.

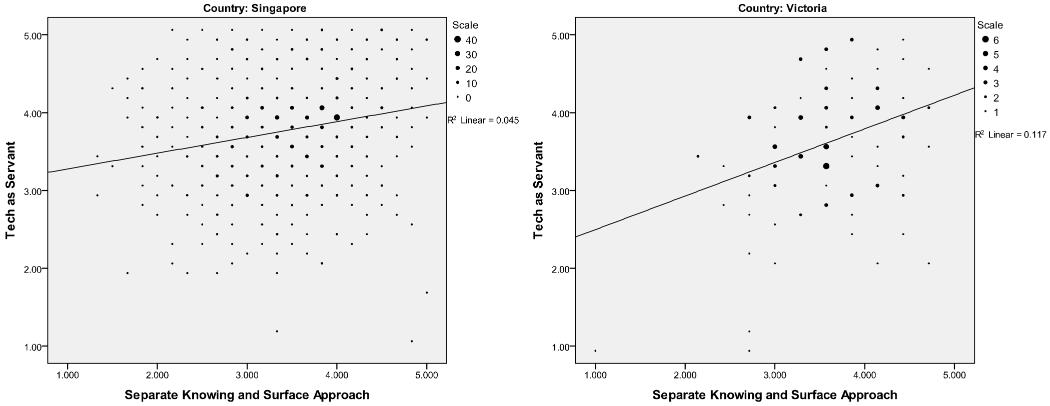

Figure 4.22. Scatter-plots of calculator as Servant against Separate Knowing and Surface Approach scores.

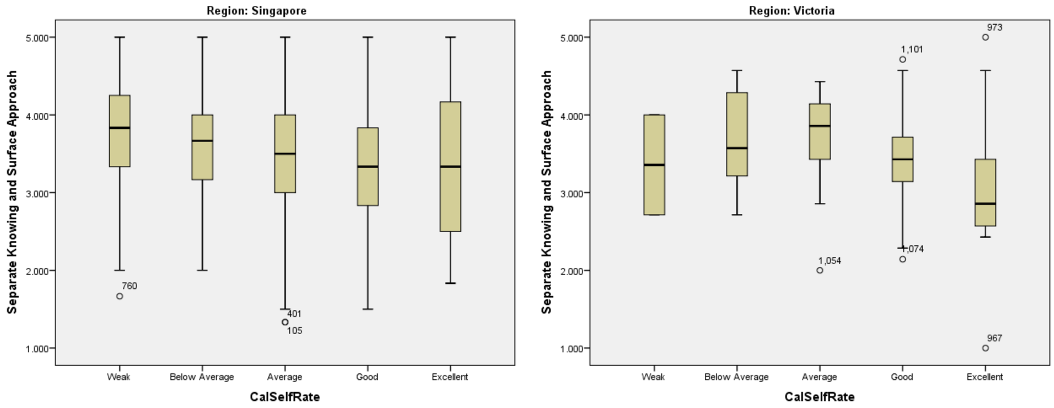

Figure 4.23. Box-plots of calculator as Servant scores for different levels of calculator competency self-ratings.

Summary. Focusing on students' ways of interacting with calculators, the overall summary of findings for research question 4 (a) are:

- Three groups of variables were found to have moderate or strong correlations with one another (see Figure 4.13). These are

  (i) students' beliefs about and attitudes toward mathematics (mathematics competency self-rating, Connected Knowing-Deep Approach, Separate Knowing-Surface Approach),

  (ii) students' beliefs about and attitudes toward calculators (calculator competency self-rating, calculator enjoyment, calculator confidence), and

  (iii) ways of interacting with calculators (calculator as Master, as Servant and as Collaborator).

- There are patterns of correlations between variables which are common across the two regions, as shown in Figure 4.13. Calculator as Master correlated positively with Separate Knowing-Surface Approach, and negatively with calculator competency. Calculator as Collaborator correlated positively with Connected Knowing-Deep approach, calculator competency, calculator enjoyment, and calculator confidence.

- Additionally for Singaporean students, calculator as Master also correlated negatively with calculator enjoyment and confidence.

- For Victorian students, besides the common pattern stated above, calculator as Master correlated positively with calculator as Servant, and correlated negatively with mathematics competency. Calculator as Servant also correlated positively with Separate Knowing-Surface Approach, and with calculator enjoyment.

In the next section, results from the multiple regression analyses conducted are presented.

(b) Which variable best explains students' ways of interacting with calculators? Researchers generally use regression analysis to (i) "predict scores on one variable based on information regarding the other variable(s)" (Huck, 2008, p. 407) and (ii) "explain why the study's people, animals, or things score differently on a particular variable of interest" (p. 407). In this study multiple regression analyses were used to seek the student variable (beliefs, attitudes, and learning preferences) that best explains students' ways of interacting with calculators. Multiple regressions were conducted for Singaporean and Victorian data separately to compare between the two regions.

Standard (or simultaneous) multiple regression analyses (Tabachnick & Fidell, 2007) were used rather than stepwise regression since the variables investigated were amalgamated from various theoretical frameworks rather than from a pre-existing theoretical model. There was no prior theoretical basis to input the variables in any hierarchical sequence. It is noted that the standard multiple regression measures the unique contribution of each of the independent variables; hence, it is possible for a variable which is highly correlated to the dependent variable to appear unimportant if it is also correlated with other independent variables. Tabachnick and Fidell (2007) illustrated this with a Venn diagram. In Figure 4.24 the independent variable IV2 is highly correlated with the dependent variable but has a smaller unique overlapping variance compared to IV1 and IV3. Hence, the full correlation matrix and the unique contribution of the independent variable need to be considered in tandem.

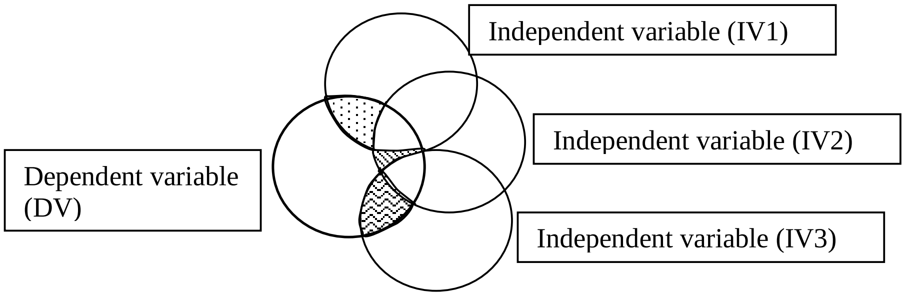

Figure 4.24. Venn diagram illustrating the unique contributions of IV1, IV2 and IV3 to the total variance of the DV (adapted from Tabachnick and Fidell, 2007, p. 137).

Daniel and Onwuegbuzie (2001) suggested investigating the bivariate correlations between each of the predictors and the dependent variable, in order to "determine at a basic level whether each of the several predictor [independent] variables, in and of itself, is appreciably related to the criterion [dependent] variable" (p. 13). From the investigation of the correlation coefficients between each of the variables and students' ways of interacting with calculators in the previous section, it can be seen that VARK preferences and social interaction for learning preferences were weakly or non-significantly correlated with calculator as Master, Servant and Collaborator, and were discarded from the multiple regression analyses (see Appendices D5 and D6). Gender was retained in the analyses despite having weak correlations because it was the focus of one of the research questions. The variables used therefore are:

Independent variables

- Gender
- Mathematics competency self-rating (MSR)
- Calculator competency self-rating (CalSR)
- Connected Knowing-Deep Approach (CK-DA)
- Separate Knowing-Surface Approach (SK-SA)
- Calculator enjoyment (Cal_Enj)
- Calculator confidence (Cal_Conf)

Dependent variables

- Calculator as Master (Cal_Ma)
- Calculator as Servant (Cal_Se)
- Calculator as Collaborator (Cal_Co)

The results of the standard multiple regression, using SPSS, including the correlations between the variables, the unstandardised regression coefficients (*B*), their standard errors (*SE B*), and the standardised regression coefficients (β) are presented in Tables 4.25 (calculator as Master), 4.26 (calculator as Servant) and 4.27 (calculator as Collaborator).

Calculator as Master. The *R* for regression was significantly different from zero, for Singapore: $R = 0.55$, $F(7,901) = 55.36$, $p < .001$, and for Victoria: $R = 0.63$, $F(7, 109) = 10.38$, $p < .001$. The model explained 30% and 40% of the total variance in the calculator as Master scores for Singaporean and Victorian samples respectively. It can be seen in Table 4.25 that six of the seven variables (excluding gender) significantly predicted 30% of the variability in Singaporean students' Cal_Ma scores, and only MSR and SK-SA significantly predicted 40% of the variability in Victorian students' Cal_Ma scores. In both regions, the variable that best explains students' calculator as Master scores is their Separate Knowing – Surface Approach (SK-SA), with the highest standardised regression coefficient (S'pore: $\beta = 0.39$, Vic: $\beta = 0.46$). Using the squared semipartial correlation (Tabachnick & Fidell, 2007) coefficients between SK-SA and Cal_Ma (S'pore: $sr^2 = (0.35)^2 = 0.12$; Vic: $sr^2 = (0.41)^2 = 0.17$), the unique contributions of SK-SA to the total variance of Cal_Ma are 12% (out of 30%) and 17% (out of 40%) for the Singaporean and Victorian data respectively.

There were only two variables found to be significant predictors of Cal_Ma in the Victorian data: SK-SA uniquely accounted for 17% and MSR uniquely accounted for 0.3% ($sr^2 = (0.055)^2 = 0.003$) of the variability of Cal_Ma. This suggests that there are some interactions between SK-SA and MSR which accounted for the remaining 22.7% of the variability.

Table 4.25

Standard Multiple Regression of Student Variables (Gender, Beliefs about and Attitudes toward Mathematics and Calculators) on Students' Use of Calculator as Master

	Calculator as Master (Cal_Ma)					
Variables	*B*		*SE B*		*β*	
	S'pore	Vic	S'pore	Vic	S'pore	Vic
Gender	-0.01	-0.06	0.05	0.17	-0.00	-0.03
MSR	0.08**	-0.21*	0.03	0.08	0.11	-0.22
CalSR	-0.19***	-0.11	0.03	0.10	-0.21	-0.10
CK-DA	0.11**	0.01	0.04	0.10	0.09	0.01
SK-SA	0.45***	0.60***	0.04	0.11	0.39	0.46
Cal_Enj	-0.10**	-0.05	0.03	0.07	-0.12	-0.07
Cal_Conf	-0.16***	-0.12	0.03	0.08	-0.19	-0.15

* $p < .05$ ** $p < .01$ *** $p < .001$

Note: For Singapore, $R^2 = 0.30$ Adjusted $R^2 = 0.30$ R = 0.55 ($p < .001$)

For Victoria, $R^2 = 0.40$ Adjusted $R^2 = 0.36$ R = 0.63 ($p < .001$)

Overall students' Separate Knowing-Surface Approach appears to best explain their use of calculators as Master. This is consistent with the finding in the previous section that amongst the correlations between Cal_Ma and other variables, the association between Cal_Ma and SK-SA is one of the largest (S'pore: $r = 0.36$, Vic: $r = 0.52$, see Table 4.24). Also, it seemed that for Victorian students using CAS calculators, students' Separate Knowing-Surface Approach to learning mathematics, together with their mathematics competency self-ratings, explains the variability in their Cal_Ma scores.

Calculator as Servant. The *R* for regression was significantly different from zero, for Singapore: $R = 0.37$, $F(7,902) = 20.63$, $p < .001$, and for Victoria: $R = 0.55$, $F(7,108) = 6.53$, $p < .001$.

It can be seen in Table 4.26 that SK-SA, Cal_Enj and Cal_Conf significantly predicted 14% of the variability in Singaporean students' Cal_Se scores, and Cal_Enj and Cal_Conf significantly predicted 30% of the variability in Victorian students' Cal_Se scores.

Table 4.26

Standard Multiple Regression of Student Variables (Gender, Beliefs and Attitudes about Mathematics and Calculators) on Students' Use of Calculator as Servant

	Calculator as Servant (Cal_Se)					
Variables	*B*		*SE B*		β	
	S'pore	Vic	S'pore	Vic	S'pore	Vic
Gender	0.05	-0.34	0.04	0.18	0.04	-0.17
MSR	-0.03	-0.03	0.02	0.09	-0.06	-0.07
CalSR	0.04	-0.14	0.03	0.10	0.05	-0.14
CK-DA	-0.09	-0.10	0.04	0.10	-0.09	-0.09
SK-SA	0.19***	0.22	0.03	0.12	0.20	0.17
Cal_Enj	0.13***	0.17*	0.03	0.08	0.18	0.22
Cal_Conf	0.07*	0.22**	0.03	0.08	0.11	0.29

* $p < .05$ ** $p < .01$ *** $p < .001$

Note: For Singapore, $R^2 = 0.14$ Adjusted $R^2 = 0.13$ $R = 0.37$ ($p < .001$)

For Victoria, $R^2 = 0.30$ Adjusted $R^2 = 0.25$ $R = 0.55$ ($p < .001$)

In Singapore, Separate Knowing-Surface Approach best explains the variability of calculator as Servant ($\beta = 0.20$), whilst in Victoria it is calculator confidence ($\beta = 0.29$). It is also noted from previous findings that:

- there are significant differences between Singaporean and Victorian students' calculator as Servant mean scores (S'pore>Vic) (see Table 4.14);
- gender difference (F > M) exists for Cal_Se in the Victorian but not the Singaporean data (see Table 4.20); and
- there is weak or non-significant associations between Cal_Se and the other variables in the Singaporean data, but in the Victorian data Cal_Se is moderately

correlated to SK-SA (r = 0.34), Cal_Enj (r = 0.31), and Cal_Conf (r = 0.28) (see Table 4.24).

Taken together, these differences suggest that the ways in which students' interact with calculators as Servant are distinct across both regions. As suggested earlier, the differences could be due to the different assessment format – there is a technology-free component in the Victorian high-stakes mathematics examinations, and there is no technology-free component in the Singaporean examinations.

It is interesting to note that SK-SA is a predictor for Cal_Se in the Singaporean sample, yet the correlation is weak (r = 0.21, see Table 4.24); whilst SK-SA is not a predictor in the Victorian sample, yet the correlation is moderate (r = 0.34). The unique contribution of SK-SA to Cal_Se is small (S'pore: sr^2 = 0.034, Vic: sr^2 = 0.02). This implies that there are interactions between SK-SA and other variables (Cal_Enj and Cal_Conf) that influence students' use of calculators as Servant. Overall, the positive correlations imply that students who have a Separate Knowing-Surface Approach also tended to use calculators as Servant.

In both regions, calculator enjoyment and confidence are predictors for calculator as Servant [Cal_Se] (see Table 4.26), and are associated with Cal_Se positively (see Table 4.24). This suggests that students who use calculators as Servant also tend to enjoy using calculators and are confident in using them.

Calculator as Collaborator. The R for regression was significantly different from zero, for Singapore: R = 0.66, $F(7,891)$ = 98.84, p < .001, and for Victoria: R = 0.65, $F(7,109)$ = 11.59, p < .001. It can be seen in Table 4.27 that CalSR, CK-DA, Cal_Enj and Cal_Conf significantly predicted 44% of the variability in Singaporean students' Cal_Co scores, and CK-DA, Cal_Enj, and Cal_Conf significantly predicted 43% of the variability in Victorian students' Cal_Co scores.

In both regions, the variable that best explains students' calculator as Collaborator scores is their Connected Knowing – Deep Approach (CK-DA), with the highest standardised regression coefficient (S'pore: β = 0.30, Vic: β = 0.33). This means that 30% (Singapore) and 33% (Victoria) of the total variability of Cal_Co scores was accounted for by CK-DA. Using the squared semipartial correlation (Tabachnick & Fidell, 2007) coefficients between CK-DA and Cal_Co (S'pore: $sr^2 = (0.26)^2 = 0.07$; Vic: $sr^2 = (0.29)^2 = 0.08$), the unique contributions of CK-DA to the total variance of Cal_Co are 7% for Singaporean and 8% for Victorian data. Since the unique contribution CK-DA is small, it implies that CK-DA interacts with other variables such as Cal_Enj and Cal_Conf to influence Cal_Co. Nonetheless, there are moderate positive correlations between Cal_Co and CK-DA (S'pore: $r = 0.41$; Vic: $r = 0.41$, see Table 4.24). Students who have a Connected Knowing-Deep Approach also tend to use calculators as Collaborator.

Table 4.27

Standard Multiple Regression of Student Variables (Gender, Beliefs about and Attitudes toward Mathematics and Calculators) on Students' Use of Calculator as Collaborator

	Calculator as Collaborator (Cal_Co)					
Variables	*B*		*SE B*		*β*	
	S'pore	Vic	S'pore	Vic	S'pore	Vic
Gender	0.01	-0.18	0.04	0.16	0.00	-0.09
MSR	-0.01	-0.06	0.02	0.07	-0.01	-0.08
CalSR	0.14***	0.17	0.03	0.09	0.16	0.19
CK-DA	0.32***	0.34***	0.03	0.09	0.30	0.33
SK-SA	0.03	0.05	0.03	0.10	0.03	0.04
Cal_Enj	0.22***	0.20**	0.03	0.07	0.29	0.27
Cal_Conf	0.19***	0.15*	0.03	0.07	0.19	0.21

* $p < .05$ ** $p < .01$ *** $p < .001$

Note: For Singapore, $R^2 = 0.44$ Adjusted $R^2 = 0.43$ R = 0.66 ($p < .001$)
For Victoria, $R^2 = 0.43$ Adjusted $R^2 = 0.39$ R = 0.65 ($p < .001$)

It is interesting to note that in both regions, there were moderate positive correlations between calculator competency self-rating (CalSR) and Cal_Co (S'pore: $r = 0.43$; Vic: $r = 0.36$, see Table 4.24). However, in the Singaporean sample but not the Victorian sample, students' CalSR was a predictor of Cal_Co (see Table 4.27). This might be due to the high CalSR scores of Victorian students (they generally rated themselves average or better in calculator competency).

Overall students' Connected Knowing-Deep Approach appears to best explain their use of calculators as Collaborator. In a previous section, it was found that the correlation between Cal_Co and CK-DA is moderate compared to the correlations between Cal_Co and the other variables (see Table 4.24). There are strong correlations between Cal_Co and Cal_Enj, and between Cal_Co and Cal_Conf, which are consistent with the finding that Cal_Enj and Cal_Conf are also predictors of Cal_Co (see Table 2.47). As can be seen in Figure 4.13, the correlation between Cal_Enj and Cal_Conf is strong. Since multiple regression measures the unique contribution of an independent variable to the total variance of the dependent variable (see Figure 4.24), so CK-DA rather than Cal_Enj or Cal_Conf was found to be the best predictor of Cal_Co.

Summary. The main findings for research question 4 (b) are:

- Separate Knowing – Surface Approach best explains students' use of calculators as Master, in both Singaporean and Victorian data;
- Connected Knowing – Deep Approach best explains students' use of calculators as Collaborator, in both Singaporean and Victorian data; and
- Separate Knowing – Surface Approach best explains students' use of calculators as Servant in the Singaporean data, whereas calculator confidence best explains students' use of calculators as Servant in the Victorian data.

The first two findings are consistent with the findings from research question 4 (a) that SK-SA is correlated to Cal_Ma and CK-DA is correlated to Cal_Co. They are also consistent with theory. A conception of mathematics that is rigid and procedural (SK), and a rote approach to learning mathematics (SA), are related to a low level of interacting with calculators where students follow calculator procedures blindly (Cal_Ma). A conception of mathematics that is dynamic, connected and creative (CK), and an emphasis on deep understanding (DA), are related to a high level of interacting with calculators as Collaborator (Cal_Co) for exploration and problem solving. It is interesting to note that although Singaporean students were less fluent in using calculators compared to Victorians (Singaporeans had higher Cal_Ma scores than

Victorians), there were no significant differences by region for CK-DA, SK-SA and Cal_Co scores (see research question 3).

The last finding that there were differences in the variable that best explains students' calculator as Servant scores was also consistent with the findings in research question 3 – Singaporeans had significantly higher Cal-Se scores than Victorians –, and for research question 4 (a), where the pattern of correlations of calculator as Servant was different for Singapore and Victoria.

Conclusions of Part 1 of Study

In this chapter, the findings for research questions 1 to 4 (b) were presented. It can be seen that as the analyses progressed towards a focused investigation of the factors that influenced students' ways of interacting with advanced calculators, the group of variables being investigated narrowed.

From research questions 1 and 2, there were similarities found in the student factors for both the Singaporean and Victorian samples, in particular their CK-DA, SK-SA, Cal_Enj and Cal_Co scores, their calculator VARK preference and their most preferred social interaction preferences for studying mathematics. The similarities in CK-DA and SK-SA scores measuring students' ways of understanding and learning mathematics suggested that these might be influenced by the commonalities in the educational systems of having high-stakes senior secondary examinations. Students from both regions also agreed that they enjoyed using advanced calculators to learn mathematics, and that they were neutral about using calculators as Collaborators. There were similarities in the calculator VARK preferences. The top two most preferred methods of learning how to use the calculators by students in both regions were: method (i) – to try out the calculator steps the same time they see a demonstration, listen to an explanation or read the instructions, and method (a) – to watch a teacher demonstration. Method (i) is considered Kinesthetic and method (a), Visual. This suggests that the calculator lent itself to Kinesthetic and Visual methods. Relating to social interaction preference for studying mathematics, a majority of students in both regions most preferred to study mathematics individually than cooperatively or competitively. However when it came to working with calculators, a majority of students in both regions most preferred to work cooperatively than individually or competitively. From the analysis of students’ explanations for why they most preferred to cooperate, a majority of students (S’pore: 68%; Vic: 67%) described some sort of peer interaction, mainly to get help from their friends regarding the calculator steps or the solution. They also referred to improved learning outcomes (S’pore: 37%; Vic: 46%) such as able to clear doubts, check answers and calculator steps (see Table 4.19). This implied that while the use of calculators seemed to promote more students to work cooperatively, some of their interactions might be focused on discussing calculator procedures and solutions rather than mathematical discoveries. The findings are consistent with those from the longitudinal study of 12 senior secondary students by Geiger (1998). Geiger found that students generally preferred a collaborative environment, and as they gained more experiences with technology (computers and graphing calculators), they were less likely to require technical assistance and the collaborations were more likely to be associated with the mathematics rather than technological issues. However, the students also commented that the GC small screen size made it difficult to share ideas; they were less likely to share their discoveries but tended to discuss with peers only when they could not solve a problem (Geiger, 1998).

There were regional differences: Singaporeans rated themselves lower for mathematics competency, calculator competency, and calculator confidence; Singaporeans rated themselves higher for using calculator as Master and as Servant. It seems that Singaporean students were less fluent users of advanced calculators than Victorian students. It might be that Victorian teachers were more familiar with advanced calculators than Singaporean teachers, having used GC in senior secondary mathematics classrooms for more than a decade. Additionally, some of these differences might have a socio-cultural basis, or be due to a difference in assessment formats, or due to sampling bias (high percentage of students from Independent schools in the Victorian sample). A higher percentage of Singaporean than Victorian students had a Visual preference, whilst a higher percentage of Victorian than Singaporean students had a Read/Write preference. However, students’ general VARK preferences were not significantly associated with their ways of interacting with calculators.

In research question 3, gender differences were found in favour of males. Males rated themselves higher than females for mathematics and calculator self-competencies, Connected Knowing - Deep Approach (CK-DA), calculator enjoyment, calculator confidence, and calculator as Collaborator; whilst females rated themselves higher for Separate Knowing –Surface Approach (SK-SA) and calculator as Master. All of these differences were statistically significant for the Singaporean sample and some of these were statistically significant for the Victorian sample. However, the effect sizes were slightly higher for the Victorian than the Singaporean samples. Overall the gender differences are consistent with past research on mathematics and technology use in mathematics (e.g., Barkatsas, Kasimatis, & Gialams, 2009; Vale, 2008). In Australia, the issue of gender differences seemed to have re-emerged in recent years (Forgasz, Leder, & Tan, 2011; Thomson, De Bortoli, Nicholas, Hillman, & Buckley, 2011; Vale, 2008). Although the gender differences found for Victorian students for mathematics and calculator self-competencies (males scored higher than females) were not statistically significant, the gender differences were significant for their CK-DA and SK-SA scores, which were the variables that best explain students' ways of interacting with calculators. Females in both regions were found to score higher than males for using calculator as Master. Since advanced calculator use is necessary in high stakes mathematics examinations, having a lower level of calculator use (having technical and mathematical dependence) potentially handicaps females. Further research on gender differences in students' achievement needs to be conducted to examine for trends and further evidence of this (Forgasz, 2008; Forgasz & Tan, 2010).

In research questions 4 (a) and (b), the relationships between student factors and their ways of interacting with advanced calculators were examined. Students' ways of interacting with calculators were found to be associated with two sets of variables: students' beliefs about and attitudes toward mathematics (mathematics self-competency, CK-DA, and SK-SA); and their beliefs about and attitudes toward calculators (calculator self-competency, calculator enjoyment, and calculator confidence). It was interesting to note that their VARK preferences and social interaction for mathematics learning preferences were weakly or not significantly associated with the ways they interact with calculators. Students' calculator VARK preferences (which method they most prefer when learning how to use the calculator) were different from their general VARK preferences, suggesting that the preferences may change with contexts and that students tended to prefer Visual and Kinesthetic approaches when learning how to use the calculators. Reports of past research on students’ calculator attitudes and beliefs in which other learning style theories such as brain dominance (Ali & Kor, 2007) and personality types (Alfonso & Long, 2005) were used reveal no significant differences in calculator attitudes between students with different learning styles.

From the two sets of variables (mathematics beliefs and attitudes, and calculator beliefs and attitudes) that were found to be associated with the ways students interact with calculators (see research question 4 (a), Figure 4.12), the variable that best predicts students’ use of calculator as Master is their Separate Knowing – Surface Approach (SK-SA), and the variable that best predicts their use of calculator as Collaborator is Connected Knowing – Deep Approach. This suggests that students’ conceptions about mathematics and their approaches to learning mathematics may play a vital part in the quality of interactions they have with advanced calculators, perhaps even more than do their beliefs about and attitudes toward calculators.

In the next chapter (Part 2 of the study), findings on the relationships between students’ ways of understanding and learning mathematics (CK-DA and SK-SA) and their ways of interacting with calculators (Cal_Ma, Cal_Se and Cal_Co) based on a small scale study are reported. Other factors that affect the ways students interact with calculators are also examined.

Chapter 5 Results and Analysis of Part 2 of Study

Introduction

In the previous chapter, the results and analysis of the large scale study were presented. In this chapter, the results and analysis of a small scale study of a group of Year 12 students from a Singaporean junior college are presented. As discussed in Chapter 3, Methodology, the analysis of Part 2 of the study is meant to enrich the overall findings of the study by examining qualitative data from a group of students to better understand and find explanations for the relationships found between students' beliefs, attitudes, learning preferences and ways of interacting with calculators (research question 4) in Part 1 of the study.

Explicitly, the aim of the Part 2 of the study is to answer research question 4(c). The research question 4 is reiterated here.

What are the relationships among students' gender, beliefs, attitudes, learning preferences, and ways of interacting with the calculators? Specifically:

(a) What are the correlations between all the variables?
(b) Which variable best explains students' ways of interacting with calculators?
(c) How can these relationships be explained?

The key findings of research question 4 (a) and (b) from Part 1 of the study are reported in the following.

Key findings of research question 4 from part 1 of the study. Of the relationships found between student factors (beliefs, attitudes, and learning preferences) and their ways of interacting with the calculators, only those which are common to both regions (Singapore and Victoria) are investigated in Part 2 of the study. In other words, only the correlations that were moderate to high ($r \geq 0.3$) in both regions were considered (see Table 4.24).

The key findings from research question 4 in Part 1 of the study are recapitulated as follows.

1. There were moderate to strong positive correlations between Calculator as Collaborator (Cal_Co), the highest level of calculator use, and calculator attitudinal variables:
    - Cal_Co and calculator competency self-rating (CalSR), $r_{S'pore} = 0.43$, $r_{Vic} = 0.36$;
    - Cal_Co and calculator enjoyment (Cal_Enj), $r_{S'pore} = 0.55$, $r_{Vic} = 0.50$;
    - Cal_Co and calculator confidence (Cal_Conf), $r_{S'pore} = 0.53$, $r_{Vic} = 0.52$.

2. A moderate association was found between Calculator as Collaborator (Cal_Co) and Connected Knowing-Deep Approach (CK-DA), the way of knowing mathematics and approach to learning mathematics that emphasises deep understanding, relating ideas, and intrinsic motivation ($r_{S'pore} = 0.41$, $r_{Vic} = 0.41$). Using multiple regression analysis, CK-DA was found to be the variable that best explained Cal_Co.

3. Calculator as Master (Cal_Ma), the lowest level of calculator use in which students are subservient to the calculator, was found to be moderately negatively correlated to calculator competency (CalSR) ($r_{S'pore} = –0.35$, $r_{Vic} = –0.40$).

4. A moderate association was also found between Cal_Ma and Separate Knowing-Surface Approach (SK-SA), the way of knowing mathematics and approach to learning mathematics that emphasises absolute certainty of knowledge, superficial rote-understanding, minimising the scope of study, and fear of failure ($r_{S'pore} = 0.36$, $r_{Vic} = 0.52$). Using multiple regression analysis, SK-SA was found to be the variable that best explained Cal_Ma.

5. There were weak or no correlations between students' ways of using the calculators (Cal_Ma, Cal_Se, Cal_Co) and other learning preferences such as the VARK and social interaction for learning preferences (Ma_Indv, Ma_Coop, Ma_Comp, Cal_Indv, Cal_Coop, Cal_Comp).

Additionally, the qualitative data were inspected for any gender differences even though there were only weak Point bi-serial correlations found in Part 1 of the study between gender and the other student variables ($r < 0.3$) for both regions. The data was also studied to reveal if there were other factors that affected the ways Singaporean students used graphing calculators for mathematics learning.

The methods used to collect data were semi-structured interviews, lesson observations, and teacher and student surveys. The interview protocol and surveys for teachers and students can be found in Appendix B. The teacher survey contained items that investigated teachers' calculator competency, their beliefs about mathematics (Separate and Connected Knowing), and their approaches to teaching mathematics. The items in the instruments for general VARK preference, calculator VARK preference, social interaction preference using calculators, and deep and surface approaches to learning were modified and couched in terms of the teachers' teaching preferences rather than teachers' own learning preferences. This is so that comparisons could be made between teachers' teaching preferences and students' learning preferences. For example, the surface approach item used for students "I learn maths formulae by heart even if I don't understand them" was modified into "I expect my students to learn maths formulae by heart even if they don't understand them". The teacher survey also contained items that aimed to find out the teachers' general VARK teaching preferences, as well as what VARK modes they used when teaching students how to use the GC. An example of a general VARK item in the teachers' survey is

I want to provide an overview of a maths chapter for students. I would

- ☐ explain it verbally to the students (Aural)
- ☐ show a list of the important points/sections of the chapter to the students (Read/Write)
- ☐ draw a mind-map of the chapter to illustrate to the students (Visual)
- ☐ give a context, story, game or problem to let students learn through the experience, simulation, or application. (Kinesthetic)

The student survey was the same as those used in Part 1 of the study. The survey was given to the students to complete on their own after their interviews, and collected at a later date.

In the following sections, the background information about the school, the profiles of the teachers, their classes and students, and the analyses of the student interview and survey data are presented. Pseudonyms are used for the names of the school, students and teachers. The survey data from the students were compared with the mean scores for those from the large sample data in Part 1 of the study to provide a profile of the students. The information from students' interviews was then analysed together with the survey data and findings presented, in relation to the key findings outlined above.

The School

The school participated in the pilot study (see Chapter 3) for the large scale survey, but was not involved in Part 1 of the study reported in the previous chapter. The college, Orchid Junior College (OJC), lies in the heartland of a housing estate, and receives its intake of students mainly from the secondary schools in the neighbourhood. OJC, like all the other 16 junior colleges in Singapore at the time of the study, is co-educational. There are about 800 students per year level (Years 11 and 12) in the school.

As detailed in Chapter 1, pre-university students take three subjects at the H2 level and one subject at the H1 level. The selected entry into pre-university institutions is based on students' Year 10 national examination results, aggregated into a point score. Students choose the institutions and streams (Science or Arts), and the Ministry of Education posts them to various institutions and streams based on the demand by students and places available in schools. Generally, in a school the Science stream has a stricter cut-off point (students have to score better) than the Arts stream. Schools with a strong tradition of excellent academic results have stricter cut-off points than the others. In OJC, the distinction between Science and Arts streams was not clearly demarcated since students can take any of the subject combinations if they meet the required pre-requisites (e.g., have taken and passed the Year 10 Biology subject in order to take H2 Biology). The pre-requisite for H2 mathematics is a pass in Year 10 Additional Mathematics, which is the higher level of the two mathematics subjects in Year 10 (Additional and Elementary Mathematics). Hence, most students who take H1 mathematics either have not taken Additional mathematics in Year 10, or did not pass it.

The school runs a lecture-tutorial system for H2 mathematics (2 lectures and 3 tutorials per week), and a classroom-based system for H1 mathematics (3 lessons per week). Lectures are conducted in special lecture theatres (ranging from 200 to 600 seats) and tutorials in the classrooms. Each lesson lasts for about 50 minutes, and students are given 10 minutes to travel to the venue (classrooms or lecture theatres) for their next class. No homeroom system was used at the time of the study, but usually a class of students is assigned to the same few classrooms for tutorials. Each classroom is equipped with a ceiling-mounted data projector and projector screen, a pair of wall-mounted speakers, a teacher's table with data and audio connection cables for a teacher's laptop and a visualiser (a machine that projects anything placed on it onto the screen), and a whiteboard. Teachers are provided with a tablet PC each for teaching purposes. The mathematics department had procured the GC emulator software called SmartView from Texas Instruments that allowed teachers to use their PCs to show the GC steps and screens. The software also enabled easy calculator screen-captures to be taken and pasted into lecture notes as part of the teaching materials.

There are no textbooks published for the Singaporean A-level curriculum; lecture notes are provided by the teachers. At OJC, both H1 and H2 mathematics students use the TI 84+ or TI 83 GCs from Texas Instruments. The lecture notes include the main mathematical concepts and formulae, worked examples, and written instructions together with screen shots of the calculator to guide students in learning how to use the GC for solving problems. They also contain partially completed worked examples for students to solve beforehand, and to follow the lecturer's discussion of the solutions during lectures. Students also buy an assessment book which is a compilation of previous A-levels mathematics examination questions, grouped by topic, paper, and year. Such assessment books are popular in the Singaporean education context, used by secondary schools and pre-universities, and commonly referred to as the "Ten Year Series" (TYS). In the tutorials and lectures observed, the questions and worked examples were mostly taken from the TYS.

The schooling environment is an intense one to prepare students for the high-stakes GCE A-level examinations at the end of Year 12. There are end-of-year examinations for Year 11; students may have to repeat the grade if they fail to meet the passing criteria for most subjects. There are also two major school-based examinations for Year 12 OJC students in July and September, to prepare them for the final national examinations in November. At the time of the data collection in August 2009, students had finished their first school-based examinations, and were being taught the last two topics of the statistics syllabus on Hypothesis Testing and Correlation and Regression. Once the full syllabus was covered, the remaining curriculum time was spent on the revision of Year 11 and 12 topics.

The Classes, Teachers, and Students

Three female teachers out of 22 in the mathematics department (8 M, 14 F) agreed to participate in the study. They each selected one class for the researcher to observe and recruit student participants for interviewing. In two out of the three classes, the Higher Level 2 (H2) mathematics subject was taught, while in the third class, students took the Higher Level 1 (H1) mathematics subject. Of the two H2 mathematics classes, one was a science class, with students taking science and mathematics subjects at the H2 level, and the other was a blended class, with students taking a combination of science and mathematics subjects, and arts and humanities subjects. The H1 mathematics class was an arts class because students in the class took arts and humanities subjects at the H2 level. The H2 mathematics classes followed a lecture-tutorial structure, while the H1 mathematics class followed a regular classroom teaching structure. The researcher observed the common H2 lectures (two lectures) and the three classes for a week (three lessons for each class), and invited students from the classes to be interviewed. Most of the student participants volunteered only after becoming more comfortable with the researcher's presence. Since the participants were interviewed after the classroom observations were conducted, limited information was collected on individual participant's behaviour during the classroom observations.

In the following sections, the H2 mathematics lectures are described, followed by a description of the profiles of each class, their teacher and students.

H2 mathematics lectures. Teachers at OJC took turns to conduct the H2 mathematics lectures and prepare the lecture notes and tutorial questions for the topic they would lecture. Students bought the notes and tutorials printed by the school bookshop, and brought them to lectures. After explaining the mathematical concepts, the lecturer guided students to solve a worked example. Students keyed in the steps on the GC at the same time the lecturer demonstrated on the projector screen using the TI

SmartView software. They were also given some time to do more examples before moving on to the next concept.

All the topics for the syllabus had already been taught at the time of the observation. One of the three participating teachers, Patricia, was observed conducting a series of lectures on revision of past topics. A set of revision questions by topic was uploaded to the school intranet for students to download, print and practise, and the purpose of the lectures was to go through the solutions to highlight difficult concepts and problem solving techniques.

Patricia emphasised the recapitulation of concepts and formulae, proper presentation of answers during the A-level examination, alternative methods, and examination preparation, e.g., “I’ve been told by Cambridge that they don’t accept…”, “there are four main points you need to know… to check if you know this topic…”, and “if you are able to zoom properly using your GC you will be able to get this graph, and then you can find its stationary point. For people who are weak in the GC zooming skills, there is an alternative way. … You can actually do a simple differentiation”. There seemed to be an expectation or recognition that some students were not competent with the calculators, hence instead of explaining the GC zoom functions and the limitations of the GC in setting the range of the x and y values to graph, Patricia chose to ask students to use an alternative method without using GC. Overall, there was a strong focus in preparing students for the senior secondary high-stakes examinations, which were about two months away. There was a sense of urgency conveyed by Patricia that the students did not have much time to prepare for the examinations. As can be seen in the above examples of what Patricia said, there was emphasis on understanding of concepts (connected knowing), and on the procedures and steps (separate knowing).

Patricia also demonstrated the GC steps to solve particular problems on the projector screen, using the SmartView software on her tablet PC. She gave time for students to take down notes. Students were observed to be taking down notes and following the steps using their GCs.

Class 1: ScienceH2maths. There were 20 students in this class, 3 girls and 17 boys. This huge gender imbalance was not reflective of all the science classes, but peculiar to this class. The subjects taken by the students were H2 Mathematics, H2 Physics, H2 Chemistry and various H1 subjects from the Humanities and Arts discipline depending on individual student choices. Students with these combinations are considered to be in the science stream.

The H2 mathematics teacher, Candice, had been on personal leave earlier the year and had only taught the class for about four months (since April). She had found the class very boisterous and easily distracted, and commented that "there are a lot of naughty boys … and very lazy". Candice said she had difficulty "pushing them" to do work. A more experienced senior teacher, Patricia, was assigned to co-teach this particular class with Candice in order to provide more support in the second semester (second half of the academic year from July onwards). In the tutorial lessons observed, Candice generally took the lead in front of the class and Patricia walked around the class to answer any questions students had, and managed any students who were engaging in off-task behaviour. Occasionally Patricia also came to the front of the class to clarify certain mathematical misconceptions which she had found among the students. The class was very vocal, and students sometimes talked to one another when Candice was explaining the solutions to tutorial questions. It was clear that Candice was struggling at times to try to get the whole class' attention. In questioning she generally invited chorus answers from students by asking a question to the whole class; occasionally she would call on students who she perceived were off-task to answer questions.

In the lessons observed, Candice consistently used the following:

- expected students to prepare and solve the tutorial questions before the lesson;
- used the tablet PC to project tutorial questions and annotate them with explanations;
- showed a student's answer to a particular tutorial question (a student may volunteer his/her answer to be shown), discussed the answer with the class, explaining the steps in the solution;
- wrote GC steps, mathematical workings and concepts on the tutorial document in the tablet PC, or on the whiteboard, as she explained;
- marked the student's answer, correcting any mistakes or adding notes; and

- returned the marked solution back to the student, went on to the next tutorial question, and asked for another student's answer.

However, as the students in the class either did not prepare, or did not get the correct answer, most of the time Candice ended up guiding the students to the solution, with more instructions and explanations than questions. Students found her teaching to be efficient and one of the students, Hajah, said in the interview that "we really look forward to it [maths lesson], as a class".

Teacher 1: Candice Ang. At the time of the study, Ms Candice Ang was a young teacher with four years of teaching experience, and rated herself as being "advanced" in GC skills. In the teacher survey (see Appendix B), five items tapped teacher's preferences for certain modes of teaching (VARK). Similar to the scoring of the VARK preferences in the student survey, the ticks corresponding to each mode were added up over the five items to give the scores for Visual, Aural, Read/Write and Kinesthetic preferences. Candice indicated that she most preferred to teach using Visual (V = 3) and Read/Write (R = 3) modes, followed by Kinesthetic (K = 2) and Aural (A = 1) modes. For her own preference when learning how to use the calculator, she indicated that she learnt best by "trying out the buttons and playing around with the GC" (Kinesthetic).

Candice had stronger Connected Knowing (CK = 4.33) than Separate Knowing (SK = 3.33) conceptions of mathematics, and indicated that she preferred to use Deep Approach (DA = 4.50) than Surface Approach (SA = 3.00) in her teaching. She also indicated that she only got her students to work with the GC individually and not cooperatively nor competitively.

In particular about teaching using the GC, Candice agreed to the statements "I enjoy using the GC to teach maths" (Cal_Enj = 4) and "I feel confident teaching maths using GC" (Cal_Conf = 4). In terms of the pedagogical activities used when teaching students how to use the GC, the activities which she indicated that she used regularly (every week or every lesson) were:

- provide a demonstration (Visual);

- refer to the screenshots shown in notes or textbooks or manual (Visual);
- explain the steps and concepts verbally (Aural);
- write out the steps on the board (Read-Write);
- ask students to make their own notes (Read-Write);
- (during demonstration) ask students to follow the steps as shown (Kinesthetic); and
- encourage students to play around with the GC (Kinesthetic).

However, not all of the espoused strategies were observed during the three lesson observations. She was not observed to encourage students to play around with the GC, to refer students to screenshots shown in learning materials, to ask students to make their own notes, or to ask students to follow the steps during a demonstration.

Candice also responded in the survey saying that her teaching practice had changed over the last three years, but did not elaborate on her response. She felt that the GC helped students "to visualise certain things" but "they don't learn the concepts when they rely too much on the GC".

ScienceH2maths Students: Hajah and Nuru. Two students from Candice's class agreed to be interviewed. Hajah was a male Indian student who usually sat with his friends and was very vocal in class. Nuru was a female Malay student who sometimes sat with another female student, and sometimes with other male classmates. A summary of their survey data is presented in Table 5.1.

Table 5.1

Summary of Survey Data for ScienceH2maths Students Hajah and Nuru, with Comparison to the Mean Scores for Scales from Part 1 of the Study

Measure	Hajah	Nuru	Part 1 (N = 964)
Mathematics competency self-rating (MSR)	3	3	2.90
GC competency self-rating (CalSR)	3	3	2.94
Most preferred VARK mode	Aural	Aural	Aural (44.4%)

Measure	Hajah	Nuru	Part 1 (N = 964)
Most preferred calculator VARK mode	(i) try out the steps the same time as I see a demonstration, hear or read the instructions	(b) see the steps my friends show me on their GC	(i) try out the steps the same time as I see a demonstration, hear or read the instructions
Connected Knowing-Deep Approach (CK-DA)	3.85	3.43	3.28
Separate Knowing-Surface Approach (SK-SA)	3.57	3.14	3.47
Most preferred to study mathematics…	Cooperatively "The problem can be solved faster and things we do not know, my friend might know and vice versa."	Individually "I am able to find out my own capability from how much I have learnt in school, and during tutorials".	Individually (52.9%)
Most preferred to work with GC…	Cooperatively. "Can learn from each other."	Cooperatively. "I learn more when my friends show me the step by step way of finding the answer using the GC."	Cooperatively (65.7%)
Calculator enjoyment (Cal_Enj)	5	3	3.36
Calculator confidence (Cal_Conf)	5	3	3.20
Calculator as Master (Cal_Ma)	4.00	2.66	3.19
Calculator as Servant (Cal_Se)	4.50	5.00	3.78
Calculator as Collaborator (Cal_Co)	4.20	3.40	3.03

It can be seen in Table 5.1 that:

- Both Hajah and Nuru scored themselves average in mathematics and GC competencies. They also had Aural as their most preferred VARK mode. However, they had different VARK preferences when it came to learning how to use the GC, with Hajah most preferring to try out the steps during a demonstration or explanation, and Nuru most preferring to see the steps on her friends' GC. This is consistent with the conclusion found in Part 1 of the study where GC VARK preferences tended to be kinesthetic or visual, compared to general VARK preferences.

- Both Hajah and Nuru scored higher in CK-DA than SK-SA, which was different from the trend in the mean scores for Part 1 of the study.

- Hajah preferred to study mathematics and work with GC cooperatively, and strongly agreed to enjoying and being confident in using GC. He almost equally agreed to using the calculator in each mode: as Master (4.00), Servant (4.50) and Collaborator (4.20). His scores relating to GC enjoyment, confidence, and use (Master, Servant, Collaborator) were higher than the mean scores found in the large scale study.

- Nuru preferred to study mathematics individually, but most preferred to work with GC cooperatively, which was consistent with the findings from the large scale study. She disagreed with using calculator as Master (2.66), and agreed slightly to using calculator as Collaborator (3.40), and her main preference was using calculator as Servant (5.00).

Class 2: BlendH2maths. There were 22 students in this class, 8 girls and 14 boys. The subjects taken by the students were H2 Mathematics, H2 Economics, H2 Geography and various H1 subjects depending on individual student choices. Economics and geography are subjects from the Humanities and Arts discipline, and mathematics is a subject from the Science and Mathematics discipline. Hence, students are considered to be taking a blend of science and arts subjects and not purely belonging to the science or arts stream.

The H2 mathematics teacher, Patricia, had taught the Year 12 class for about three months at the time of the study. She took over the class in the second semester, after completing her Masters studies. In the tutorial lessons observed, she had good rapport with the students. They were focused, on task and asked questions during lessons. Similar to Candice, Patricia consistently used the following:

- expected students to prepare and solve the tutorial questions before the lesson;
- explained the question using the tutorial sheet shown on the visualiser, showed a student's answer to a particular tutorial question (a student may volunteer his/her answer to be shown), discussed the answer with the class, questioned the class about the accuracy of the student's answer, or asked for alternative solutions;
- wrote GC steps, mathematical workings and concepts on the whiteboard as she explained;
- marked the student's answer, correcting any mistakes or adding notes; and
- returned the marked solution back to the student, went on to the next tutorial question, and asked for another student's answer.

During discussions, Patricia regularly asked the class if they had any questions and checked that they were following the discussion by asking probing and "why" questions. She toggled between annotating the tutorial questions, discussing students' answers on the visualiser, and writing specific steps or workings on the whiteboard. The main focus was on equipping students with the skills and knowledge to do well for the high-stakes examinations, for example, in relation to the GC, Patricia explained that there were two different marking schemes in the A-level examinations. When students used the GC and wrote down the final answer without any workings, marks were allocated depending on whether the final answer was correct or wrong. However, when the method and workings were written down as well, method marks were given even if the final answer was wrong due to errors in GC calculations. Conversely if the presentation was confusing or the variables were written wrongly, method marks would be deducted even if the final answer was correct. Hence, Patricia said that "if your presentation is wrong, you show that you are confused, it's better that you don't write it down". This example seems to also indicate that Patricia expressed a lack of confidence in her students' ability to present a correct method, and reinforced the surface approach of rote-learning the GC steps to obtain the final answer.

Teacher 2: Patricia Chan. At the time of the data collection in August-September 2009, Mrs Patricia Chan was a senior teacher. Her role included developing young teachers in their pedagogy and content knowledge, through mentoring and professional sharing. She had 24 years of teaching experience at pre-university level and rated herself as "average" in her GC skills, able to perform only what was required in the H1 and H2 mathematics syllabus. Patricia had completed a full-time Masters in Education course and returned to OJC in June 2009 to teach Year 12 classes. She had a strong presence among the Year 12 teachers and led them in weekly professional discussions.

In the teacher survey, out of the five items on teachers' preferences for general VARK modes of teaching, Patricia indicated that she most preferred to teach using Visual mode (V = 5), followed by Kinesthetic (K = 3), Read/Write (R = 1), and Aural (A = 0) modes. In the lectures observed which were conducted by Patricia, she used the SmartView software to demonstrate how to use the GC for problem solving, which was predominantly a Visual mode, consistent with her survey response. She also wrote and explained the solutions to problems, which were Read/Write and Aural modes. However in the three tutorials observed on the topics of correlation, regression, and hypothesis testing, Patricia mainly used verbal explanations and questioning students (Aural), together with writing notes and mathematical workings on the whiteboard (Read/Write). There were a few diagrams and graphs drawn as part of the solutions to mathematical questions on trigonometry, vectors and statistics, but the SmartView was not used. Students were sometimes given time to use their GCs to key in the statistical data given in tutorial questions and obtain the solution (Kinesthetic mode). Hence, it seemed that Patricia employed different modes depending on whether she was lecturing or tutoring, and her survey responses matched modes seen in her lectures but not tutorials. Also, although she indicated no Aural teaching preference, she sometimes described mathematical steps without writing on the board in tutorials.

For her own preference when learning how to use the calculator, Patricia indicated that she learnt best by "reading the written instructions on a manual or a book" (Read/Write) and "trying out the buttons and playing around with the GC" (Kinesthetic). These learning preferences are different from her espoused teaching modes (mainly Visual), and also was observed in her lessons (mainly Aural and Read/Write modes).

Patricia also had stronger Connected Knowing (CK = 4.33) than Separate Knowing (SK = 3.33) conceptions of mathematics, and indicated that she preferred to use a Deep Approach (DA = 4.00) than a Surface Approach (SA = 2.50) in her teaching. In the tutorials observed, Patricia focused on equipping students with knowledge and skills to do well in the national examinations. Since the teaching of the mathematical concepts was done in the lectures, Patricia emphasised the process of applying the concepts learnt to answer the tutorial questions instead: understanding and interpreting a question in terms of the mathematical concepts and equations, knowing which formula is applicable to the question, common misconceptions and mistakes, and proper presentation of the mathematical solution in order to maximise marks gained in examinations. While there was no exploration of mathematical concepts using the GC in the tutorials observed, she also did not ask students to blindly memorise mathematical formulae or the GC steps. Students interviewed said Patricia gave them links to websites for exploring graphs and practising questions on graphing techniques. Hence, generally, Patricia used a combination of deep (relating ideas, emphasising understanding, commitment to work) and surface (aim for qualification, fear of failure, focusing on the proper presentation of solutions) approaches. However, even though she had higher CK-DA than SK-SA scores, there is an indication that she might value the surface approach more than the deep approach, as seen in the previous example of her emphasis on procedures over understanding – if students were not sure of their workings (i.e. did not understand the concepts well enough to present them correctly), they should just write down the final answer (which might be calculated from blindly following the GC steps without understanding) without the workings.

With regard to teaching using the GC, Patricia agreed with the statements “I enjoy using the GC to teach maths” (Cal_Enj = 4) and “I feel confident teaching maths using GC” (Cal_Conf = 4). In terms of the pedagogical activities used when teaching students how to use the GC, she indicated that she most commonly (about once a week) wrote out the steps on the board and got students to work the GC individually. These were observed in her tutorials.

She also responded in the survey saying that her teaching practice had changed over the last three years, explaining that she "... tap[s] more on GC to allow students to get more familiar with the gadget. Also teaching becomes more effective when I use more hands-on in class – students are more engaged". "Hands-on" refers to students using the GC to practise working out a problem on-the-spot in class, compared to students solving the tutorial problems before class. She felt that the GC provided opportunities for hands-on activities to engage students, but "... some slower students may take too long time to learn to manipulate the GC, slowing down the class".

BlendH2maths Students: RuiGang, Stephanie and Michelle. Three students from Patricia's class agreed to be interviewed. RuiGang was a student who repeated Year 11; he usually worked by himself during lessons. Michelle and Stephanie sat together during tutorials; they requested to be interviewed together.

A summary of the students' survey data is presented in Table 5.2. Note that the mathematics and GC competency self-ratings are on a 5-point scale (1 = weak, 5 = excellent), and the other interval data (CK-DA, SK-SA, Cal_Ma, Cal_Se, Cal_Co) are on 5-point Likert scales (1 = strongly disagree, 5 = strongly agree).

Table 5.2

Summary of Survey Data for BlendH2maths Students RuiGang, Michelle and Stephanie, with Comparison to the Mean Scores and Mode from Part 1 of the Study

Measure	RuiGang	Michelle	Stephanie	Part 1 (N = 964)
Mathematics competency self-rating (MSR)	3	4	2	2.90
GC competency self-rating (CalSR)	3	4	3	2.94
Most preferred VARK mode	Aural	Visual	Read/Write	Aural (44.4%)
Most preferred calculator VARK mode	Left Blank	(i) try out the steps the same time as I see a demonstration, hear or read the instructions	(i) try out the steps the same time as I see a demonstration, hear or read the instructions	(i) try out the steps the same time as I see a demonstration, hear or read the instructions

Measure	RuiGang	Michelle	Stephanie	Part 1 (N = 964)
Connected Knowing- Deep Approach (CK-DA)	3.43	3.71	2.86	3.28
Separate Knowing-Surface Approach (SK-SA)	3.29	3.43	3.71	3.47
Most preferred to study mathematics…	Individually “Less distraction and stress.”	Individually “I can concentrate better and focus is there”.	“Cooperate with friends as they can teach me whatever I don’t know, and vice versa.”	Individually (52.9%)
Most preferred to work with GC…	Individually “Didn’t see a need for cooperation or competition”	Cooperatively “They might have new insights or shortcuts to get the answers.”	Individually “It is more efficient.”	Cooperatively (65.7%)
Calculator enjoyment (Cal_Enj)	3	4	4	3.36
Calculator confidence (Cal_Conf)	4	4	3	3.20
Calculator as Master (Cal_Ma)	3.00	3.00	3.33	3.19
Calculator as Servant (Cal_Se)	3.00	4.75	3.75	3.78
Calculator as Collaborator (Cal_Co)	3.20	3.20	2.80	3.03

It can be seen in Table 5.2 that:

- RuiGang scored himself average for most items. He agreed to holding both CK-DA and SK-SA conceptions of mathematics, and scored slightly higher for CK-DA (3.43) than SK-SA (3.29). He had a strong Aural preference, preferred to study mathematics and work with GC individually, and was confident in using GC.

- Michelle rated herself stronger in mathematics and GC competencies than RuiGang and Stephanie. She also agreed to holding both CK-DA and SK-SA conceptions of mathematics, and scored higher for CK-DA (3.71) than SK-SA (3.43). She had a strong Visual preference, preferred to study mathematics individually and work with GC cooperatively. Her preference was for using calculator as a Servant (4.75) rather than as Master (3) or Collaborator (3.2).

- Stephanie rated herself below average in mathematics, but average in the use of GC. Correspondingly, she disagreed slightly to holding CK-DA (2.86) conceptions about mathematics and agreed to SK-SA (3.71) conceptions. She indicated that she most preferred to cooperate with friends when studying mathematics as they could help her, but most preferred to work individually with GC. She enjoyed using the GC, and had stronger preference to using GC as Servant (3.75) rather than Master (3.33) or Collaborator (2.8). She had a Read/Write general VARK preference.

Overall, these three students had slightly different profiles. In comparison with the large scale data, RuiGang's scores were close to the average values, Michelle seemed to score higher for mathematics and GC competencies and calculator as Servant, and Stephanie had lower mathematics competency and CK-DA scores.

Class 3: ArtsH1maths. There were 16 students in this class, 11 girls and 5 boys. The subjects taken by the students were H2 Economics, H2 Geography, H2 English Literature and H1 Mathematics. Students with this combination are considered to be in the Arts stream.

The H1 Mathematics lessons ran on a classroom teaching system rather than the lecture-tutorial system, and the lecture notes followed a textbook format: a section on teaching the concepts and mathematics formulae, followed by worked examples and exercise questions. Since the statistics topics for both the H1 and H2 Mathematics curricula were the same, the set of lecture notes and tutorial/exercise questions were similar. However, there was more flexibility in how teachers teaching the H1 mathematics classes decide to use the materials, compared to the lecture system of H2 mathematics where there was only one lecturer.

Sarah had taught the class since Year 11, and she generally had good rapport with the students. The atmosphere of the lessons was relaxed and friendly. There was a group of vocal girls who asked many questions during the lessons and often talked amongst themselves. During lessons Sarah would make corny jokes or comments about mathematics in a way that made it interesting and entertaining to the students (e.g., “it’s an ugly formula so [rather than having to memorise it] it is in the formula list”). In introducing the concept of correlation and regression, she started with example 2 of the notes instead of beginning from the first page. She then used an example of students’ marks in two fictional high-stakes examinations, papers 1 and 2, to describe the correlation between the marks for the two papers. She gave the hypothetical situation that two students in the class sat for paper 1 but not paper 2, and asked students if they were able to predict the two students’ results for paper 2 given their paper 1 marks and the marks for two papers for the rest of the students in the class. She used the students’ names in the examples. Students were engaged and asked questions like “Why must we draw a straight line [for regression]?” to clarify their understanding. In this instance Sarah appeared to use a teaching approach that was consistent with connected knowing, which was to link the concept to students’ personal experiences and making hypotheses. Sarah used a combination of writing on the white board, writing on the tablet PC, and using SmartView to show how to key in the GC commands when teaching.

Students seemed to be happy after her lessons. However, the class was academically weak in mathematics, and only one or two students passed the school-based H1 examinations in July.

Teacher 3: Sarah Ng. Ms Sarah Ng was the head of the mathematics department and had 21 years of teaching experience. She rated herself as “average” in GC skills, and disclosed that she sometimes still had to refer to the catalogue menu in the GC for the proper syntax and functions. However, she did not feel she needed further professional development in using GC for mathematics education, saying that she could ask for help from others or explore the GC functions independently. She also mentioned in the interview that she only explored those functions of the GC which were within the Mathematics syllabus.

In the teacher survey, out of the five items on teachers’ preferences for general VARK modes for teaching, Sarah indicated that she most preferred to teach using the Read/Write (R = 5) mode, followed by Aural (A = 3), Visual (V = 2), and Kinesthetic (K = 2) modes. She was observed during lessons to write key points on the whiteboard and tablet PC while explaining mathematical concepts and solutions to questions. For her own preference when learning how to use the calculator, she indicated that she learnt best by “looking at the GC screen captures in notes, textbooks or manual” (Visual) and “reading the written instructions on a manual or a book” (Read/Write). It is clear that she had a strong Read/Write preference in both teaching mathematics and learning how to use the GC.

Similar to Patricia and Candice, Sarah also had stronger Connected Knowing (CK = 4.00) than Separate Knowing (SK = 3.33) conceptions of mathematics. However, different from the other two teachers, Sarah indicated that she preferred to use Surface Approach (SA = 4.00) rather than Deep Approach (DA = 3.50) in her teaching. In particular, she strongly agreed to the statement “I expect my students to learn maths formulae by heart even if they don’t understand them”. Both Patricia and Candice had strongly disagreed with this statement. Sarah’s beliefs about the role of memorisation appears to be similar to that of teachers from Mainland China and Hong Kong in the cross-cultural study by Bryan, Wang, Perry, Wong, and Cai (2007), where it did not matter whether memorisation came before or after understanding.

Also similar to the other two teachers, Sarah agreed to the statements “I enjoy using the GC to teach maths” and “I feel confident teaching maths using GC”. In terms of the pedagogical activities used when teaching students how to use the GC, she indicated that she regularly (every week or every lesson) used the following:

- provide a demonstration (Visual);
- refer to the screenshots shown in notes or textbooks or manual (Visual);
- let students discuss answers with one another (Aural);
- explain the steps and concepts verbally (Aural);
- read out the steps given in notes, textbooks or manual (Aural);
- (during a demonstration) ask students to follow the steps as shown (Kinesthetic);
- get students to work with the GC individually (Cal_Indv); and
- get students to memorise the step-by-step instructions on how to use the GC (SK-SA).

Most of the activities were observed in the lessons, however, she did not explicitly tell the students to memorise the steps as she demonstrated them on the SmartView software. Students followed the steps as she demonstrated, and some took notes.

Sarah also responded in the survey saying that her teaching practice had changed over the last three years, explaining that she made "... more reference to GC for checking [answers], e.g., calculated value of area [by hand] versus area [calculated] from GC". She felt that the GC made it "... easy to do Hypothesis Testing, correlation, find sums, and [I] can discuss more questions [in class] because [there was] no need to focus on manipulation of numbers". When asked what she disliked about using GC in mathematics classes, she responded that:

- IT SmartView [calculator emulator] is too slow to load and "hangs" during my lesson;
- the projection of GC using the visualiser is too dark and small to be seen; and
- students forget commands/syntax so [I have to] waste time reminding [them] instead of discussing Maths.

Overall, it seemed that Sarah had used GC mainly as a Servant and had scored high on Surface Approach in teaching, compared to Patricia and Candice. However, in the lessons observed, she did not explicitly tell students to memorise the GC steps or mathematical formulae. In the observed lesson on the topic of correlation, she started with an example, instructed students to follow the notes and use the GC to plot the data graph and regression line, and then related it to the mathematical concept of correlation. This can be considered as a combination of deep (starting with example and linking it to the concepts) and surface (following the formula and GC steps in the notes blindly before explaining what they meant) approaches.

ArtsH1maths Students: Sulleh, Asyraff, Amira, and Umah.

Four students from Sarah's class agreed to be interviewed. Sulleh indicated that he was of Arab descent. Asyraff and Amira were of Malay ethnicity, and Umah was an Indian student. The group of ethnic Chinese girls who were vocal in class did not agree to participate in the study, unfortunately. Although they were vocal in class, they seemed shy and were reluctant to speak to the researcher. A summary of the four participants' survey data is presented in Table 5.3.

Table 5.3

Summary of Survey Data for ArtsH1Maths Students Sulleh, Asyraff, Amira and Umah with Comparison to the Mean Scores for Scales from Part 1 of the Study

Measure	Sulleh	Asyraff	Amira	Umah	Part 1 (N=964)
Mathematics competency self-rating (MSR)	Left Blank	1	1	4	2.90
GC competency self-rating (CalSR)	3	3	1	4	2.94
Most preferred VARK mode	Aural and Read/Write	Visual	Visual, Aural and Read/Write	Visual	Aural (44.4%)
Most preferred GC VARK mode	(c) look at GC screen captures in notes, textbooks or manual.	(h) make my own notes.	(i) try out the steps the same time as I see a demonstration, hear or read the instructions.	(a) see my teacher's demonstration.	(i) try out the steps the same time as I see a demonstration, hear or read the instructions.

Measure	Sulleh	Asyraff	Amira	Umah	Part 1 (N=964)
Connected Knowing-Deep Approach (CK-DA)	2.43	3.43	1.43	4.00	3.28
Separate Knowing-Surface Approach (SK-SA)	3.71	3.57	4.00	4.29	3.47
Most preferred to study mathematics…	Cooperatively “They can help out on sums that I can’t do on my own.”	Cooperatively “They can help me if I get stuck. Easier to ask [them] also.”	Cooperatively “Friends can assist in my learning when I’m in doubt.”	Individually “Able to concentrate more.”	Individually (52.9%)
Most preferred to work with GC…	Cooperatively “If I miss a step, they can tell me what I need to do, or did wrong.”	Cooperatively “It is easier to learn than learning [it] yourself.”	Cooperatively “Friends can assist and help me when I go wrong.”	Individually “I am able to concentrate on my own.”	Cooperatively (65.7%)
Calculator enjoyment (Cal_Enj)	3	4	3	5	3.36
Calculator confidence (Cal_Conf)	3	3	3	5	3.20
Calculator as Master (Cal_Ma)	3.33	3.33	3.67	3.33	3.19
Calculator as Servant (Cal_Se)	4.75	3.75	4.75	3.5	3.78
Calculator as Collaborator (Cal_Co)	1.80	3.00	1.00	5.00	3.03

It can be seen in Table 5.3 that:

- The students have strikingly different profiles. Sulleh and Asyraff were good friends who studied together, and they rated themselves average in the use of

GC. Sulleh did not rate himself for mathematics competency, but Asyraff indicated that he was weak in mathematics. Amira and Umah usually worked on their own in class, and were opposite in their beliefs about their mathematics and GC competencies. Amira rated herself weak and Umah, good, in both competencies.

- For general VARK preferences, Sulleh and Amira most preferred multiple modes, whereas Asyraff and Umah most preferred the Visual mode. The four students had different VARK preferences for learning how to use the GC, and these preferences were visual or kinesthetic in nature - (a) and (c) were Visual, (h) and (i) were Kinesthetic.

- All four students had higher SK-SA than CK-DA scores. This was different from the other two classes. The two participating students in the ScienceH2Maths class had higher CK-DA than SK-SA scores (see Table 5.1) and the three students in the BlendH2Maths class had mixed findings (see Table 5.2). Also, the SK-SA scores for the four students were higher than the mean SK-SA score in Part 1 of the study.

- The students consistently preferred to study mathematics and work with GC cooperatively, except for Umah, who most preferred to do both individually. Those who preferred to cooperate with friends said their friends could help them, whereas Umah felt that she could concentrate and focus better working on her own.

- In terms of ways of interacting with the GC, Sulleh and Amira seemed to have similar profiles, scoring high in calculator as Servant (4.75) and low in calculator as Collaborator (Sulleh = 1.80, Amira = 1.00). Asyraff also had higher Cal_Se than Cal_Co scores, but they were closer to the mean scores for Part 1 than were the scores for the other three students. Umah, on the other hand, strongly agreed to using the GC as Collaborator (5.00).

In this section, the profiles of the teachers, classes and students were presented. In the following, the results and discussion of the relevant research questions are presented.

Research Question 1

What are Singaporean students' beliefs about and attitudes and learning preferences toward mathematics learning, graphing calculators and their use?

Overall, the nine students had a range of different beliefs about and attitudes and learning preferences toward mathematics learning, GC and their uses. The following are trends seen from their profiles:

- Students doing more H2 science subjects and H2 mathematics seemed to score higher in CK-DA and lower in SK-SA, compared to students taking H2 arts subjects and H1 mathematics.

- Students generally scored themselves average for mathematics and GC competencies, GC enjoyment and confidence. However, two of the H1 mathematics students said they were weak in mathematics (Asyraff and Amira), whereas none of the students from the other classes rated themselves academically weak.

- In Part 1 of the study, students' general VARK preferences and their VARK preferences when learning how to use advanced calculators were different, with a majority of the students most preferring to use Visual and Kinesthetic modes when learning how to use calculators. This finding is consistent with Part 2 of the study; all of the students' calculator VARK preferences were visual or kinesthetic. This suggests that students adopt different modes according to different learning situations, and that the GC lends itself to visual and kinesthetic modes.

- The reasons for preferring to study mathematics and working with GC individually (able to concentrate better) and cooperatively (friends could provide help) were similar to those found in Part 1 of the study.

- For ways of interacting with the GC, the students scored within a small range from 2.66 to 4.00 for Cal_Ma, with five out of the nine students scoring 3.33, despite being in different classes and taking different levels of mathematics (H2 and H1). It would appear that there are other factors that affect the use of the Calculator as Master for these students. This may be linked to a similar school learning environment and duration of exposure to the use of GC (1.5 years). Their Cal_Se scores ranged between 3.00 to 5.00, indicating a moderate to strong agreement for using GC as Servant, similar to the findings in Part 1 of the study (mean Cal_Se = 3.78). There was also a much larger range of responses for using GC as Collaborator, between 1.8 and 5.00. The relationships between Cal_Co, Cal_Ma and other learning preferences are discussed under research question 4(c) in the next section of this chapter.

Although there were more Malay than Chinese students in Part 2 of the study compared to the general Singaporean population, there did not seem to be any obvious trend or difference in the profiles between students of different ethnicities. Also, there was no obvious gender difference.

In the following, data gathered from the students' interviews and surveys are examined in relation to the relationships found in Part 1 of the study as part of research question 4(c). A copy of the interview protocol is included in Appendix B. Relevant responses from students will be presented within the context of the research questions discussed. During the interviews, it was clear that certain students were able to articulate their thoughts very well (e.g. Sulleh), whereas others found it difficult to voice their thoughts, even after much prompting (e.g. RuiGang).

Research Question 4 (c)

What are the relationships among students' gender, beliefs, attitudes, learning preferences, and ways of interacting with the calculators? Specifically:

(a) What are the correlations between the variables?
(b) Which variable best explains students' ways of interacting with calculators?
(c) How can these relationships be explained?

The relationships found in Part 1 of the study (research question 4 (a), see Table 4.24) were between:

(a) Calculator as Collaborator (Cal_Co) and calculator competency (CalSR) (r = 0.43), enjoyment (Cal_Enj) (r = 0.55), and confidence (Cal_Conf) (r = 0.53);
(b) Cal_Co and Connected Knowing-Deep Approach (CK-DA) (r = 0.41);
(c) Calculator as Master (Cal_Ma) and calculator competency (CalSR) (r = –0.35); and
(d) Cal_Ma and Separate Knowing-Surface Approach (SK-SA) (r = 0.36).

Other relationships examined were:

(e) students' ways of interacting with the calculators (Cal_Ma, Cal_Se, Cal_Co) and other learning preferences such as the VARK and social interaction for learning preferences (Ma_Indv, Ma_Coop, Ma_Comp, Cal_Indv, Cal_Coop, Cal_Comp); and
(f) gender differences.

Relationship between calculator as Collaborator and calculator attitudes. In Part 1 of the study there were moderate to strong positive correlations between calculator attitudes (competency, enjoyment and confidence) and using calculator as Collaborator. GC as Collaborator correlated positively with CalSR (r = 0.43), Cal_Enj (r = 0.55) and Cal_Conf (r = 0.53). In the interview for Part 2, students were asked to describe the GC using three adjectives. A summary of students' calculator attitudes (CalSR, Cal_Enj, Cal_Conf) and Cal_Co scores from their survey, as well as their views of the GC from their interview, is presented in Table 5.4.

It can be seen in Table 5.4 that Hajah and Umah strongly agreed to enjoying the use of GC and being confident in it. They also scored highly in Cal_Co and exhibited positive attitude towards the GC, to the extent that they found the GC to be part of themselves and its use became second nature. This is consistent with the theory of calculator as Collaborator being the highest level of sophistication of use where students treat the calculator as a partner and extension of self. Hajah referred to the GC as his "buddy" and "superpower" for mathematics. He said that he could only use the GC and not go back to a scientific calculator:

> nowadays when I start using graphic calculator and when I go back to that [scientific calculator], it's like, I kind of forgot, it's like it's past me already,…I'm more or less programmed to keep using the graphics calculator now, it's like I only know how to use that calculator and nothing else.

Table 5.4

Summary of Students' CalSR, Cal_Enj, Cal_Conf, Cal_Co and GC Attitudes from Survey and Interviews

Name*	Survey				Interview
	CalSR	Cal_ Enj	Cal_ Conf	Cal_ Co	GC attitude
Hajah (Science H2maths)	3	5	5	4.2	Found GC to be efficient, superpower (tool) for mathematics, versatile (can be used in other subjects such as Physics). Could not imagine doing mathematics without it.
Nuru (Science H2maths)	3	3	3	3.4	Found GC to be interesting yet confusing. Needed to practise to know the GC steps. Viewed GC as important in problem solving "I can't really do one question without referring to the GC".
RuiGang (Blend H2maths)	3	3	4	3.2	Found GC convenient to use, but not familiar with the GC keys, therefore needed practice.
Michelle (Blend H2maths)	4	4	4	3.2	Found GC to be useful, easy to use, but difficult to remember the keys and needed practice.
Stephanie (Blend H2maths)	3	4	3	2.8	Same as Michelle.
Sulleh (ArtsH1maths)	3	3	3	1.8	Viewed GC as a tool, manageable, similar to the scientific calculator (e.g., second function key).
Asyraff (ArtsH1maths)	3	4	3	3.0	Viewed using GC as just memory work, but played around with the GC to draw cars.

Name*	Survey				Interview
	CalSR	Cal_ Enj	Cal_ Conf	Cal_ Co	GC attitude
Amira (ArtsH1maths)	1	3	3	1.0	Found GC to be helpful, easy to use, user-friendly, but confusing if she could not catch up with the teacher.
Uma (ArtsH1maths)	4	5	5	5.0	Found GC to be very important and useful, accessible and get answers quickly. Not easy to learn, but believed in having a positive attitude. Automatically took out the GC for every lesson and had it with her all the time.

* Students are group by class in order: ScienceH2Maths, BlendH2Maths, and ArtsH1Maths.

Hajah further explained that the GC is like a pal, something important that he could not do without:

> Because it is like a pen-pal, I mean it's not say pen-pal, it's like a pal. Your calculator is really very very important to you, as far as I know, because it's [based on my] experience…, when you go through the two years you realised how much you've come to because of just the calculator, so… it is rather important that they [students] NEED [Hajah's emphasis] to know what's inside.

This close relationship with the GC was also disclosed by Umah:

> I mean I really need the GC always … it's just that it's like, too useful that I always have it with me. I feel very, I don't know, feel very handicapped without it when I'm doing maths. I feel very weird if I don't have my GC, even if I'm not using it I should at least have it on the table.

Uma also agreed that she was comfortable with using the GC and using the GC had become "automatic". She did not have to think about when she needed it but had it with her all of the time.

It is interesting to note that while both had high Cal_Co scores, Hajah only rated himself as average in GC competency, and Umah rated herself as good. Both of them had high GC enjoyment and confidence scores in the survey. This is consistent with the findings in Part 1 of the study where the correlations between calculator as Collaborator (Cal_Co) and calculator attitudes (calculator enjoyment and calculator confidence) were stronger than the correlations between Cal_Co and calculator competency (see Table 4.24). It appears that students who are passionate about and have positive attitudes towards the calculators also tend to interact with the calculators in a more sophisticated way. On the other hand, Amira rated herself as weak in GC competency and also had a low Cal_Co score (1.0), suggesting that a certain level of calculator competency would be necessary to be able to use the GC at a more sophisticated level. It was noted that both Umah and Hajah did not explicitly mention in the interviews that they enjoyed using the GC or were confident in using it, nor were they asked. It can be assumed that their perceptions of the GC as an indispensable partner and tool implied that they enjoyed using the GC and were confident in using it.

Relationship between calculator as Collaborator and Connected Knowing-Deep Approach. In Part 1 of the study there was a moderate positive correlation ($r = 0.41$) between CK-DA and Cal_Co, and students' CK-DA scores were found to best explain their Cal_Co scores. Based on theory, students having a Connected Knowing conception of mathematics tend to see mathematics as an interconnected and creative body of knowledge (see Table 3.4), and those having a Deep Approach to learning tend to have an intrinsic interest in mathematics, commitment to work on mathematics, seek understanding, and relate ideas to other topics/subjects (Kember, Biggs, & Leung, 2004). In Part 2 of the study, the positive association between CK-DA and Cal-Co can be clearly seen in the survey scores of the nine students (see scatter plot in Figure 5.1).

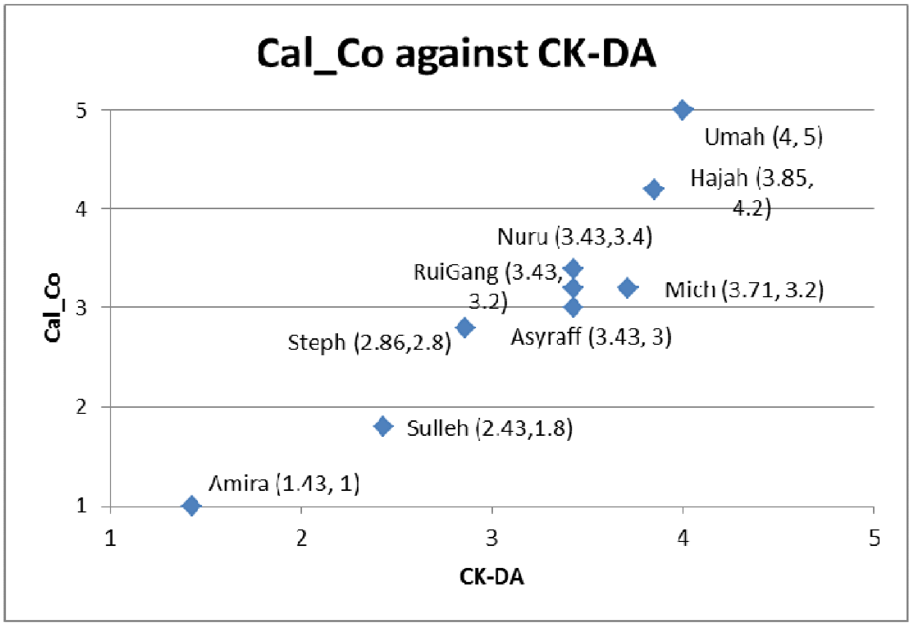

Figure 5.1. Scatter plot of Cal_Co against CK-DA

In the interviews for Part 2, to find out students' beliefs about and attitudes toward mathematics, students were asked to describe mathematics using three adjectives, and to describe how they studied mathematics. A summary of their CK-DA and Cal_Co scores and their views about mathematics and how they studied mathematics is presented in Table 5.5.

Table 5.5

Summary of Students' CK-DA, Cal_Co and Interview Descriptions

Name*	CK-DA	Cal_Co	Descriptions of mathematics and how they studied mathematics
Hajah	3.85	4.2	Did not do well in mathematics in primary and secondary, but was able to turn his attitude around and be confident in it. Found mathematics to be interesting, tough, and repetitive (revisit the topic again across year levels). (CK: interconnectedness; DA: intrinsic interest)
Nuru	3.43	3.4	Favourite subject since secondary school. Described mathematics as being able to link from one topic and equation to another (e.g. differentiation), revisiting the topics across the years, each time going more in depth. Linked to real-life. Interesting, creative (using numbers to solve something), fun. Get the "flow". (CK: interconnectedness, creative; DA: intrinsic interest)
RuiGang	3.43	3.2	Found mathematics to be interesting, applicable to real-life. Challenging but felt a sense of satisfaction if he could solve a difficult problem on his own. (CK: related to real-life; DA: intrinsic interest, commitment to work)
Michelle	3.71	3.2	Found mathematics to be complex, requiring techniques and skills. Felt accomplished if she manage to solve difficult questions. "It's the answer but it's also the process of you doing it." Need lots of practice. (CK: complexity, process; DA: commitment to work)
Stephanie	2.86	2.8	Found mathematics interesting. Being able to solve problems gave sense of satisfaction, but if she could not solve, she got "really pissed off". (DA: intrinsic interest)
Sulleh	2.43	1.8	Viewed mathematics as rigid, repetitive, "I don't have to think, I just look at the formula and apply". Only one right answer and everything else is wrong. There is only one best way of solving a question in examinations. (no CK described; SK: rigid, certainty of answers, no acceptance of alternative methods)
Asyraff	3.43	3.0	No choice but to take H1 mathematics because he did not take Additional Mathematics at Year 10. Mathematics "is like a recollection thing". He only did a couple of mathematics problems at home and read the notes. (no CK described; SK: reliance on memory; SA: minimise scope of study)
Amira	1.43	1.0	Anxious about mathematics. "I can't relate to maths because I'm an Arts student", "except for addition, subtraction, division, I don't find maths related to my daily life". She wanted to understand the mathematics

Name*	CK-DA	Cal_Co	Descriptions of mathematics and how they studied mathematics
			concepts, but felt that the teacher thought her questions were strange. However, she also felt that “maths is more of practice more than anything else.” (low CK described: cannot relate to mathematics)
Uma	4.00	5.0	Initially hated mathematics in secondary school, but realised that she needed to have the confidence to try and do mathematics. Felt that mathematics was about “practice, understanding and confidence”. She practised starting from the easy questions and then went on to harder questions. “Practicing means like, not doing more questions, but it’s like doing it in depth and you like, understand”. (DA: seek understanding; commitment to work)

* Students are group by class in order: ScienceH2Maths, BlendH2Maths, and ArtsH1Maths.

It can be seen in Table 5.5 and Figure 5.1 that there is a clear positive correlation between CK-DA conceptions of mathematics (i.e., creative, complex, inter-relatedness of ideas, intrinsic interest, commitment to work, emphasis on conceptual understanding and relating ideas) and the use of calculator as Collaborator (as a partner to help in understanding concepts, and as an extension of self in allowing oneself to explore mathematics). This trend is similar to that found in Part 1 of the study ($r = 0.41$), and is consistent with the finding in research question 4 (b) that CK-DA is the variable that best explains students’ Cal_Co scores.

It can be seen in Figure 5.1 that Amira from ArtsH1Maths class had low CK-DA and Cal_Co scores, whereas Hajah from ScienceH2Maths class and Umah from ArtsH1Maths class were high in their CK-DA and Cal_Co scores. In the following, students’ comments relating to CK-DA and Cal_Co in their interviews are examined for explanations of the positive correlation found in Part 1 of the study.

Hajah and Umah were high in both Cal_Co and CK-DA. They both had positive attitudes towards mathematics and GC. In particular, Hajah found mathematics to be interesting and tough, and related topics learnt in earlier grades in primary and secondary schools to what he was studying at Years 11 and 12. With regard to the GC, he mentioned its versatility of use across different subjects, giving an example of Physics:

> Physics basically is related to mathematics in a way, so when it comes to certain topics like kinematics and … because they require equations… when it comes to solving for unknowns, our graphics calculators … have our own applications specifically for it.

Hajah also described using the GC to plot graphs in Physics, and to calculate ionic equilibrium in Chemistry. It seems that his Connected Knowing conceptions about mathematics also include the use of GC as part of mathematics. For example he spoke of the idea of inter-relatedness within mathematics (revisiting same topics over the year levels) and between mathematics and other subjects ("Physics basically is related to mathematics in a way..."). Hajah's argument was that since mathematics is related to other subjects, the GC (as part of a tool for mathematics) is also useful in other subjects, as the above example illustrated. It might be due to his connected knowing conceptions (seeing the versatility and the usefulness of the GC) and strong positive attitudes about the calculator, that he interacted with the GC in the more sophisticated way as a personal indispensable tool, "like your next pencil box you see, your pencil box is where you keep your stationery, your calculator is the next thing that has to be on your table".

Uma mentioned having a love of mathematics and overcoming problems in learning mathematics as very important, as seen in the following interview extract.

> It's just that I heard some of my friends they say they come to Arts [stream] because they really want to avoid maths... [but] every subject [has] got [its] problems, … it's just like, a matter of how you attack it and… counter the problems…

Uma went on to describe how she "hated maths initially" at secondary school, but wanted to enrol in a pre-university course rather a polytechnic diploma course after her Year 10.

> So I did the [Year 10 or O-Level] ten-year-series again and again and again, until I got it… So it's like, for me it's just that, try to love something you're

> like, if you love something…, you really care for it, you really… work for it. That's how maths should be…, if it's really a problem.

For mathematics she said that she practised starting from the easy questions and then went on to harder questions. "Practicing means like, not doing more questions, but it's like doing it in depth and you like, understand". Her descriptions were consistent with a Deep Approach to learning mathematics, having an intrinsic interest and being committed to work on understanding mathematics.

As for learning how to use the GC, she said that she needed to go through the lecture notes step by step to figure them out, and then try the problems in the notes again without looking at the solutions:

> Usually in our notes they [the teachers] will… type out all the methods…, so I'm like, ok, just follow one by one. For me it's like, I have to follow... if you tell me [altogether in] one shot I won't get it. I have to go step by step… Then … I'd cancel everything, then I'll like, throw away my notes and I'll try to do it again.

This description was also consistent with a Deep Approach – being committed to work on using GC to solve mathematics problems.

Since most of the mathematics problems required the use of GC, Umah had found the GC to be an indispensable part of her learning of mathematics:

> It's just that it's… too useful that I always have it with me. I feel very… handicapped without it when I'm doing maths. I feel very weird if I don't have my GC, even if I'm not using it I should at least have it on the table.

Hence in Umah's case, there seemed to be a link between her emphasis on the love for mathematics, the willingness to work and understand mathematics (all of which are related to Deep Approach), and the willingness to practise and understand the use of GC; it was "...a matter of practice with GC…, you have to recognise your GC, you have to… get more used to it". Umah's deep approach to learning mathematics extended to learning to use the GC, and it might be that her passion and commitment towards mathematics and strong positive attitudes towards the GC led her to treat the GC as a Collaborator.

For Amira, with very low CK-DA score (1.43), she could not relate to mathematics:

> I can't relate to maths because I'm an Arts student… except for addition, subtraction, division, I don't find maths related to my daily life… Because I'm the type of person, when I have the passion for it… I like language, so I can relate to literature, because it's more of, you know, the human emotions, and psychology. That's why I can relate to literature much more. I also take geography [as a subject], so geography, it is around me… like nature…, so I can find relations to my other subjects.

Amira implied that she did not have any passion for mathematics. Consequently she also could not relate to the GC, and strongly disagreed with all the five GC as Collaborator items in the survey. Although she thought that the GC is a useful tool, she rated herself as weak in calculator competency and did not interact with the GC at a higher level like Hajah and Umah.

The finding in research question 4 (b) that students' CK-DA scores (i.e., held stronger Connected Knowing and Deep Approach conceptions of mathematics) best explains their Cal_Co scores (use calculator as Collaborator) illustrated the close relationships between the two. It can be assumed that students' attitudes towards GC were formed in Years 11 and 12 when they started using the GC, and that they already had pre-existing conceptions of mathematics from earlier school years (e.g., Hajah and Umah changed their attitudes towards mathematics from negative to positive). From the examples of the students with very high CK-DA (Hajah and Umah) and very low CK-DA (Amira) scores, it seems that students' connected knowing conceptions of mathematics and deep approach to learning mathematics also included their conceptions about GC as a tool for mathematics, and consequently affected how they interact with the GC. Students who hold a connected knowing and deep approach to learning mathematics also tend to hold the same conceptions towards the calculator. Their connected knowing and deep approach to using the calculator, together with their strong positive attitudes towards the calculator, lead to the use of the calculator as a partner and an extension of themselves.

Relationships between calculator as Master and calculator competency. From Part 1 of the study (Table 4.24), a moderate negative correlation between calculator as Master (Cal_Ma) and calculator competency self-rating (CalSR) was found ($r = -0.35$). This suggests that there was a tendency for students with lower calculator competency to have higher scores for calculator as Master. In Part 2 of the study this trend was not as clearly seen, as shown in the scatter plot for CalSR against Cal_Ma in Figure 5.2.

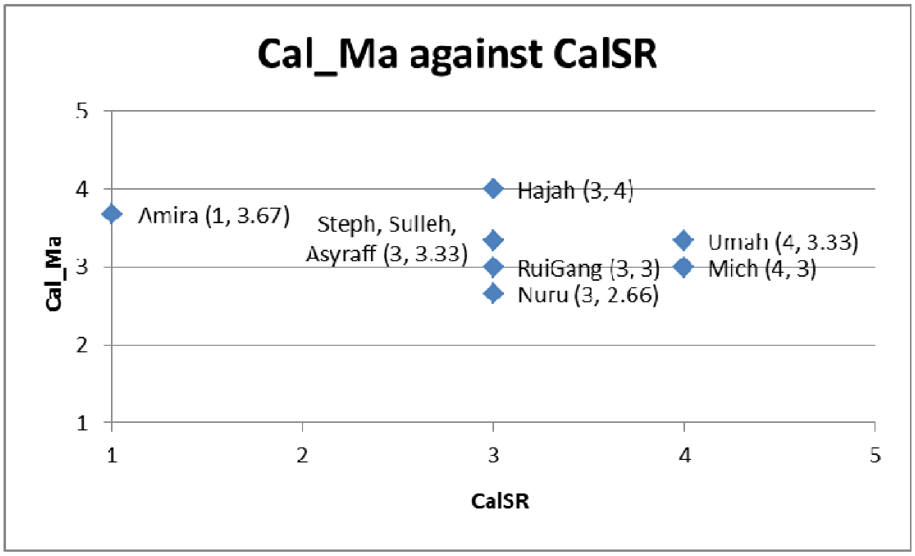

Figure 5.2. Scatter plot of CalSR against Cal_Ma

As can be seen in Figure 5.2, most of the nine students rated themselves average (CalSR = 3) in calculator competency. Only Amira rated herself weak in GC and scored above average (3.67) for Cal_Ma, consistent with the trend in Part 1 of the study. She mentioned learning how to use the GC by following the teacher and the notes step-by-step:

> There are the tutorial notes. First it gives the step by step, so it's like it's easier to follow. They say first step, this this this, and then you follow, then…they

> provide answers besides the steps also, so we know if we are on the same screen, same correct answers.

However, being weak in mathematics, Amira also said that she could not relate to mathematics. She agreed to the statements “I do not know why sometimes the GC does not give me the answer that I want”, and “I usually just follow the steps taught when using the GC to solve problems, and do not really understand the maths involved”. It seems that she found it easy to follow the steps in the notes, but lacked the mathematical understanding to be able to use the GC meaningfully to solve mathematics problems.

The scores for Cal_Ma had a narrow range of 2.66 to 4. The weak trend seen may be due to the small sample size and variability of the individual students’ responses. It should also be noted that the variable that best explains students’ Cal_Ma scores is not CalSR but students’ SK-SA (see next section).

A consideration for the narrow range of Cal_Ma scores is that students in Part 2 of the study were in the same year level (Year 12) and had spent a similar amount of time (about 1.5 years) working with the GC. For Part 1 of the study, the data were collected over a period of time with students of different year levels, and consequently the students vary in the length of time spent with advanced calculators. In the literature reviewed in Chapter 2, the length of time spent was found to influence students’ mathematical outcomes (e.g., Hong, Thomas, & Kiernan, 2000) and calculator confidence (e.g., Barkatsas, 2012).

Relationship between calculator as Master and Separate Knowing-Surface Approach. In Part 1 of the study Cal_Ma correlated positively with SK-SA (r = 0.362). Based on theory, students having a Separate Knowing conception of mathematics tend to see mathematics as a set of rigid rules and focus on mathematical procedures, and those having a Surface Approach to learning tend to use rote memorisation (memorisation of facts and procedures without understanding) and minimise the scope of learning in order to cope with course requirements (see Table 2.3). The positive correlation found in Part 1 of the study between Cal_Ma and SK-SA suggests that students adopting a separate knowing and surface approach to learning tend to employ rote learning and memorisation strategies, and have a tendency to be subservient to technology, blindly memorising the GC steps without real understanding.

In the interviews for Part 2, there were some indications of this. However, there were other complexities brought up through the interviews, in particular, students' beliefs about the role of practice and memorisation in learning how to use the GC.

The scatter plot of Cal_Ma against SK-SA is shown in Figure 5.3, confirming a weak to moderate positive correlation between the two variables, consistent with that found in Part 1 of the study (*r* = 0.362).

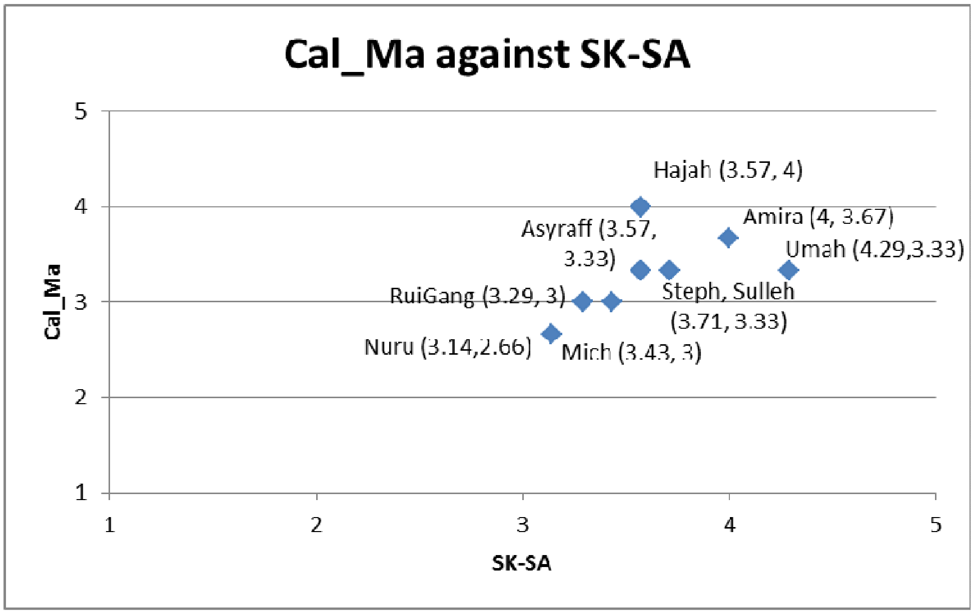

Figure 5.3. Scatter plot of Cal_Ma against SK-SA

A clear example of how students' conception of Separate Knowing – Surface Approach to learning mathematics also extended to their attitude and strategy towards learning to use the GC can be seen in Sulleh's case. Sulleh had a high score for SK-SA (3.71), compared to the mean SK-SA score found in Part 1 of the study (3.47). His interview responses indicated that he had a strong separate knowing conception about mathematics, viewing mathematics as "rigid" and "repetitive", "I don't have to think, I just look at the formula and apply", "[there is] only one right answer and everything else is wrong" (see Table 5.3). He also adopted a surface approach towards learning mathematics, evident in his aim to minimise the scope of learning:

> Of course there are other ways [of solving a problem], but the teacher will only teach you the one she thinks is the best. And you also only want to learn what you need to know for the exams. And… because maths is the way it is, there is a chance that if there is one formula that can fit to every question, then you only have to learn one formula.

His approach towards learning to use the GC was consistent with his SK-SA:

> I won't check [the notes] like new stuff [not yet taught], it's going to be something like you already did in class. So you already pressed the same buttons in your graphic calculator, then you can see how you ALREADY [Sulleh's emphasis] applied it in the past, and you can try to reapply.

Sulleh had agreed to using calculator as Master (3.33). He had agreed (score = 4) to the statement "I usually just follow the steps taught when using GC to solve problems, and do not really understand the maths involved", but was neutral (score = 3) to the other two statements "I do not know why sometimes the GC does not give me the answer that I want", and "I find GC confusing because it uses different conventions and symbols than normal maths". It seemed that based on his learning approach, Sulleh had found using the GC to be "manageable":

> At first I don't know how to find where anything, I didn't know my way round, because it's a new calculator. But after a while I think it's ok, it's manageable. As in like, if you look at the notes, then especially combine with the notes they [teachers] put [the] step by step [guide of] what buttons you [should] press, so then after that you get familiar with the different functions, then so it won't be much of a problem.

Perhaps in restricting what he learnt and by following the lecture notes, he was able to use the GC to solve mathematics problems without feeling confused. Nevertheless, it can be seen that Sulleh's interaction with the GC is consistent with his views about mathematics and how mathematics should be learnt.

Another example is Asyraff, with above average scores for SK-SA (3.57) and Cal_Ma (3.33), who said that he did not understand how to use the GC and had to memorise the steps:

> we follow that [teacher demonstration], we try to memorise, cannot understand the GC, so must memorise… everything is like [in] short form, like VARS, variables or what, I don't know. So we just remember where is Y1, where is everything.

He also had problems with understanding the mathematics and seemed to employ a surface approach:

> [The pure mathematics portion of the curriculum is] insane. It's like everything was confusing, it's very hard to catch up. [I find it] very easy to lose motivation to study for maths. That's why my results were quite sucky [bad]. … Maths I think, it's like a recollection thing. Like every day [I] go home, then do one or two problems, and that's my study [laughs]. And [I just] read the notes.

It can be seen in Asyraff's case that due to the lack of understanding in mathematics, he memorised the calculator steps without any understanding. This is consistent with the Master, Servant, Partner and Extension of self (MSPE) theory by Goos, Galbraith, Renshaw, and Geiger (2000) that technology as Master is

> a relationship induced by technological or mathematical dependence….If mathematical understanding is absent, the student is reduced to blind consumption of whatever output is generated, irrespective of its accuracy or worth (Geiger, 2005, p. 371).

The importance of practice when learning how to use the GC. Most students initially found the use of GC difficult. A number of students (Nuru, RuiGang, Michelle, Stephanie, and Umah) emphasised the need to practise how to use the GC in order to be familiar with the function keys. These students scored between 2.66 and 3.33 for Cal_Ma, which meant that they either disagreed or agreed slightly to the use of GC as Master. Overall, this suggests that the students were not entirely subservient to the calculator, having practised using the GC.

From the literature, the role of practice can be related to rote-memorisation or to understanding (Biggs, 1993). Watkins and Biggs (2001) described cultural differences in the perception of the relationship between memorising and understanding for Western and Chinese students. The researchers distinguished between rote learning – memorising without thought or understanding – and repetitive learning – "learning in order to enhance future recall alongside understanding" (p. 6). Referring to studies conducted in Mainland China and Hong Kong, Watkins and Biggs (2001) concluded that "many of the teachers and better students do not see memorising and understanding as separate but rather as interlocking processes, and that high quality learning outcomes usually require both processes, as complementary to each other" (p. 6). From students' interviews in this study, it can be seen that most of the Singaporean students had a similar view of repetitive practice and memorisation. For example, RuiGang found the GC to be convenient to use, but said that "we're still not as familiar with the keys, so we'll take some time to find maybe where the keys are". He mentioned that he seldom used the GC in Year 11, but "practice makes perfect". He said he learnt how to use the GC from lectures and then practised doing the tutorials:

> I will learn, then when I go home to do the tutorials… I practise. Because we have to use it [the GC]. Then as we practise more and more, then we get accustomed to it [the GC].… When the teacher gives us homework to do, I will make it a point to do it… [Doing the tutorials] is actually quite useful. Because the moment you do the tutorials, it sort of reinforce everything [we learnt], so it's like during [the preparation for] exams I will just try, redo the tutorials or do [past year questions from the] ten year series.

There were variations in students' beliefs about the relationship between practice and understanding. For example in their joint interview, both Michelle and Stephanie described having difficulties in memorising the GC steps:

> Stephanie: [the GC is] pretty useful, it's easy, but you need to memorise… all the steps, like the keys, where are the keys, where to find what [this], where to find what [that].

When asked how they memorised the steps, they replied:

> Michelle: you just keep doing it.
> Stephanie: if you keep doing it right, somehow or other the general steps get into your head, so you know where to find the key, the basic stuff…
> Michelle: you just keep practising. Then, because like for example… [the topic of] hypothesis testing… what [types of statistical tests] do you need, like, for

> your p-value, you need to use Z test,… there is just the basic few keys…, then you key in your values, so there is a certain structure to it.

It is interesting to note that Stephanie articulated what seemed like a rote learning approach towards memorising the GC steps (“somehow or other the general steps get into your head”), whilst Michelle associated the mathematical concepts with the structure of the GC syntax/commands. This is consistent with their SK-SA and Cal_Ma scores. Stephanie had higher SK-SA (3.71) and Cal_Ma (3.33) scores than Michelle (SK-SA = 3.43, Cal_Ma = 3.00).

Another example is Nuru, who had the lowest Cal_Ma (2.66) and SK-SA (3.14) scores amongst the group of students. She thought that the GC was interesting, but sometimes confusing, “because one button can mean a second function to another thing, so it... there’s a lot more to it”. She also felt that practice was important: “when we do more practice right, so we get more used to the functions of the graphics calculator, then it gets easier to use”. Despite initial difficulties learning to use the GC, she had “gotten the hang of it” after practising and learning the steps from her friends to solve a problem so that she could solve a similar problem on her own. Nuru, like Michelle, had practised with understanding rather than by rote. This is reflected both in her low SK-SA score, and by her view of learning mathematics:

> I think maths is not really about memorising. When you practise right, you tend to be more…, it is like when you do the questions… it will be more natural, as in when you do more, so you know that this equation is for this equation, this formula is for this equation… You will just get the hang of it.

When asked if she ever blindly followed the demonstration by teacher or friend on how to use the GC, she replied “no”, and that the GC steps “as in when which one to press first and everything” was “quite easy to understand”.

In summary, there is an association between Separate Knowing-Surface Approach and Calculator as Master, seen in both Part 1 and Part 2 of the study. In Part 1 of the study SK-SA was found to be the variable that best explained Cal_Ma. It can be seen in Part 2 of the study that students holding Separate Knowing conceptions about mathematics as a rigid and absolute (right or wrong) set of rules and procedures, and who simultaneously adopted a Surface Approach of memorising without understanding and minimising the scope of learning, tended to also adopt the same conceptions and approach to learning how to use the GC. Hence, they tended to memorise the calculator steps blindly without understanding, and to be confused about the notations and the way the calculator works (i.e., interact with the GC as Master).

From the student interviews in Part 2 of the study, most of the students described having to practise the use of the GC to familiarise themselves with the steps and function keys. Analysis suggests that some students may have gained a certain level of mastery of the GC by practising mathematics questions, until they "just get the hang of it" (e.g., Nuru, RuiGang, and Stephanie), see the structure (Michelle) or memorised the steps (Asyraff and Sulleh). Most of the students in Part 2 of the study only agreed slightly to using calculator as Master; it seemed that students used a surface approach to memorise the GC steps, yet felt that they were able to master the GC to some extent through practice. The level of mastery could be a combination of memorisation and understanding. Further studies are needed to examine the links between SK-SA and Cal_Ma, in particular, the relationship between the way students memorise the functions of the GC – the extent of rote-memorisation versus memorisation with understanding – and how they solve mathematics problems using the GC.

Relationships between VARK and ways of interacting with the GC. In part 1 of the study there were very weak or no associations between VARK preferences and students' ways of using the calculator (see Chapter 4). This was also seen in the survey replies of the nine students in Part 2 of the study. Students' VARK preferences and their most preferred method of learning how to use the GC (calculator VARK preferences) are shown in Table 5.7.

It can also be seen in Table 5.7 that almost all of the VARK methods that students most preferred when learning how to use the GC were either Kinesthetic or Visual. The only exception was Asyraff, who had a strong Visual general preference but most preferred to make his own notes (Read/Write) when learning how to use the GC to solve mathematics problems. About half of the students (four out of nine) most preferred to try out the steps on the GC at the same time they see a demonstration, listen to an explanation or read the instructions (method (i)), than other methods. This was a common method employed during teaching which students found useful, as described by Stephanie and Michelle in the interview extract below:

> Stephanie: because we are asked to bring our GC at every lecture, so the moment that the lecturer goes through [how to use the GC]… we are supposed to do hands-on [follow the steps as the lecturer explained].
> Michelle: actually… it's… step-by-step.
> Stephanie: ya… we're supposed to follow [the teacher]
> Michelle: Mrs Chan will go through, "ok, you press here". Then "L1" "L2", then "Stats" [keys on the GC]. So … ya, it gets registered in the mind.
> Stephanie: ya.

Table 5.6

Students' General VARK Preferences and Their Most Preferred Method of Learning How to Use the GC

Name*	General VARK	Cal_Ma	Cal_Se	Cal_Co	Most preferred method to learn to use the GC
Hajah	V	4.0	4.5	4.2	(i) try out the steps on the GC at the same time I see a demonstration or hear an explanation or read the instructions. (Kinesthetic)
Nuru	A	2.7	5.0	3.4	(b) see the steps my friends show me on their GC. (Visual)
RuiGang	A	3.0	3.0	3.2	Left blank
Michelle	V	3.3	4.8	3.2	(i) try out the steps on the GC at the same time I see a demonstration or hear an explanation or read the instructions. (Kinesthetic)
Stephanie	R	3.3	3.8	2.8	(i) try out the steps on the GC at the same time I see a demonstration or hear an explanation or read the instructions. (Kinesthetic)
Sulleh	AR**	3.3	4.8	1.8	(c) look at the GC screen captures in notes, textbooks or manual. (Visual)
Asyraff	V	3.3	3.8	3.0	(h) make my own notes. (Read/Write)
Amira	VAR*	3.7	4.8	1.0	(i) try out the steps on the GC at the same time I see a demonstration or hear an explanation or read the

Name*	General VARK	Cal_Ma	Cal_Se	Cal_Co	Most preferred method to learn to use the GC
					instructions. (Kinesthetic)
Uma	V	3.3	3.5	5.0	(a) see my teacher’s demonstration in class. (Visual)

* Students are group by class in order: ScienceH2Maths, BlendH2Maths, and ArtsH1Maths.

** Multiple highest scores from the VARK instrument

Students’ calculator VARK preferences were different from their general VARK preferences. Nuru had an Aural general preference but preferred to see visually the steps shown by her friends on the GC. Sulleh was strong in Aural and Read/Write general preferences, but most preferred to look at the GC screen captures from notes (Visual). This supports the finding in Part 1 of the study that a higher proportion of students preferred Kinesthetic or Visual methods for learning how to use the calculator, rather than Aural or Read/Write methods. In her interview, Nuru also mentioned that she sometimes used MSN (Microsoft Network, referring to the online instant messaging system) and its writing function to ask her friends questions about mathematics. However, when she had problems with the GC functions, she preferred to clear her doubts in school rather than call or chat with her friends “because [for] this use of GC we need physical presence right, for them to teach me”. These findings are consistent with the findings in Part 1 of the study that students vary their VARK preferences according to the learning context, and that the GC lends itself more to Visual and Kinesthetic methods of learning and use than other modes. Overall, there was no discernible pattern in students’ calculator VARK preferences and their scores for the ways of interacting with calculators (Cal_Ma, Cal_Se, and Cal_Co).

Relationships between social interaction for learning preferences and ways of interacting with the GC. In Part 1 of the study, a high percentage of Singaporean students was found to most prefer working with GC cooperatively (65.7%) than individually (32.3%) or competitively (2.1%). Reflecting this trend, six out of the nine students in Part 2 of the study most preferred to work with GC cooperatively, and the remaining three students most preferred to work with GC individually. Their reasons were also among those categorised in Part 1 of the study (see Table 4.12) such as improved learning outcomes for Nuru, Michelle, Stephanie, Sulleh, Asyraff, and Umah (e.g., Nuru: “I learn more when my friends show me the step by step way of finding the answer using the GC.”); peer interaction to support learning for Hajah and Amira (e.g., Amira: “Friends can assist and help me when I go wrong.”).

Weak correlations between students’ social interaction for learning preferences for using GC and their ways of using GC were found in Part 1 of the study (see Appendix D6, Table D18). In Part 2 of the study, there also did not appear to be any relationship between students’ social interaction for learning preferences and their views about the GC. Generally students’ social interaction for learning preferences when studying maths and when working with GC were the same, since most of the topics needed the use of the GC. However, where there were differences, the context of the situation plays important part in students’ decisions to cooperate with their friends or work individually. For example, in Hajah’s case, there seemed to be a difference between how he learnt to use the GC and how he worked with the GC in solving tutorial problems and revising for examinations. At the interview Hajah mentioned that he learnt to use the GC by trying it out himself:

> How I did was that I just kept on trying certain [functions], try the new functions myself to see what is possible what is not possible. And I came to more or less soon realise that, that I know that what this graphics calculator CAN do, and what it CAN’T do [Hajah’s emphasis]. So that’s how I did. I didn’t really learn it from other people, I didn’t really learn it from the manual, I just kept on trying [the GC functions] myself. I didn’t really have many [*sic*] help [from others] trying to do it as well.

However, in the survey, he said he most preferred to work with the GC cooperatively because they “can learn from each other”. This response was more consistent with his interview comments when he said he preferred to study mathematics with his friend:

> We find it rather effective because we can speed up things, by doing alone you are actually just to yourself, certain things you might not know you wouldn’t know how to do it. But when you are with your friends, certain things that he might not know you might know, certain things you might not know he might know, so... I find studying together is more efficient than studying alone.

Michelle and Stephanie distinguished between doing tutorial questions (everyday work) and revising for examinations. They said they worked on the tutorial on their own, but planned revision together. This can be seen in the following interview extract:

> Stephanie: I mean because tutorial is practically everyday kind of thing, so we don't really purposely stay back and study.
>
> Michelle: study together.
>
> Stephanie: We will just go home and do our own tutorial and stuff…But if it's like revision… then…we do this topic over the weekend. Then… on Monday then we'll discuss about it.
>
> Michelle: Ya, as in this one [question], I don't know how to do and then I'll ask her.
>
> Stephanie: Then if we don't know something together, then we'll find the teacher [to clarify our doubts].

Interestingly, Michelle wrote in her survey that she most preferred to study mathematics individually because she could concentrate better, but most preferred to compete with friends when working with the GC because "they might have new insights or short cuts to get the answers". Stephanie had different preferences. She most preferred to cooperate with friends when studying mathematics because "they can teach me whatever I don't know, and vice versa", and most preferred to work with GC individually because "it's more efficient". It is possible that the two girls used a common study strategy for revision that suited their different learning preferences – they worked on problems individually before meeting to check their answers and cooperate to solve more difficult problems that they could not solve on their own. Unfortunately they were not asked to explain further their social interaction for learning preferences in relation to their study strategy, since they completed the surveys after the interview.

In Nuru's survey, she responded explaining that she most preferred to study mathematics individually because "I am able to find out my own capability from how much I have learnt in school, and during tutorials". However, in the interview, she revealed that her decision depended on her perception of the difficulty of the topic and her need for peer support:

> Actually it depends on what topic. So if it's the more difficult topic, the one, the topics I don't really get during lectures or something, I have to have my friends around, so that they can… peer studying… But if not, if it's subjects I just need more practice in, I'll just need a quiet place, then study on my own.

Nuru had found the GC confusing, and most preferred to cooperate with friends when working with the GC because "I learn more when my friends show me the step by step way of finding the answer, using the GC".

The environment and technology available also made a difference to Nuru's social strategy when studying. If she was at home and needed to ask her friends, she called her friends, used the MSN (Microsoft network instant messaging service) chat and wrote her questions on the computer using the mouse. However, for GC, she preferred to ask friends face to face rather than call them or chat via MSN so that she could see the GC screens and buttons. Besides studying at home on her own and seeking help when needed, Nuru also said she sometimes studied at school with a group of friends.

These examples show that using GC is a complex process that is part of mathematics learning. The issue of learning preferences for social interaction for studying mathematics and when working with GC is complicated and seemed to vary with different learning contexts, like learning how to use GC, using the GC to solve tutorial problems, using the GC to practise questions for revision of topics. Students had their own set of strategies and combinations of preferences for the various contexts. For example, Amira said she relied on the notes for learning the GC commands, on the teacher for discussing what the common errors were, and on friends for explaining concepts and steps to her with reference to lecture notes. This rich and complex variety of responses could partially explain why there were weak or no correlations found between social interaction for learning preferences and the ways students interact with the GCs. The general survey questions were not able to capture the variety of responses to different learning situations.

Nevertheless, there were a significantly higher proportion of students most preferring to work with GC cooperatively, compared to the proportion of students most preferring to study mathematics cooperatively, as found in Part 1 of the study. The question in the survey in Part 1 asked students for their most preferred social interaction for learning preference, which forced students to consider their preferences from a general view rather than considering various learning contexts. Therefore an implication of the findings might be for teachers to provide more opportunities for students to collaborate when working with the GC in general. At the same time, teachers should also consider the student-calculator interactions situated in different learning contexts (e.g., daily work or revision) and students' individual social learning preferences, when structuring different learning activities.

Gender differences and students' use of GC. In Part 1 of the study, there were significant gender differences in the students' beliefs, attitudes and ways of interacting with the calculators, in favour of males (see Table 4.20). Despite having more variables with gender differences, the effect sizes were smaller in the Singaporean than Victorian samples. Overall, the effect sizes were small. There were also weak or non-significant associations found between gender and the other student variables (see Table 4.24).

Social interaction for learning preferences. In Part 2 of the study, there were four boys and five girls. Inspection of these students' survey data by gender did not reveal any discerning pattern in their beliefs, attitudes, and learning preferences with regard to gender (Appendix E1), with the exception of the social interaction preference for studying mathematics. More females than males (F = 3, M = 1) most preferred to study mathematics individually, whilst more males than females (F = 2, M = 3) most preferred to cooperate with friends when studying mathematics. That more females than males most preferred to study mathematics individually is consistent with the finding from Part 1 of the study where a significantly higher percentage of females than males most preferred to study mathematics individually (S'pore: F = 54.5%, M = 50.1%; Vic: F = 59.8%, M = 24.0%). However, the finding that a higher proportion of males than females most preferred to study mathematics cooperatively, seen in the small scale study, is similar to the pattern in the Victorian sample (F = 33.3%, M = 44.0%) rather than the Singaporean sample (F = 41.2%, M = 39.4%) found in Part 1 of the study. There was no obvious reason for this; the sample size in Part 2 of the study was too small to establish any definitive conclusion. It was also noted that none of the students in Part 2 of the study most preferred to compete with friends.

The reasons given by the nine students for their most preferred social interaction preferences were similar to those found in the large scale study. Reasons for preferring to cooperate with friends when studying mathematics were that friends could help them. For example, Sulleh and Asyraff studied together and they both mentioned that friends can help when they get stuck. Asyraff further said that “because his [Sulleh’s] weakness is what I’m better at, and my weakness is what he is better at. He is better at pure maths, I’m better at statistics, so… that [we] complement [each other]”. Hajah, who also preferred to cooperate with friends, gave a similar reason that friends can help when he got stuck on a mathematics problem and vice versa. The two females who most preferred to study mathematics cooperatively, Amira and Stephanie, had similar reasons. For the remaining three girls who most preferred to study mathematics individually, Nuru gave the reason that “I am able to find out my own capability; from how much I have learnt in school, and during tutorials.” Michelle’s and Umah’s reasons were that they could concentrate better if they studied individually. RuiGang, the only male who most preferred to study mathematics individually, also said that there were fewer distractions compared to cooperating with friends and less stress compared to competing with friends. It is interesting that in their joint interview, Michelle and Stephanie said they worked on the tutorial problems on their own, but revised past topics to prepare for examinations together. Even though they had a similar study strategy, their social interaction preferences were different. Of the two, Michelle was more confident of her mathematics ability, rating herself as good in both mathematics and with the GC. Stephanie was less confident, rating herself as below average in mathematics and average with the GC. It could be that Stephanie felt that she was weak in mathematics, and needed help from friends, thus most preferring to cooperate with friends when studying mathematics. On the other hand, Michelle was more confident of her mathematics ability and most preferred to work individually in order to concentrate better and not be distracted by friends.

Students with high CK-DA and Calculator as Collaborator scores. The students displayed different personalities, learning preferences, and beliefs about themselves as learners, about mathematics and about the GCs.

Hajah and Umah stood out as students who were passionate about mathematics and enthusiastic about the use of GCs. They both described changing their attitudes from negative to positive towards mathematics in their secondary schools, and viewed mathematics as difficult but interesting. Both of them had very high connected knowing-deep approach (CK-DA) and calculator as Collaborator (Cal_Co) scores. They also had high separate knowing-surface approach (SK-SA) scores. Consistent with their high scores in both CK-DA and SK-SA, they described both surface and deep approaches to learning in their interviews. Hajah mentioned that he sometimes copied the lecture notes blindly when he was tired (surface approach), and at other times he tried the examples before the lecturer went through them (deep approach). Umah mentioned the need to go step-by-step and to do lots of practice (separate knowing), and at the same time she emphasised the understanding of the concepts (connected knowing). For the two of them, there seemed to be no difference in their responses that could be attributed to gender.

Students with high SK-SA and Calculator as Master scores. Another pair of students who stood out was Asyraff and Amira. They both rated themselves as weak in mathematics and had relatively high SK-SA scores. Both of them did not have any interest in mathematics as a subject. Asyraff said that he had no choice but to choose to take H1 mathematics because he did not satisfy the requirements for other subject combinations, and Amira said that she could not relate to mathematics because she was an Arts student.

For these two students, there seemed to be a difference in their attitudes towards studying mathematics and towards GCs that was consistent with the gender literature. Although Asyraff rated himself as weak in mathematics and found it easy to lose motivation, he treated mathematics as “a recollection thing”. He described the way he studied mathematics as reading the lecture notes and doing a couple of mathematics problems at home. For Amira, she believed that as an Arts student she was not good at mathematics (learned helplessness, see Dweck, Davidson, Nelson, & Enna, 1978). She said that she had a weak foundation in mathematics, and since mathematics knowledge was cumulative, she did not have any interest to study the current topics as she did not know the previous topics. She also perceived that the teacher, Sarah, was negative towards her ("That's why Ms Ng feels like strangling me.") and did not cater to her need to understand the concepts behind certain formulae ("like what Ms Ng always said, I ask strange questions"). This is consistent with the gender literature that boys regard mathematics as "a system of rule following and rote learning" (Boaler, 2002, p. 140) and are more confident than girls even when there are no differences in actual achievement (Pajares, 2005). Boaler (2002) noted that girls preferred to find meaning and understanding, and where they were unable to do so, they "would often become anxious and fall behind" (p. 140).

The difference in attitudes also extended towards calculators. Using the same rote learning strategy as for learning mathematics, Asyraff memorised GC steps in order to solve mathematics problems. However, he did not see himself as weak in using the GC and rated himself as average in GC competency. He also was using GC non-academically to draw cars on the GC screen for fun and agreed that he enjoyed using the GC. In comparison, Amira rated herself weak in GC competency, and had higher calculator as Master (Amira = 3.67; Asyraff = 3.33) and calculator as Servant (Amira = 4.75; Asyraff = 3.75) scores than Asyraff. Amira also had much lower score for calculator as Collaborator (Amira = 1.00; Asyraff = 3.00) than Asyraff. Her Cal_Co score of 1.00 was the lowest amongst the nine students. In her interview Amira said that she found the GC to be useful and user-friendly and followed the lecture notes step-by-step on how to use the GC. When asked if she liked to use the GC, her answer was tentative – "for now, yes".

The attitudes towards GC by Asyraff and Amira were consistent with some of the gender literature on the use of technology, that is, that the females in this study expressed less confidence about technology use than the males (Forgasz, 2004a; Forgasz, 2004b; Pierce, Stacey, & Barkatsas, 2007; Vale & Leder, 2004), and that the females' attitudes towards technology were more closely associated with their attitudes towards mathematics, whilst the males' attitudes towards using technology for mathematics were more closely associated with their attitudes towards technology (Pierce, Stacey, & Barkatsas, 2007).

Perceived gender differences. Although there was no specific question on gender differences in the interview protocol, the flow of the interview discussions for two students, Nuru and Umah, led to the researcher asking the students if they perceived any gender differences. Both Nuru and Umah said that boys were more confident and better at using the GC.

Nuru’s class had only three girls and 14 boys. Nuru herself found the calculator to be indispensable (“I can’t really do one question without referring to the GC”), but did not explore or play around with the GC to learn it. She referred to her notes to recall the GC commands before tests and examinations. Regarding her class, Nuru thought that there were no gender differences with respect to mathematics learning and how the teacher treated students, but there was a difference in the use of GC:

> I think they [boys and girls] are quite the same in the same level when it comes to maths in general. But the use of GC ah [there is a difference]…

Nuru thought that “the guys are more confident in using GC”:

> I think in general the guys seem to be faster in learning how to use it. They seem to be, for example…, when we want to find answer, they will be just clicking away while we have to actually find something [the keys]… And they don’t really have to actually [see]… the apps right? We actually have to see the apps [on the GC] and press [the correct GC keys]…, but then it’s like, they [are] kind of a natural, [they] don’t have to look ... [to] find the answer.

She then mimed how she thought the girls and boys used the GC – the girls had to refer to the lecture notes and then look for and press the GC keys, whereas the boys could use it like a mobile phone and press the keys with both thumbs without looking.

Uma also described her use of the GC as “automatic” and felt handicapped without it. Regarding her class, Umah thought that “guys, they learn it quickly” and gave an example of a boy who was good with using the GC. However she also realised that her views seemed stereotypical.

> I personally feel [that there is a difference]. Because I have seen some of the guys, especially one boy… Even if he doesn’t know [how to use the GC] … [he

> will] quickly click, just press, and he will just… get it… For us [girls] it's like, if we take… 5 mins, he will take… 2 mins or something. … Maybe… there is a difference… Girls are like, not really, I don't know … it's like very cliché or something… [They] don't really appreciate [the GC] or something. Girls… [do] not really… go for the tools...

There seems to be a perception that boys are better at using the GC than girls, which is consistent with the survey findings in Part 1 of the study (see Chapter 4, research question 3), as well as some of the literature on gender and mathematics learning about attitudes towards technology use (see Chapter 2). Interestingly, there was no perceived gender difference in mathematics learning raised by Nuru in the interview. Although the boys in her class (ScienceH2maths) were more vocal, Nuru did not feel overwhelmed or left out, and instead, if she had any questions, she said "I just ask my friends, how to do [the problem], then they also don't know [the answer] so they ask the teacher, so whenever the teacher is explaining it's actually my enquiries".

In the teacher interviews, both Patricia and Candice said they did not perceive any gender difference in students using the GCs, but Sarah said that for the ArtsH1class (with Umah, Sulleh, Asyraff and Amira), "the boys seemed more secure in it; the girls tend to forget the commands". She noticed that when a couple of the boys were absent from class "for a long time", they were able to "pick it up very fast" when she told them what to do. However, some of the girls, Sarah said, "will forget the (GC) commands very fast". Sarah also noted that there were gender differences when students work collaboratively:

> If you are taking about group work the girls like to ask each other what the question means. The boys will compete to try to finish the questions as soon as possible. After they have done it they will compare with each other whether their answers are the same.

This is consistent with the literature on gender that females tend to seek understanding while males tend to compete (e.g., Boaler, 2002). Sarah's description may be related to the reason why more boys than girls (in Part 2 of the study and in the Part 1 Victorian data) said they preferred to cooperate with friends when studying mathematics – from the boys' perspective it might not be viewed as serious competition, but rather as cooperating and checking answers with friends after completing the questions quickly.

In summary, there were some trends seen in Part 2 of the study that might be attributable to gender. Females tended to seek understanding (whether preferring to study individually or in groups) while males tended to prefer to compare answers with their friends and work cooperatively. The trend for females is consistent with the literature on gender and learning, but not the trend for males. For students with high calculator as Collaborator and Connected Knowing-Deep Approach scores (Uma and Hajah) there did not seem to be any differences attributable to gender. However, for students with high calculator as Master and Separate Knowing-Surface Approach scores (Amira and Asyraff), there was a difference which was consistent with the literature on gender and learning. Asyraff enjoyed using the GC more than Amira, and had higher calculator as Collaborator scores, even as he relied on rote learning for GC procedures. Amira seemed less confident and more tentative about liking the GC. Additionally, there were common perceptions that males were more competent than females in learning how to use the GC (from interviews with Sarah, Nuru and Umah). This trend might be more obvious among mathematically weaker students than among better students. An implication could be that for academically weaker students, girls might be more disadvantaged than boys in that they needed to overcome an additional hurdle of poorer attitude and confidence towards calculator use.

Other factors relating to students' use of GC: the teacher. The teacher has a great influence on students' learning, being the person who designed the pedagogical learning activities and providing the learning environment and support for students as they used calculators in their mathematical learning. Although this study focuses on student factors, the impact of the teacher on students' understanding of mathematics and use of GC could be seen in Part 2 of the study.

Students in the two classes ScienceH2Maths and BlendH2Maths had experienced changes in mathematics tutors since Year 11, and appreciated Candice's and Patricia's teaching. For the BlendH2Maths class, Stephanie and Michelle said their previous substitute teacher could not teach and explain the graphing techniques, such as sketching the inverse graph of a function ($y = f^{-1}(x)$), or sketching the reciprocal of a function ($y = \frac{1}{f(x)}$). They appreciated Patricia explaining the concepts and giving them links to online websites to practise graphing. In the interview, Stephanie said:

> So then, only until recently then Mrs [Patricia] Chan was telling us, said actually… [There are] a lot of online websites which we can go and practise, and they [have] got answers also. But previously they [the substitute teacher]… even in lectures they didn't even [explain]… [and said] "Ok, this, copy", then we draw the graph, then we draw the inverse [function], then [said] "ok, go home and do your tutorial" …, so we totally… don't know how to do it.

Additionally, Stephanie said she preferred what her mathematics teacher in her secondary school did, which was to let students use graphing software where they could key in the equations and see the graphs drawn to explore various graphs and their relationships.

The use of a hands-on, step-by-step approach to teaching calculator use was effective and was mentioned by a number of students. For example, Nuru preferred to follow the calculator steps at the same time she saw the demonstration:

> As in lecture they will also [be] showing like that, like this screen there… I thought that one [demonstration] is better, actually. As compared to reading notes, I don't really like to read notes and then… they also wrote the thing down [in the notes]… the steps. But I prefer [to see] the demonstration… so while she's clicking the things [keystrokes shown on the screen] I will sort of press mine [GC].

In the above examples, the teachers' explanations, pedagogical support and guidance in technology use were important in helping students like Nuru, Stephanie and Michelle understand the mathematical concepts and the use of the GC to solve related mathematics problems.

The teacher's teaching preferences appeared to affect students' preferences, for example, teacher privileging (see Chapter 2). In this study, the teacher Sarah believed that students should memorise the steps even if they do not understand the concepts, and her teaching reflected her beliefs. Sarah was observed to tell the students the objective of the lesson (e.g., to predict missing *y* values based on *x* values given a set of data), teach the GC steps by telling students to follow the instructions in the notes, and then followed with a discussion of the mathematics behind the GC steps. She expected her students to follow the GC steps first without understanding ("please follow the steps first, later I will explain why"). Sulleh, who had a very strong Separate Knowing conception of mathematics (viewed mathematics as rigid and absolute, see table 5.5), noted that it might be better to understand the concepts first before memorising:

> She [Sarah] did explain [the concepts] in class, like because she taught us to memorise the formula first, so after we understood the formula already, then she explained it, then I think… maybe if she had explained it at the start it would have been better.

This suggests that Sulleh might have preferred a different teaching approach focusing on understanding rather than rote memorisation of the formula, which is different from what his high SK-SA (3.71) and low CK-DA (2.43) scores indicated. However, from Sarah's interview, she was aware of Sulleh's strong Separate Knowing and Surface Approach to studying:

> [When] we talk about meaning, he gets very confused, because he has just memorised it [the concept] with no context and no meaning. So when you put in context and meaning, it upsets his balance… he likes to memorise, "if I see this I'll do that". He has a lot of recipes... maybe that's why he can't do well, because his recipes don't work all the time, [it] depends on the question.

Sarah thought that if she described all the context and explanations, it might confuse Sulleh and interfered with his way of thinking. She added that she told Sulleh to do the mathematics his own way. It could be that Sarah's way of teaching mathematics catered to and reinforced Sulleh's surface approach to learning.

On the other hand, Umah, who was also in Sarah's ArtsH1Maths class, found Sarah's way of teaching effective:

> I think we've got a very good teacher, Ms [Sarah] Ng… She explains everything. Even though it's not important… she explains the formula and everything. When you… understand the formula, like how it works, she makes it

> sound like stories or something or [create] all kinds of stories and everything… so you remember…
>
> [When learning how to use GC, for] some of the topics it's like, I can just see [the notes] and… I understand and then move on to [do the tutorial] questions. But sometimes it's really good if she explains [the concepts behind the GC steps]…, because the notes don't really… explain why should we use this [GC] function... she really explains to us what's the use of this, and what can we… do, what can we not do with this function.

It seemed that Umah, who scored high in both SK-SA (4.29) and CK-DA (4.0), could follow and appreciate Sarah's teaching approach of focusing on the GC steps before explaining the related mathematical concepts.

With regard to learning to use the GC, Amira commented that Sarah's approach of projecting the calculator emulator on the screen and guiding students through the step-by-step procedure was useful.

> I think I still prefer someone to teach [how to use the GC] like Ms [Sarah] Ng. Because she use the laptop… tablet pc, that have the GC application installed inside, so we can see step by step, it's like she shows what we have to do and we do it on the spot, so I think we learn better that way. We see every step on the screen... we can relate because we are on par with her, … and then in between she'll talk about common mistakes and then my classmates will ask questions. So we know what's wrong here and there, so we feel that we're on par with Ms Ng, we're not digressing or anything like that.

However, with regard to mathematics, Amira found it hard to relate and understand mathematics. She also felt that Sarah did not cater to her needs:

> Because I need reasons why the formula is like that, but then certain times, she said like 'you want to know why the formula is like that you go to the uni [university], and then you'll understand. You study for a few years then you understand the concept.' So for me… I need to find some sort of relationship, you know, and understanding why the formula is like that, why is it like that. 'cause [because] then I can understand better, then maybe I don't have to

> memorise, ‘cause [because] I [would] know it. I know how it gets there, I know how the formula is designed or formulated.

Amira seemed to want to understand (i.e., Connected knowing and deep approach), but it was not met by the teacher. Due to Amira’s perception that Sarah’s teaching approach focused on the application of formulae rather than understanding of the concepts behind the formulae, Amira was unable to relate to the mathematics. This may have led her to adopt a memorising and rote learning approach to learning, seen in her high SK-SA score (4.0) and very low CK-DA score (1.0). From Sarah’s point of view, she felt that Amira was “hiding” behind her fear of mathematics and using that as an excuse not to put in any effort into studying mathematics. Sarah said that on the first day they met Amira had told her

> She cannot do maths and she has never been able to do maths. I told her she has to try, but she said “no no no I’ll never be able to do maths”… She wants to be in the class but she doesn’t want to do anything. And she hides behind this excuse that she can’t do and she can’t learn.

Sarah also said that earlier in the year, she had sat with Amira for two hours to practise solving questions on probability until she could do at least some of the problems. However, Sarah was disappointed that Amira did not put in any further effort after the session to try to improve her mathematics. She was also aware of Amira’s concern for understanding, but felt that it was another excuse without real effort.

> When you try to teach her, she asks you “why the formula is like that?” but for example for variance [of a set of data]… I’ve actually told the class before, can’t remember whether she was absent [or not]. So she asked again. So when I offered to explain to her, her friend scolded her: “you don’t understand [it] anyway so why are you asking?” … because the class does know her. They know that she’s quite the complainer.

It would seem that Amira had very low self-efficacy beliefs towards mathematics, and Sarah was unable to influence her beliefs positively.

Generally, Sarah’s students appreciated the step-by-step process of teaching how to use the GC, but found it hard to link GC procedures with mathematical understandings. There was a tendency to use a rote learning approach to memorise the

GC steps. It can be seen in Table 5.5 that amongst the nine students, those in Sarah's ArtsH1Maths class had the highest SK-SA scores (Asyraff = 3.57; Sulleh = 3.71; Amira = 4.0; and Umah = 4.29), and high Cal_Ma scores (Asyraff = 3.33; Sulleh = 3.33; Amira = 3.67; Umah = 3.33). In her interview, Sarah said that she gave her students a summary of the topics for revision, and changed her summary to emphasise the GC steps because that was based on students' feedback that there were not enough detailed GC commands. She also said that her H1 mathematics students told her to "just teach according to the syllabus" and not to tell them stories:

> So I said "don't you want to know the context?" [and they said] "No need, show us the question and how to do it"

She realised that these students were not interested in mathematics and just wanted to meet the minimum requirements for university entrance. It appears that Sarah's teaching approach may be reacting to students' separate knowing-surface approach, and at the same time was reinforcing the separate knowing-surface approach rather than promoting the connected knowing-deep approach to learning.

In summary, the teacher plays an important role in helping students understand the mathematics and guide students on how to use the GC. Concomitantly, the teachers' actions and decisions depend on what they perceive students need. When learning to use the GC, many students said they most preferred to try out the GC steps at the same time they see a demonstration or listen to explanations. This strategy was observed to be employed by Mrs Patricia Chan during the H2 mathematics lectures and by Ms Sarah Ng in the H1 classroom teaching. In the observed tutorials Patricia and Candice explained the GC steps in relation to the mathematics concepts and skills required to solve the tutorial questions. However, Sarah was observed to focus on the calculator procedures first before explaining the mathematics. The interview responses of students from Sarah's class suggested that her students tended to employ a surface approach to learning mathematics and to learning the use of the GC. In Part 1 of the study it was found that students' conceptions of mathematics and approaches to learning mathematics (SK-SA and CK-DA) best explained their ways of interacting with calculators (Cal_Ma and Cal_Co). Teachers' own beliefs about learning mathematics and their perceptions of students' learning approaches can affect the way they teach and, in turn, affect students' learning preferences and the way they learn mathematics and

GC procedures, as suggested by students’ reactions to Sarah’s teaching. Further studies are needed to examine the longitudinal and reciprocal effects of teachers’ beliefs about mathematics and approaches to learning mathematics on students’ ways of understanding and learning mathematics and their use of the calculators.

Conclusion

In this chapter, the results and analysis of Part 2 of the study were presented. Nine students from three classes and their mathematics teachers were interviewed. Analysis of their interviews and survey responses revealed that:

- Students who had high calculator as Collaborator scores tended to enjoy and be confident in using the GC, and described the calculator as being indispensable.

- Students with high Connected Knowing and Deep Approach scores had characteristics (e.g., inter-relatedness of ideas, intrinsic interest, commitment to work) that also enabled them to use calculators at the highest level of sophistication, i.e. the GC as Collaborator (as partners and as an extension of self).

- The relationship between calculator as Master (Cal_Ma) and calculator competency was not clearly evident among the nine students, since the range of values for Cal_Ma was small (2.66 to 4.00). The small range could be due to other factors such as a similar learning environment (from one school) and duration of exposure to the GC (Year 12 students).

- Students with high Separate Knowing and Surface Approach scores exhibited similar characteristics (e.g., saw mathematics as a rigid set of rules and procedures, used rote memorisation, and minimised the scope of their study) that also appeared to be related to them being subservient to the use of calculators, i.e. using GC as Master. Also, a number of students mentioned having practised using the GC in order to be familiar with it. The practice may be carried out through rote learning or with understanding.

- Students seemed to vary their VARK and social interaction for learning preferences with context. This may partially explain why there were weak or no correlations between these preferences and the ways students interact with the GC. The different learning contexts mentioned by students were: learning how to use the GC when learning a new topic, using the GC for working on tutorial problems and 'everyday' study, and revising past topics with GC use for examinations. Generally students worked on questions individually, asked their friends for help if they had problems, and asked the teacher for help if they and their friends had difficulties.

- There seems to be a gender difference relating to use of calculators, in favour of boys. Students weak in mathematics (Amira and Asyraff) had high separate knowing-surface approach and also used rote learning strategies to study mathematics and to learn how to use the calculators. However, the male student, Asyraff, seem to be more proficient and confident than Amira (female) in calculator use.

- The teachers' preferences (e.g., SK-SA oriented), beliefs about students' learning approaches, and the way they teach, appear to affect students' understanding of mathematics and their learning of the GC. Teachers used Visual and Kinesthetic modes such as providing a demonstration and getting students to follow the GC steps during demonstration, which students found effective. The relationship between students' preferences and teacher's approaches appeared to be reciprocal, in that the teacher (Sarah) also changed her practice based on students' feedback (e.g., put in more detailed GC steps in chapter summaries) and tried to cater to student differences (e.g., let Sulleh have his own way of thinking based on rules without understanding). How students use the GC (e.g., blindly following the steps) both influenced and was influenced by the teaching approach (e.g., emphasising the GC steps before linking to the mathematical concepts).

In summary, the links found in Part 1 of the study between students' conceptions of mathematics and approaches to learning mathematics (SK-SA and CK-DA) and their ways of interacting with the calculators (in particular Cal_Ma and Cal_Co) were confirmed in Part 2 of the study. Students' beliefs about and attitudes toward the calculators seemed to be an extension of their beliefs about and attitudes toward mathematics. Students who saw mathematics as a connected, creative body of knowledge (CK) and were interested and committed to work on mathematics (DA) tended to view the advanced calculators as interesting, useful, versatile and as a partner for their learning. They were more willing to work on understanding how the calculator works, and to relate the GC steps to the mathematical concepts and structure. Students who saw mathematics as a rigid, disconnected body of knowledge (SK) and used rote learning approach to minimise their scope of study (SA) tended to be either technologically or mathematically dependent on the calculator. They applied rote learning approach to using the GC and followed the calculator steps blindly without understanding.

The finding in Part 2 of the study also supports the explanation in Part 1 of the study that Singaporean and Victorian students have higher SK-SA than CK-DA scores due to examination pressures (see Tables 4.8 and 4.14). In Part 2 of the study, students' SK-SA scores were higher (ranging from 3.14 to 4.29, see Figure 5.3), compared to CK-DA scores (ranging from 1.43 to 4, see Figure 5.1). In the lessons observed, there was an emphasis on examination preparation, step-by-step procedures, as well as understanding of mathematics concepts. Academically weaker students who had difficulties understanding the concepts tended to use Surface Approach (rote memorisation) in order to meet the minimum requirements. The advanced calculator was viewed by the Singaporean students as a complex tool, which needed much practice to memorise the keystroke sequences. Students described how they learnt to use the GC with a combination of memorisation and understanding through repetitive practice. This view of learning is similar to that of students from Mainland China and Hong Kong (Watkins & Biggs, 2001). Since there are no significant differences in the SK-SA and CK-DA scores between Singaporean and Victorian students found in Part 1 of the study, it might be surmised that the Victorian students have similar focus on memorisation, practice and understanding. This will have to be confirmed through further small scale study of Victorian students.

Overall, the findings from Part 2 of the study enriches the data from Part 1 by providing qualitative perspectives of students' SK-SA and CK-DA approaches, and the explanations for the relationships between SK-SA and calculator as Master, and between CK-DA and calculator as Collaborator. In addition, the findings in Part 2 of the study also provided further support to the validity and reliability of the instrument measuring calculator as Master, Servant and Collaborator, in the Singaporean context. The instrument for calculator as Master, Servant and Collaborator was originally adapted using data from Australian students (Geiger, 2005). In Part 2 of the study, students' interview descriptions of how they viewed and used the GCs were consistent with their calculator as Master, Servant and Collaborator scores. In particular, the use of calculator as Collaborator was clearly seen in students who said that the calculator was indispensable and its use was automatic.

As there was no prior research found on VARK modality preferences and students' advanced calculator use, data from Part 2 of the study help to explain the findings in Part 1of the study. In both learning contexts – lecture (H2 mathematics) or classroom teaching (H1 mathematics) – students described learning how to use the GC through a hands-on approach of following the GC steps as the teacher demonstrated its use. This is consistent with the finding in Part 1 of the study where in both Singaporean (mainly lecture-tutorial format) and Victorian (mainly classroom teaching) samples, the highest percentage of students indicated that they most preferred to follow the calculator steps as they watched a demonstration, read the notes, or listen to the explanations. Students in Part 2 of the study also believed that they needed a lot of practice of the GC steps to become proficient in it, and needed to follow the procedures step-by-step. This highlighted the importance of the kinesthetic modality in learning how to use the advanced calculators. This calculator VARK preference was found to be independent of students' general VARK preferences in Part 1 of the study. In Part 1 of the study Singaporean and Victorian most preferred the hands-on Kinesthetic method of learning how to use the calculator even though they had different general VARK preferences (Singaporean students tended to have Visual and Aural preferences, whereas Victorian students tended to have Read-Write preference, see Figure 4.9).

With regard to social interaction for learning preferences, findings from Part 2 of the study also revealed the complexities of how students study mathematics socially. Generally in both Parts 1 and 2 of the study, students said that they most preferred to study individually because they could concentrate better with no distractions, and others said they most preferred to study cooperatively with friends because friends could help them when they were stuck. However in Part 2 of the study, it can be seen that students' study strategies changed depending on different contexts, such as doing their tutorial questions (day-to-day work), revising for examinations, their views of their friends (having a 'nerd' friend, or someone whom they can study with), and the difficulty of the topics studied (easy or hard). These complexities may be why there were weak or no correlation found between students' social preferences and their ways of interacting with the calculators in Part 1 of the study.

Another point relating to the social interaction for learning preferences is that most students interviewed in Part 2 of the study said that it was difficult to learn how to use the GC at the start. Knowing where the calculator keys are and how to use them appropriately to solve mathematics problems required both technical and mathematical competencies. Although students viewed practice as the way to improve their GC skills, a number of them mentioned asking their friends or the teacher for help when they got stuck. Hence, the difficulty in learning a new tool may be one of the reasons why a higher percentage of Singaporean and Victorian students in Part 1 of the study tended to prefer to cooperate with friends rather than working individually with the calculator (see Figure 4.11). Also in Part 1 of the study, a higher percentage of Singaporean students than Victorian students (S'pore = 65.7%, Vic = 52.5%) most preferred to cooperate with friends when working with calculators, consistent with the finding that Singaporean students were less competent in advanced calculator than their Victorian counterparts.

Gender differences were found in Part 1 of the study in both SK-SA, CK-DA, calculator confidence and ways of interacting with calculators (see Table 4.20), and the data in Part 2 of the study supported the findings of gender differences for calculator confidence and ways of interacting with calculators. There was a perception that there was no difference between males and females with regard to mathematics, but males tended to be more confident and competent in using calculators. In looking at pairs of male-female students, the gender difference regarding attitude towards the GC was more prominent in the pair that was weak in mathematics (Amira and Asyraff) and used Separate Knowing-Surface Approach to learn mathematics and the GC. Consistent with the gender literature, the male student was more confident with the GC and played around with it to draw cars, whereas the female student exhibited a more tentative attitude. The female student also mentioned that she would like to understand mathematics concepts and to relate the mathematics to contexts, consistent with gender literature (e.g. Boaler, 2002); whereas the male student seemed satisfied with using rote learning strategy. Hence, it seemed that the gender differences in mathematics might be exacerbated with GC use, particularly for students weak in mathematics.

The above section highlighted the ways in which the data in Part 2 of the study enrich the findings in Part 1 of the study, through providing a qualitative perspective of the students' attitudes, beliefs, and learning preferences. These perspectives supported the validity and reliability of the instruments used, explained the relationships (correlations) found, and provided details for the gender differences found in Part 1 of the study. In the next section, the conclusions and implications of the entire study, together with its limitations, are presented.

Chapter 6 Conclusions and Implications

"I find it [GC] the most effective, fastest and most accurate device that can be used to solve for even the toughest mathematical problems." (interview by Hajah)

"You will get it once you start practising." (survey by Umah on what she liked about using GC)

"[Using GC] would be quite confusing, as it would involve multitasking in class, e.g. listening to the teacher, understanding, copy down the answer etc." (survey by Nuru on what she disliked about using GC)

Introduction

The above quotes from students illustrate that students have their own conceptions about advanced calculators as a tool and how they should go about learning and using these calculators. These conceptions are related to their perceptions about the calculator (e.g. as a personal device, or a part of themselves), mathematics as a subject and how they prefer to study mathematics (e.g., as a subject that needed practice, or needed solving by hand to understand the concepts), as well as students' own learning preferences (e.g., multitasking, working with others or by themselves). In this study, the relationships between a number of student factors (beliefs about, attitude and learning preferences toward mathematics and calculators) and students' ways of using calculators were investigated. The study is situated in two learning contexts where advanced calculators were used in the senior secondary high-stakes examinations – Singapore and Victoria, Australia.

Research questions that were investigated

1) What are Singaporean and Victorian students':
    (a) beliefs about and attitudes toward mathematics learning and advanced calculators;
    (b) learning preferences; and
    (c) ways of interacting with the advanced calculators?

2) Are there differences in the above for students in the two regions, Singapore and Victoria?

3) Are there gender differences within each region?

4) What are the relationships among students' gender, beliefs, attitudes, learning preferences, and ways of interacting with the calculators? Specifically:
    (a) What are the correlations between all the variables?
    (b) Which variable best explains students' ways of interacting with calculators?
    (c) How can these relationships be explained?

5) Are there other factors that affect the ways students interact with the graphing and CAS calculators for mathematics learning?

In this final chapter, a brief overview of the bricolage of theories used in the study followed by discussions of the methodology and findings are presented. Then the conclusions and implications for practice and policy as well as the implications for further research are discussed.

A Bricolage of Theories

Following a pragmatic paradigm, a bricolage of theories from different fields was used to answer the research questions. Studies on students' advanced calculator use in mathematics were reviewed first to search for possible student factors influencing calculator use (see Chapter 2). Generally there were ambivalent outcomes of calculator use; in some studies advanced calculators were found to improve students' mathematical understanding in different areas such as algebra, calculus and functions, but no significant differences were found in other studies (see e.g., Burrill et al., 2002 for a discussion). There was evidence that calculators were underutilised in examinations (Boers & Jones, 1994) and that there was a significant number of students who lacked continuous personal access to calculators (Goos & Bennison, 2008). Differences were also found in students' performance in conceptual versus procedural tasks (Ellington, 2006) and their representational preferences (Keller & Hirsch, 1998) using calculators. Representational preferences were found to be influenced by the learning contexts and students' own understanding of the relationships between the algebraic and graphical representations (Keller & Hirsch, 1998). The length of time and the amount of experience with the tool seemed to impact students' learning outcomes (Hong, Thomas, & Kiernan, 2000), along with the type of assessment tasks used, teacher instruction, and students' perceptions and attitudes (Burrill et al., 2002). As handheld technologies increased in complexity, the technological demands imposed on students also increased. Technological demands included the know-how to deal with the input of information, the technical procedures, and the interpretation of the output from these advanced calculators (Forster, 2006), all of which required associating calculator skills and knowledge with mathematical understanding. This suggested that there is an intimate and dialectic relationship between the mathematical and technical demands of calculator use. Additionally, researchers have found that calculators could be used in mediating student-teacher-peer communications (Goos et al., 2000, 2003), or be viewed as a personal device which inhibited collaboration (Doerr & Zangor, 2000).

Based on the review of the literature on calculator use, students' conceptions about and attitudes towards mathematics and calculators were identified as factors to be investigated. From theories about learning mathematics and learning styles, students' conceptions about mathematics can be thought of as belonging to two categories, (1) abstract, rigid, composed of rules, formulae and procedures, and (2) connected, dynamic, applicable to the real world, and creative (e.g., separate and connected knowing in mathematics by Becker, 1995). The two views might lead students to approach the subject in different ways, the former, learning through a surface strategy such as rote memorisation, and the latter, learning through deep understanding (Biggs, 1993; Crawford et al., 1994). There were indications that these conceptions influenced students' preferences to use algebraic or numeric representations when solving problems (Merriweather & Tharp, 1999).

Although there was a body of literature in which students' use of the Big Three representations (algebraic, numeric and graphic) (Kaput, 1998) when using advanced calculators was examined (e.g. Forster, Mueller, Haimes, & Malone, 2003), there was scant literature found on students' modality preferences (Visual, Aural, Read/Write, Kinesthetic) in the calculator context. Treacy (1996) found that an auditory preference and positive feelings and beliefs towards computers and graphing calculators influenced the mathematics achievement of Year 8-12 students.

Studies of learning styles and technology use in mathematics learning were also few and yielded fragmented results due to the variety of learning style instruments used. Styles that involved stable personality types, such as the Myer-Briggs Type Indicator or brain hemisphericity, did not seem to influence students' learning outcomes with advanced calculators (Alfonso & Long, 2005; Ali & Kor, 2007). From the literature reviewed, styles belonging to the categories of information processing and instructional preferences (Curry, 1983), such as students' approaches to learning (SAL, Biggs, 1993) and their Visual Aural Read/Write Kinesthetic modality preferences (VARK, Fleming, 2006), seemed to offer more potential for investigation. For example, the SAL framework, used mainly in the higher education sector, was found to be associated with students' conceptions of mathematics and their achievement (Crawford et al., 1994, 1995, 1998).

As there were mixed findings on how students prefer to interact and collaborate when using calculators, the literature on students' learning styles relating to social interaction preferences was reviewed as well. There were several learning style models regarding social interaction, including Owens and Barnes' (1992) cooperative, competitive and individualised preferences, Grasha and Riechmann's (1974) six student types, and the Dunn and Dunn (1978) model of learning styles preferences. However, there were critiques about the reliability of the instruments developed for the latter two models. The first model was developed more recently and has been less popular. Eventually a shortened adaptation of the Owens and Barnes (1992) model was used in this study.

For literature on how student use calculators, various frameworks for students' use of technology in mathematics education were perused (see Table 2.2). The models that have been developed were based on the functionalities of the tool (e.g., Lee & Hollerbrands, 2006), students' perspectives (e.g., Goos et al., 2000), pedagogical perspectives (e.g., Kutzler, 2003), and on the role of calculators in specific mathematics topics (e.g., Brown, 2005). The four metaphor framework developed by Goos et al. (2003) categorised the roles of technology as Master, Servant, Partner, and Extension of

Self. It was viewed to be flexible enough to be applied to general mathematics learning as well as to specific learning contexts. Geiger (2005) provided further sub-categories for the four metaphors with representative statements from students, based on his qualitative longitudinal study. These representative statements were developed into items in the instrument used in this study (Tan, 2009).

Gender differences in technology use for mathematics learning, generally in favour of males, have been reported (e.g., Forgasz, 2008). Males were generally found to have greater confidence and enjoyment in using technology and higher levels of participation and engagement in mathematics that included the use of technologies (e.g., Forgasz & Tan, 2010), but there were exceptions where females benefitted more from the use of calculators (e.g., Ruthven, 1990). Gender differences were also found in the ways students used calculators with, for example, high achieving females being more likely to use algebraic approaches and less likely to use graphs, whereas high achieving males were more likely to use a mix of graphic and algebraic methods; low achieving females were more likely to rely heavily on GC, compared to others (Dunham, 1990).

Overall, student factors that were found to influence or have the potential to influence how students learn and use the advanced calculators were: gender, students' attitude toward and conceptions of mathematics and the calculators, their approaches to studying mathematics, and their preferences among the VARK modalities, and social interaction. These were investigated in this study; details are described in the following sections.

Methodology

The study used a pragmatic paradigm, embracing the use of a multitude of epistemologies, methods, and theories in order to answer the research questions. The study was conducted in two parts: a quantitative large scale online survey of Singaporean and Victorian senior secondary mathematics students, and a qualitative small scale study of nine Singaporean students and three teachers.

Before Part 1 of the study commenced, a pilot study was conducted to develop and refine the survey instruments measuring various student factors and how students use advanced calculators. From factor analyses of the pilot study (see Appendix A), it was found that the items for student's ways of knowing (Separate and Connected Knowing) and approaches to learning (Surface and Deep Approaches) were loaded onto two factors, labelled as Separate Knowing-Surface Approach and Connected Knowing-Deep Approach. Additionally, the items for students' ways of interacting with technology were loaded onto three factors instead of four, with the items for technology as Partner and Extension of Self combined as one factor, called technology as Collaborator.

In the large scale study (Part 1 of the study), the refined survey instruments were used. The data were analysed using descriptive and inferential statistics, comparing between Singaporean (N = 964) and Victorian (N = 176) students as well as between males and females. Correlational and multiple regression analyses were also conducted to find the relationships between the student factors and how students used the calculators (as Master, Servant or Collaborator).

In the small scale study (Part 2 of the study), nine Year 12 students from three classes in a Singaporean school were interviewed and surveyed using the same survey instruments used in the large scale study. Additionally, their classes were observed and their teachers were interviewed. The interview data were coded and analysed to further investigate the relationships between the student factors and how students used calculators identified in Part 1 of the study.

Methodological challenges. There were two challenges encountered in the design of this study: first, the issue of ensuring that the theories formed a connected network which would inform the study, rather than just a random set of piecewise models; second, the need to integrate the findings from the qualitative and quantitative components of the study.

For the first challenge, the theories used were selected from a variety of fields, but were identified either directly from empirical studies as having an influence on students' calculator use (e.g., students' attitude towards and beliefs about mathematics and calculators), or indirectly as having the potential to influence the ways students use calculators (e.g., VARK modality preference and social interaction for learning preferences). The bricolage of theories formed a network - much like a fishnet - to cover various areas, incorporating beliefs, attitudes, gender, conceptions about mathematics, ways of interacting with technology, learning modality preferences, and social interaction for learning preferences. Next, the study was conducted in two parts. For the large scale quantitative study (Part 1), the aim was to investigate and distil the student factors which influenced how students used the calculators, as well as finding the relationships between these student factors and how students interact with the calculators.

The study was conducted in two regions, Singapore and Victoria, to gain further insights and investigate the generalisability of findings. The small scale qualitative study (Part 2), conducted in Singapore, aimed to better understand and further explore the relationships that were found in the quantitative study. In other words the quantitative analysis provided the objective knowledge from the researcher's perspective, whereas the qualitative knowledge provided interpretations from a subjective perspective (Harrits, 2011). The two perspectives enrich the resultant interpretations. The research process was also true to the pragmatic approach, in the use of *abductive* reasoning "that moves back and forth between induction and deduction" (Morgan, 2007, p. 71) to connect theory and data, employing *intersubjectivity* to work between objective and subjective frames of reference, and inferring *transferability* of findings from the data through investigating the conditions under which the knowledge gained could be transferred to other contexts (Morgan, 2007).

The issue of integration of the quantitative and qualitative methods has been a concern for researchers pursuing a pragmatic paradigm. Bryman (2007) conducted interviews with 20 social scientists regarding barriers to integrating qualitative and quantitative research, and found that the main concern "was the bringing together (of) the analysis and interpretation of the quantitative and qualitative data and writing a narrative that linked the analyses and interpretations …" (p. 10), rather than at the level of research design, and/or of the development of research instruments. In their analysis of the degree of integration between quantitative and qualitative methods in 57 research articles, Green, Caracelli, and Graham (1989) found that 44% of them contained no integration, i.e., the analysis and interpretation of findings for each method were treated separately, and in 32% the data were analysed from both methods separately but the results were integrated during interpretation of the findings. In only a few studies (9%)

did the researchers manage to integrate the mixed-methods in both analysis and interpretation of the research.

In the current study a limitation was that the two parts of this study were originally conceived to occur sequentially, but due to timing constraints set by schools they were conducted concurrently. This restricted the interview questions in Part 2 of the study to broad questions rather than to hone in on the specific relationships found in Part 1. And this, in turn, placed certain limitations on the amount and quality of data obtained and consequently their analysis and findings.

In spite of this, the analysis and interpretation of Part 2 of the study involved the integration of the quantitative and the qualitative data from both parts of the study. The large scale survey in Part 1 of the study was mainly quantitative, but with some qualitative components in the open-ended questions of the survey. The small scale study (Part 2) involved nine Year 12 students and their teachers in one Singaporean school. Data were collected from student and teacher semi-structured interviews, classroom observations, and completed surveys by the students, using the same student survey as in Part 1 of the study. Analyses and discussions of Part 2 findings focused on the relationships found in Part 1 of the study, comparing the Part 1 findings with both the quantitative and the qualitative results in Part 2. In this respect, it is hoped that the challenge of conducting an effective and integrated mixed-methods research was met.

In the next section, the findings from both parts of the study are summarised, with an attempt to integrate and draw implications that impact practice and policy.

Findings

In Part 1 of the study, a sample of 964 Singaporean students (37.1% M, 62.9% F) and 176 Victorian students (31.3% M, 68.8% F) participated in the online survey. While the Singaporean students were fairly representative of the population, Victorian students from independent schools (73.9%) were over-represented due to difficulties in obtaining consent from government schools. It is noted that in both samples there were about twice as many females than males who responded. Students completed an online questionnaire (see Appendix B) comprising instruments related to attitudes, conceptions towards mathematics, approaches to studying mathematics, VARK modality preferences, social interaction for learning preferences, attitudes towards calculators, and ways of using calculators. In Part 2 of the study, nine Year 12 students in three classes in a Singaporean junior college were interviewed and surveyed. Their classes were observed and teachers interviewed. The interviews were transcribed, coded and analysed for the relationships between the student factors found in Part 1 of the study.

The main findings are presented in the following.

Research question 1. What are Singaporean and Victorian students':

(a) beliefs toward and attitudes about mathematics learning and advanced calculators;
(b) learning preferences; and
(c) ways of interacting with the advanced calculators?

Based on a five-point scale for easy comparison of the interval variables, the Singaporean students:

– rated themselves slightly below average for mathematics ($\bar{x}$ = 2.90) and for calculator ($\bar{x}$ = 2.94) competencies;

– agreed to having both a Connected Knowing and Deep Approach ($\bar{x}$ = 3.28) and a Separate Knowing and Surface Approach ($\bar{x}$ = 3.47) to mathematics learning;

– enjoyed using calculators ($\bar{x}$ = 3.36) and were somewhat confident in using them ($\bar{x}$ = 3.20);

– agreed somewhat to using the calculator as Master ($\bar{x}$ = 3.19); agreed fairly strongly to using the calculator as Servant ($\bar{x}$ = 3.78), and were neutral to using the calculator as Collaborator ($\bar{x}$ = 3.03).

A higher percentage of Singaporean students:

- had Aural (44.4%) and Visual (43.8%) preferences than Read/Write (32.5%) and Kinesthetic (13.2%) preferences as their general VARK preference;

- (when learning how to use the GC) most preferred a Kinesthetic approach of trying out the calculator steps at the same time they see a demonstration or listen or read the instructions (42.3%), a Visual approach of watching their teachers' demonstration (19.8%), and a Kinesthetic approach of trying the buttons out and playing around with the GC (13.1%);

- most preferred to study mathematics individually (52.9%) than cooperatively (40.5%) or competitively (6.6%);

- most preferred to work with the GC cooperatively (65.7%) than individually (32.3%) or competitively (2.1%).

In comparison, the Victorian students:

- rated themselves fairly good at mathematics ($\bar{x}$ = 3.57) and at using the calculator ($\bar{x}$ = 3.60);

- agreed to having both a Connected Knowing and Deep Approach ($\bar{x}$ = 3.34) and a Separate Knowing and Surface Approach ($\bar{x}$ = 3.50) to mathematics learning;

- enjoyed using calculators ($\bar{x}$ = 3.39) and were quite confident in using them ($\bar{x}$ = 3.63);

- disagreed to using the calculator as Master ($\bar{x}$ = 2.77); agreed to using the calculator as Servant ($\bar{x}$ = 3.56), and were neutral about using the calculator as Collaborator ($\bar{x}$ = 3.06).

A higher percentage of Victorian students:

- had a Read/Write (69.0%) preference than an Aural (38.7%), Visual (25.4%) or Kinesthetic (7.0%) preferences as their general VARK preference;

- (when learning how to use the CAS calculator) most preferred a Kinesthetic approach of trying out the calculator steps at the same time they see a demonstration or listen or read the instructions (37.0%), a Visual approach of watching their teachers' demonstration (22.5%), and a Kinesthetic approach of trying the buttons out and playing around with the CAS calculator (17.5%);

- most preferred to study mathematics individually (52.8%) than cooperatively (35.4%) or competitively (11.8%);

- most preferred to work with the CAS calculator cooperatively (52.5%) than individually (44.1%) or competitively (3.4%).

Research question 2. Are there differences in students' beliefs about and attitudes and learning preferences toward mathematics and calculators for students in the two regions, Singapore and Victoria?

Compared to Singaporean students, Victorian students generally:

- rated themselves better on mathematics (Vic = 3.57, S’pore = 2.90) and calculator competencies (Vic = 3.60, S’pore = 2.94);

- had similar scores for Connected Knowing and Deep Approach (Vic = 3.34, S’pore = 3.28), Separate Knowing and Surface Approach (Vic = 3.50, S’pore = 3.47), and calculator enjoyment (Vic = 3.39, S’pore = 3.36);

- were more confident in using calculators (Vic = 3.63, S’pore = 3.20);

- disagreed more to using the calculator as Master (Vic = 2.77, S’pore = 3.19) and as Servant (Vic = 3.56, S’pore = 3.78), and were similarly neutral in using the calculator as Collaborator (Vic = 3.06, S’pore = 3.03).

These differences were statistically significant.

Compared to Singaporean students, a significantly higher percentage of Victorian students:

- had general Read/Write preferences (Vic = 69.0%, Sing = 32.5%) rather than Visual (Vic = 25.4%, Sing = 43.8%), Aural (Vic = 38.7%, Sing = 44.4%) or Kinesthetic (Vic = 7.0%, Sing = 13.2%);

- most preferred to work with advanced calculators individually (Vic = 44.1%, Sing = 32.3%) and competitively (Vic = 3.4%, Sing = 2.1%) rather than cooperatively (Vic = 52.5%, Sing = 65.7%)

There were similarities across the regions:

- the top three most preferred calculator VARK preferences were the same for Singaporean and Victorian students: “(i) trying out the calculator steps at the same time they see/listen/read the instructions” (Kinesthetic; Vic = 37.0%, S’pore = 42.3%); “(a) watching the teacher’s demonstration” (Visual: Vic = 22.5%, S’pore = 19.8%); and “(j) trying the buttons out and playing around with the calculator” (Kinesthetic; Vic = 17.5%, S’pore = 13.1%);

- relating to the explanations for students’ most preferred social interaction for learning preferences, the patterns of distribution of categories of explanations (learning outcomes, learning performance, learning process, learning environment, attitudes, peer interaction, technology) were generally similar (see Tables 4.18 and 4.19, p. 167-168).

Research question 3. Are there gender difference in students' beliefs about and attitudes and learning preferences toward learning mathematics and using the calculators?

There were statistically significant gender differences common to both regions:

- Connected Knowing-Deep Approach (CK-DA; Males > Females);
- Separate Knowing-Surface Approach (SK-DA; Females > Males);
- Calculator as Master (Cal_Ma; Females > Males); and
- Calculator confidence (Cal_Conf; Males > Females) scores.

Although statistically significant for the Singaporean sample but not for the Victorian sample, males also had higher mean scores than females for

- Mathematics competency self-rating (MSR);
- Calculator competency self-rating (CalSR);
- Calculator as Collaborator (Cal_Co); and
- Calculator enjoyment (Cal_Enj).

In both Singapore and Victoria, a significantly higher percentage of males than females:

- (when learning how to use the calculator) most preferred to "(j) try the buttons out and play around with the calculator" (S'pore: M = 17.5%, F = 10.6%; Vic: M = 30.0%, F = 8.3%);
- most preferred to compete with friends when studying mathematics (S'pore: M = 10.5%, F = 4.3%; Vic: M = 32.0%, F = 6.9%) and when working with the calculator (S'pore: M = 2.7%, F = 1.7%; Vic: M = 4.5%, F = 3.1%).

In both Singapore and Victoria, a significantly higher percentage of females than males:

- (when learning how to use the calculator) most preferred to "(i) try out the calculator steps at the same time as they watch a demonstration, listen or read the instructions" (S'pore: F = 46.6%, M = 35.0%; Vic: F = 39.8%, M = 26.7%);

- most preferred to study mathematics individually (F = 54.5%, M = 50.1%) or cooperatively (F = 41.2%, M = 39.4%);

- most preferred to work with the calculator cooperatively (F = 68.9%, M = 60.1%).

A majority of students in both regions most preferred to work with calculators cooperatively than individually or competitively. However, higher percentages of Singaporean females than males most preferred to work with the GC cooperatively (M = 60.1%, F = 68.9%) whilst a higher percentage of Singaporean males than females most preferred to work with the GC individually (M = 37.2%, F = 29.3%). The trend was opposite for Victorian students: higher percentages of Victorian females than males most preferred to work with the CAS calculator individually (M = 36.4%, F = 45.8%), and higher percentages of Victorian males than females most preferred to with CAS calculators cooperatively (M = 59.1%, F = 51.0%). The gender difference was found to be statistically significant in the Singaporean but not the Victorian analyses.

When learning how to use the GC or CAS calculator, a significantly higher percentage of:

- Singaporean males than females most preferred to “(a) watch their teachers demonstrate in class” (M = 22.9%, F = 17.9%); while there was no gender difference among the Victorian students for this method (M = 23.3%, F = 22.2%);

- Victorian females than males most preferred to “(e) listen to a teacher who explained the steps and concepts clearly and thoroughly” (M = 3.3%, F = 8.3%); there was no gender difference in Singaporean students for this method (M = 10.0%; F = 9.7%).

Gender differences occurred for a higher number of variables among Singaporean than Victorian students, but the effect sizes calculated for the interval data were larger in the Victorian (ranged from 0.18 to 0.28) than Singaporean (ranged from 0.08 to 0.18) samples (see Table 4.20).

Discussion of the gender difference found in Part 2 of the study is described in the findings for the next research question.

Research question 4. What are the relationships among students' gender, beliefs, attitudes, learning preferences, and ways of interacting with the calculators? Specifically:

(a) What are the correlations between all the variables?
(b) Which variable best explains students' ways of interacting with calculators?
(c) How can these relationships be explained?

Correlations between all the variables. There were moderate to strong correlations between students' ways of using calculators (Cal_Ma, Cal_Se, and Cal_Co) and two groups of variables: students' mathematics attitudes and beliefs, and their calculator attitudes.

Figure 6.1 shows the relationships between the groups of variables common to both regions. The blue lines represent positive correlations, whereas the red line represents a negative correlation. It can be seen that calculator as Master (Cal_Ma) is associated positively with a Separate Knowing-Surface Approach (SK-SA) to mathematics learning, and negatively with calculator competency (CalSR). Calculator as Collaborator (Cal_Co) is associated positively with a Connected Knowing-Deep Approach (CK-DA) to mathematics learning, calculator competency, enjoyment and confidence. There was no common pattern of association between calculator as Servant and other variables.

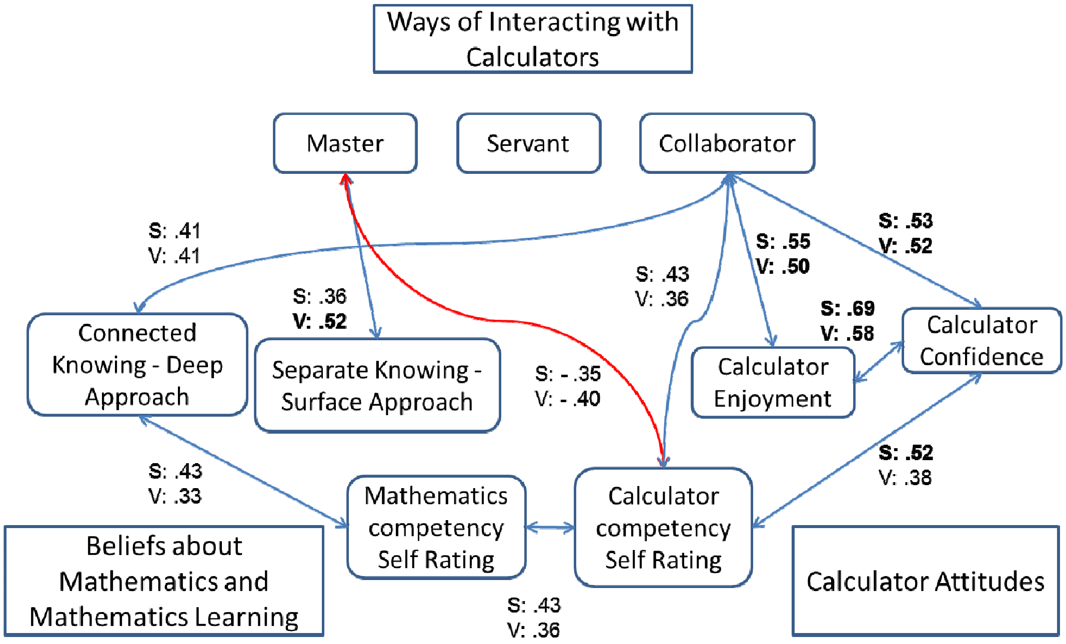

Figure 6.1. Pattern of moderate to strong correlations (*r*>0.3) between the variables common to both Singaporean and Victorian students. (Red indicates a negative correlation; blue indicates a positive correlation).

Variable that best explains students' ways of interacting with calculators. Multiple regression analyses were used to analyse the large scale data in Part 1 of the study to find the variable that best explains students' ways of interacting with the calculators. It was found that in both regions, a Separate Knowing-Surface Approach (SK-SA) to learning mathematics best explained their use of calculator as Master, and a Connected Knowing-Deep Approach (CK-DA) to learning mathematics best explained their use of calculator as Collaborator. The variable that best explained students' calculator as Servant scores was different in the two regions – SK-SA for Singaporean students, and calculator confidence for Victorian students.

Explanations for relationships found. Overall it seems that students who conceived mathematics as composed of rigid rules and procedures and learnt mathematics by memorising the steps without real understanding, also tended to be subservient to the calculator and used it without real understanding. They also tended to have low calculator competency. On the other hand, students who conceived mathematics as a connected set of knowledge and skills which are applicable to real life, and learnt mathematics through intrinsic interest and deep understanding, also tended to use the calculators as a Collaborator for problem solving and exploration. They tended to have high calculator competency, enjoyment and confidence.

In Part 2 of the study, the associations between students' conceptions of mathematics and approaches to learning mathematics (CK-DA and SK-SA) and their ways of interacting with calculators (Cal_Ma and Cal_Co) were seen. From the student interviews, two students who were high in both CK-DA and Cal_Co were positive in their attitudes toward mathematics and described calculators as their pals which they kept at hand at all times. They were more willing to work on understanding how the calculator works, and related the GC steps to mathematical concepts and structure. Although they did not have high calculator competencies, they enjoyed and were confident in using calculators. Another student, who scored the lowest for Cal_Co (strongly disagreed with all the items on the scale), said that she could not relate to mathematics. She also scored the lowest for CK-DA (strongly disagreed with most items on the scale).

In Part 2 of the study the association between SK-SA and Cal_Ma was not as clear as the association between CK-DA and Cal_Co. This is consistent with Part 1 of the study where the correlation between CK-DA and Cal_Co was stronger ($r = 0.412$) than that between SK-SA and Cal_Ma ($r = 0.362$) for Singaporean students. Students who saw mathematics as a rigid, disconnected body of knowledge (SK) and used rote learning approaches to minimise their scope of study (SA) tended to be either technologically or mathematically dependent on the calculator. In particular, students who were disinterested and weak in mathematics relied on memorisation of mathematics formulae and procedures to solve problems with the intention to pass the examinations in order to meet the requirements for university entrance. They also applied a rote learning approach to using the GC and followed the calculator steps blindly without understanding.

Additionally most of the nine students in Part 2 of the study mentioned having initial difficulties in learning how to use the GC, and described having to practise using the GC to be familiar with it. The role of practice could be seen as part of a deep approach or a surface approach, depending on whether the intent was for deep understanding or for rote-memorisation (Biggs, 1993). Two students described practising by rote-memorisation and three students described practising to understand the structure behind the GC or to be able to solve problems on their own. Students seemed to be able to master the use of GC through practice, whether by rote-memorisation or by deep understanding or a combination of the two.

Gender differences. There was an indication of gender differences in Part 2 of the study. There were two students who rated themselves as weak in mathematics, a male and a female. Their attitude towards mathematics and towards the calculator seemed consistent with the gender literature. The female student talked about wanting to understand the mathematics concepts, but stereotyped herself as an Arts student and thus not good at mathematics (learned helplessness), whilst the male student treated mathematics as “a recollection thing”. While the female student was tentative about liking the calculator and rated herself as weak in GC competency, the male student rated himself as average in GC competency, and indicated that he enjoyed GC use and played around with the GC for non-academic purposes. The female student had a high calculator as Master score and a low calculator as Collaborator score, whilst the male student had a lower calculator as Master score and a higher calculator as Collaborator score. There was no difference in the beliefs, attitudes, and learning preferences evident among the other students which might be attributable to gender. This finding suggests that amongst students who are weak at mathematics, the use of advanced calculators might further disadvantage females.

There was also a social perception espoused by two students and a teacher that males are generally better at using advanced calculators than females. They gave anecdotal examples based on their experiences with students in their classes. Correspondingly, from the interviews, there was no mention of any perceived gender difference regarding mathematics competency; one student explicitly mentioned that there was no difference between girls and boys in her class with regard to mathematics.

Research question 5. Are there other factors that affected the ways students use graphing and CAS calculators for mathematics learning?

From Part 2 of the study, the most significant factor affecting students' understanding of mathematics and use of advanced calculators that emerged was the teacher. The teacher was seen to play an important role in helping students understand the mathematics and guides students on how to use the GC. Two out of the three Year 12 classes observed had experienced changes in mathematics tutors since Year 11. The students were appreciative of their current teachers. They described teacher qualities which they appreciated, such as efficiency in giving shortcuts to solve problems, clarity in explanations, strictness in expecting students to solve their tutorial questions before lessons, giving students online resources for learning graphing transformations, and providing opportunities for hands-on work with the GC during mathematics lectures. One of the three teachers believed that students should memorise the steps to solve problems even if they do not understand the mathematical concepts. This view is consistent with a surface approach. Her teaching reflected her beliefs. The four students in her class who participated in the study had high Separate Knowing-Surface Approach scores and high calculator as Master scores. Interviews with her students suggested that a few of them might prefer a Deep Approach (to understand the concepts) rather than rote learning, and that they might have been influenced by the teacher's teaching approach and their own lack of mathematical understanding. On the other hand, at interview the teacher revealed that she employed more surface approaches (e.g., emphasising GC steps and procedures) due to her perception of students' needs as well as feedback from students. This suggests that there is a complex and reciprocal teacher-student relationship between teachers' beliefs and preferences, the way they teach, and students' learning preferences, learning processes, and outcomes.

Overall, the findings from Parts 1 and 2 of the study revealed that students' attitudes toward and beliefs about mathematics and calculators, as well as some learning preferences, were associated with how they used advanced calculators. A number of these associations were seen in both the Singaporean and the Victorian data. There were also gender differences in some of the variables measured, in favour of males. Additionally, Singaporean students were generally less confident in advanced calculator use and rated themselves lower in mathematics and calculator competencies than Victorian students. Finally, besides student factors, an important factor found to be influencing students' calculator use was the teacher.

In the next section, the conclusions and implications for the study are presented.

Conclusions and Implications

There are several conclusions that can be drawn from this study. The conclusions and their implications for teaching, learning and research are discussed in the following.

(i) How students interact with the advanced calculator was influenced by their beliefs about and attitudes toward mathematics and their approaches to studying mathematics.

A main conclusion was that students’ *ways of knowing and studying mathematics* and their *ways of interacting with advanced calculators* were closely associated. Students' Connected Knowing-Deep Approach to learning was associated with their use of calculators as Collaborator, with correlation coefficients of 0.41 for the Singaporean and 0.41 for the Victorian students. Their Separate Knowing-Surface Approach to learning was associated with their use of calculators as Master, with correlation coefficients of 0.36 for the Singaporean and 0.52 for the Victorian students. Although causality cannot be established from the study, students' conceptions of mathematics could be thought of as existing and stable prior to their exposure to advanced calculators at secondary or senior secondary years, and hence potentially influencing their perceptions of the calculators. Therefore, an implication would be to encourage connected knowing and deep approaches to learning mathematics among students. Activities which involve the use of calculators and other technologies to solve authentic problems or conduct investigations of real life issues could promote sophisticated use of calculators as well as connected knowing and deep understanding. Discussions of different ways of solving a problem rather than solving additional examples in the same way (Ocean, 1998) and establishing personal relevance of mathematics for the learner through group investigations of a topic (Ernest, 2004) are ways teachers can nurture connected knowing. Incorporation of calculator use in these discussions and explorations (e.g., data analysis and presentation) may result in students developing an appreciation for more sophisticated uses for calculators, compared to merely teaching them calculator skills.

Teachers' own beliefs about deep or surface approaches, and connected or separate knowing with respect to the learning of mathematics, as well as their perceptions about students’ needs and preferences, might play a part in influencing students' beliefs about mathematics and approaches to learning, as was seen in the example of the teacher who agreed that students should memorise the mathematical steps even when they did not understand the concepts (see Part 2 of the study). In the previous studies (e.g., Kendal & Stacey, 2001, delos Santos & Thomas, 2002), it has been found that students tended to follow what their teachers privileged (beliefs about mathematics and approaches to solve mathematics problems). The finding from this study extends the previous finding in that the privileging might be reciprocal – teachers may choose to employ certain approaches due to students privileging that approach.

Besides teaching approaches, teaching resources also can carry epistemological messages that potentially influence students' beliefs (Raman, 2004). Conflicting emphasis on “syntax (manipulation of symbols without recourse to meaning) and or [*sic*] semantics (focus on the meaning or conceptual understanding)” (Raman, 2004, p. 391) might be found in textbooks or lecture notes. One implication of this study is that if teachers had greater awareness of their own beliefs and conceptions about mathematics, and understanding of how these can affect their teaching approaches and choice of teaching resources, then they could select appropriate approaches and resources with the aim of influencing students' beliefs, attitudes and use of calculators.

In an environment where the emphasis on high-stakes examinations is very strong, the development of deep approaches to learning might be hindered (Ramsden, Martin, & Bowden, 1989). In Part 1 of the current study, students in both regions had higher separate knowing-surface approach than connected knowing-deep approach scores, consistent with the findings of past research that surface approach scores were positively associated with an emphasis on academic achievement (Ramsden, Martin, & Bowden, 1989). From Part 2 of the study, the teachers observed used a combination of deep and surface strategies in their teaching, emphasising achievement with understanding and the reproduction of steps to solve particular types of problems in order to achieve maximum marks in the examinations. This suggested that the teaching experienced by the students might have some influence in their adoption of both deep and surface approaches. This association between students’ learning environments and their approaches to learning, particularly in school environments with high stakes testing, is also consistent with the findings of other studies (e.g., Kılıç & Sağlam, 2010; Ramsden, Martin, & Bowden, 1989). Furthermore, an emphasis by teachers on practising mathematics problems does not necessarily mean developing a surface learning approach. In synthesising meta-analyses of experimental studies investigating the effects of various components of teaching and learning on student achievement, Hattie (2009) established that deliberative practice (as opposed to drill and practice) which provides opportunities for different learning experiences, ample feedback, and extending students’ knowledge and skills through contextual variability, can lead to mastery as well as fluency. The role of practice was seen in Part 2 of the study as important to both memorising and understanding the functions of the calculator. Thus an implication of this finding is for teachers to attend to the learning objectives and outcomes of practice activities before assigning them to students, that is, using practice as a means to develop deep understanding, rather than to lead to repetitive rote learning.

(ii) Students' learning preferences were situated, and the use of advanced calculators was associated with visual and kinesthetic modes and preference to work cooperatively.

Another finding from this study was that a majority of students in both regions most preferred to learn how to use the advanced calculators through *kinesthetic* (trying out the buttons at the same time that they see a demonstration or listen to or read the instructions; playing around with the buttons on the calculator) or *visual* (seeing teacher's demonstration) approaches. Students' VARK preferences when learning how to use the calculators were found to be different from their general VARK preferences, consistent with Fleming’s (2006) theory that students' modality preferences are flexible and not rigid. Hence, an implication of this finding is for teachers to be aware that students differ in their modality preferences when learning mathematics with calculators, and employ a range of teaching strategies to engage these modes. For example it was found that 95% of Singaporean and 74% of Victorian students said that the kinesthetic approach (trying out the buttons while seeing/ listening/ reading) was useful, but only 72% of Singaporean and 55% of Victorian students indicated that their teachers encouraged students to try out the steps during demonstrations.

In both Parts 1 and 2 of the study, it was found that when working with calculators, higher percentages of students most preferred to *cooperate* with friends (66% Singaporean, 53% Victorian) rather than work individually (32% Singaporean, 44% Victorian) or competitively (2% Singaporean, 3% Victorian). This preference for cooperation was specific to working with calculators because a lower percentage of students said they most preferred to cooperate when studying mathematics (41% Singaporean, 35% Victorian). Students who were interviewed said they employed different study strategies for different situations, such as preferring to solve day-to-day tutorial problems on their own and to revise past topics for examinations together with friends. A number of students also preferred to ask friends for help when they encountered problems. While an examination oriented culture might lead teachers to employ teaching modes (with calculator use) that are individualistic rather than cooperative in nature (Tan, 2005), findings from this study suggest that encouraging students to work cooperatively and form peer support groups could be beneficial to their learning mathematics with calculators. This was also evidenced in the finding that a majority of students found it useful to see the steps from a friend's calculator screen (90% Singaporean, 74% Victorian) and discuss answers with friends (88% Singaporean, 59% Victorian), but considerably fewer said that their teachers let students demonstrate their answers to the whole class (8% Singaporean, 19% Victorian), or let students discuss answers with one another (28% Singaporean, 35% Victorian).

(iii) There were regional differences in how Singaporean and Victorian students use the advanced calculators and their attitudes towards calculators.

Before describing the regional differences, it is to be noted that the Victorian sample is not representative of the population of students in Victoria due to the difficulty in obtaining participants from government schools (see Chapter 3 Methodology). There was also an over-representation of female students in both regions. In spite of this, there was a large sample of respondents from Singapore across different schools, and in the Victorian data, the sample was large enough to enable inferential statistics to be used.

Overall, it can be seen that Singaporean students were *less confident and less fluent* in the use of calculators than the Victorian students. There were regional differences in some of the student characteristics such as mathematics and calculator competencies, which might be due to cultural differences (Elliot, Hufton, Willis, & Illushin, 2005) or to the fact that there were a higher percentage of Victorian students from independent schools. There were also other variables with no significant differences, such as their Connected Knowing-Deep Approach and Separate Knowing-Surface Approach scores, which may be due to similarities in the learning contexts such as the strong focus on academic excellence (see Biggs, 1993, for a discussion on the relationship between learning contexts and deep and surface approaches to learning). Since there were some variables with regional differences and others with no differences, this suggests that there was no response bias associated with regional cultures (e.g., when one group of students consistently under-rate or over-rate themselves in all the items compared to the other group). Hence, the significantly lower calculator confidence scores and higher calculator as Master and as Servant scores of Singaporean than Victorian students suggest that there might be other non-cultural (e.g., systemic) factors implicated, such as types of assessment tasks, or teachers' familiarity with the tool. Victorian teachers had been using graphing calculators for fifteen years, and their transition from GC to CAS calculators might be easier than the Singaporean teachers' transition from scientific calculators to GC. In an earlier study of Singaporean and Victorian senior secondary mathematics teachers conducted prior to the adoption of GCs in the Singaporean and CAS calculators in the Victorian mainstream curricula, Tan (2005) found differences in the senior secondary mathematics teachers' profiles and beliefs about calculators. Compared to the 35 Victorian teachers from 14 independent schools, the 33 teachers from five Singaporean schools were younger, had fewer years of teaching experience, indicated lower competency with technology, and had used technology for fewer years. Additionally, a higher percentage of the Victorian teachers (80%) agreed that graphic calculators were useful, compared to 39.4% of the Singaporean teachers (Tan, 2005). In Part 2 of the current study, two out of the three Singaporean teachers said that they only knew how to use the GC as required for the examinations and no more. An implication of this finding is that more cross-regional research studies are needed to investigate these differences in levels of calculator use in teachers, and the impact of teachers' calculator competencies and confidence on their students' interactions with the calculators.

Another finding when the Singaporean and Victorian samples were compared was that there was a moderate negative association between *calculator as Master* and *mathematics competency self-rating* (r = -0.35) in the Victorian sample but only weakly in the Singaporean sample (r = -0.15). This leads to the possible conclusion that the CAS calculator may impose greater mathematical demands on students compared to using the GC. Although there are studies that showed that using CAS has not affected Victorian students' achievement in the high-stakes examinations (Leigh-Lancaster, Les, & Evans, 2010), student enrolments into the intermediate and advanced level mathematics courses on offer have declined, and there are indications of increased gender differences in participation and achievement with the transition from GC to CAS (Forgasz & Tan, 2010). Since this has implications for the debate on the digital divide (whether using more advanced technology further widens the gap, or narrows the academic gap), further research is needed. Also, the implication for teaching and learning is to have a strong focus on relating calculator skills to mathematical concepts when teaching students how to use the advanced calculators, particularly the CAS calculators.

(iv) There were gender differences in students' attitudes towards mathematics and advanced calculators, and how they used the calculators.

Gender differences occurred for a higher number of variables among Singaporean than Victorian students, but the effect sizes were larger in the Victorian than Singaporean samples. The gender differences were *in favour of males in both regions*, with males scoring higher in Connected Knowing-Deep Approach (CK-DA) and calculator confidence, and scoring lower in Separate Knowing-Surface Approach (SK-SA) and calculator as Master. These findings, taken together with the finding that students' beliefs about and attitudes toward mathematics (CK-DA and SK-SA) were the variables that best explained the ways that students interact with the calculators (calculator as Collaborator and as Master), suggest that the use of advanced calculators might exacerbate gender differences in mathematics learning outcomes. Additionally, the largest effect sizes for the gender differences in Part 1 of the study were for calculator confidence in both regions (see Table 4.20). In part 2 of the study, there was evidence to suggest that amongst students who were weak in mathematics, males tended to be more confident, and expressed greater enjoyment, in calculator use, compared to females. Lack of calculator confidence and competency in the use of advanced calculators can hinder students' effective use of the calculators under examination conditions (e.g., Boers & Jones, 1994; Graham, Headlam, Honey, Sharp, & Smith, 2003). Hence, females, being less confident in using advanced calculators than males (seen in Part 1 of the study), are at higher risk of performing more poorly than males in examinations. An implication for teaching and learning would be for teachers to develop an awareness of the potential of female students being discouraged by advanced calculator use, and to encourage female students to develop confidence in using calculators (e.g., through activities which promote connected knowing and deep understanding). The use of a feminist pedagogy in mathematics classroom (Jacobs, 2010) may be effective, through:

1. real-world or classroom based experiences;
2. engaging learners to inquire and reflect on their work;
3. encouraging alternate methods of solutions;
4. emphasis on generating hypotheses rather than proving stated theorems;
5. cooperative rather than competitive or individual activities; and
6. making extensive use of writing as a means of learning maths.

These strategies could be used to improve all students' learning and not disadvantage or discourage males.

In Part 1 of the study, gender differences were found in most variables in the Singaporean sample, particularly in their beliefs about and attitudes toward mathematics and their ways of interacting with GCs. From past studies, gender differences have been found in mathematics achievement and attitudes (e.g., self-concept and achievement attribution) in Singaporean students (see Kaur, 1995, for a review). In a more recent study of senior secondary mathematics students in a high achieving Singaporean pre-university, Lim (2010) found that there was no significant difference in the achievement of males and females for a three-hour test similar to one of the two papers in the national mathematics examination. However, males had higher confidence in their ability to do mathematics than females (Lim, 2010). In Part 2 of the current study, two Singaporean students perceived gender differences in the learning and the use of GCs in favour of males, but not in the learning of mathematics. Comparison between a pair of male-female students who were weak in mathematics indicated gender-related differences in their attitudes towards calculators. This suggested that academically weaker males may have a disadvantage over academically weaker females because they are more positive towards calculator use. The findings suggest that further comprehensive study is required to investigate the gender differences in GC use for academically weaker students and the relationship between GC attitudes and Singaporean students' achievement at national examinations.

For Victorian students, although there were no significant gender differences in their self-ratings of mathematics and calculator competencies, there were gender differences in students' beliefs about and attitudes toward mathematics (CK-DA and SK-SA), their calculator confidence, and their use of calculators as Master and as Servant. Studies suggest that attitudinal factors such as self-efficacy, self-confidence and self-concept might be variables that mediate gender differences in mathematics performance (Caplan & Caplan, 2005). Hence, Victorian students' mathematics achievement in the high-stakes examinations should continue to be monitored for any trends of exacerbating gender differences. With the implementation of the Australian National Curriculum, comparisons can also be made between Victoria and the other Australian states and territories relating to any trends of gender differences in the use of advanced calculators in mathematics assessment.

Implications for policy. Several of the conclusions discussed above might be related to an educational context with high-stakes examinations. Hence, policy makers developing policies relating to the adoption of advanced calculator use in schools would need to examine several areas: teacher professional development relating to the connected knowing of mathematics and technological pedagogical content knowledge (Mishra & Koehler, 2006), and the role of advanced calculators in curriculum resources (e.g., textbooks, web-based resources) and in assessment (e.g., the modes of assessment and types of tasks). Although both Singapore and Victoria have high-stakes examinations for entrance into university, the amount of calculator use in assessment is different. In Singapore the advanced calculator is required in the two examination papers for each mathematics subject; whilst in Victoria for each of the intermediate and advanced level mathematics subjects there is a school-based assessment and two examination papers, one of which is technology-free. The presence of a technology-free paper could explain the lower calculator as Servant (using calculators to replace pen-paper computations) scores of the Victorian students, compared to the Singaporeans. Further research is needed to compare students' ways of using calculators between different educational contexts with different examination formats (e.g., where there are no high stakes examinations) in order to build a better picture of the impact of curricula and assessment modes on students' mathematics achievement and calculator use.

Implications for research. The conclusions and implications drawn from the study discussed above can be further explored in order to use the findings to benefit the teaching and learning of mathematics. Further research is needed to (i) explore how students develop their ways of knowing mathematics and approaches to learn mathematics, and if the use advanced calculators influence this development; (ii) find out the best ways for teachers to teach and students to learn how to use the advanced calculators for deep understanding, catering for students' different learning preferences (e.g., VARK and social interaction for learning preferences); (iii) investigate systemic factors that influence how students use advanced calculators (across different educational systems); and (iv) to investigate systemic factors that are implicated in gender differences related to calculator use.

Further research such as longitudinal studies could be conducted to examine the role of student factors in students' development of calculator skills and attitudes. Such a study might be extended to relate the student factors explored (e.g., VARK preferences when learning how to use the calculators) to existing theories (e.g., students' representational preference when using calculators).

Action research is also needed to actualise and transform the implications of the research findings of this study into practical and useful instructional strategies to improve student outcomes and cultivate more sophisticated use of the advanced calculators.

One significant contribution of this study to the research field is in the use of Facebook as a method of recruitment (Tan, 2010). As social networking sites like Facebook gain popularity, researchers have started exploring the potential of these sites for research. The issues surrounding this method of data collection, such as representativeness of the sample and response bias, are still in need of further study.

In the next section, the limitations of the current study are presented, followed by the concluding words.

Limitations of Current Study and Suggestions for Further Research

The study used a bricolage of theories to investigate the relationships between students' attitudes, beliefs, and learning preferences, and their ways of using advanced calculators. Since the instruments were developed or modified from existing instruments, and used in the two regions, the generalisability of the findings is limited to the extent that these instruments are valid in their measuring of the constructs investigated, and are reliable in the precision of the measurement. Although the reliability tests of the data were conducted with satisfactory results, further validation and testing of the instruments across other learning contexts and regions are needed to strengthen their validity and reliability. For example the combined instrument CK-DA and SK-SA seemed to measure students’ ways of knowing and studying mathematics, and more can be done to build a knowledge base regarding the construct validity through comparing students’ scores on these measures with their scores for other similar instruments measuring Deep and Surface Approaches, such as Biggs’ (1987c) Learning Process Questionnaire, Entwistle and Tait’s (1996) Approaches to Study Skills Inventory for Students, and Ocean’s (1998) instrument for measuring Connected and Separate Knowing.

Also, the instrument measuring ways of using advanced calculators (Calculators as Master, Servant and Collaborator) was developed from the four metaphor framework proposed by Goos et al. (2000) and Geiger (2005), and used to measure Singaporean students’ use of GC and Victorian students’ use of CAS calculators. The assumption was that the items were general enough to cover broad types of usage of the different calculators. Given that there are differences in the capabilities of GC and CAS calculators, more research and refinement are needed to test the validity and reliability of the instrument across the different types of technologies, and to ensure that the instrument is generalisable to future handheld technologies and integrated technological systems, such as advanced calculators or mobile devices connected to wireless networks (Roschelle & Singleton, 2008).

In Part 1 of the study, the Victorian students were mainly from independent schools, with more female than male respondents, and the sample was therefore not representative of the population of Victorian senior secondary students. This limited the generalisability of the findings of the Victorian data, and of the comparisons made between Singaporean and Victorian students.

Part 2 of the study was conducted in a Singaporean junior college rather than in both regions. Hence, the findings were interpreted within the particular learning context and cultural environment. Further study is needed to investigate and compare cultural or contextual influences on students’ attitudes, beliefs, and learning preferences that might impact students’ ways of using calculators. For example, prior experiences with calculators and other technologies might play a part in students' conceptions and confidence with advanced calculators. Victorian students may have been exposed to the GC in earlier years before progressing to CAS calculators at the senior secondary level or have been using CAS calculators in earlier years (e.g. Driver, 2012). Furthermore, Victorian teachers' prior experiences with GC might also have influenced their confidence and pedagogical use of the CAS calculators when they transitioned from teaching with the GC to teaching with the CAS calculators. Some Victorian teachers may even have used them as students.

In summary, the main limitations of the present study are those concerned with generalisability of the results due to assumptions that the instruments and findings are applicable and comparable across regions.

Final Words

Reflecting on the state of, and trends in, research on mathematics teaching and learning, Niss (2007) concluded that research on students' beliefs, affect, and attitudes toward mathematics seemed to have waned in recent decades and called for further inquiry into this area. In this study, the relationships between students' beliefs about and attitudes and learning preferences toward mathematics and advanced calculators, and their levels of advanced calculator use were investigated. It was found that there was an association between students' beliefs about and attitudes toward mathematics and how they used advanced calculators. Connected knowing and deep approaches to learning were associated with a sophisticated use of the calculator for mathematical exploration, and separate knowing and surface approaches to learning were associated with a technological or mathematical dependency on the calculators. Students indicated that they most preferred to learn how to use the advanced calculators using methods that involved visual or kinesthetic modalities. They also most preferred to work with the calculators cooperatively with their friends. Regional differences were found, with Singaporean students having less confidence and fluency in advanced calculators than Victorian students. Gender differences were found in both regions in favour of males on the survey data. Interviews with a group of Singaporean students suggest that amongst academically weaker students, females may be disadvantaged more than males because of their more negative attitudes towards calculator use.

Overall, there is increased complexity in the issues and challenges surrounding mathematics education as technology use becomes part and parcel of the mathematics curriculum. Gender differences might be exacerbated with the use of advanced calculators in high-stakes assessment, and teachers have to attend to students' beliefs about and attitudes towards mathematics, as well as their attitudes and confidence towards calculators and their learning preferences when learning how to use the calculators. In order to nurture students as discerning users who take control of the technology to support mathematics inquiry and learning rather than as blind consumers of technology, teachers need to question their own beliefs about mathematics and mathematics learning, as well as their classroom practices involving technology. Teachers can cater best to the range of different preferences when they recognise that students have different learning preferences and not assume that students have the same preferences and beliefs as themselves. The challenge is to translate the findings of this study into sound pedagogical teaching approaches, engaging curriculum, equitable and carefully directed assessment, and effective teacher professional development if students are to realise and maximise the potential of calculators and other technologies for mathematics learning.

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Responses to Examiner's Questions

- How may the clustering of students within classes breach assumptions on which the single-level statistical methods used in this study are based, and to what effect? Are suitable multi-level methods available that would take better account of this clustering?

- If you were to conduct a similar study again, how could you improve the persuasiveness of the regional and gender comparisons; for example, by developing a more explicit sampling frame, and by mitigating skews in the achieved sample?

Dear Professor Ruthven,

Thank you for your insightful comments and questions relating to my thesis. The responses to the two questions raised are as follows:

Question 1. Multi-level statistical methods

The main argument against the use of single-level statistics is that it ignores the fact that respondents may be clustered into groups of different sizes (for example, students in the same class having the same teacher and attending the same school). As a consequence, respondents in particular groups may respond similarly, thus skewing results and affecting the validity of the findings. Hence, statistically significant findings may be due to group factors (e.g., in this study, class or school factors). According to Goldstein (2011), a "well-known and influential study" (p. 2) of the clustering of students within groups impacting the findings of a study was an investigation of different teaching styles on primary school pupils conducted by Bennett in 1976. Using traditional single-level multivariate techniques, Goldstein reported that Bennett found significant performance differences in reading for students taught by "formal" and "informal" approaches. However, Goldstein noted that the re-analysis of Bennett's data by Aitkin, Anderson, and Hinde in 1981, using multi-level statistics which accounted for the grouping of students into classes, resulted in the statistically significant difference being eliminated.

Despite the known disadvantages of single-level analyses, the use of multi-level statistics to account for class effects in the present study was inappropriate for the following reasons.

1. Although the Singaporean students were grouped in tutorial classes with one teacher, they also attended common lectures where the teaching of mathematical concepts and skills took place. These lectures were taught by the mathematics teachers of all senior classes who took turns to lecture different topics. This practice of having a range of different lecturers would have added a confounding effect on between-class variations if a multi-level analysis by class grouping had been conducted.
2. For the Victorian data, it was not possible to analyse by class grouping for several reasons related to the sample obtained. It was recognised that while Singaporean junior colleges have large enrolments of students in years 11 and 12 only (over 1000 students per school) and many mathematics classes, Victorian high schools enrol students from years 7-12 (around 600-1000 in total) and have relatively fewer senior mathematics classes. As a result, many Victorian schools were invited to participate; unfortunately, very few agreed. Individual student participation was also voluntary and resulted in very small numbers of respondents per school. The total number of responses from participating schools was insufficient to conduct between-school analyses, let alone between-class analyses. In addition, the student response rate in total was considered too small to make comparisons with the Singaporean data, so additional Victorian respondents were sought via Facebook. It should be noted that school information was not gathered using this approach.

Clustering of students at the school level (and/or class level) should be considered in future studies to investigate school (and/or teacher) effects on students' beliefs, attitudes, learning preferences, and use of advanced calculators for mathematics. However, based on the current pedagogical approaches for the teaching of senior mathematics, future studies in Singapore could include school effects, but not teacher effects.

Question 2. Improve the persuasiveness of regional and gender comparisons

As mentioned in Professor Ruthven's examination report, it is acknowledged that more detail could have been provided regarding the method of sampling used, in particular more detail about the sampling frame and sampling approaches adopted.

In the study, multi-stage sampling was planned for and carried out. Random stratified sampling procedures were used to select the schools to invite to participate in the study. To recruit students, participating schools agreed to send emails to students inviting them to complete anonymous surveys. It should be noted that this procedure was consistent with the requirements of Monash University (and Educational authorities) for the conduct of ethical research with students attending participating schools.

For Singaporean schools (junior colleges), the stratification was based on the level of academic performance of schools (above/below average performance) using past rankings by the Ministry of Education (MOE), Singapore (see MOE, 2003, Jan) as a reference. Six Singaporean schools were invited, three from each level.

For the Victorian schools, the strata were based on school type (Government, Catholic and Independent) and regions (metropolitan Melbourne and nine non-metropolitan regions). Invitations were sent to a representative sample (by region and school type) of 110 Victorian schools. The response rate was poor with only a few non-government schools agreeing to participate. No government schools participated due to the Department of Education and Early Childhood Development's [DEECD] extra administrative procedure requiring written parental consent for completion of anonymous online surveys by students, even though Monash University ethics did not require this of 17-year olds. This led to further rounds of recruitment:

a. targeting non-government schools (no parental consent was required), and
b. the use of a Facebook advertisement, resulting in some representation from Victorian government schools.

Participation of a more representative sample of Victorian schools and students would have greatly increased the persuasiveness of the comparisons with the Singapore sample. Despite a well-planned stratified sampling design, time was the major factor precluding the pursuit of this ideal. Significant effort was spent in the recruitment of the Victorian participants. The problem of a lack of response severely affected the representativeness of the sample obtained. Facebook was used as a fall-back measure to increase the number of participants in order to enable statistical analyses to be conducted. There was also a recognised sampling problem associated with using Facebook as a tool for recruitment, that is, only students with internet access, Facebook accounts, and relevant account information (age and region) matching those set by the researcher could participate. It is also possible that Facebook respondents were more technologically savvy, thus affecting findings related to capabilities with advanced calculators.

Having more females than male participants in both regions (Singapore: 63% females; Victoria: 69% females) is not inconsistent with other survey studies. Findings from other studies seem to indicate that survey response rates are generally higher for female than male students (e.g., Porter & Umbach, 2006). In one study, a national survey for first year U.S. college students was conducted by Sax, Gilmartin, and Bryant (2003) who obtained response rates of 25% for females and 12% for males to the emailed invitations for the online version of the survey.

The low response rates of male students in this PhD study, in particular the male Victorian students, may have affected the findings as they might "produce biased estimators of survey variables" (Pike, 2008, p. 154). Weighting adjustments could have been used to mitigate skewness in the achieved sample (Pike, 2008). However, the independent-groups t-tests in the SPSS package are robust and allow for different sample sizes (Field, 2005). While it may have been better to have obtained greater representativeness through active sampling of more participants, random sampling, with voluntary participation cannot guarantee this.

If this study were to be conducted again and time was not a constraint, clearly the achievement of a more representative sample would be desirable. Representative random sampling may be the ideal. However, in reality, this is rarely achieved. Thus, despite not being random, non-probabilistic sampling methods, such as quota sampling, might yield better results in order to ensure representation and to have sufficient responses for analyses. However, this could introduce unforseen alternative biases. Yet, this may be preferable to having samples with under- (or over-) representation of certain strata as happened in this study initially (e.g. no students from Victorian government schools). As noted above, it is not unusual to have higher female than male survey response rates, and contemporary statistical testing can take this into account unless there is a huge imbalance in numbers. Again, equal numbers may be preferable but not always achievable.

General comment

Finally, Professor Ruthven's two questions can be seen to be related. With more representative samples and samples with more grouping information (e.g. students' class and school information), a multi-level model could have been used. Students could then have been grouped into gender, class/teacher, school, and region, to investigate the between-gender, between-class, between-school, and between-region variations and their effects on the relationships between students' beliefs, attitudes, learning preferences, and use of advanced calculators. [NB. As noted above, for a Singaporean sample, class/teacher groupings may not be appropriate.] For missing data, multi-level models can also handle multiple imputations of responses at different levels of a data hierarchy (Goldstein, 2011). As a recently advanced statistical technique, multi-level modelling has much to offer to increase the validity of the findings, provided that methodological issues such as model development and specification, sample and data distributional assumptions, estimation procedures, and statistical inferences about variance parameters (Dedrick et al., 2009) are taken into account and soundly set up.

Many thanks for the opportunity to address your questions. Please note that these responses will be included in the final, bound version of the thesis.

[redacted]

Hazel Tan

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Appendix A: Pilot Study

In this appendix, the details of the pilot study referred to in Chapter 3 are discussed. Based on the frameworks presented in Chapter 3, a survey instrument was developed with the items that were either modified from existing instruments or researcher developed. The sections of the survey instrument were:

1) Demographic data including students' mathematics and calculator competency self-ratings;

2) General VARK preferences and VARK preferences when learning how to use calculators;

3) Connected and Separate Knowing (views about mathematics);

4) Deep and Surface Approaches to learning (views about studying mathematics);

5) Social interaction for learning preferences when studying mathematics;

6) Ways of interacting with calculators;

7) Views about calculators;

8) Social interaction for learning preferences when working with calculators; and

9) Any other comments.

The initial instrument was reviewed by a panel of 3 teachers and 7 students from Singapore who were asked to comment on the appropriateness of the items and highlight any ambiguities. The pilot study was then conducted in October 2008 to January 2009 in two trials. First, the survey was trialled online for a small group of students (46 participants) in one school. Based on the comments and initial analysis, the instrument was revised and shorted and trialled in another school administered via pen-and-paper to selected classes (189 participants). A copy of the instrument follows the report of this pilot study.

Comments from the first phase of pilot of 46 students:

Survey Items	Comments/ Problems	Remarks/ Solutions
The whole survey	Most students found survey too long	To shorten it to 20mins
5. How many graphic calculators (GC) do you have?	One respondent commented that the question is confusing or difficult to answer. This is open-ended question, so students key in the number ‘1’ or ‘one’ etc.	To make it multiple choice: 1, 2, 3 or more (Please specify the number)
9. In terms of GC skills, I consider myself… (Weak, Below Average, Average, Good, Excellent)	One respondent commented “How do you define average and where's the standard?”	Considered changing “Average” to “Average (compared with students in my cohort)”. Decided to keep item as it is since the others understood the item.
How do you work with GC? Indicate whether or not you like each of the following (Individual, Cooperate, or Compete). Which of the above do you most prefer? Please explain.	One respondent commented that “It's a freaking calculator, what's there to compete? -.- No comments”. Also, none of the respondents chose “compete” in the panel as their most preferred style.	There were still a number of students who said they preferred to compete when working with GC, even though they did not select it as their MOST preferred mode. This meant that they found the question meaningful. In consideration of the theory, the question was kept.

In the following pages, the modified and new items developed for (1) Connected and Separate Knowing, (2) Deep and Surface Approaches to Learning, (3) ways of interacting with calculators, and (4) VARK preferences, are presented in Tables A1, A3, A7 and A8 respectively. Each table is followed by a brief description of the process of reducing the items to eliminate poor performing items and to shorten the survey.

In summary, for Connected and Separate Knowing, duplicated items in Ocean’s (1998) questionnaire were removed and new items added to balance the number of Separate and Connected Knowing items. The ten items in Table A1 were reduced to eight after the first trial, and further reduced to six items in the second trial. In Table A3, the 22 items for Deep and Surface Approaches to Learning were modified to learning mathematics as a subject. This was reduced to 12 items after the first trial and to 8 items after the second trial. The 14 items of ways of interacting with calculators, seen in Table A7, were reduced to 12 items after the second trial. In Table A8, 13 modified items of Fleming's (2006) instrument were used based on his original complex scoring system which measured students' multiple modes of preferences. This instrument was reduced to six items with a new and simplified scoring system of measuring students' most preferred VARK mode.

(1) Connected and separate knowing.

Table A1

Separate and Connected Knowing Items (Adapted from Ocean, 1988)

	Items	Separate and Connected Knowing (SK and CK) codes	Source of items
1	Maths is mostly facts and procedures that have to be remembered.	SK1: Reliance on memory, facts, formulas and procedures.	Ocean (1998) Q1.
2	Maths makes you think creatively.	CK1: Creativity	Ocean (1998) Q2.
3	It is important in maths to know how different concepts and ideas relate to each other.	CK2: Conceptual understanding, inter-relatedness of ideas. This aspect of Connected Knowing was not found in Ocean's original items.	Item developed for this study in the pilot instrument
4	In maths, something is either right or it's wrong.	SK2: Certainty	Ocean (1998) Q6.
5	Good maths teachers show students several different ways to look at the same question.	CK3: Alternative paths to solution are possible, creativity.	Ocean (1998) Q7.
6	In maths you can be creative and discover things for yourself.	CK4: Creativity, Hypothesizing	Ocean (1998) Q9.
7	Some people are good at maths and some just aren't.	SK3: Certainty	Ocean (1998) Q10.
8	It is very important to know and understand the basis and derivation of maths formulas. (i.e. how a formula works and why)	CK5: Context, conceptual understanding. This aspect of Connected Knowing wasn't in Ocean's original items.	Item developed for this study in the pilot instrument.

	Items	Separate and Connected Knowing (SK and CK) codes	Source of items
9	To solve maths problems you have to be taught the right procedure or you can't do anything.	SK4: Certainty, maths is absolute and finite	Ocean (1998) Q12.
10	When I solve maths problems, I'm often stuck if I can't remember the next step.	SK5: Reliance on memory, facts, formulas and procedures.	Ocean (1998) Q15.

In the first trial (N = 46), the Cronbach's alphas were 0.583 for SK and 0.731 for CK. Exploratory factor analysis was conducted using Principal Component Analysis (PCA) with Varimax rotation and reliability tests. The Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO) value was 0.719, which was above 0.6, and the Bartlett's Test of Sphericity value was significant ($p < 0.001$), thus indicating that PCA was appropriate to be conducted. Through inspection of the scree plot, a 2-factor solution was used. The factors explained 54.1% of the variance. Through examining the PCA and reliability tests' results, items SK1 and CK2 were found to be poor performing and removed. From the second trial (N = 189), PCA with Varimax rotation was conducted. The KMO was 0.595 and Bartlett's Test of Sphericity was significant ($p < 0.001$). PCA yielded two factors accounting for 59.3% of the total variance, with one factor comprising of the three items for Connected Knowing (CK1, CK3, and CK4), and the other comprising the items for Separate Knowing (SK2, SK4, and SK5). The results of the Varimax oration are shown in Table A2. Through examining the PCA and reliability tests' results, SK3 and CK5 were further removed to further shorten the survey. The final Cronbach's alphas were 0.537 for SK and 0.684 for CK.

Table A2
Varimax Factor Loadings for Final CK and SK Items

	Factors and Loadings*	
Items	1	2
CK1 Maths makes you think creatively.	.828	
CK4 In maths you can be creative and discover things for yourself.	.827	
CK3 Good maths teachers show students several different ways to look at the same question.	.624	
SK4 To solve maths problems you have to be taught the right procedure or you can't do anything.		.776

SK5 When I solve maths problems, I’m often stuck if I can’t remember the next step.	-.365	.687
SK2 In maths, something is either right or it is wrong.		.644

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

* Loadings less than 0.300 are not shown.

(2) Deep and surface approach to learning

Table A3

Deep and Surface Approach Items (Adapted from Biggs, Kember, & Leung, 2004)

	Items from Learning Process Questionnaire (LPQ) (Biggs, Kember & Leung, 2004). All items modified to incorporate Mathematics as the subject in focus.	Deep and Surface Approaches Codes	Source and Modification
1	I find that at times studying maths makes me feel really happy and satisfied.	Deep motive (DM1): Intrinsic Interest	LPQ Q1
2	I try to relate what I have learned in maths to what I learn in other subjects.	Deep strategy (DS1): Relating Ideas	LPQ Q2
3	When I score poorly on a maths test, I worry a lot about how I will do on the next one. (Original: I am discouraged by a poor mark on a maths test and worry about how I will do on the next one.)	Surface motive (SM1): Fear of Failure	Modified from LPQ Q3 (double-barrelled)
4	I see no point in learning material which is not likely to be in the examination.	Surface strategy (SS1): Minimising scope of study	LPQ Q4
5	Any maths topic can be interesting if I understand it in depth. (Original: I feel that nearly any topic can be highly interesting once I get into it.)	Deep motive (DM2): Intrinsic Interest	Modified from LPQ Q5 (confusion of wording “get into it”)
6	I like to think deeply about how one maths concept relates to another. (Original: I like constructing theories to fit odd things together.)	Deep strategy (DS2): Relating Ideas	Modified from LPQ Q6 (confusion of wording “odd things”)
7	Even when I have studied hard for a maths test, I worry that I may not be able to do well in it.	Surface motive (SM2): Fear of Failure	LPQ Q7

	Items from Learning Process Questionnaire (LPQ) (Biggs, Kember & Leung, 2004). All items modified to incorporate Mathematics as the subject in focus.	Deep and Surface Approaches Codes	Source and Modification
8	As long as I feel I am doing enough to pass, I devote as little time to studying as I can. (Removed second sentence: There are many more interesting things to do.)	Surface strategy (SS2): Minimising scope of study	Shortened from LPQ Q8 (double-barrelled)
9	I work hard at my studies because I find mathematics interesting.	Deep motive (DM3): Intrinsic Interest	LPQ Q9
10	As I am reading, I try to relate new concepts and ideas to what I already know about that topic. (Original: I try to relate new material, as I am reading it, to what I already know on that topic.)	Deep strategy (DS3): Understanding	Rephrased LPQ Q10 (complicated phrasing)
11	Whether I like it or not, I can see that doing well in maths is a good way to get a well-paid job.	Surface motive (SM3): Aim for Qualification	LPQ Q11
12	I only do the exercises that my maths teacher tells me to do and nothing extra. (Original: I generally restrict my study to what is specifically set as I think it is unnecessary to do anything extra.)	Surface strategy (SS3): Minimising scope of study	Modified from LPQ Q12 (confusion of wording and double-barrelled)
13	I spend a lot of my free time finding out more about interesting topics which have been discussed in maths classes.	Deep motive (DM4): Commitment to work	LPQ Q13
14	When I read a maths textbook or notes, I try to understand the meaning behind what is written. (Original: When I read a textbook, I try to understand what the author means.)	Deep strategy (DS4): Understanding	Modified from LPQ Q14 (adapted to maths context.)
15	I want to do well in my A-Levels (or VCE) so that I can get a better job in the future. (Original: I intend to do well in my A-Levels because I feel that I will then be able to get a better job.)	Surface motive (SM4): Aim for Qualification	Modified from LPQ Q15 (complicated phrasing)
16	I don’t need to study maths in depth in order to get by at school. (Original: I find it is not helpful to study topics in depth. You don’t really need to know much in order to get by in most topics.)	Surface strategy (SS4): Minimising scope of study	Modified from LPQ Q16 (double-barrelled)
17	I come to most maths classes with questions in mind that I want answering.	Deep motive (DM5): Commitment to work	LPQ Q17

	Items from Learning Process Questionnaire (LPQ) (Biggs, Kember & Leung, 2004). All items modified to incorporate Mathematics as the subject in focus.	Deep and Surface Approaches Codes	Source and Modification
18	I learn maths formulae by heart even if I don't understand them. (Original: I learn some things (e.g. formulas) by rote, going over and over them until I know them by heart even if I do not understand them.)	Surface strategy (SS5): Memorisation	Modified from LPQ Q18 (complicated phrasing)
19	I frequently think about how to solve maths problems even while travelling or lying on my bed. (Original: I find I am continually going over my school work in my mind at times like when I am on the bus, walking, or lying in bed, and so on.)	Deep motive (DM6): Commitment to work	Modified from LPQ Q19 (complicated wording)
20	I find the best way to pass maths examinations is to try to remember answers to likely questions.	Surface strategy (SS6): Memorisation	LPQ Q20
21	I like to study a maths topic thoroughly before I am satisfied. (Original: I like to do enough work on a topic so that I can form my own conclusions before I am satisfied.)	Deep motive (DM7): Commitment to work	Modified from LPQ Q21 (double-barrelled)
22	I find I can get by in most maths tests and examinations by memorising key formulae and methods rather than trying to understand them. (Original: I find I can get by in most assessment by memorising key sections rather than trying to understand them.)	Surface strategy (SS7): Memorisation	Modified from LPQ Q22 (adapted to maths context)

After the first trial, using principal component analysis (PCA) and reliability tests, 12 items were selected – 6 for Deep Approach (DM1, DM3, DM6, DS1, DS2, and DS3) with Cronbach's alpha of 0.818, and 6 items for Surface Approach (SM1, SM2, SS1, SS5, SS6, and SS7) with Cronbach's alpha of 0.637.

Table A4

Varimax Factor Loadings for Final DA and SA Items

Items	Factors and Loadings*	
	1	2
DM3 I work hard at my studies because I find mathematics interesting.	.792	
DS1 I try to relate what I have learned in maths to what I learn in other subjects.	.753	
DS3 As I am reading, I try to relate new concepts and ideas to what I already know about that topic.	.715	

Items	Factors and Loadings*	
	1	2
DM6 I frequently think about how to solve maths problems even while on the bus or lying on my bed.	.678	
SM2 Even when I have studied hard for a maths test, I worry that I may not be able to do well in it.		.836
SM1 When I score poorly on a maths test, I worry a lot about how I will do on the next one.	.335	.734
SS5 I learn maths formulas by heart even if I don't understand them.		.675
SS1 I see no point in learning material which is not likely to be in the examination.	-.427	.492

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

* Loadings less than 0.300 are not shown.

After the second trial, PCA with Varimax rotation yielded two factors accounting for 55.3% of the total variance, with one factor comprising of the four items for Deep Approach, and the other comprising the items for Surface Approach. The KMO value was 0.704 and the Bartlett's test of sphericity was significant ($p < 0.0001$), indicating that the factor analysis was appropriate to be conducted. The results of the PCA Varimax rotation are shown in Table A4. Through examining the PCA and reliability tests' results, the instrument was reduced to 8 items (DM3, DM6, DS1, DS3, SM1, SM2, SS1, SS5) with Cronbach's alphas as 0.742 for Deep Approach and 0.624 for Surface Approach.

(3) Combined ways of knowing and learning mathematics

From the research literature, the two constructs – ways of knowing and approaches to learning - are related. How students approach learning is affected by their beliefs about knowing (e.g., Crawford et al., 1994, 1995, 1998). The data was analysed to see if the two instruments could be merged. Initial results from performing the PCA with Varimax rotation indicated four components, with in the seven items for Connected Knowing (CK) and Deep Approach (DA) cross-loading to two components and the seven items for Separate Knowing (SK) and Surface Approach (SA) mainly cross-loading to the other two components (see Table A5). The KMO value was 0.792, and Bartlett's test of sphericity was significant ($p <0.0001$), indicating that PCA was suitable to be conducted. Two items, SS1 and SS5, also cross-loaded onto the CK-DA component. Inspection of the scree plot also suggested that there might be only two components (see Figure A1). When two factors were set in the PCA, the items of CK and DA formed one component, and items for SK and SA formed the other (see Table A6), with some cross-loadings for SS1, SM1 and SK5. Since the three items still loaded higher onto the SK-SA component, there was evidence that a two-factor instrument for measuring ways of knowing and learning mathematics (CK-DA and SK-SA) was better than two separate instruments. The reliability coefficients of the two new factors were better than that for the individual subscales. The Cronbachs' alpahs for CK-DA and SK-SA were 0.814 and 0.691 respectively.

Table A5

Initial Varimax Factor Loadings for the CK, SK, DA, and SA Items, Showing Four Components

Items		Component			
		1	2	3	4
DM6	I frequently think about how to solve maths problems even while on the bus or lying on my bed.	.849			
DM3	I work hard at my studies because I find mathematics interesting.	.818			
CK1	Maths makes you think creatively.	.620	.538		
DS1	I try to relate what I have learned in maths to what I learn in other subjects.	.596	.351		
CK3	Good maths teachers show students several different ways to look at the same question.		.695		
CK4	In maths you can be creative and discover things for yourself.	.412	.690		
DS3	As I am reading, I try to relate new concepts and ideas to what I already know about that topic.	.417	.550		
SS1	I see no point in learning material which is not likely to be in the examination.		-.540		.322
SM2	Even when I have studied hard for a maths test, I worry that I may not be able to do well in it.			.857	
SM1	When I score poorly on a maths test, I worry a lot about how I will do on the next one.			.744	
SS5	I learn maths formulas by heart even if I don't understand them.			.664	
SK2	In maths, something is either right or it is wrong.				.795
SK4	To solve maths problems you have to be taught the right procedure or you can't do anything.			.325	.629
SK5	When I solve maths problems, I'm often stuck if I can't remember the next step.		-.312	.418	.488

Items	Component			
	1	2	3	4

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

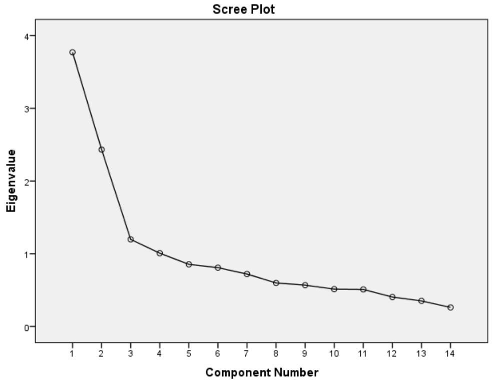


Figure A1. Scree plot of the PCA conducted on the CK, SK, DA and SA items.

Table A6

Final Varimax Factor Loadings for the CK, SK, DA, and SA Items, Using Two Components

Items		Component	
		1	2
CK1	Maths makes you think creatively.	.810	
DM3	I work hard at my studies because I find mathematics interesting.	.768	
CK4	In maths you can be creative and discover things for yourself.	.744	
DS1	I try to relate what I have learned in maths to what I learn in other subjects.	.695	
DS3	As I am reading, I try to relate new concepts and ideas to what I already know about that topic.	.688	
DM6	I frequently think about how to solve maths problems even while on the bus or lying on my bed.	.608	
CK3	Good maths teachers show students several different ways to look at the same question.	.367	
SM2	Even when I have studied hard for a maths test, I worry that I may not be able to do well in it.		.739
SM1	When I score poorly on a maths test, I worry a lot about how I will do on the next one.	.332	.695
SK5	When I solve maths problems, I’m often stuck if I can’t remember the next step.	-.317	.634
SK4	To solve maths problems you have to be taught the right procedure or you can’t do anything.		.623
SS5	I learn maths formulas by heart even if I don't understand them.		.586
SS1	I see no point in learning material which is not likely to be in the examination.	-.392	.467
SK2	In maths, something is either right or it is wrong.		.330

Items	Component	
	1	2

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

(4) Ways of interacting with the calculator

There was no existing instrument. The researcher developed the instrument based on Geiger's (2005) description of students' representative statements corresponding to the sub-categories of each metaphor (calculator as Master, Servant, Partner and Extension of Self).

Table A7

Ways of Interacting with Calculator Items (Adapted from Framework by Geiger, 2005)

	Reworded items	GC as Master/ Servant/ Partner/ Extension of Self Codes	Original representative students' comment (Geiger, 2005)
1	I do not know why sometimes the GC does not give me the answer that I want.	GC as Master: Lack of technology skills (M1)	Technology can also cause confusion if you are not competent enough with the machine to understand why it may make mistakes.
2	I usually just follow the steps taught when using the GC to solve problems, and do not really understand the maths involved.	GC as Master: Mathematical dependence (M2)	Sometimes you can rely on it too much. And then not understand the full process.
3	I find the GC confusing because it uses different conventions and symbols than normal maths.	GC as Master: Unfamiliar conventions (M3)	Technology can often confuse the issue because it uses different conventions and symbols than normal.
4	I use the GC for basic calculations because it is more accurate than working by hand.	GC as Servant: Reduces errors in calculation (S1)	Less chance of error in calculations.
5	I use the GC for calculations because it is faster than working by hand.	GC as Servant: Performs calculation more quickly and efficiently (S2)	I much prefer technology because of its efficiency. The work can be done much quicker.

	Reworded items	GC as Master/ Servant/ Partner/ Extension of Self Codes	Original representative students' comment (Geiger, 2005)
6	I use the GC to look after large calculations and tedious repetitive methods.	GC as Servant: Looking after large calculation and tedious repetitive methods (S3)	It gives you something to blame when things go wrong. It does all the small calculations you can't be bothered to do.
7	I copy the graphs on the GC in my answers because they are more accurate than drawing by hand.	GC as Servant: Presentation (S4)	Displays everything in a neater and more succinct manner. You can illustrate equations, graphs, etc.
8	I usually use the GC to help me check my answers.	GC as Servant: Checking answers (S5)	When graphs or functions are needed or to check answers of integration or derivative.
9	I use the GC to solve problems that I usually cannot do by hand.	GC as Partner: Scaffolding (P1)	Can do problems that I usually cannot do myself because of lack of basic skills.
10	I use the GC to help me simplify steps in a complex problem.	GC as Partner: Looking after cognitive load (P2)	It quite often helps to simplify steps in a complex problem.
11	I use the GC to help me look at the same problem or concept in different ways (e.g., using graphs and tables to understand the process of differentiation in addition to the algebraic method).	GC as Partner: Different perspectives (P3)	With the learning of integration and differentiation, the seeing of the examples graphically helps [me] understand the whole concept, and thus makes you think on a wide scale (graphically and manually) when doing a problem.
12	The GC helps me understand concepts better.	GC as Partner: Facilitating understanding (P4)	The study of chaos theory would have been virtually impossible as the graphs enable us to visualise the functions more clearly.
13	I often use the GC to explore maths even before the teacher tells me to.	GC as Extension of Self: Freedom (E1)	You have much more freedom. (Technology also offers students the opportunity of exploring, more freely, conjectures that are the product of their intuition. p. 375)

	Reworded items	GC as Master/ Servant/ Partner/ Extension of Self Codes	Original representative students' comment (Geiger, 2005)
14	The GC allows me to expand my ideas and to do the work my own way.	GC as Extension of Self: Mind Expander (E2)	Technology allows you to expand ideas and to do the work your own way. Think differently? No – act differently, yes. To work out unfamiliar problems you must first figure out what type of process you need to solve it, and then execute the process. What you use is irrelevant.

Since the instrument was newly developed, the items were not modified in the first trial when the sample size was small. At the second trial, based on the 178 valid responses for the items, reliability tests and principal component analysis (PCA) were conducted. Two poor performing items were eliminated (P1 and S5), and three components were found instead of four. The items for Calculator as Partner and as Extension of Self formed one factor (labelled Calculator as Collaborator). The resulting Cronbach's alphas were 0.542 for Calculator as Master, 0.664 for Calculator as Servant, and 0.788 for Calculator as Collaborator. Further details are reported in Tan (2009).

(5) Visual, Aural, Read-Write, and Kinesthetic modes (VARK)

In Fleming's (2006) instrument for high school students (p. 127), there were 13 items. The list of items used in the pilot study first trial (valid N = 41) is shown in Table A8. The items were rephrased in first person's perspective, and modified to fit the relevant context (e.g., "CD player" changed to "mp3 player", "project for English class" changed to "mathematics project", "summer program" changed to "holiday program").

Table A8
VARK Instrument Used in Pilot First Trial

	VARK items adapted from Fleming (2006, p. 127)*
1	When I have a few minutes with nothing better to do I would be more likely to - stare into space, or doodle. (V) - talk to myself or to others. (A)

	VARK items adapted from Fleming (2006, p. 127)*
	- pick something up to read. (R)
	- do something practical, like fixing something, clean-up, re-organize my drawers or room (K)
2	I am not sure whether the word should be spelled ‘dependent’ or ‘dependant’. I would
	- picture the word in my mind and choose by the way it looks. (V)
	- sound them out in my mind or out loud. (A)
	- look them up in the dictionary. (R)
	- write both words down on paper and choose one. (K)
3	I want to plan a surprise party for a friend. I would
	- imagine the party happening. (V)
	- talk about it on the phone or text others. (A)
	- make lists of what to do and what to buy for the party. (R)
	- invite friends and just let it happen. (K)
4	I am going to make something special for my family. I would
	- look for ideas and plans in books and magazines. (V)
	- talk it over with my friends. (A)
	- find written instructions to make it. (R)
	- make something I have made before. (K)
5	I have been selected as a leader for a holiday program. This is interesting for my friends. I would
	- show them the map of where it will be held and photos about it. (V)
	- describe the activities I will be doing in the program. (A)
	- show them the list of activities in the program. (R)
	- start practising the activities I will be doing in the program. (K)
6	I am about to buy a new mp3 player. Other than price, what would most influence my decision is
	- it is the latest design and looks good. (V)
	- the salesperson telling me about it. (A)
	- reading the details about its features. (R)
	- trying it out. (K)
7	I like websites that have
	- interesting design and visual effects. (V)
	- audio channels for music, chat and discussion. (A)
	- interesting written information and articles. (R)
	- things I can click and do. (K)
8	I am about to try to hook up my parents’ new computer. I would
	- follow the diagrams that show how it is done. (V)
	- phone, text or email a friend and ask how to do it. (A)
	- read the instructions that came with it. (R)
	- unpack the box and start putting the pieces together (K)
9	I need to give directions to someone to go to a house nearby. I would

	VARK items adapted from Fleming (2006, p. 127)*
	- draw a map on a piece of paper or get a map online (V) - tell them the directions. (A) - write down the directions as a list. (R) - walk them there. (K)
10	I have a problem with my knee. I would prefer the doctor to - show me a diagram of what is wrong. (V) - describe to me what is wrong. (A) - give me an article or brochure that explains knee injuries. (R) - demonstrate what is wrong using a model of a knee. (K)
11	A new movie has arrived in town. I would be most influenced to go watch it because - I saw a preview of it. (V) - I heard friends talking about it. (A) - I read a movie review about it. (R) - it is similar to other movies I liked. (K)
12	I need to do a maths project about a story of a famous mathematician. I would prefer to - design or draw a diagram depicting the story. (V) - read out a version of the story to the class. (A) - read some articles related to the story and then write my own article about the story. (R) - act out a scene from the story. (K)
13	I prefer a maths teacher who likes to use - diagrams or graphs or pictures. (V) - class discussions or online discussions. (A) - textbooks or handouts or notes. (R) - hands-on activities or outdoor maths investigations. (K)

* All items were modified to incorporate Mathematics as the subject in focus. In each item, the VARK codes are found in brackets at the end of each option. Options were randomised in the pilot study.

Participants are scored for each mode (V, A, R, & K) they selected in each item. The scores are added up over the 13 items to give the scores for V, A, R, and K. The mode with the highest score is the preference mode. To find if there are any other modes that are preferred, a stepping distance is calculated based on the total VARK scores (see Table A9). If the distance between the highest score and the next highest is within the stepping distance, then the next highest mode is also a preference; and so on. Hence, for example, someone with scores V = 7, A = 8, R = 1, K = 5 will have a total VARK score of 21, so the person will have an Aural preference (highest score). And since the difference between the V score and the A score is 1 (within the stepping distance), the person will have AV as their modal preference. The difference between the K score and V score is more than the stepping distance, so K is not a modality preference.

Table A9
Stepping Distance According to Different Total VARK Scores (Fleming 2006, p. 6)

Total of VARK scores	Stepping Distance
14-21	1
22-27	2
28-32	3
More than 32	4

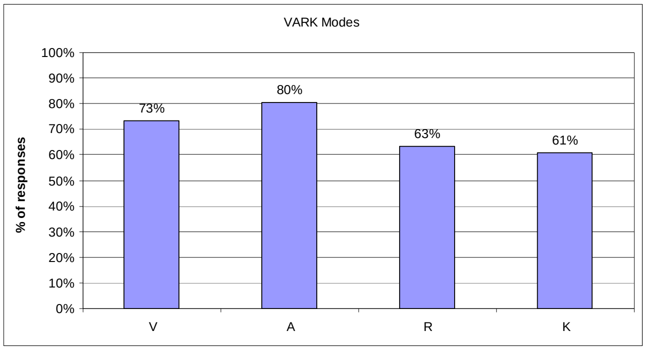


Figure A2. Percentage of students with VARK modes as one of their preference modes.

Data from the pilot study (valid N = 41) indicated that there was a high percentage of student respondents who prefer Aural mode (80%), followed by the Visual mode (73%). This is different from the results from Fleming's data of participants that used the instrument online (Fleming, 2006, p. 9), which showed that highest percentage of students having Kinesthetic (29.7%) and Read/Write modes (29.7%). There were lower percentages of students with visual (16.1%) and aural (24.5%) preferences. In Table A10, the frequency and percentage of students with each of the 15 different combination of single and multiple modal preferences is shown. There was also a higher percentage of repondents having multiple modes (73%) compared to Fleming's data (59%).

Table A10

Frequency and Percentages of Students for Each VARK Combination.

	Pilot Study (n = 41)		Fleming's online data (2006)
	Number	Percentage	n = 12873
Multiple Preferences			
VARK	16	39%	34.2%
VRK	0	0%	2.4%
VAK	4	10%	2.8%
VAR	6	15%	1.1%
ARK	1	2%	6.7%
VR	0	0%	1.1%
VA	0	0%	0.6%
VK	1	2%	2.5%
AK	2	5%	4.5%
RK	0	0%	3.4%
AR	0	0%	3.4%
Subtotal	30	73%	62.7%
Single Preferences			
V	3	7%	3.4%
A	4	10%	7.5%
R	3	7%	14.6%
K	1	2%	11.8%
Subtotal	11	27%	37.3%

Among the repondents with multiple preferences, most students have all four VARK preferences (39%), which is consistent with Fleming's data (34.2%). The higher percentages of participants with multiple preferences (73%) is also consistent with Fleming's data (62.7%).

Within the single preference respondents, the mode with highest percentage is Aural (11%), compared to Flemings' data (Read/Write, 14.6%). It is interesting to note that although Kinesthetic is one of common modes for respondents with multiple preferences, it is not their strongest mode. Only one participant has single Kinesthetic mode, and only 17% has Kinethetic as one of their most preferred modes, compared to the other modes (see Figure A3).

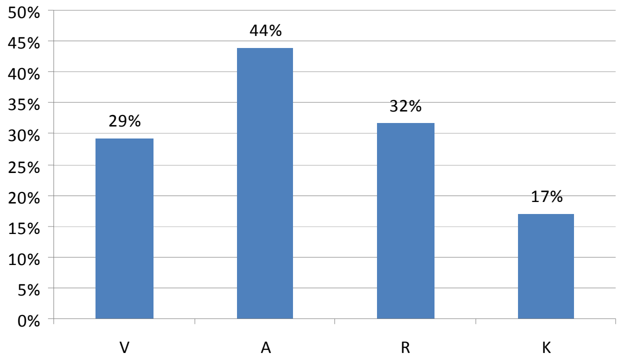


Figure A3. Percentages of students with their most preferred VARK mode.

Validity and reliability of VARK instrument. Fleming stated in his book that because his items are not Likert-like but have multiple choices per item, the VARK constructs cannot be tested like the other psychometric tests. However, there is strong theoretical foundation to the formation of the instruments (see Fleming 2006 for a discussion of VARK and other learning style frameworks such as Kolb’s experiential learning and Myer Briggs Type Indicator), and there were anecdotal agreement by students when they went through the training on learning preferences after doing the VARK survey (Fleming, 2006). Comparison of the pilot study responses with Fleming’s online data in the above section shows some consistency between the modified instrument used and Fleming’s original instrument. Assuming that there is face and content validity in measuring VARK modes using the modified instrument, the reliability of each item is discussed next.

In order to reduce the number of items, two methods are used to find the better performing items to include in the main study. Firstly for each of the modes, a 2x2 matrix is formed as follows, using Visual mode and item 1 as an example (see Table A11). In Table A11, the percentage of the total number of respondents in the two shaded cells ([00]+[11]) indicate a certain amount of “reliability” and “predictability” of the item. The higher the percentage, the more “reliable” the item is in predicting the final modal preference. In the data shown in Table A13, those with 60% or higher are highlighted in yellow.

Table A11

Example of Method 1: Counting Number of Participants

	Modal preference after scoring (e.g. Visual)	
	0 = Visual not one of the preferred modes (NonV)	1 = Visual is one of the preferred modes (V)
Item 1 0 = Visual is not one of the prefence indicated by participants in the item	[00] Number of participants who did not indicate Visual preference in item 1, and did not have Visual preference in their final score.	Number of participants who did not indicate Visual preference in item 1, but have Visual preference in their final score.
1 = Visual is one of the preference indicated	Number of participants who indicated Visual preference in item 1, but did not have Visual preference in their final score.	[11] Number of participants who indicated Visual preference in item 1, and have Visual preference in their final score.

Besides counting the percentages, the ratio of respondents indicating non-visual versus visual preference for each item is calculated. This is compared with the ratio of that of the final visual preference. If the ratio for an item is close to the ratio of the final preference, then the ratio is highlighted in orange (see Table A13). The definition of “close” is when the number of respondents falls within ±3 of that of final preference. The number 3 was arbitarily chosen, since 1 was too small and 5 was too large for the small sample size. For example, there were 11 respondents with final non-visual preference and 30 with visual preference. The ratio for the final V preference is (NonV/V) = 11/30 = 0.367. So the ratios that were considered close to 0.367 fell between (11-3)/(30+3) = 0.242 and (11+3)/(30-3) = 0.519. Only for item 11 that the ratio of NonV/V that fell between this range, and this ratio is highlighted in orange.

The acceptable range of ratios are found in the table A12.

Table A12

Acceptable Range of Ratios for Final VARK Scores

	V		A		R		K
Min	0.242	Min	0.139	Min	0.414	Min	0.464
Max	0.519	Max	0.367	Max	0.783	Max	0.864

Table A13 *Data Counted Using SPSS Crosstabs for VARK Final Preference, by Modes (N = 41)*

		V		% 00+11	A		% 00+11	R		% 00+11	K		% 00+11
		0 (NonV)	1 (V)	Ratio = NonV/V	0 (NonA)	1 (A)	Ratio = NonA/A	0 (NonR)	1 (R)	Ratio = NonR/R	0 (NonK)	1 (K)	Ratio = NonK/K
Number of respondents:		11	30	0.367	8	33	0.242	15	26	0.577	16	25	0.640
Item 1	0	9	15	59%	7	21	46%	10	11	61%	13	13	61%
Nothing to do	1	2	15	1.412	1	12	2.154	5	15	1.050	3	12	1.733
Item 2	0	9	20	46%	7	27	32%	10	13	56%	12	11	63%
Spelling 'dependent'	1	2	10	2.417	1	6	4.857	5	13	1.278	4	14	1.278
Item 3	0	10	16	59%	7	11	71%	12	9	71%	15	22	44%
Plan surprise party	1	1	14	1.733	1	22	0.783	3	17	1.050	1	3	9.250
Item 4	0	7	14	56%	5	18	49%	14	21	46%	14	18	51%
Make something special	1	4	16	1.050	3	15	1.278	1	5	5.833	2	7	3.556
Item 5	0	11	22	46%	3	11	61%	10	14	54%	13	20	44%
Leader of holiday program	1	0	8	4.125	5	22	0.519	5	12	1.412	3	5	4.125
Item 6	0	7	12	61%	8	30	27%	8	8	63%	15	14	63%
Buy new mp3 player	1	4	18	0.864	0	3	12.667	7	18	0.640	1	11	2.417
Item 7	0	6	10	63%	7	15	61%	14	12	68%	15	18	54%
I prefer websites…	1	5	20	0.640	1	18	1.158	1	14	1.733	1	7	4.125
Item 8	0	10	11	71%	8	28	32%	13	9	73%	12	8	71%
Setup parents’ computer	1	1	19	1.050	0	5	7.200	2	17	1.158	4	17	0.952
Item 9	0	11	24	41%	3	3	80%	15	24	41%	12	11	63%
Give directions	1	0	6	5.833	5	30	0.171	0	2	19.500	4	14	1.278
Item 10	0	10	21	46%	3	7	71%	15	22	46%	15	12	68%
Problem with knee	1	1	9	3.100	5	26	0.323	0	4	9.250	1	13	1.929
Item 11	0	6	6	73%	5	9	71%	9	12	56%	13	19	46%
Watch new movie	1	5	24	0.414	3	24	0.519	6	14	1.050	3	6	3.556
Item 12	0	9	24	34%	8	25	39%	12	17	51%	11	8	68%
Maths project	1	2	5	4.714	0	8	4.125	3	9	2.417	5	17	0.864
Item 13	0	10	13	66%	6	22	41%	12	11	66%	11	10	63%
I prefer Maths teacher…	1	1	17	1.278	2	11	2.154	3	15	1.278	5	15	1.050

As can be seen from table A13, items 6, 7, 8, 9, 10, 11, and 13 seemed to have higher reliability based on the two methods. However, the level of reliability is low – mainly only 3 cells out of the total possible of 8 percentage and ratio cells are highlighted. One reason for the poor reliability could be that way that the final VARK preference is calculated based on stepping distance. If a student scores 9, 7, 5, 3 for VARK, her total score is 22, and the stepping distance is 2 (see table A9). So her highest preference is V, and she is scored as VARK multi-modal with all the modes. But the difference between her highest score (9 for V) and lowest score (3 for K) is 6, which is very large (in fact, twice her K score!). Hence, the predictability of the items to the lowest scoring mode is low. And since there is a high percentage of students with multiple preference (73%), there will be a number of such instances that affected the reliability of the items. To reduce the interference of low scoring modes being counted due to stepping distance, the same procedure is repeated but using the *most preferred VARK mode* instead of final VARK preference scored (using stepping distance). The resulting Table A15 shows that the items are more "reliable" in predicting the most preferred VARK mode, with a larger proportion of the percentages being 60% and higher. There are also more items with ratios similar to the most preferred VARK mode ratios, highlighted in orange. The range of ratios used for each of VARK are calculated in the same way using ±3 and can be found in Table A14.

Table A14
Acceptable Range of Ratios for Most Preferred VARK Mode.

	V		A		R		K
Min	1.733	Min	0.952	Min	1.563	Min	2.727
Max	3.556	Max	1.733	Max	3.100	Max	7.200

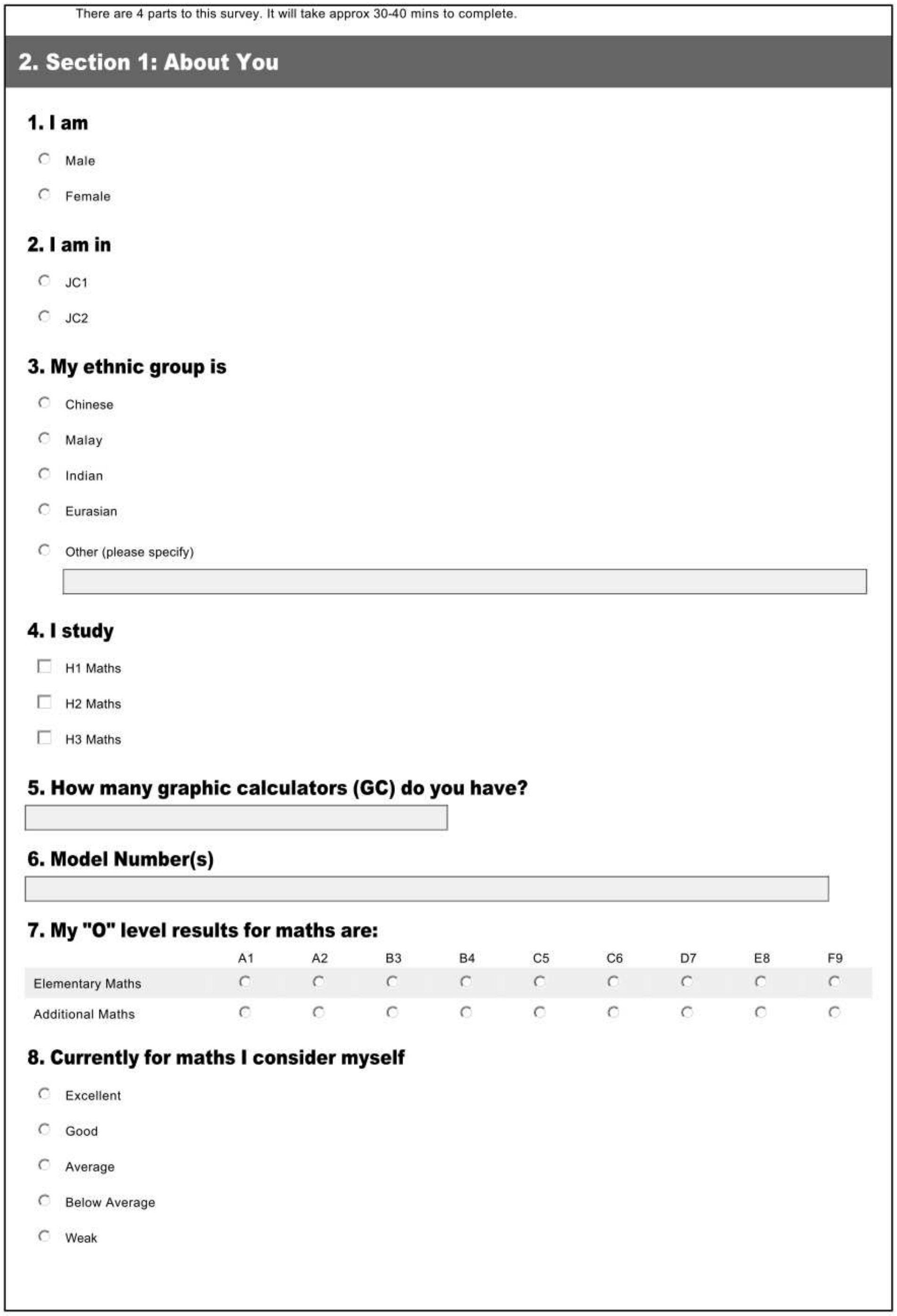
From Table A15, it can be seen that item 7 has the highest "predictability", with 7 out of 8 of the percentage and ratio cells highlighted. This is followed by item 4, with 6 out of 8 cells highlighted. Items 3, 5, 10 and 13 have 4 out of 8 cells highlighted. These six items (3, 4, 5, 7, 10 and 13) will be used in the final survey and the the most preferred modal preference(s) will be used as a measure of students' modal preference. It is interesting to note that when the calculation of the VARK preference using Fleming's method (with stepping distance) was used, the lowest "predictor" is Item 12 (about doing a Maths project), which shows only 34% “predictability” for visual and 39% for aural. However, when the most preferred VARK preference is used instead, item 12 did not show such “unreliability”. Perhaps the item prompted students to respond according to their most preferred VARK preference, rather than their other multi-modal preferences. Nevertheless, this item was included in the final survey. More research might be needed to further improve the validity and reliability of the items.

In summary, the 13 items of Fleming’s (2006) instrument have been modified and from analyses of the items using two methods, seven items were selected. They are items 3, 4, 5, 7, 10, 12 and 13. The scoring method was simplified from having to calculate stepping distances between the VARK scores, to using the preference mode(s) with the highest score as their most preferred VARK modal preference.

Table A15 *Data Counted Using SPSS Crosstabs for Most Preferred VARK Mode, by Modes (N = 41)*

		V Strongest		% 00+11	A Strongest		% 00+11	R Strongest		% 00+11	K Strongest		% 00+11
		0 (NonV)	1 (V)	Ratio = NonV/V	0 (NonA)	1 (A)	Ratio = NonA/A	0 (NonR)	1 (R)	Ratio = NonR/R	0 (NonK)	1 (K)	Ratio = NonK/K
Number of respondents:		29	12	2.417	23	18	1.278	28	13	2.154	33	8	4.125
Item 1	0	20	4	68%	19	9	68%	16	5	59%	23	3	68%
Nothing to do	1	9	8	1.412	4	9	2.154	12	8	1.050	10	5	1.733
Item 2	0	20	9	56%	19	15	54%	19	4	68%	19	4	56%
Spelling 'dependent'	1	9	3	2.417	4	3	4.857	9	9	1.278	14	4	1.278
Item 3	0	21	5	68%	13	5	63%	16	5	59%	30	7	76%
Plan surprise party	1	8	7	1.733	10	13	0.783	12	8	1.050	3	1	9.250
Item 4	0	17	4	61%	15	8	61%	25	10	68%	27	5	73%
Make something special	1	12	8	1.050	8	10	1.278	3	3	5.833	6	3	3.556
Item 5	0	24	9	66%	8	6	49%	19	5	66%	27	6	71%
Leader of holiday program	1	5	3	4.125	15	12	0.519	9	8	1.412	6	2	4.125
Item 6	0	16	3	61%	21	17	54%	12	4	51%	24	5	66%
Buy new mp3 player	1	13	9	0.864	2	1	12.667	16	9	0.640	9	3	2.417
Item 7	0	15	1	63%	15	7	63%	21	5	71%	27	6	71%
I prefer websites…	1	14	11	0.640	8	11	1.158	7	8	1.733	6	2	4.125
Item 8	0	17	4	61%	21	15	59%	19	3	71%	18	2	59%
Setup parents’ computer	1	12	8	1.050	2	3	7.200	9	10	1.158	15	6	0.952
Item 9	0	26	9	71%	6	0	59%	28	11	73%	18	5	51%
Give directions	1	3	3	5.833	17	18	0.171	0	2	19.500	15	3	1.278
Item 10	0	23	8	66%	7	3	54%	26	11	68%	24	3	71%
Problem with knee	1	6	4	3.100	16	15	0.323	2	2	9.250	9	5	1.929
Item 11	0	10	2	49%	11	3	63%	15	6	54%	27	5	73%
Watch new movie	1	19	10	0.414	12	15	0.519	13	7	1.050	6	3	3.556
Item 12	0	25	8	71%	18	51	51%	22	7	68%	17	2	56%
Maths project	1	4	4	4.125	5	3	8.625	6	6	2.417	16	6	0.864
Item 13	0	19	4	66%	19	9	68%	19	4	68%	19	2	61%
I prefer Maths teacher…	1	10	8	1.278	4	9	2.154	9	9	1.278	14	6	1.050

Original instrument used in pilot study



There are 4 parts to this survey. It will take approx 30-40 mins to complete.

2. Section 1: About You

1. I am

○ Male

○ Female

2. I am in

○ JC1

○ JC2

3. My ethnic group is

○ Chinese

○ Malay

○ Indian

○ Eurasian

○ Other (please specify)

4. I study

☐ H1 Maths

☐ H2 Maths

☐ H3 Maths

5. How many graphic calculators (GC) do you have?

6. Model Number(s)

7. My "O" level results for maths are:

	A1	A2	B3	B4	C5	C6	D7	E8	F9
Elementary Maths	○	○	○	○	○	○	○	○	○
Additional Maths	○	○	○	○	○	○	○	○	○

8. Currently for maths I consider myself

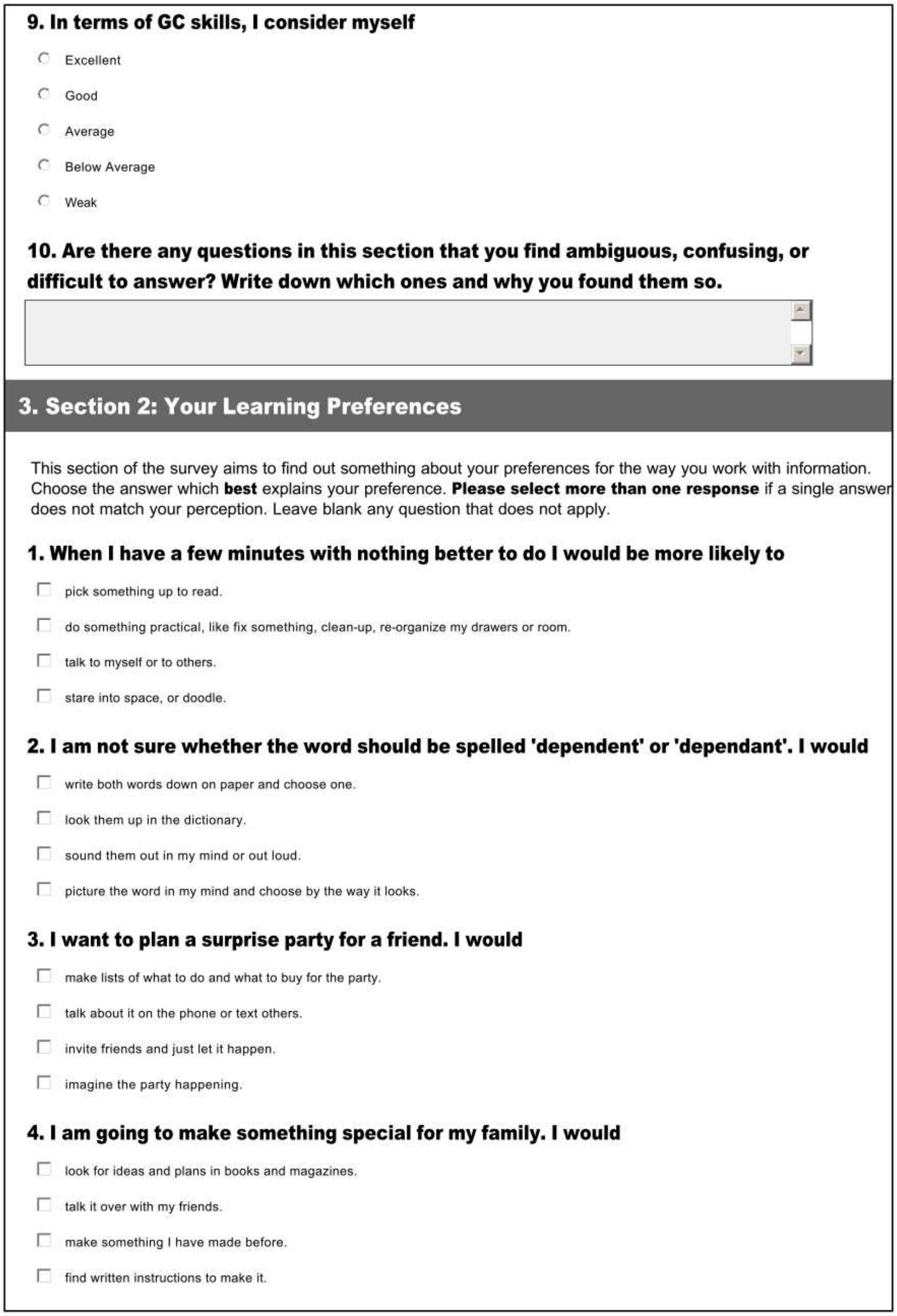
○ Excellent

○ Good

○ Average

○ Below Average

○ Weak



9. In terms of GC skills, I consider myself

○ Excellent

○ Good

○ Average

○ Below Average

○ Weak

10. Are there any questions in this section that you find ambiguous, confusing, or difficult to answer? Write down which ones and why you found them so.

3. Section 2: Your Learning Preferences

This section of the survey aims to find out something about your preferences for the way you work with information. Choose the answer which **best** explains your preference. **Please select more than one response** if a single answer does not match your perception. Leave blank any question that does not apply.

1. When I have a few minutes with nothing better to do I would be more likely to

☐ pick something up to read.

☐ do something practical, like fix something, clean-up, re-organize my drawers or room.

☐ talk to myself or to others.

☐ stare into space, or doodle.

2. I am not sure whether the word should be spelled 'dependent' or 'dependant'. I would

☐ write both words down on paper and choose one.

☐ look them up in the dictionary.

☐ sound them out in my mind or out loud.

☐ picture the word in my mind and choose by the way it looks.

3. I want to plan a surprise party for a friend. I would

☐ make lists of what to do and what to buy for the party.

☐ talk about it on the phone or text others.

☐ invite friends and just let it happen.

☐ imagine the party happening.

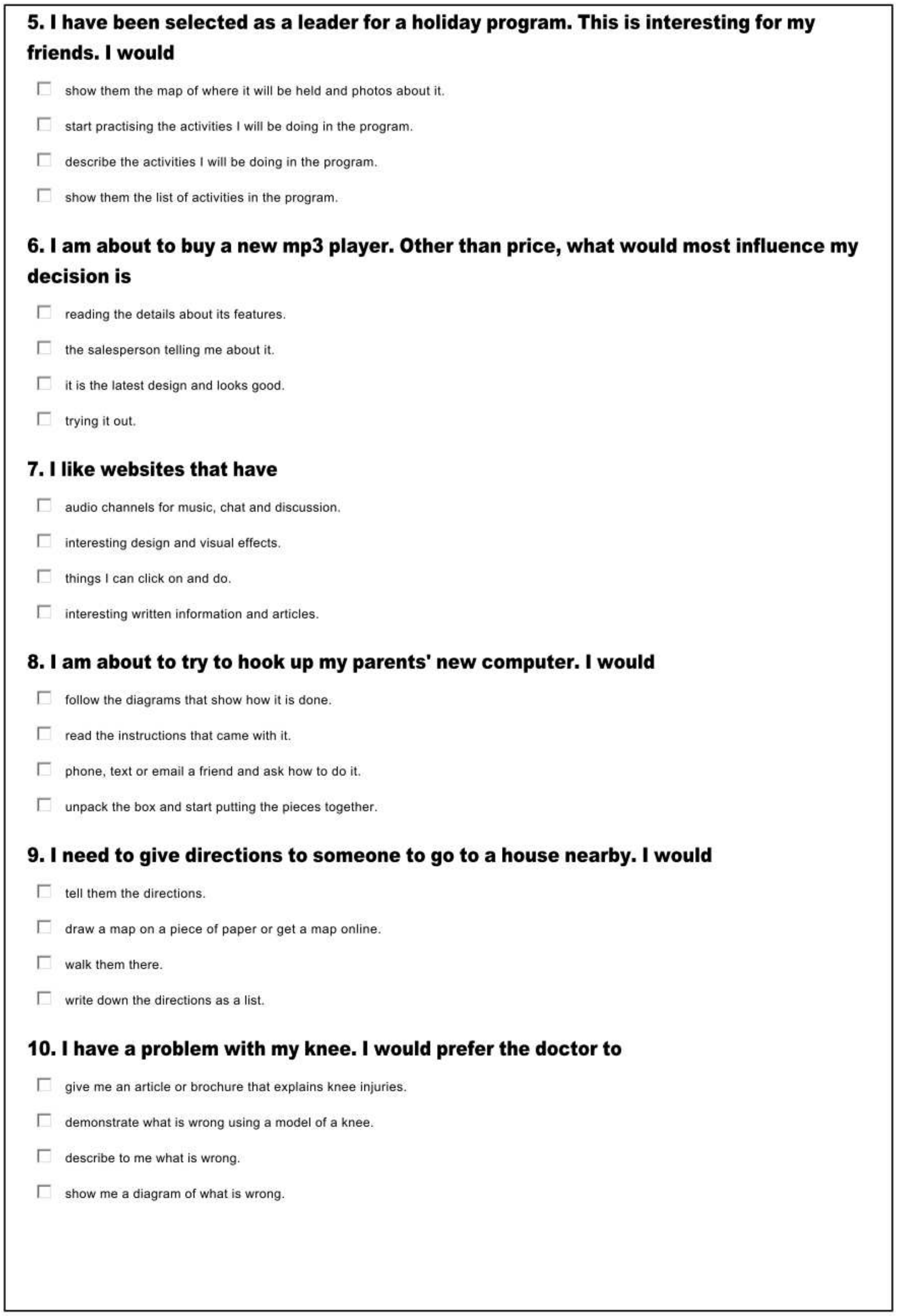
4. I am going to make something special for my family. I would

☐ look for ideas and plans in books and magazines.

☐ talk it over with my friends.

☐ make something I have made before.

☐ find written instructions to make it.



5. I have been selected as a leader for a holiday program. This is interesting for my friends. I would

☐ show them the map of where it will be held and photos about it.

☐ start practising the activities I will be doing in the program.

☐ describe the activities I will be doing in the program.

☐ show them the list of activities in the program.

6. I am about to buy a new mp3 player. Other than price, what would most influence my decision is

☐ reading the details about its features.

☐ the salesperson telling me about it.

☐ it is the latest design and looks good.

☐ trying it out.

7. I like websites that have

☐ audio channels for music, chat and discussion.

☐ interesting design and visual effects.

☐ things I can click on and do.

☐ interesting written information and articles.

8. I am about to try to hook up my parents' new computer. I would

☐ follow the diagrams that show how it is done.

☐ read the instructions that came with it.

☐ phone, text or email a friend and ask how to do it.

☐ unpack the box and start putting the pieces together.

9. I need to give directions to someone to go to a house nearby. I would

☐ tell them the directions.

☐ draw a map on a piece of paper or get a map online.

☐ walk them there.

☐ write down the directions as a list.

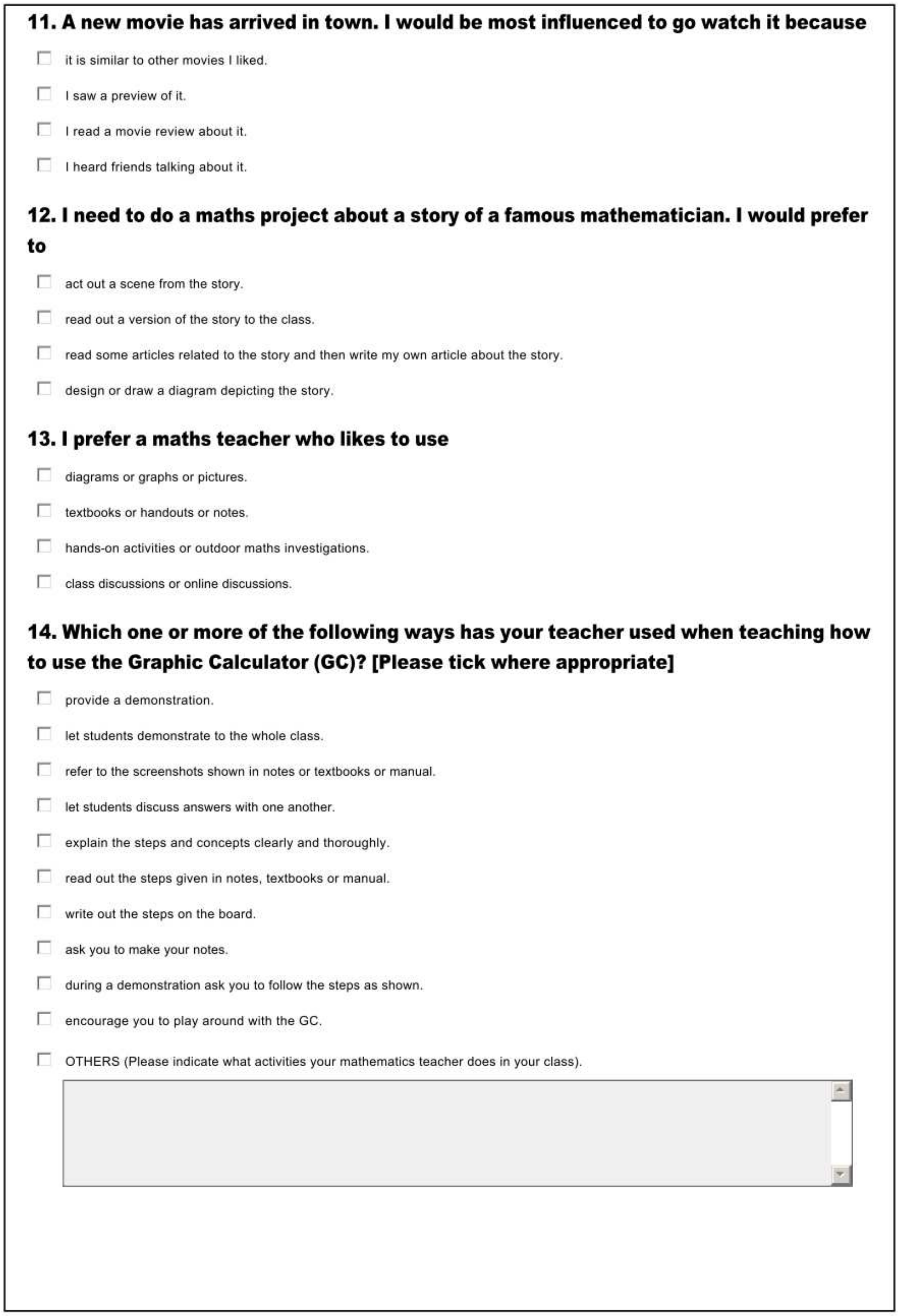
10. I have a problem with my knee. I would prefer the doctor to

☐ give me an article or brochure that explains knee injuries.

☐ demonstrate what is wrong using a model of a knee.

☐ describe to me what is wrong.

☐ show me a diagram of what is wrong.



11. A new movie has arrived in town. I would be most influenced to go watch it because

☐ it is similar to other movies I liked.
☐ I saw a preview of it.
☐ I read a movie review about it.
☐ I heard friends talking about it.

12. I need to do a maths project about a story of a famous mathematician. I would prefer to

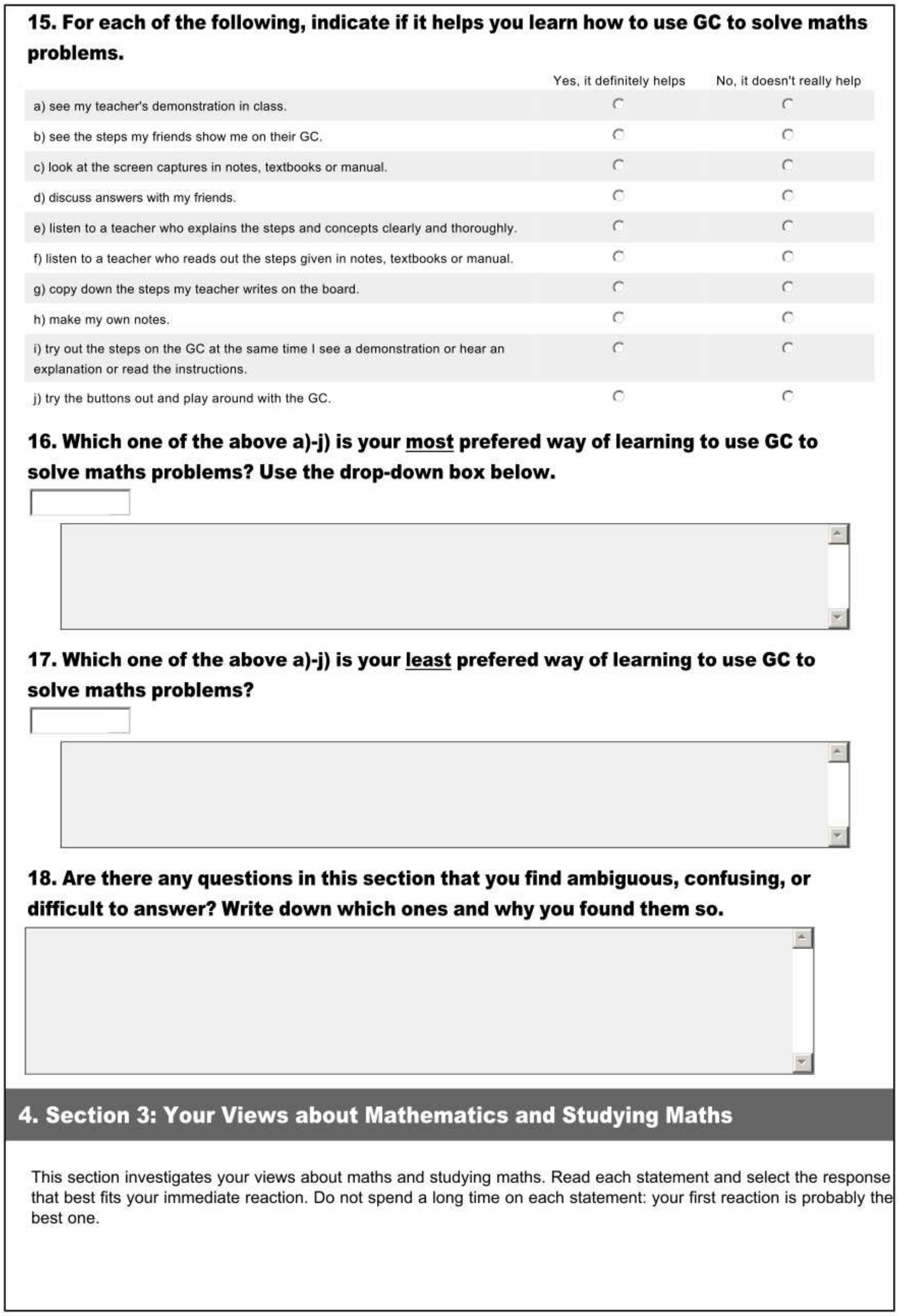
☐ act out a scene from the story.
☐ read out a version of the story to the class.
☐ read some articles related to the story and then write my own article about the story.
☐ design or draw a diagram depicting the story.

13. I prefer a maths teacher who likes to use

☐ diagrams or graphs or pictures.
☐ textbooks or handouts or notes.
☐ hands-on activities or outdoor maths investigations.
☐ class discussions or online discussions.

14. Which one or more of the following ways has your teacher used when teaching how to use the Graphic Calculator (GC)? [Please tick where appropriate]

☐ provide a demonstration.
☐ let students demonstrate to the whole class.
☐ refer to the screenshots shown in notes or textbooks or manual.
☐ let students discuss answers with one another.
☐ explain the steps and concepts clearly and thoroughly.
☐ read out the steps given in notes, textbooks or manual.
☐ write out the steps on the board.
☐ ask you to make your notes.
☐ during a demonstration ask you to follow the steps as shown.
☐ encourage you to play around with the GC.
☐ OTHERS (Please indicate what activities your mathematics teacher does in your class).



15. For each of the following, indicate if it helps you learn how to use GC to solve maths problems.

	Yes, it definitely helps	No, it doesn't really help
a) see my teacher's demonstration in class.	○	○
b) see the steps my friends show me on their GC.	○	○
c) look at the screen captures in notes, textbooks or manual.	○	○
d) discuss answers with my friends.	○	○
e) listen to a teacher who explains the steps and concepts clearly and thoroughly.	○	○
f) listen to a teacher who reads out the steps given in notes, textbooks or manual.	○	○
g) copy down the steps my teacher writes on the board.	○	○
h) make my own notes.	○	○
i) try out the steps on the GC at the same time I see a demonstration or hear an explanation or read the instructions.	○	○
j) try the buttons out and play around with the GC.	○	○

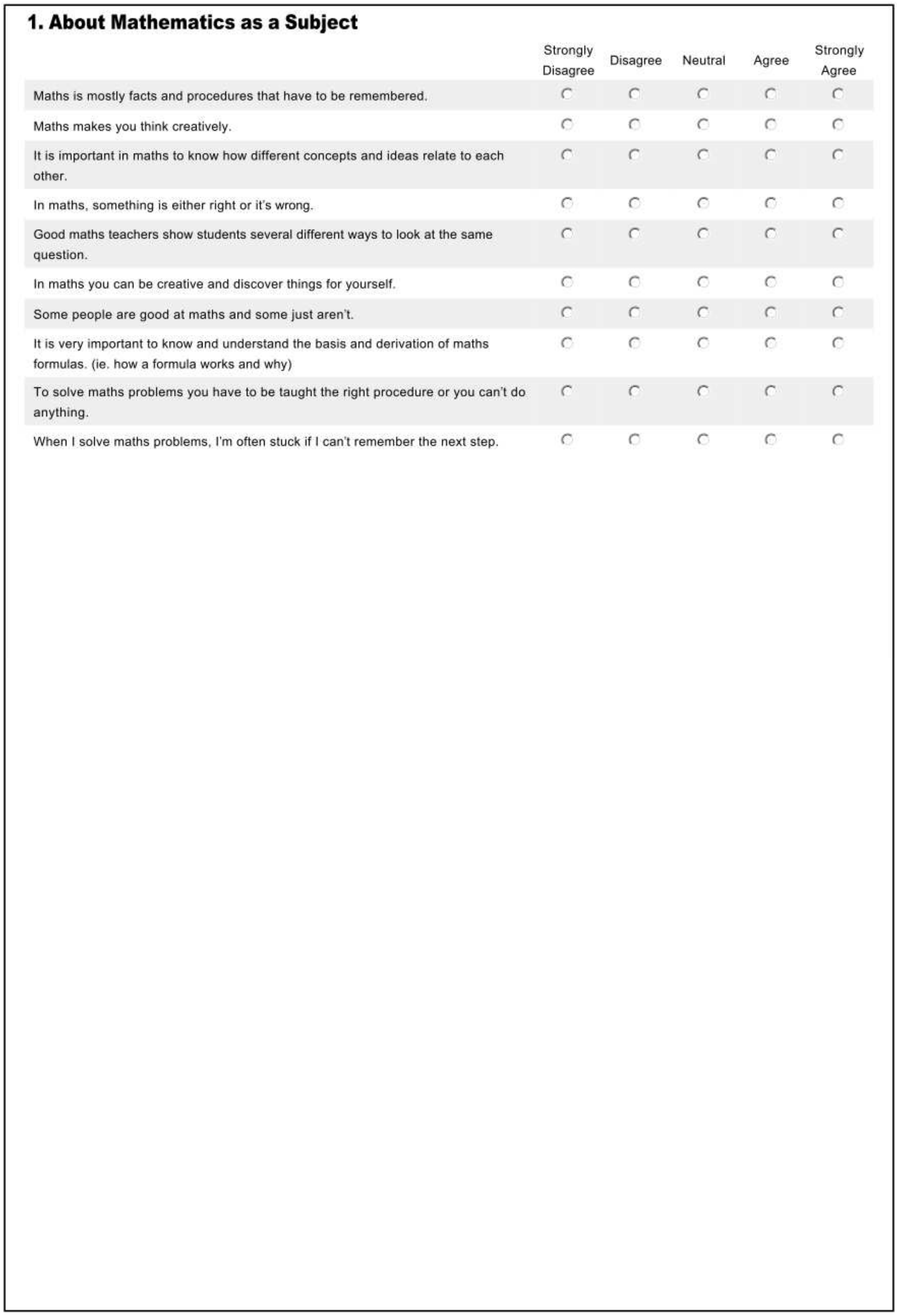
16. Which one of the above a)-j) is your <u>most</u> prefered way of learning to use GC to solve maths problems? Use the drop-down box below.

17. Which one of the above a)-j) is your <u>least</u> prefered way of learning to use GC to solve maths problems?

18. Are there any questions in this section that you find ambiguous, confusing, or difficult to answer? Write down which ones and why you found them so.

4. Section 3: Your Views about Mathematics and Studying Maths

This section investigates your views about maths and studying maths. Read each statement and select the response that best fits your immediate reaction. Do not spend a long time on each statement: your first reaction is probably the best one.



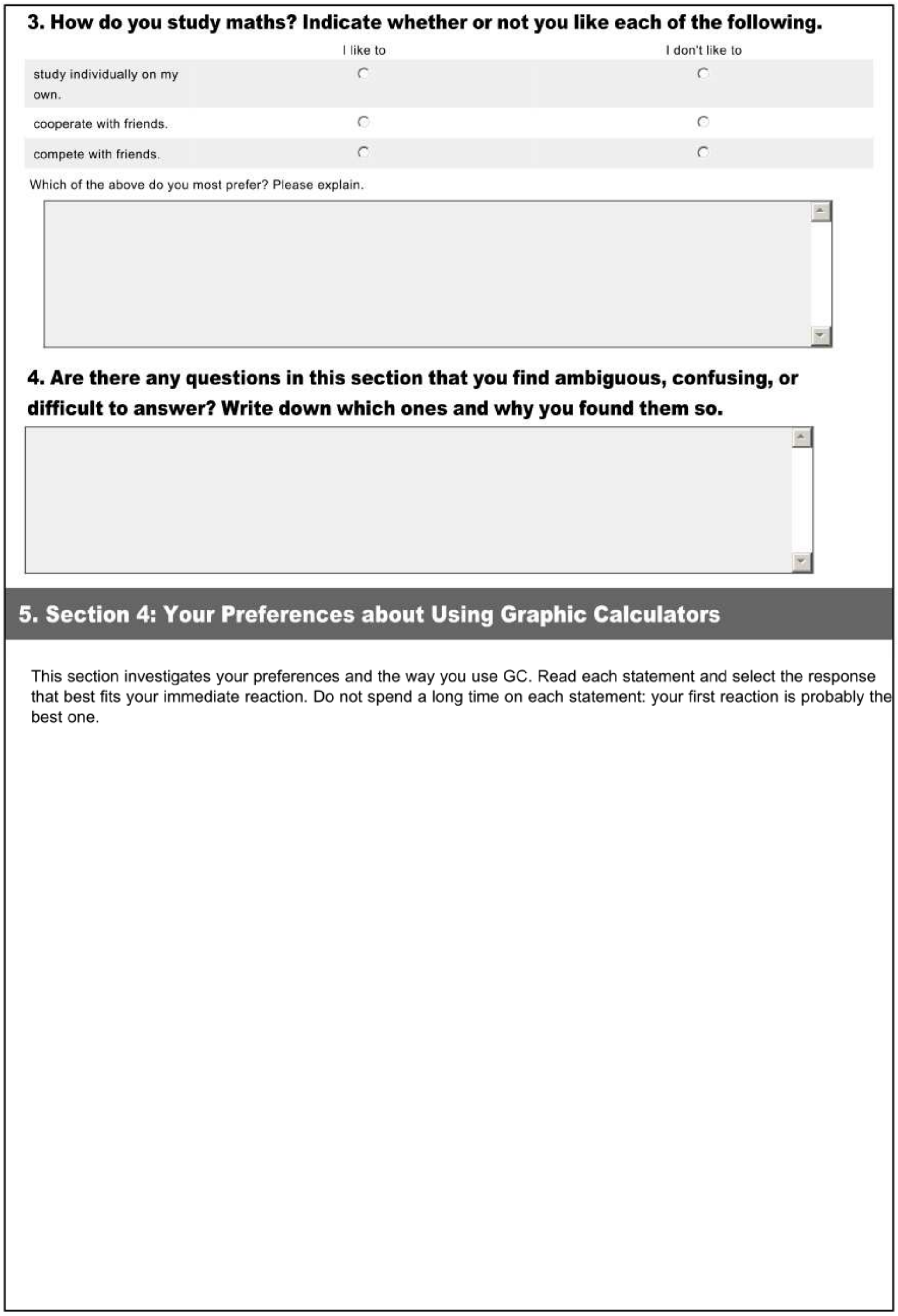
1. About Mathematics as a Subject

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Maths is mostly facts and procedures that have to be remembered.	○	○	○	○	○
Maths makes you think creatively.	○	○	○	○	○
It is important in maths to know how different concepts and ideas relate to each other.	○	○	○	○	○
In maths, something is either right or it's wrong.	○	○	○	○	○
Good maths teachers show students several different ways to look at the same question.	○	○	○	○	○
In maths you can be creative and discover things for yourself.	○	○	○	○	○
Some people are good at maths and some just aren't.	○	○	○	○	○
It is very important to know and understand the basis and derivation of maths formulas. (ie. how a formula works and why)	○	○	○	○	○
To solve maths problems you have to be taught the right procedure or you can't do anything.	○	○	○	○	○
When I solve maths problems, I'm often stuck if I can't remember the next step.	○	○	○	○	○

2. About How You Study Maths

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I find that at times studying maths makes me feel really happy and satisfied.	○	○	○	○	○
I try to relate what I have learned in maths to what I learn in other subjects.	○	○	○	○	○
When I score poorly on a maths test, I worry a lot about how I will do on the next one.	○	○	○	○	○
I see no point in learning material which is not likely to be in the examination.	○	○	○	○	○
Any maths topic can be interesting if I understand it in depth.	○	○	○	○	○
I like to think deeply about how one maths concept relates to another.	○	○	○	○	○
Even when I have studied hard for a maths test, I worry that I may not be able to do well in it.	○	○	○	○	○
As long as I feel I am doing enough to pass, I devote as little time to studying as I can.	○	○	○	○	○
I work hard at my studies because I find mathematics interesting.	○	○	○	○	○
As I am reading, I try to relate new concepts and ideas to what I already know about that topic.	○	○	○	○	○
Whether I like it or not, I can see that doing well in maths is a good way to get a well-paid job.	○	○	○	○	○
I only do the exercises that my maths teacher tells me to do and nothing extra.	○	○	○	○	○
I spend a lot of my free time finding out more about interesting topics which have been discussed in maths classes.	○	○	○	○	○
When I read a maths textbook or notes, I try to understand the meaning behind what is written.	○	○	○	○	○
I want to do well in my A-Levels so that I can get a better job in the future.	○	○	○	○	○
I don't need to study maths in depth in order to get by at school.	○	○	○	○	○
I come to most maths classes with questions in mind that I want answering.	○	○	○	○	○
I learn maths formulas by heart even if I don't understand them.	○	○	○	○	○
I frequently think about how to solve maths problems even while on the bus or lying on my bed.	○	○	○	○	○
I find the best way to pass maths examinations is to try to remember answers to likely questions.	○	○	○	○	○
I like to study a maths topic thoroughly before I am satisfied.	○	○	○	○	○
I find I can get by in most maths tests and examinations by memorising key formulas and methods rather than trying to understand them.	○	○	○	○	○

Your Preference when Studying Maths



3. How do you study maths? Indicate whether or not you like each of the following.

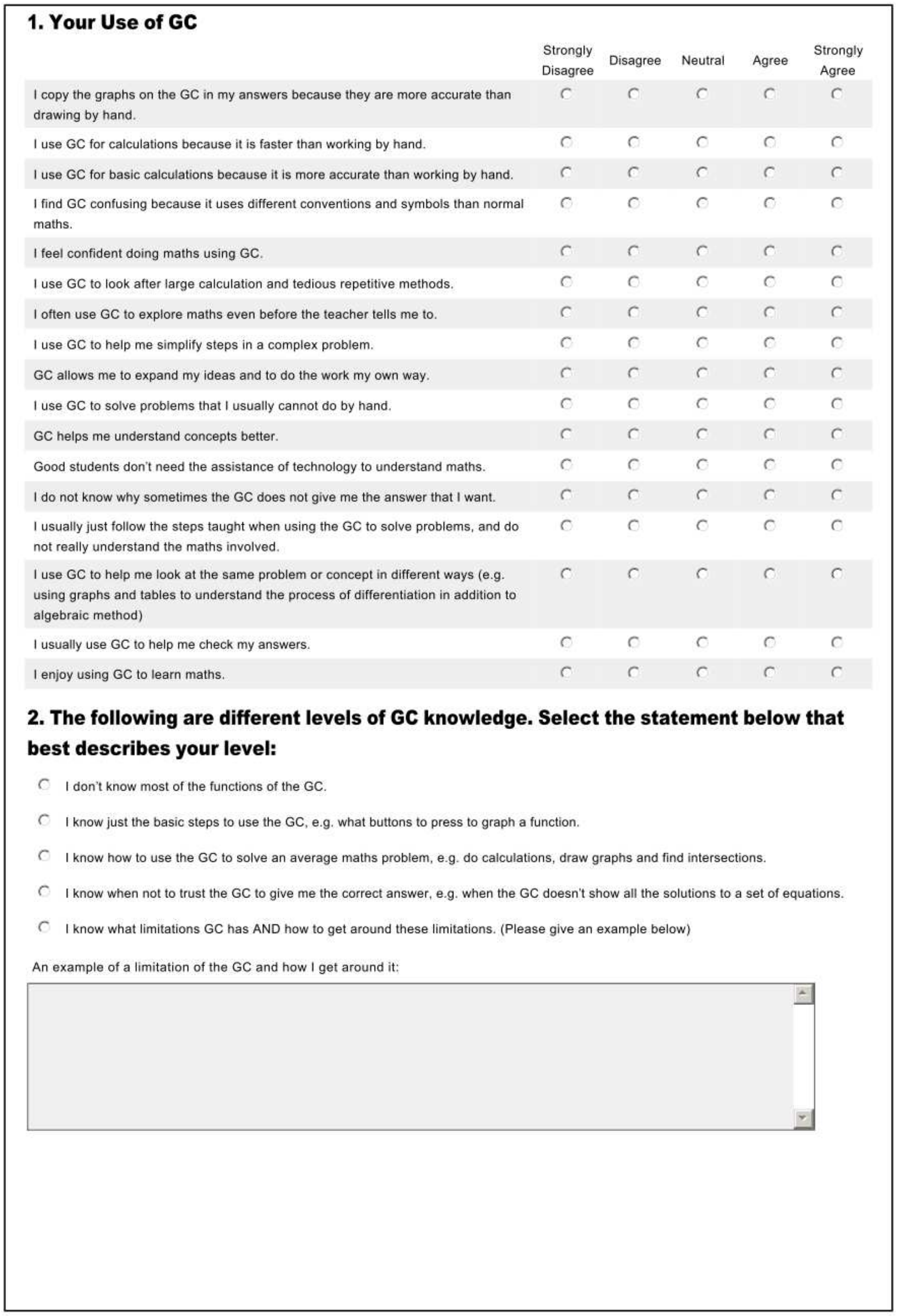
	I like to	I don't like to
study individually on my own.	○	○
cooperate with friends.	○	○
compete with friends.	○	○

Which of the above do you most prefer? Please explain.

4. Are there any questions in this section that you find ambiguous, confusing, or difficult to answer? Write down which ones and why you found them so.

5. Section 4: Your Preferences about Using Graphic Calculators

This section investigates your preferences and the way you use GC. Read each statement and select the response that best fits your immediate reaction. Do not spend a long time on each statement: your first reaction is probably the best one.



1. Your Use of GC

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I copy the graphs on the GC in my answers because they are more accurate than drawing by hand.	○	○	○	○	○
I use GC for calculations because it is faster than working by hand.	○	○	○	○	○
I use GC for basic calculations because it is more accurate than working by hand.	○	○	○	○	○
I find GC confusing because it uses different conventions and symbols than normal maths.	○	○	○	○	○
I feel confident doing maths using GC.	○	○	○	○	○
I use GC to look after large calculation and tedious repetitive methods.	○	○	○	○	○
I often use GC to explore maths even before the teacher tells me to.	○	○	○	○	○
I use GC to help me simplify steps in a complex problem.	○	○	○	○	○
GC allows me to expand my ideas and to do the work my own way.	○	○	○	○	○
I use GC to solve problems that I usually cannot do by hand.	○	○	○	○	○
GC helps me understand concepts better.	○	○	○	○	○
Good students don't need the assistance of technology to understand maths.	○	○	○	○	○
I do not know why sometimes the GC does not give me the answer that I want.	○	○	○	○	○
I usually just follow the steps taught when using the GC to solve problems, and do not really understand the maths involved.	○	○	○	○	○
I use GC to help me look at the same problem or concept in different ways (e.g. using graphs and tables to understand the process of differentiation in addition to algebraic method)	○	○	○	○	○
I usually use GC to help me check my answers.	○	○	○	○	○
I enjoy using GC to learn maths.	○	○	○	○	○

2. The following are different levels of GC knowledge. Select the statement below that best describes your level:

○ I don't know most of the functions of the GC.

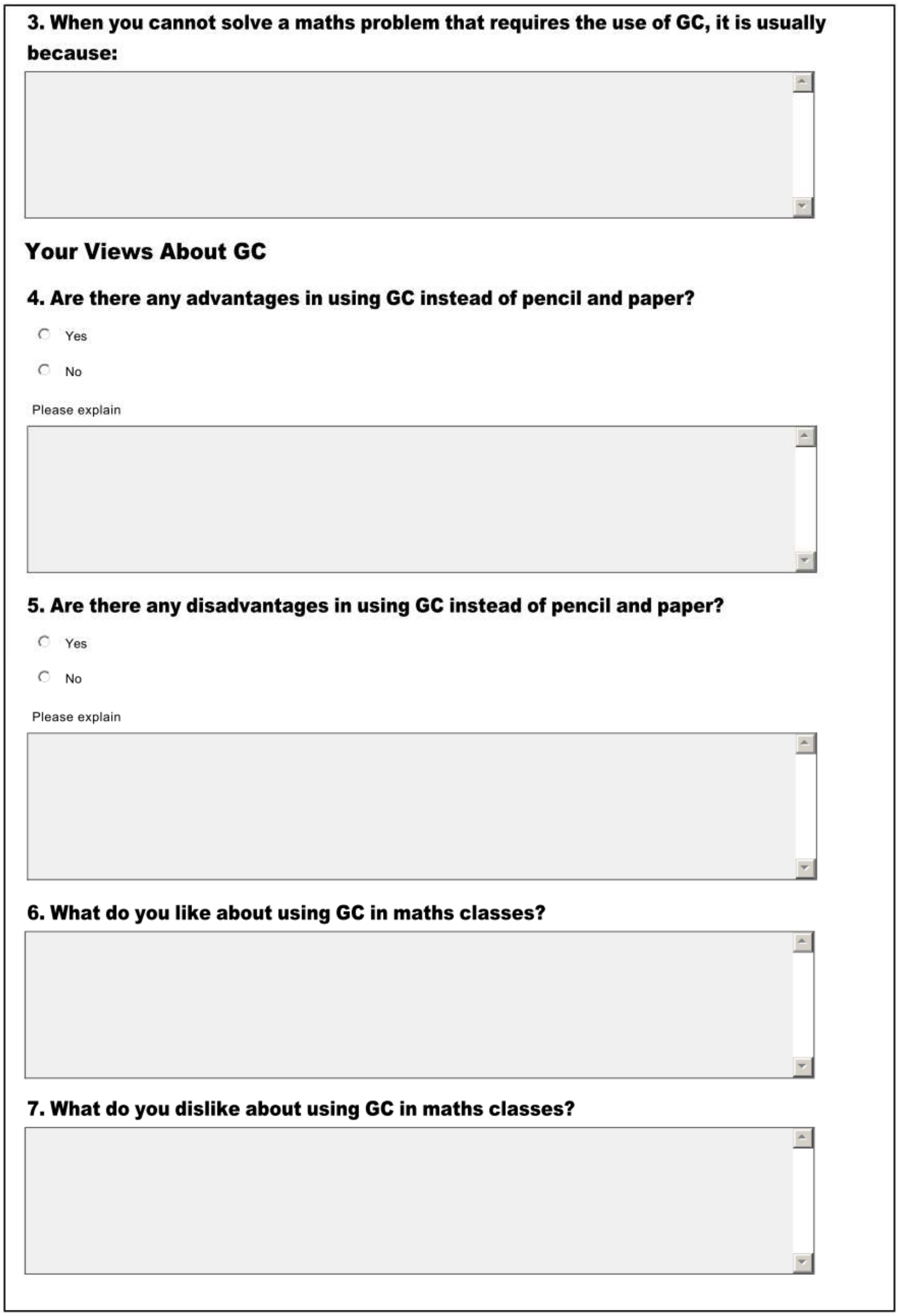
○ I know just the basic steps to use the GC, e.g. what buttons to press to graph a function.

○ I know how to use the GC to solve an average maths problem, e.g. do calculations, draw graphs and find intersections.

○ I know when not to trust the GC to give me the correct answer, e.g. when the GC doesn't show all the solutions to a set of equations.

○ I know what limitations GC has AND how to get around these limitations. (Please give an example below)

An example of a limitation of the GC and how I get around it:



3. When you cannot solve a maths problem that requires the use of GC, it is usually because:

Your Views About GC

4. Are there any advantages in using GC instead of pencil and paper?

○ Yes

○ No

Please explain

5. Are there any disadvantages in using GC instead of pencil and paper?

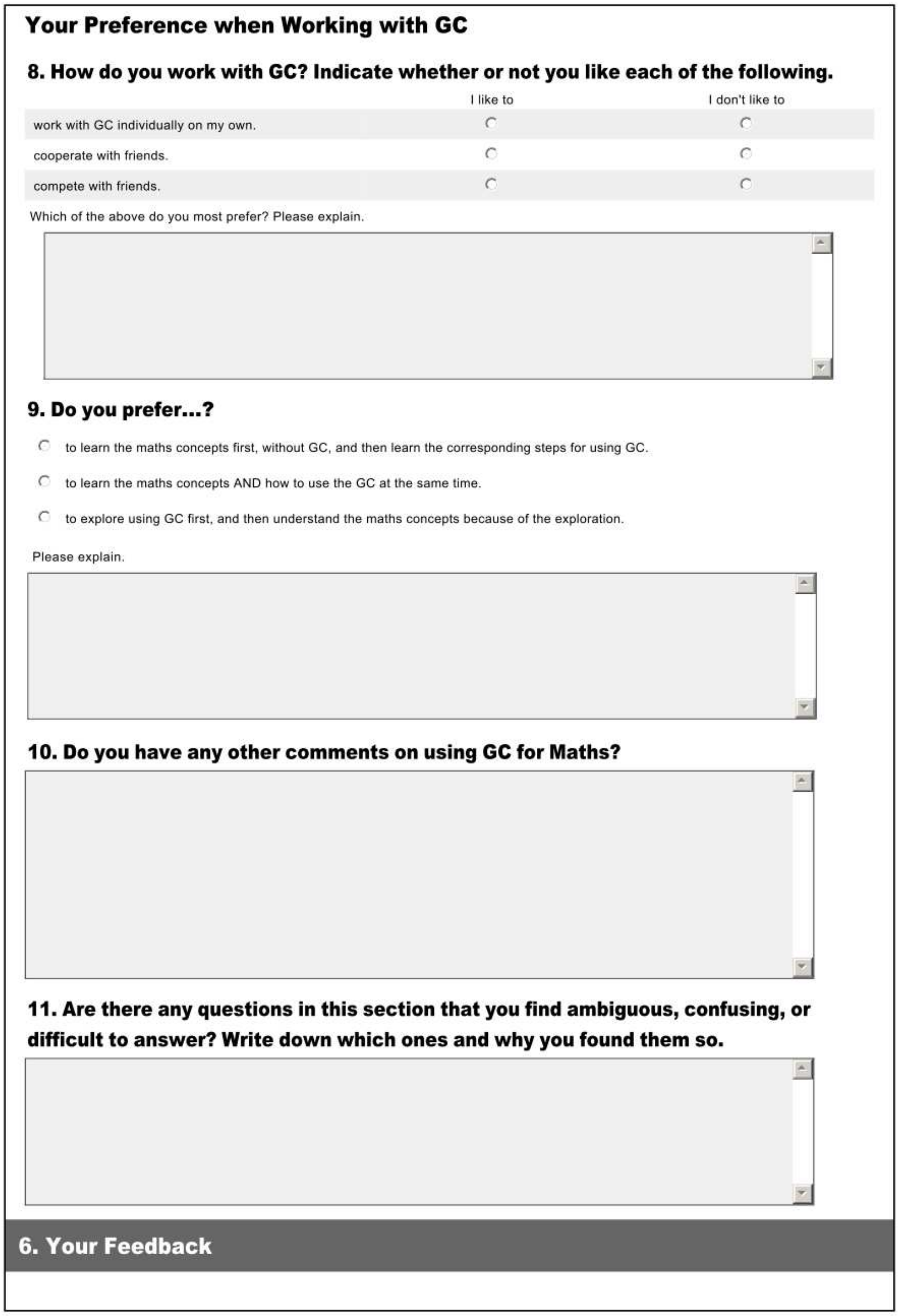
○ Yes

○ No

Please explain

6. What do you like about using GC in maths classes?

7. What do you dislike about using GC in maths classes?



Your Preference when Working with GC

8. How do you work with GC? Indicate whether or not you like each of the following.

	I like to	I don't like to
work with GC individually on my own.	○	○
cooperate with friends.	○	○
compete with friends.	○	○

Which of the above do you most prefer? Please explain.

9. Do you prefer...?

○ to learn the maths concepts first, without GC, and then learn the corresponding steps for using GC.

○ to learn the maths concepts AND how to use the GC at the same time.

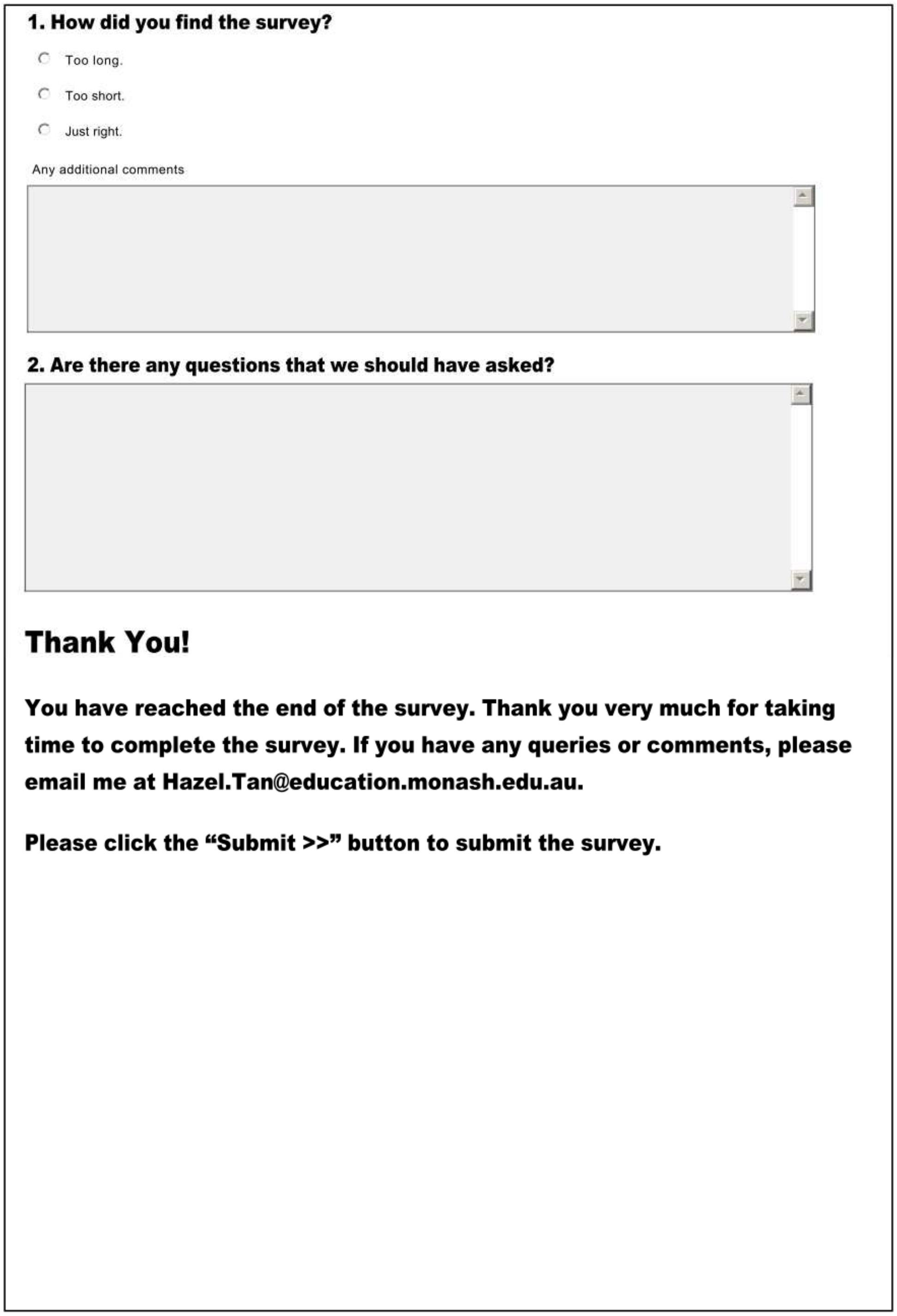
○ to explore using GC first, and then understand the maths concepts because of the exploration.

Please explain.

10. Do you have any other comments on using GC for Maths?

11. Are there any questions in this section that you find ambiguous, confusing, or difficult to answer? Write down which ones and why you found them so.

6. Your Feedback



1. How did you find the survey?

○ Too long.

○ Too short.

○ Just right.

Any additional comments

2. Are there any questions that we should have asked?

Thank You!

You have reached the end of the survey. Thank you very much for taking time to complete the survey. If you have any queries or comments, please email me at Hazel.Tan@education.monash.edu.au.

Please click the "Submit >>" button to submit the survey.

Appendix B: Instruments used

The following instruments are presented in this appendix:

- Singaporean students' survey (Part 1 of the study)
- Victorian students' survey (Part 1 of the study)
- Singaporean teachers' survey (Part 2 of the study)
- Singaporean student's interview protocol (Part 2 of the study)
- Singaporean teacher's interview protocol (Part 2 of the study)

Note that the medium of instruction used in schools in Singapore and Victoria is English; no translation was needed. The student surveys were conducted online for the main study. The Singaporean student survey showed the version before conversion to an online format, and the Victorian survey showed the online version printed from the SurveyMonkey website.

(1) Singaporean students' survey

Students' Mathematics Learning Styles and Their Ways of Learning and Using Graphic Calculators

This survey aims to find out about how you learn maths and use the GC. There are 4 parts to this survey. It will take approximately 15-20 mins to complete.

Section 1 : About You

Answer each of the following questions by ticking the appropriate response and/or filling in the spaces.

1. I am Male ☐ Female ☐

2. I am in JC1 ☐ JC2 ☐

3. My ethnic group is
Chinese ☐ Malay ☐ Indian ☐ OTHER (Please specify)_______

4. I study H1 Maths ☐ H2 Maths ☐

5. How many GCs do you have?
1 ☐ 2 ☐ 3 ☐ More than 3:___

Model Number(s): _____________________

6. My 'O' level results for Elementary Maths is
A1 ☐ A2 ☐ B3 ☐ B4 ☐ C5 ☐ D6 ☐ E7 ☐ E8 ☐ F9 ☐

7. My ‘O’ level results for Additional Maths is

A1 ☐ A2 ☐ B3 ☐ B4 ☐ C5 ☐ D6 ☐ E7 ☐ E8 ☐ F9 ☐

8. My JC1 year end maths exam grade is

A ☐ B ☐ C ☐ D ☐ E ☐ S ☐ U ☐ NA (I have just started JC1) ☐

9. Currently for Maths I consider myself

Excellent ☐ Good ☐ Average ☐ Below Average ☐ Weak ☐

10. In terms of GC skills, I consider myself

Excellent ☐ Good ☐ Average ☐ Below Average ☐ Weak ☐

Section 2 : Your Learning Preferences

This section of the survey aims to find out something about your preferences for the way you work with information. Tick the answer which **best** explains your preference. **Please tick more than one response** if a single answer does not match your perception.

1. I want to plan a surprise party for a friend. I would
   - ☐ talk about it on the phone or text others.
   - ☐ make lists of what to do and what to buy for the party.
   - ☐ imagine the party happening.
   - ☐ invite friends and just let it happen.
2. I am going to make something special for my family. I would
   - ☐ make something I have made before.
   - ☐ look for ideas and designs in books and magazines.
   - ☐ find written instructions to make it.
   - ☐ talk it over with my friends.
3. I have been selected as a leader for a holiday program. This is interesting for my friends. I would
   - ☐ show them the map of where it will be held and photos about it.
   - ☐ show them the list of activities in the program.
   - ☐ start practising the activities I will be doing in the program.
   - ☐ describe the activities I will be doing in the program.
4. I like websites that have
   - ☐ interesting design and visual effects.
   - ☐ interesting written information and articles.
   - ☐ audio channels for music, chat and discussion.
   - ☐ things I can click on and do.
5. I have a problem with my knee. I would prefer the doctor to
   - ☐ describe to me what is wrong.
   - ☐ give me an article or brochure that explains knee injuries.
   - ☐ show me a diagram of what is wrong.
   - ☐ demonstrate what is wrong using a model of a knee.

6. I need to do a maths project about a story of a famous mathematician. I would prefer to
   - ☐ read out a version of the story to the class.
   - ☐ design or draw a diagram depicting the story.
   - ☐ act out a scene from the story.
   - ☐ read some articles related to the story and then write my own article about the story.
7. I prefer a maths teacher who likes to use
   - ☐ textbooks or handouts or notes.
   - ☐ diagrams or graphs or pictures.
   - ☐ hands-on activities or outdoor maths investigations.
   - ☐ class discussions or online discussions.

8. Which one or more of the following ways has your teacher used when teaching how to use the Graphic Calculator (GC)? [Please tick where appropriate]
   - ☐ provide a demonstration.
   - ☐ let students demonstrate to the whole class.
   - ☐ refer to the GC screen captures shown in notes or textbooks or manual.
   - ☐ let students discuss answers with one another.
   - ☐ explain the steps and concepts clearly and thoroughly.
   - ☐ read out the steps given in notes, textbooks or manual.
   - ☐ write out the steps on the board.
   - ☐ ask you to make your own notes.
   - ☐ during a demonstration ask you to follow the steps as shown.
   - ☐ encourage you to play around with the GC.
   - ☐ OTHERS (Please indicate what activities)

   ____

9. For each of the following, indicate if it helps you learn how to use GC to solve maths problems.

	Yes, it definitely helps	No, it doesn't really help
a. see my teacher's demonstration in class.	☐	☐
b. see the steps my friends show me on their GC.	☐	☐
c. look at the GC screen captures in notes, textbooks or manual.	☐	☐
d. discuss answers with my friends.	☐	☐
e. listen to a teacher who explains the steps and concepts clearly and thoroughly.	☐	☐
f. listen to a teacher who reads out the steps given in notes, textbooks or manual.	☐	☐
g. copy down the steps my teacher writes on the board.	☐	☐
h. make my own notes.	☐	☐
i. try out the steps on the GC at the same time I see a demonstration or hear an explanation or read the instructions.	☐	☐
j. try the buttons out and play around with the GC.	☐	☐

11. Which one of the above a) – j) is your <u>most</u> preferred way of learning to use GC to solve maths problems? ☐

If not any of the above a)-j), please specify your most preferred way.

____

12. Which one of the above a) – j) is your least preferred way? ☐

Section 3 : Your Views About Studying Maths

This section investigates your views about maths and studying maths. Read each statement and tick the response that best fits your immediate reaction. Do not spend a long time on each statement: your first reaction is probably the best one.

		Strongly Agree	**Agree**	**Neutral**	**Disagree**	**Strongly Disagree**
1	Maths makes you think creatively.	☐	☐	☐	☐	☐
2	In maths, something is either right or it's wrong.	☐	☐	☐	☐	☐
3	Good maths teachers show students several different ways to look at the same question.	☐	☐	☐	☐	☐
4	In maths you can be creative and discover things for yourself.	☐	☐	☐	☐	☐
5	To solve maths problems you have to be taught the right procedure or you can't do anything.	☐	☐	☐	☐	☐
6	When I solve maths problems, I'm often stuck if I can't remember the next step.	☐	☐	☐	☐	☐
7	I try to relate what I have learned in maths to what I learn in other subjects.	☐	☐	☐	☐	☐
8	When I score poorly on a maths test, I worry a lot about how I will do on the next one.	☐	☐	☐	☐	☐
9	I see no point in learning material which is not likely to be in the examination.	☐	☐	☐	☐	☐
10	Even when I have studied hard for a maths test, I worry that I may not be able to do well in it.	☐	☐	☐	☐	☐
11	I work hard at my studies because I find mathematics interesting.	☐	☐	☐	☐	☐
12	As I am reading, I try to relate new maths concepts and ideas to what I already know about that topic.	☐	☐	☐	☐	☐
13	I learn maths formulas by heart even if I don't understand them.	☐	☐	☐	☐	☐
14	I frequently think about how to solve maths problems even while on the bus or lying on my bed.	☐	☐	☐	☐	☐

15. How do you study maths? Indicate whether or not you like each of the following.

I like to	I don't like to	
☐	☐	study individually on my own.
☐	☐	cooperate with friends.
☐	☐	compete with friends.

Which of the above do you **most** prefer? Please explain.

____

Section 4: Your Preferences About Using Graphic Calculators (GC)

Read each statement and tick the response that best fits your immediate reaction. Do not spend a long time on each statement: your first reaction is probably the best one.

		Strongly Agree	**Agree**	**Neutral**	**Disagree**	**Strongly Disagree**
1	I enjoy using GC to learn maths.	☐	☐	☐	☐	☐
2	I feel confident doing maths using GC.	☐	☐	☐	☐	☐
3	I do not know why sometimes the GC does not give me the answer that I want.	☐	☐	☐	☐	☐
4	I usually just follow the steps taught when using the GC to solve problems, and do not really understand the maths involved.	☐	☐	☐	☐	☐
5	I find GC confusing because it uses different conventions and symbols than normal maths.	☐	☐	☐	☐	☐
6	I use GC for basic calculations because it is more accurate than working by hand.	☐	☐	☐	☐	☐
7	I use GC for calculations because it is faster than working by hand.	☐	☐	☐	☐	☐
8	I use GC to look after large calculations and tedious repetitive methods.	☐	☐	☐	☐	☐
9	I copy the graphs on the GC in my answers because they are more accurate than drawing by hand.	☐	☐	☐	☐	☐
10	I often use GC to explore maths even before the teacher tells me to.	☐	☐	☐	☐	☐
11	GC allows me to expand my ideas and to do the work my own way.	☐	☐	☐	☐	☐
12	I use GC to help me simplify steps in a complex problem.	☐	☐	☐	☐	☐
13	I use GC to help me look at the same problem or concept in different ways (e.g. using graphs and tables to understand the process of differentiation in addition to algebraic method)	☐	☐	☐	☐	☐
14	GC helps me understand mathematical concepts better.	☐	☐	☐	☐	☐

Your Preference when Working with GC

15. Do you prefer…? [Tick **one** only]

☐ to learn the maths concepts first, without GC, and then learn the corresponding steps for using GC.

☐ to learn the maths concepts AND how to use the GC at the same time.

☐ to explore using GC first, and then understand the maths concepts because of the exploration.

Please explain or give an example.

---

16. How do you work with GC? Indicate whether or not you like each of the following.

I like to	I don't like to	
☐	☐	work with GC individually on my own.
☐	☐	cooperate with friends.
☐	☐	compete with friends.

Which of the above do you **most** prefer? Please explain.

Your Views About GC

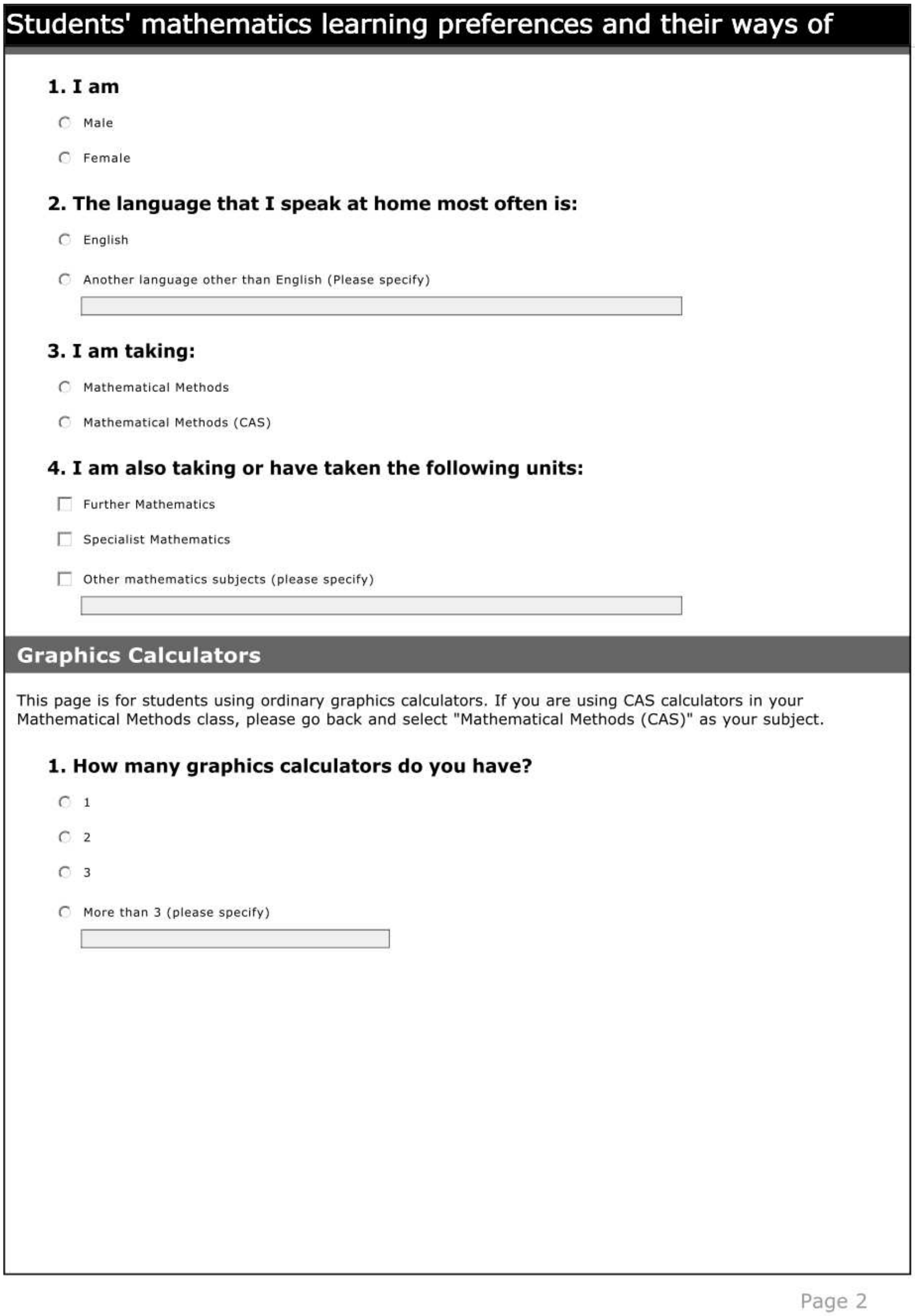
17. What do you like about using GC in maths classes?

16. What do you dislike about using GC in maths classes?

17. Any other comments on using GC for maths.

- Thank You! -

(2) Victorian students' survey



Students' mathematics learning preferences and their ways of

1. I am

○ Male

○ Female

2. The language that I speak at home most often is:

○ English

○ Another language other than English (Please specify)

3. I am taking:

○ Mathematical Methods

○ Mathematical Methods (CAS)

4. I am also taking or have taken the following units:

☐ Further Mathematics

☐ Specialist Mathematics

☐ Other mathematics subjects (please specify)

Graphics Calculators

This page is for students using ordinary graphics calculators. If you are using CAS calculators in your Mathematical Methods class, please go back and select "Mathematical Methods (CAS)" as your subject.

1. How many graphics calculators do you have?

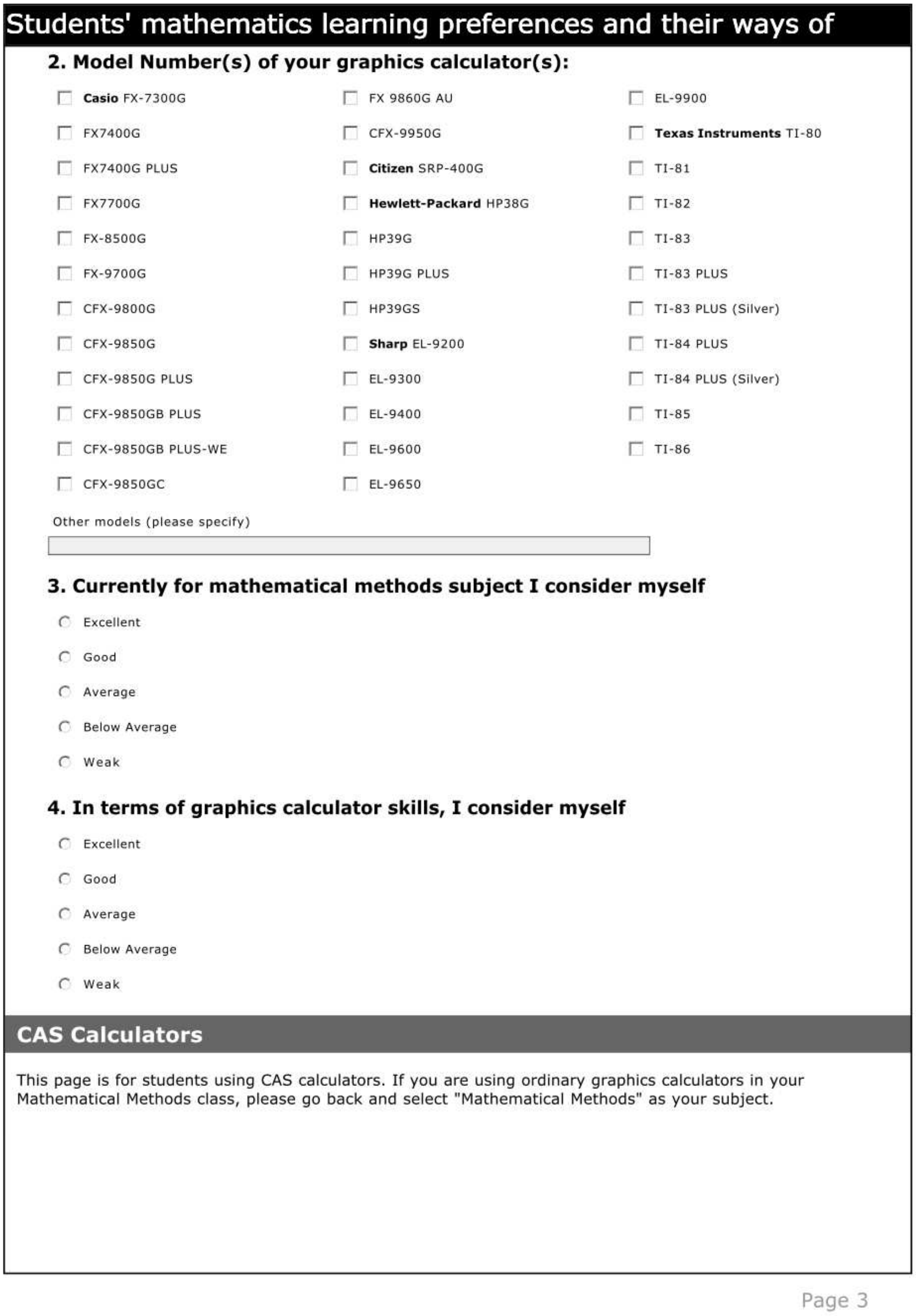
○ 1

○ 2

○ 3

○ More than 3 (please specify)

Page 2



Students' mathematics learning preferences and their ways of

2. Model Number(s) of your graphics calculator(s):

☐ **Casio** FX-7300G
☐ FX7400G
☐ FX7400G PLUS
☐ FX7700G
☐ FX-8500G
☐ FX-9700G
☐ CFX-9800G
☐ CFX-9850G
☐ CFX-9850G PLUS
☐ CFX-9850GB PLUS
☐ CFX-9850GB PLUS-WE
☐ CFX-9850GC
☐ FX 9860G AU
☐ CFX-9950G
☐ **Citizen** SRP-400G
☐ **Hewlett-Packard** HP38G
☐ HP39G
☐ HP39G PLUS
☐ HP39GS
☐ **Sharp** EL-9200
☐ EL-9300
☐ EL-9400
☐ EL-9600
☐ EL-9650
☐ EL-9900
☐ **Texas Instruments** TI-80
☐ TI-81
☐ TI-82
☐ TI-83
☐ TI-83 PLUS
☐ TI-83 PLUS (Silver)
☐ TI-84 PLUS
☐ TI-84 PLUS (Silver)
☐ TI-85
☐ TI-86

Other models (please specify)

3. Currently for mathematical methods subject I consider myself

○ Excellent
○ Good
○ Average
○ Below Average
○ Weak

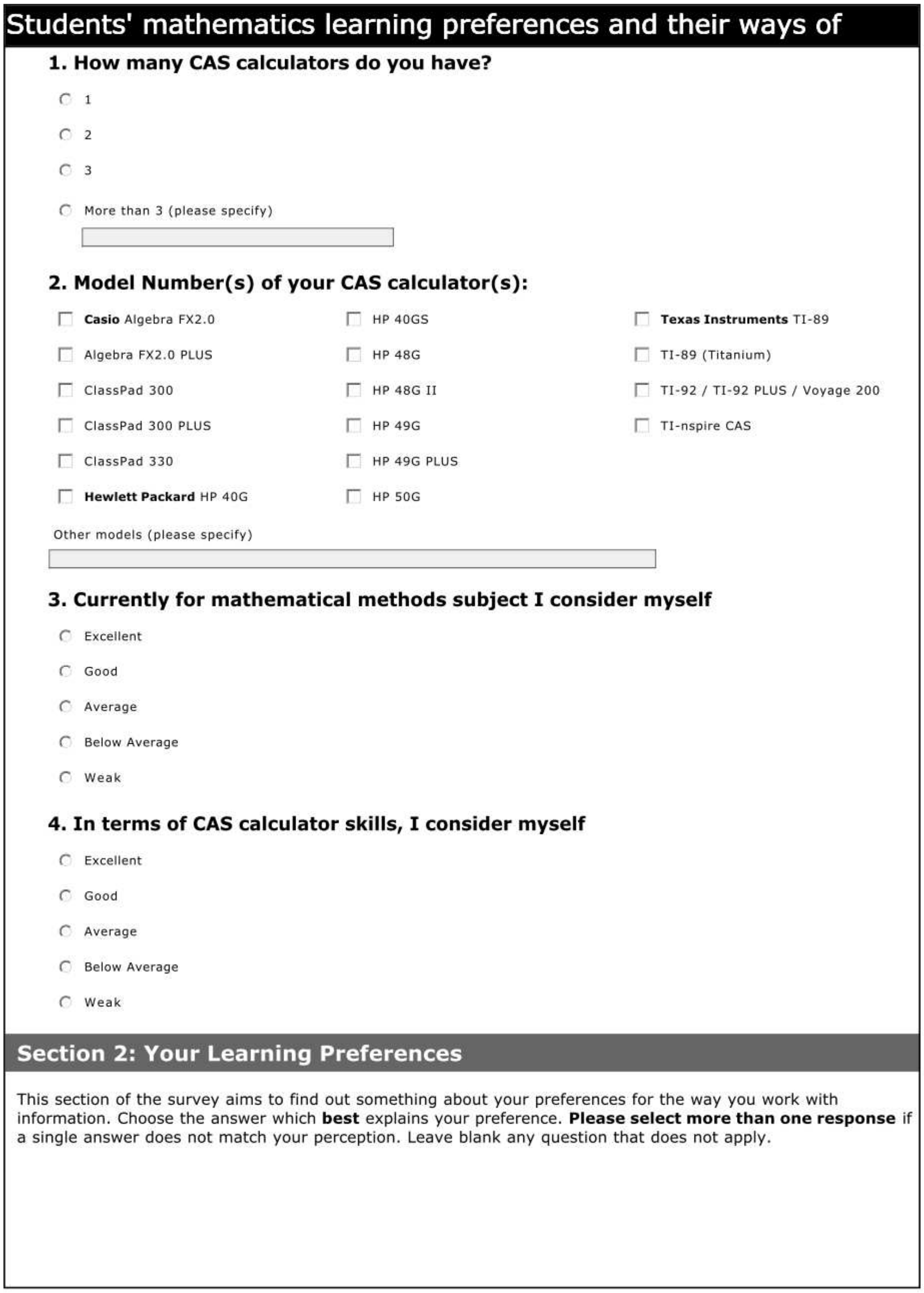
4. In terms of graphics calculator skills, I consider myself

○ Excellent
○ Good
○ Average
○ Below Average
○ Weak

CAS Calculators

This page is for students using CAS calculators. If you are using ordinary graphics calculators in your Mathematical Methods class, please go back and select "Mathematical Methods" as your subject.

Page 3



Students' mathematics learning preferences and their ways of

1. How many CAS calculators do you have?

○ 1

○ 2

○ 3

○ More than 3 (please specify)

2. Model Number(s) of your CAS calculator(s):

☐ **Casio** Algebra FX2.0
☐ Algebra FX2.0 PLUS
☐ ClassPad 300
☐ ClassPad 300 PLUS
☐ ClassPad 330
☐ **Hewlett Packard** HP 40G
☐ HP 40GS
☐ HP 48G
☐ HP 48G II
☐ HP 49G
☐ HP 49G PLUS
☐ HP 50G
☐ **Texas Instruments** TI-89
☐ TI-89 (Titanium)
☐ TI-92 / TI-92 PLUS / Voyage 200
☐ TI-nspire CAS

Other models (please specify)

3. Currently for mathematical methods subject I consider myself

○ Excellent

○ Good

○ Average

○ Below Average

○ Weak

4. In terms of CAS calculator skills, I consider myself

○ Excellent

○ Good

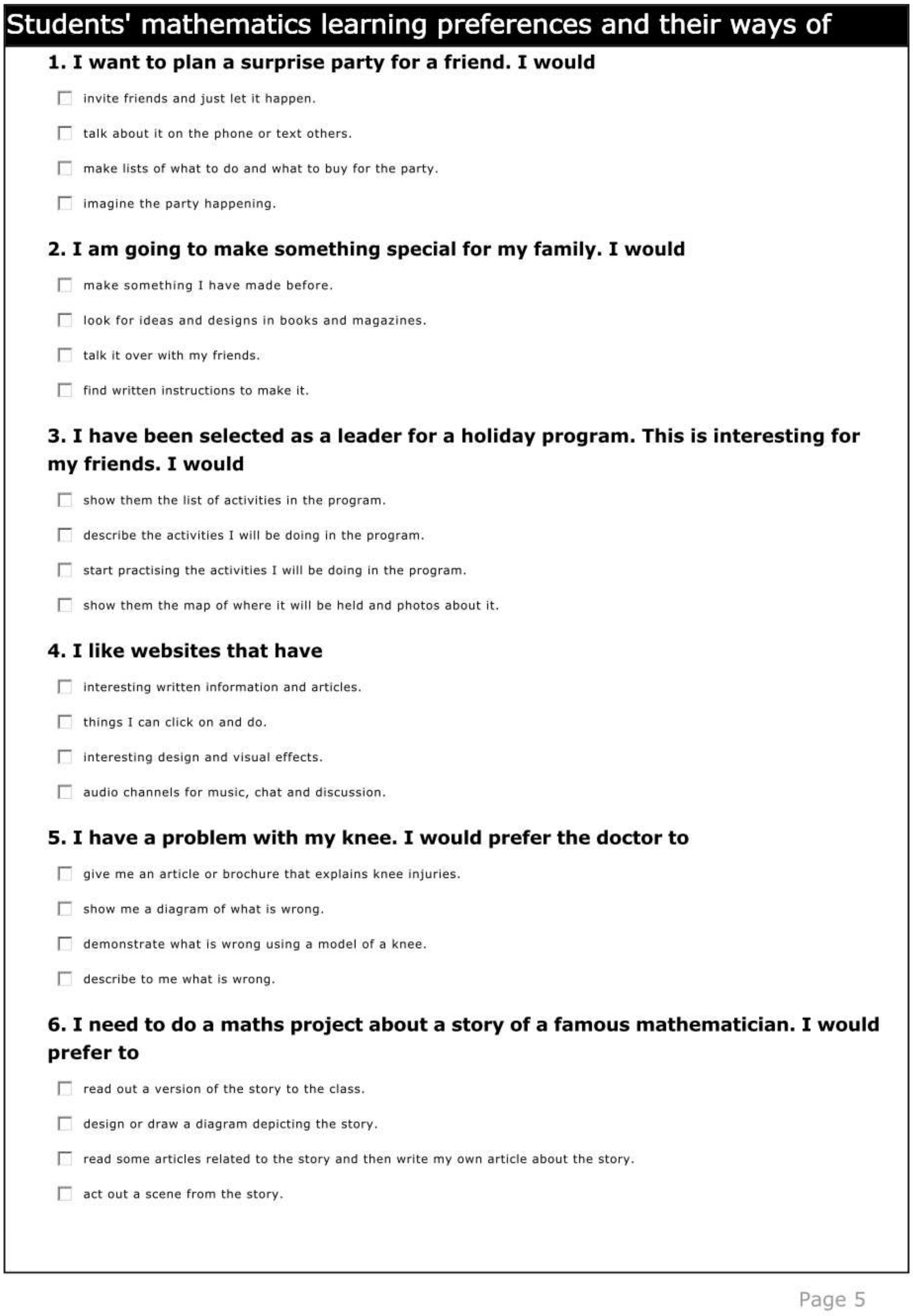
○ Average

○ Below Average

○ Weak

Section 2: Your Learning Preferences

This section of the survey aims to find out something about your preferences for the way you work with information. Choose the answer which **best** explains your preference. **Please select more than one response** if a single answer does not match your perception. Leave blank any question that does not apply.



Students' mathematics learning preferences and their ways of

1. I want to plan a surprise party for a friend. I would

☐ invite friends and just let it happen.
☐ talk about it on the phone or text others.
☐ make lists of what to do and what to buy for the party.
☐ imagine the party happening.

2. I am going to make something special for my family. I would

☐ make something I have made before.
☐ look for ideas and designs in books and magazines.
☐ talk it over with my friends.
☐ find written instructions to make it.

3. I have been selected as a leader for a holiday program. This is interesting for my friends. I would

☐ show them the list of activities in the program.
☐ describe the activities I will be doing in the program.
☐ start practising the activities I will be doing in the program.
☐ show them the map of where it will be held and photos about it.

4. I like websites that have

☐ interesting written information and articles.
☐ things I can click on and do.
☐ interesting design and visual effects.
☐ audio channels for music, chat and discussion.

5. I have a problem with my knee. I would prefer the doctor to

☐ give me an article or brochure that explains knee injuries.
☐ show me a diagram of what is wrong.
☐ demonstrate what is wrong using a model of a knee.
☐ describe to me what is wrong.

6. I need to do a maths project about a story of a famous mathematician. I would prefer to

☐ read out a version of the story to the class.
☐ design or draw a diagram depicting the story.
☐ read some articles related to the story and then write my own article about the story.
☐ act out a scene from the story.

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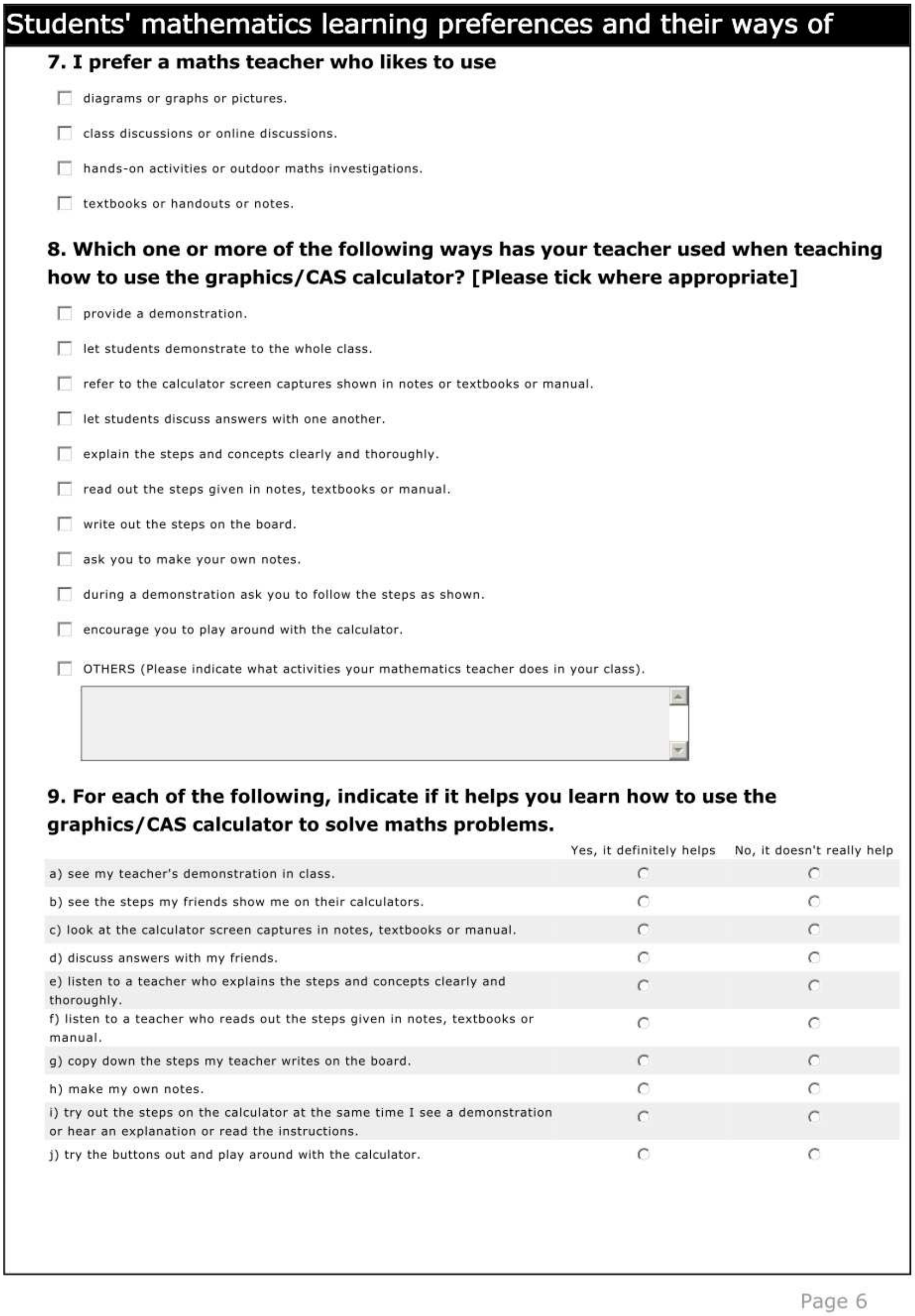

Students' mathematics learning preferences and their ways of

7. I prefer a maths teacher who likes to use

☐ diagrams or graphs or pictures.

☐ class discussions or online discussions.

☐ hands-on activities or outdoor maths investigations.

☐ textbooks or handouts or notes.

8. Which one or more of the following ways has your teacher used when teaching how to use the graphics/CAS calculator? [Please tick where appropriate]

☐ provide a demonstration.

☐ let students demonstrate to the whole class.

☐ refer to the calculator screen captures shown in notes or textbooks or manual.

☐ let students discuss answers with one another.

☐ explain the steps and concepts clearly and thoroughly.

☐ read out the steps given in notes, textbooks or manual.

☐ write out the steps on the board.

☐ ask you to make your own notes.

☐ during a demonstration ask you to follow the steps as shown.

☐ encourage you to play around with the calculator.

☐ OTHERS (Please indicate what activities your mathematics teacher does in your class).

9. For each of the following, indicate if it helps you learn how to use the graphics/CAS calculator to solve maths problems.

	Yes, it definitely helps	No, it doesn't really help
a) see my teacher's demonstration in class.	○	○
b) see the steps my friends show me on their calculators.	○	○
c) look at the calculator screen captures in notes, textbooks or manual.	○	○
d) discuss answers with my friends.	○	○
e) listen to a teacher who explains the steps and concepts clearly and thoroughly.	○	○
f) listen to a teacher who reads out the steps given in notes, textbooks or manual.	○	○
g) copy down the steps my teacher writes on the board.	○	○
h) make my own notes.	○	○
i) try out the steps on the calculator at the same time I see a demonstration or hear an explanation or read the instructions.	○	○
j) try the buttons out and play around with the calculator.	○	○

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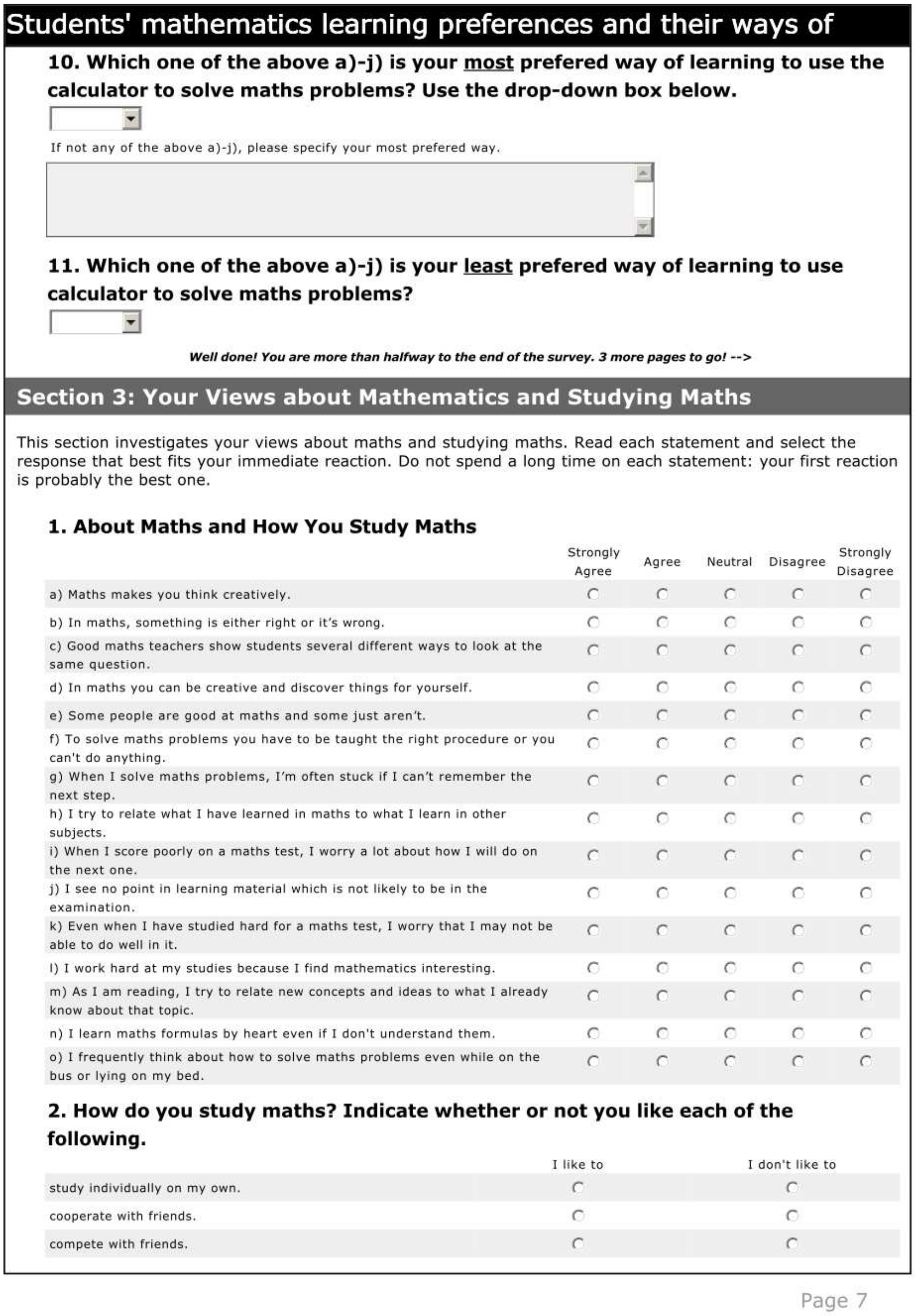

Students' mathematics learning preferences and their ways of

10. Which one of the above a)-j) is your <u>most</u> prefered way of learning to use the calculator to solve maths problems? Use the drop-down box below.

If not any of the above a)-j), please specify your most prefered way.

11. Which one of the above a)-j) is your <u>least</u> prefered way of learning to use calculator to solve maths problems?

Well done! You are more than halfway to the end of the survey. 3 more pages to go! -->

Section 3: Your Views about Mathematics and Studying Maths

This section investigates your views about maths and studying maths. Read each statement and select the response that best fits your immediate reaction. Do not spend a long time on each statement: your first reaction is probably the best one.

1. About Maths and How You Study Maths

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
a) Maths makes you think creatively.	○	○	○	○	○
b) In maths, something is either right or it's wrong.	○	○	○	○	○
c) Good maths teachers show students several different ways to look at the same question.	○	○	○	○	○
d) In maths you can be creative and discover things for yourself.	○	○	○	○	○
e) Some people are good at maths and some just aren't.	○	○	○	○	○
f) To solve maths problems you have to be taught the right procedure or you can't do anything.	○	○	○	○	○
g) When I solve maths problems, I'm often stuck if I can't remember the next step.	○	○	○	○	○
h) I try to relate what I have learned in maths to what I learn in other subjects.	○	○	○	○	○
i) When I score poorly on a maths test, I worry a lot about how I will do on the next one.	○	○	○	○	○
j) I see no point in learning material which is not likely to be in the examination.	○	○	○	○	○
k) Even when I have studied hard for a maths test, I worry that I may not be able to do well in it.	○	○	○	○	○
l) I work hard at my studies because I find mathematics interesting.	○	○	○	○	○
m) As I am reading, I try to relate new concepts and ideas to what I already know about that topic.	○	○	○	○	○
n) I learn maths formulas by heart even if I don't understand them.	○	○	○	○	○
o) I frequently think about how to solve maths problems even while on the bus or lying on my bed.	○	○	○	○	○

2. How do you study maths? Indicate whether or not you like each of the following.

	I like to	I don't like to
study individually on my own.	○	○
cooperate with friends.	○	○
compete with friends.	○	○

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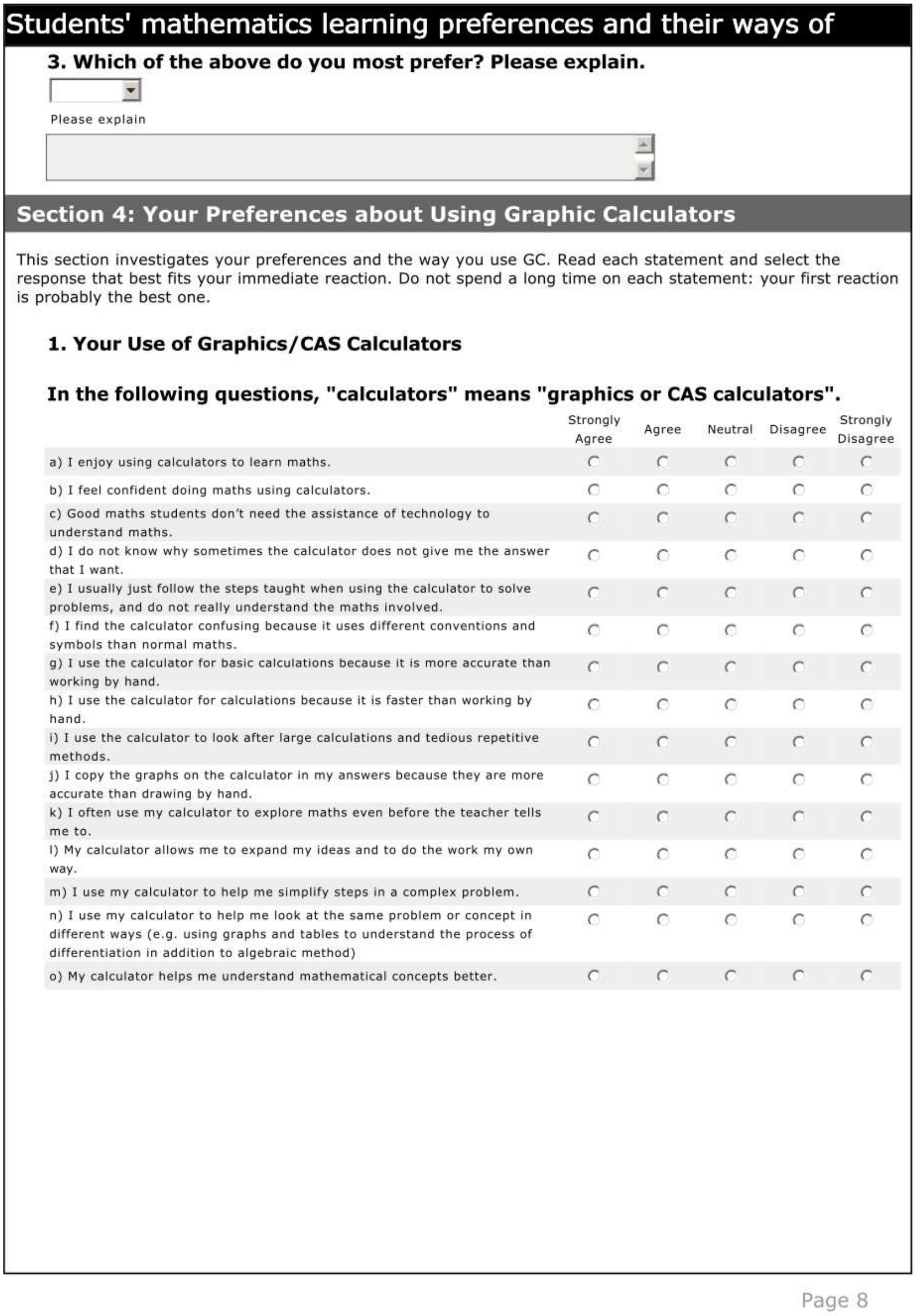

Students' mathematics learning preferences and their ways of

3. Which of the above do you most prefer? Please explain.

Please explain

Section 4: Your Preferences about Using Graphic Calculators

This section investigates your preferences and the way you use GC. Read each statement and select the response that best fits your immediate reaction. Do not spend a long time on each statement: your first reaction is probably the best one.

1. Your Use of Graphics/CAS Calculators

In the following questions, "calculators" means "graphics or CAS calculators".

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
a) I enjoy using calculators to learn maths.	○	○	○	○	○
b) I feel confident doing maths using calculators.	○	○	○	○	○
c) Good maths students don't need the assistance of technology to understand maths.	○	○	○	○	○
d) I do not know why sometimes the calculator does not give me the answer that I want.	○	○	○	○	○
e) I usually just follow the steps taught when using the calculator to solve problems, and do not really understand the maths involved.	○	○	○	○	○
f) I find the calculator confusing because it uses different conventions and symbols than normal maths.	○	○	○	○	○
g) I use the calculator for basic calculations because it is more accurate than working by hand.	○	○	○	○	○
h) I use the calculator for calculations because it is faster than working by hand.	○	○	○	○	○
i) I use the calculator to look after large calculations and tedious repetitive methods.	○	○	○	○	○
j) I copy the graphs on the calculator in my answers because they are more accurate than drawing by hand.	○	○	○	○	○
k) I often use my calculator to explore maths even before the teacher tells me to.	○	○	○	○	○
l) My calculator allows me to expand my ideas and to do the work my own way.	○	○	○	○	○
m) I use my calculator to help me simplify steps in a complex problem.	○	○	○	○	○
n) I use my calculator to help me look at the same problem or concept in different ways (e.g. using graphs and tables to understand the process of differentiation in addition to algebraic method)	○	○	○	○	○
o) My calculator helps me understand mathematical concepts better.	○	○	○	○	○

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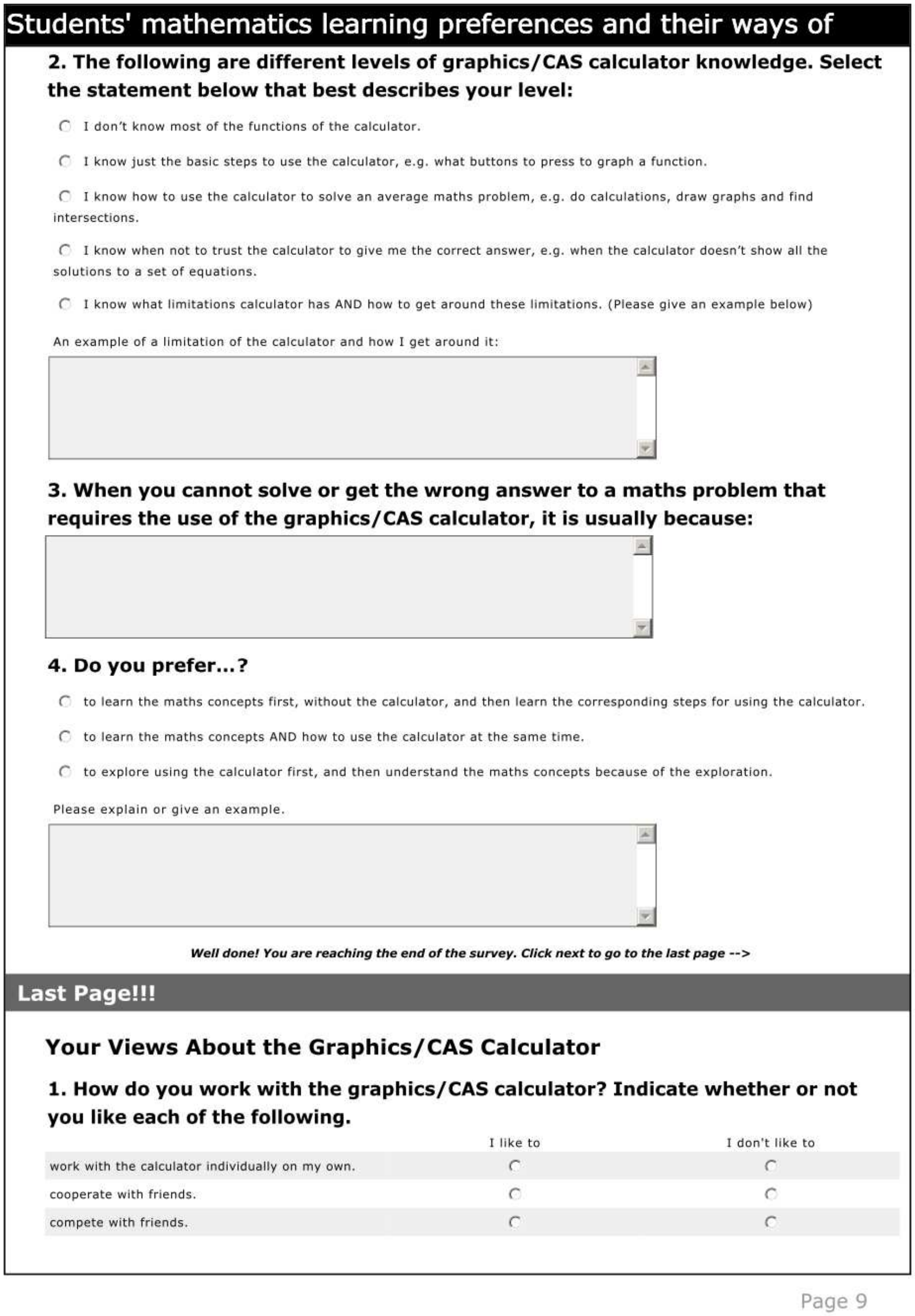

Students' mathematics learning preferences and their ways of

2. The following are different levels of graphics/CAS calculator knowledge. Select the statement below that best describes your level:

○ I don't know most of the functions of the calculator.

○ I know just the basic steps to use the calculator, e.g. what buttons to press to graph a function.

○ I know how to use the calculator to solve an average maths problem, e.g. do calculations, draw graphs and find intersections.

○ I know when not to trust the calculator to give me the correct answer, e.g. when the calculator doesn't show all the solutions to a set of equations.

○ I know what limitations calculator has AND how to get around these limitations. (Please give an example below)

An example of a limitation of the calculator and how I get around it:

3. When you cannot solve or get the wrong answer to a maths problem that requires the use of the graphics/CAS calculator, it is usually because:

4. Do you prefer...?

○ to learn the maths concepts first, without the calculator, and then learn the corresponding steps for using the calculator.

○ to learn the maths concepts AND how to use the calculator at the same time.

○ to explore using the calculator first, and then understand the maths concepts because of the exploration.

Please explain or give an example.

Well done! You are reaching the end of the survey. Click next to go to the last page -->

Last Page!!!

Your Views About the Graphics/CAS Calculator

1. How do you work with the graphics/CAS calculator? Indicate whether or not you like each of the following.

	I like to	I don't like to
work with the calculator individually on my own.	○	○
cooperate with friends.	○	○
compete with friends.	○	○

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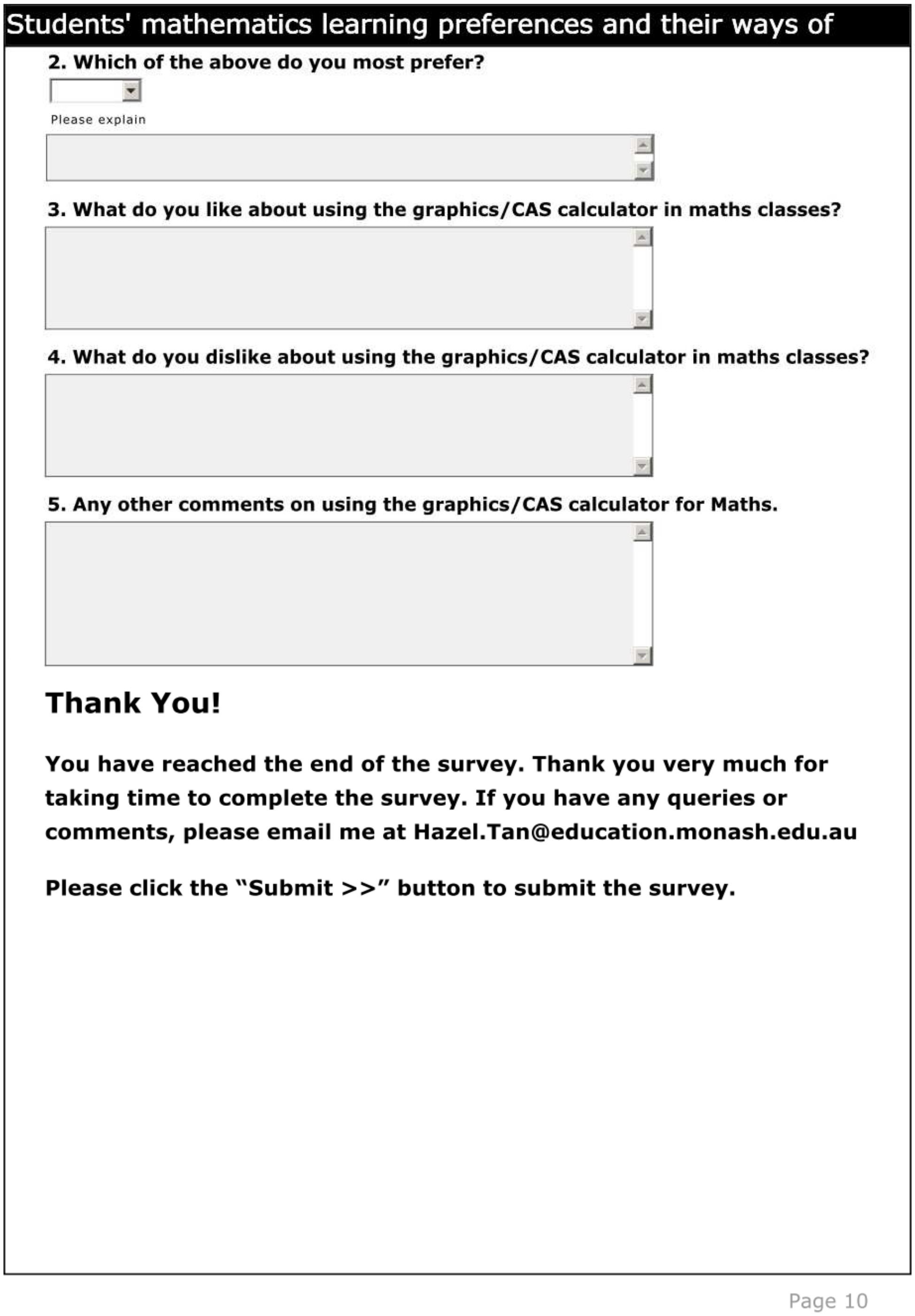

Students' mathematics learning preferences and their ways of

2. Which of the above do you most prefer?

Please explain

3. What do you like about using the graphics/CAS calculator in maths classes?

4. What do you dislike about using the graphics/CAS calculator in maths classes?

5. Any other comments on using the graphics/CAS calculator for Maths.

Thank You!

You have reached the end of the survey. Thank you very much for taking time to complete the survey. If you have any queries or comments, please email me at Hazel.Tan@education.monash.edu.au

Please click the "Submit >>" button to submit the survey.

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(3) Singaporean teachers' survey

This survey aims to find out about how you teach maths and GC use. There are 4 parts to this survey. It will take approximately 20-30 mins to complete.

Section 1 : About You
Answer each of the following questions by ticking the appropriate response and/or filling in the spaces.

1. I am Male ☐ Female ☐

2. I teach JC1 ☐ JC2 ☐

3. I teach
H1 Maths ☐ H2 Maths ☐ H3 Maths ☐

4. Classes I teach:
____

5. How many GCs do you have?
1 ☐ 2 ☐ 3 ☐ More than 3:___

Model Number(s): ______________________

6. I have taught mathematics for ________ years.

7. Among the maths teachers, currently for Maths I consider myself
Excellent ☐ Good ☐ Average ☐ Below Average ☐ Weak ☐

8. In terms of my GC skills, I consider myself
Excellent ☐ Good ☐ Average ☐ Below Average ☐ Weak ☐

Section 2 : Your Learning Preferences
This section of the survey aims to find out something about your preferences for the way you work with information. Tick the answer which best explains your preference. **Please tick more than one response** if a single answer does not match your perception.

1. I want to plan a surprise party for a friend. I would
   - ☐ talk about it on the phone or text others.
   - ☐ make lists of what to do and what to buy for the party.
   - ☐ imagine the party happening.
   - ☐ invite friends and just let it happen.
2. I am going to make something special treat for my family. I would
   - ☐ make something I have made before.
   - ☐ look for ideas and plans in books and magazines.
   - ☐ find written instructions to make it.
   - ☐ talk it over with my friends.
3. I have been selected as a leader for a holiday program. This is interesting for my friends and family. I would
   - ☐ show them the map of where it will be held and photos about it.
   - ☐ show them the list of activities in the program.
   - ☐ start practising the activities I will be doing in the program.
   - ☐ describe the activities I will be doing in the program.

4. I like websites that have
   - ☐ interesting design and visual effects.
   - ☐ interesting written information and articles.
   - ☐ audio channels for music, chat and discussion.
   - ☐ things I can click on and do.
5. I have a problem with my knee. I would prefer the doctor to
   - ☐ describe to me what is wrong.
   - ☐ give me an article or brochure that explains knee injuries.
   - ☐ show me a diagram of what is wrong.
   - ☐ demonstrate what is wrong using a model of a knee.
6. I need to do a maths project about a story of a famous mathematician. I would prefer to
   - ☐ read out a version of the story to the class.
   - ☐ design or draw a diagram depicting the story.
   - ☐ act out a scene from the story.
   - ☐ read some articles related to the story and then write my own article about the story.
7. I am a maths teacher who likes to use
   - ☐ textbooks or handouts or notes.
   - ☐ diagrams or graphs or pictures.
   - ☐ hands-on activities or outdoor maths investigations.
   - ☐ class discussion.
8. Which one or more of the following ways has you have used when teaching how to use the Graphic Calculator (GC)? [Please tick where appropriate]
   - a. ☐ provide a demonstration
   - b. ☐ let students demonstrate to the whole class
   - c. ☐ refer to the screenshots shown in notes or textbooks or manual
   - d. ☐ let students discuss answers with one another
   - e. ☐ explain the steps and concepts clearly and thoroughly
   - f. ☐ read out the steps given in notes, textbooks or manual
   - g. ☐ write out the steps on the board
   - h. ☐ ask students to make their own notes
   - i. ☐ during a demonstration ask students to follow the steps as shown
   - j. ☐ encourage students to play around with the GC
   - k. ☐ OTHERS (Please indicate what activities you do in your class).

     ____

9. For each of the following, indicate if it **helps your students learn** how to use GC to solve maths problems.

	Yes, it definitely helps	**No, it doesn't really help**
a. provide a demonstration	☐	☐
b. let students demonstrate to the whole class	☐	☐
c. refer to the screenshots shown in notes or textbooks or manual	☐	☐
d. let students discuss answers with one another	☐	☐
e. explain the steps and concepts clearly and thoroughly	☐	☐
f. read out the steps given in notes, textbooks or manual	☐	☐
g. write out the steps on the board	☐	☐
h. ask students to make their own notes	☐	☐
i. during a demonstration ask students to follow the steps as shown	☐	☐
j. encourage students to play around with the GC	☐	☐

k. OTHERS (Please indicate what activities you think will help your students learn).	☐	☐

10. Which one of the above a) – j) is your <u>most</u> preferred way of teaching to use GC to solve maths problems? ☐

11. Which one of the above a) – j) is your <u>least</u> preferred way? ☐

Section 3 : Your Views About Maths and Studying Maths

This section investigates your views about maths and studying maths. Read each statement and tick the response that best fits your immediate reaction. Do not spend a long time on each statement: your first reaction is probably the best one.

		Strongly Agree	**Agree**	**Neutral**	**Disagree**	**Strongly Disagree**
1	Maths makes you think creatively.	☐	☐	☐	☐	☐
2	In maths, something is either right or it's wrong.	☐	☐	☐	☐	☐
3	Good maths teachers show students several different ways to look at the same question.	☐	☐	☐	☐	☐
4	Some people are good at maths and some just aren't.	☐	☐	☐	☐	☐
5	In maths you can be creative and discover things for yourself.	☐	☐	☐	☐	☐
6	To solve maths problems students have to be taught the right procedure or they can't do anything.	☐	☐	☐	☐	☐
7	When I solve maths problems, I'm often stuck if I can't remember the next step.					
8	I try to relate what I teach in maths to other subjects.	☐	☐	☐	☐	☐
8	I see no point in teaching material which is not likely to be in the examination.	☐	☐	☐	☐	☐
9	I like to think deeply about how one maths concept relates to another.	☐	☐	☐	☐	☐
10	Whether I like it or not, I can see that doing well in maths is a good way to get a well-paid job.	☐	☐	☐	☐	☐
11	I go through with the students the exercises that appear in tutorials and past year papers only, and nothing extra.	☐	☐	☐	☐	☐
12	I spend a lot of my free time finding out more about interesting topics which can be discussed in maths classes.	☐	☐	☐	☐	☐
13	I expect my students to learn maths formulae by heart even if they don't understand them.	☐	☐	☐	☐	☐
14	As I teach, I try to relate new concepts and ideas to what students already know about that topic.	☐	☐	☐	☐	☐

15. How do you structure students working with mathematics? Indicate whether or not you prefer each of the following.

I prefer to	I don't prefer to	
☐	☐	encourage students to work with maths individually on their own.
☐	☐	encourage students to cooperate with friends.
☐	☐	encourage students to compete with friends.

Which of the above do you **most** prefer? Please explain.

Section 4: Your Preferences About Using GC

Read each statement and tick the response that best fits your immediate reaction. Do not spend a long time on each statement: your first reaction is probably the best one.

		Strongly Agree	**Agree**	**Neutral**	**Disagree**	**Strongly Disagree**
1	I enjoy using GC to teach maths.	☐	☐	☐	☐	☐
2	I feel confident doing maths using GC.	☐	☐	☐	☐	☐
3	Good maths students don't need the assistance of technology to understand maths.	☐	☐	☐	☐	☐
4	I do not know why sometimes the GC does not give me the answer that I want.	☐	☐	☐	☐	☐
5	I usually just follow the steps taught when using the GC to solve problems, and do not really understand the maths involved.	☐	☐	☐	☐	☐
6	I find GC confusing because it uses different conventions and symbols than normal maths.	☐	☐	☐	☐	☐
7	I use GC for basic calculations because it is more accurate than working by hand.	☐	☐	☐	☐	☐
8	I use GC for calculations because it is faster than working by hand.	☐	☐	☐	☐	☐
9	I use GC to look after large calculation and tedious repetitive methods.	☐	☐	☐	☐	☐
10	I copy the graphs on the GC in my answers because they are more accurate than drawing by hand.	☐	☐	☐	☐	☐
11	I usually use GC to help me check my answers.	☐	☐	☐	☐	☐
12	I use GC to solve problems that I usually cannot do by hand.	☐	☐	☐	☐	☐
13	I often use GC to explore maths.	☐	☐	☐	☐	☐
14	GC allows me to expand my ideas and to do the work my own way.	☐	☐	☐	☐	☐
15	I use GC to help me simplify steps in a complex problem.	☐	☐	☐	☐	☐

		Strongly Agree	**Agree**	**Neutral**	**Disagree**	**Strongly Disagree**
16	I use GC to help me look at the same problem or concept in different ways (e.g. using graphs and tables to understand the process of differentiation in addition to algebraic method)	☐	☐	☐	☐	☐
17	GC helps me understand mathematical concepts better.	☐	☐	☐	☐	☐

18. When you cannot solve or get the wrong answer to a maths problem that requires the use of GC, it is usually because:

Your Views About GC

19. What do you like about using GC in maths classes?

20. What do you dislike about using GC in maths classes?

21. How do you structure students working with GC? Indicate whether or not you prefer each of the following.

I prefer to	I don't prefer to	
☐	☐	encourage students to work with GC individually on their own.
☐	☐	encourage students to cooperate with friends.
☐	☐	encourage students to compete with friends.

Which of the above do you **most** prefer? Please explain.

22. Do you prefer…? [Tick **one** only]

☐ to teach the maths concepts first, without GC, and then learn the corresponding steps for using GC.

☐ to teach the maths concepts AND how to use the GC at the same time.

☐ to explore using GC first with students, and then teach them to understand the maths concepts because of the exploration.

Please explain or give an example.

- Thank You! -

(4) Singaporean students' interview protocol

Points for preamble:

Thank you for participating in this study. It will be tape recorded, is that okay with you? Here is the explanatory statement and consent form. Let me tell you about the study. There are no right or wrong answers; it is to find out your personal beliefs and thoughts about learning mathematics and using the GC. Confidentiality will be maintained.

Attitudes towards Mathematics and Graphing Calculators (GC)

1. How do you find mathematics as a subject?
   a. Can you use three adjectives to describe mathematics? Tell me more about one of them.

2. How do you find using GC in mathematics?
   a. Can you use three adjectives to describe how you use the GC? Tell me more about one of them.

Connected Knowing - Deep Approach and Separate Knowing - Surface Approach

3. Can you tell me how do you study mathematics?
   a. How do you prepare for mathematics tests and examinations?
   b. What are the most difficult and the easiest things for you in mathematics class?

4. How about using GC? How do you study a topic that needs the use of GC (e.g. graphs and functions)? How about a topic that does not use the GC as much (e.g. differentiation and vectors)?

Social Interaction for Learning Preference / VARK

5. Do you study mathematics with friends? Can you describe how you study?
   a. How often?
   b. What did you do?
   c. Can you give an example?

6. What about when you learn something new using the GC? Can you describe how you learn?
   a. How often?
   b. What did you do?
   c. Can you give an example?

Any other comments?

(5) Singaporean teachers' interview protocol

Points for preamble:

Thank you for participating in this study. It will be tape recorded, is that ok with you? Here is the explanatory statement and consent form. Let me tell you about the study. There are no right or wrong answers; it is to find out your personal beliefs and thoughts about learning mathematics and using the GC. Confidentiality will be maintained.

Attitudes towards Mathematics and Graphing Calculators (GC), Separate and Connected Knowing, Ways of Using GC

Attitudes towards Mathematics and Graphing Calculators (GC), Connected Knowing - Deep Approach and Separate Knowing - Surface Approach

1. How do you find mathematics itself as a subject?
    a. Can you use three adjectives to describe mathematics? Tell me more about one of them.
    b. [based on their adjectives] Do you think that maths is (creative/right or wrong/ ___)? Why do you think this way?
    c. Can you give an example?

2. How do you find using GC in mathematics?
    a. Can you use three adjectives to describe how you use the GC? Tell me more about one of them.

3. Was it easy or difficult for yourself to learn how to use the GC to solve mathematics problems before you teach the students? Tell me more

Deep and Surface Approach, Visual Aural Read/Write Kinesthetic Preferences, Social Instructional Preference

4. How do you usually teach your students mathematics?
    a. How do you think they learn best? [If they say cater to different groups, ask how. If they say use different methods, ask why.]
    b. How do you prepare them for mathematics tests and examinations?
    c. What are the most difficult and the easiest things for you in mathematics class?

5. How do you teach your students how to use the GC to solve maths problems?
    a. How do you think they learn best?
    b. What did you do?
    c. Can you give an example?
    d. What are the most difficult and the easiest things for you in mathematics class?

Ways of Using GC

6. What do you think are the advantages of using GC? Why do you say that? Can you give an example?

7. What do you think are the disadvantages of using GC? Why do you say that? Can you give an example?

Appendix C: List of codes and abbreviations used for the instruments

In the following, students' learning preferences and factors examined, and the codes and abbreviations used, are presented.

Section of survey	Learning preferences and factors examined (abbreviation)	Codes
About You	Gender (Gender)	Male = 1, Female = 2
	Year level (Year)	Year 11 = 1, Year 12 = 2, Year 10 = 3
	Mathematics competency self-rating (MSR)	Excellent = 5, Good = 4, Average = 3, Below Average = 2, Weak = 1
	Calculator competency self-rating (CalSR)	Excellent = 5, Good = 4, Average = 3, Below Average = 2, Weak = 1
Your Learning Preference	General Visual Aural Read-Write and Kinesthetic preference, 7 items with 4 options each (V, A, R, K)	Add up the number of options selected to give the score for each V, A, R or K items.
	VARK preferences for learning how to use the calculator, 10 items/methods of learning and an open-ended item	For items 1 to 10, code Yes it definitely helps = 1, No it doesn't really help = 0. Code item 11 as open-ended text.
	Most preferred method for learning how to use the calculator (Calculator VARK), 1 item with 10 methods listed.	Method (a) = 1, method (b) = 2, … method (j) = 10.
Your Views about Maths and Studying Maths	Ways of knowing and studying mathematics, 7 items for Connected Knowing-Deep Approach (CK-DA) and 7 items for Separate Knowing-Deep Approach	For each item, Strongly Agree = 5, Agree = 4, Neutral = 3, Disagree = 2, Strongly Disagree = 1. Average scores of 7 items were used for each subscale.
	Social interaction for learning preferences when studying mathematics, 3 items with 2 options each for studying Individually (Ma_Indv), Cooperatively (Ma_Coop), and Competitively (Ma_Comp).	For each item, I like to = 1, I don't like to = 0.
	Most preferred social interaction for learning preferences when studying mathematics, 1 item 3 options (Ma_Social)	Study maths individually = 1, cooperatively = 2, competitively = 3.

Section of survey	Learning preferences and factors examined (abbreviation)	Codes
Your Preferences about Using Calculators 3. Are there any gender differences within each region?	Calculator enjoyment (Cal_Enj), 1 item	Strongly Agree = 5, Agree = 4, Neutral = 3, Disagree = 2, Strongly Disagree = 1
	Calculator confidence (Cal_Conf), 1 item	Strongly Agree = 5, Agree = 4, Neutral = 3, Disagree = 2, Strongly Disagree = 1
	Ways of interacting with technology, 3 items for calculator as Master (Cal_Ma), 4 items for calculator as Servant (Cal_Se), and 5 items for calculator as Collaborator (Cal_Co)	For each item, Strongly Agree = 5, Agree = 4, Neutral = 3, Disagree = 2, Strongly Disagree = 1. Average scores of the items were calculated as the subscale score.
	Social interaction for learning preferences when working with calculators, 3 items with 2 options each for working Individually (Cal_Indv), Cooperatively (Cal_Coop), and Competitively (Cal_Comp).	For each item, I like to = 1, I don't like to = 0.
	Most preferred social interaction for learning preferences when working with calculators, 1 item 3 options (Cal_Social)	Study maths individually = 1, cooperatively = 2, competitively = 3.

Appendix D: Analyses of Part 1 of the study

(1) Factor analysis for ways of knowing and understanding mathematics

The initial principal component analysis (PCA) of the 964 Singaporean student data is shown in Table D1. Varimax rotation was used because the theory and findings from literature suggested that the components are orthogonal - Connected Knowing (CK) and Separate Knowing (SK) are different ways of knowing and Deep (DA) and Surface Approaches (SA) are fairly independent (e.g. Kember, Biggs, & Leung, 2004). There was also a relationship between students' ways of knowing and approaches to studying (e.g., Crawford, Gordon, Nicholas, & Prosser, 1994, 1995, 1998). In Table D1, it can be seen that the pooled items for CK, SK, DA, and SA were loaded onto three components, with all of the CK and DA items loaded onto component 1, and most of the SK and SA items loaded onto component 2. Component 3 comprised of two items, SK2 and CK3.

Table D1

Initial Factor Analysis of Singaporean CK, SK, DA and SA Data Showing that the Items Loaded onto Three Components

Items	Component		
	1	2	3
CK1 Maths makes you think creatively.	.733		
DM3 I work hard at my studies because I find mathematics interesting.	.709		
CK4 In maths you can be creative and discover things for yourself.	.678		
DS1 I try to relate what I have learned in maths to what I learn in other subjects.	.667		
DM6 I frequently think about how to solve maths problems even while on the bus or lying on my bed.	.632		
DS3 As I am reading, I try to relate new concepts and ideas to what I already know about that topic.	.621		
SM2 Even when I have studied hard for a maths test, I worry that I may not be able to do well in it.		.740	
SK5 When I solve maths problems, I'm often stuck if I can't remember the next step.		.698	
SM1 When I score poorly on a maths test, I worry a lot about how I will do on the next one.		.696	

Items	Component		
	1	2	3
SK4 To solve maths problems you have to be taught the right procedure or you can't do anything.		.589	
SS5 I learn maths formulas by heart even if I don't understand them.		.569	
SS1 I see no point in learning material which is not likely to be in the examination.		.497	
SK2 In maths, something is either right or it is wrong.			.849
CK3 Good maths teachers show students several different ways to look at the same question.	.423		.448

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

a. Country = Singapore

b. Loadings less than 0.3 were omitted.

Examination of the scree plot and the PCA results suggested that there were two factors instead of three, and PCA was repeated with the specification of two factors to be extracted. The results are shown in Table D2. It can be seen that SK2 has loadings smaller than 0.3 for both components.

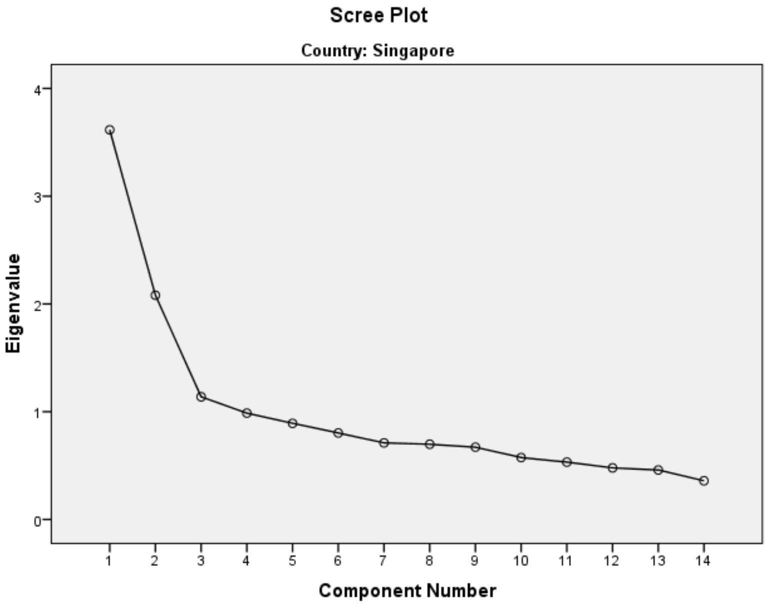

Figure A3. Scree plot for factor analysis of Singaporean CK, SK, DA, SA items.

Table D2

Final Factor Analysis of Singaporean CK, SK, DA and SA Data Showing that the Items loaded onto Two Components (CK-DA and SK-SA)

Items		Component	
		1	2
CK1	Maths makes you think creatively.	.739	
DM3	I work hard at my studies because I find mathematics interesting.	.731	
CK4	In maths you can be creative and discover things for yourself.	.673	
DS1	I try to relate what I have learned in maths to what I learn in other subjects.	.650	
DS3	As I am reading, I try to relate new concepts and ideas to what I already know about that topic.	.638	
DM6	I frequently think about how to solve maths problems even while on the bus or lying on my bed.	.601	
CK3	Good maths teachers show students several different ways to look at the same question.	.474	
SM2	Even when I have studied hard for a maths test, I worry that I may not be able to do well in it.		.713
SM1	When I score poorly on a maths test, I worry a lot about how I will do on the next one.		.695
SK5	When I solve maths problems, I'm often stuck if I can't remember the next step.		.678
SK4	To solve maths problems you have to be taught the right procedure or you can't do anything.		.622
SS5	I learn maths formulas by heart even if I don't understand them.		.567
SS1	I see no point in learning material which is not likely to be in the examination.		.504
SK2	In maths, something is either right or it is wrong.		

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

a. Country = Singapore

b. Loadings less than 0.3 were omitted.

Similarly, it can be seen in Table D3 that when the principal component analysis specifying two factors was run on the Victorian data, the CK and DA items were loaded onto one component (CK-DA) and SK and SA items loaded onto the other (SK-SA). The item SS1 was loaded onto both components, but the loading was slightly higher for SK-SA than CK-DA. It is noted that the item SK2 had loadings smaller than 0.3 for both components. This implied that for future studies, SK2 might be modified or removed.

Table D3

Final Factor Analysis of Victorian CK, SK, DA and SA Data Showing that the Items Loaded onto Two Components (CK-DA and SK-SA)

Items	Component	
	1	2
DS3 As I am reading, I try to relate new concepts and ideas to what I already know about that topic.	.780	
DM3 I work hard at my studies because I find mathematics interesting.	.778	
CK1 Maths makes you think creatively.	.745	
DS1 I try to relate what I have learned in maths to what I learn in other subjects.	.679	
CK4 In maths you can be creative and discover things for yourself.	.646	
DM6 I frequently think about how to solve maths problems even while on the bus or lying on my bed.	.606	
CK3 Good maths teachers show students several different ways to look at the same question.	.426	
SM2 Even when I have studied hard for a maths test, I worry that I may not be able to do well in it.		.777
SM1 When I score poorly on a maths test, I worry a lot about how I will do on the next one.		.728
SK5 When I solve maths problems, I'm often stuck if I can't remember the next step.		.666
SK4 To solve maths problems you have to be taught the right procedure or you can't do anything.		.535
SS1 I see no point in learning material which is not likely to be in the examination.	-.437	.494
SS5 I learn maths formulas by heart even if I don't understand them.		.302
SK2 In maths, something is either right or it is wrong.		

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

a. Country = Victoria

b. Loadings less than 0.3 were omitted.

The results and findings were also reported in Tan (2012).

(2) Factor analysis for ways of interacting with calculators

For the Singaporean data, the initial principal component analysis (PCA) of the calculator as Master (Cal_Ma), as Servant (Cal_Se) and as Collaborator (Cal_Co) items is shown in Table D4.

Table D4

Factor Analysis of Singaporean Cal_Ma, Cal_Se, and Cal_Co Data Showing that the Items Loaded onto Three Components

Items	Component		
	1	2	3
(P3) GC as Partner/ Different Perspective: I use GC to help me look at the same problem or concept in different ways.	.808		
(E2) GC as Extension/ Mind Expander: GC allows me to expand my ideas and to do the work my own way.	.806		
(P4) GC as Partner/ Facilitate Understanding: GC helps me understand concepts better.	.750		
(E1) GC as Extension/ Freedom: I often use GC to explore maths even before the teacher tells me to.	.723		
(P2) GC as Partner/ Cognitive Load: I use GC to help me simplify steps in a complex problem.	.674		
(S2) GC as Servant/ Efficient Calculations: I use GC for calculations because it is faster than working by hand.		.872	
(S1) GC as Servant/ Reduce Errors in Calculations: I use GC for basic calculations because it is more accurate than working by hand.		.819	
(S3) GC as Servant/ Repetitive Calculations: I use GC to look after large calculation and tedious repetitive methods.		.702	
(S4) GC as Servant/ Presentation: I copy the graph on the GC in my answers because they are more accurate than drawing by hand.		.446	
(M3) GC as Master/ Unfamiliar Conventions: I find GC confusing because it uses different conventions and symbols than normal maths.			.793
(M2) GC as Master/ Math Dependence: I usually just follow the steps taught when using the GC to solve problems, and do not really understand the maths involved.			.780
(M1) GC as Master/ Lack of Tech Skills: I do not know why sometimes the GC does not give me the answer that I want.			.776

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

The items were loaded onto three factors, which corresponded to calculator as Master, as Servant and as Collaborator. This result was similar to those from the pilot study.

Table D5

Initial Factor Analysis of Victorian Data Showing that the Cal_Ma, Cal_Se, and Cal_Co Items Loaded onto Four Components

Items	Component			
	1	2	3	4
(S3) Cal as Servant/ Repetitive Calculations: I use the calculator to look after large calculation and tedious repetitive methods.	.818			
(S2) Cal as Servant/ Efficient Calculations: I use the calculator for calculations because it is faster than working by hand.	.797			
(S1) Cal as Servant/ Reduce Errors in Calculations: I use the calculator for basic calculations because it is more accurate than working by hand.	.698			
(S4) Cal as Servant/ Presentation: I copy the graph on the calculator in my answers because they are more accurate than drawing by hand.	.492			
(P3) Cal as Partner/ Different Perspective: I use the calculator to help me look at the same problem or concept in different ways.		.822		
(P4) Cal as Partner/ Facilitate Understanding: the calculator helps me understand concepts better.		.762		
(P2) Cal as Partner/ Cognitive Load: I use the calculator to help me simplify steps in a complex problem.	.307	.756		
(M2) Cal as Master/ Math Dependence: I usually just follow the steps taught when using the calculator to solve problems, and do not really understand the maths involved.			.836	
(M3) Cal as Master/ Unfamiliar Conventions: I find the calculator confusing because it uses different conventions and symbols than normal maths.			.835	
(M1) Cal as Master/ Lack of Tech Skills: I do not know why sometimes the calculator does not give me the answer that I want.	.402		.598	
(E1) Cal as Extension/ Freedom: I often use the calculator to explore maths even before the teacher tells me to.				.875
(E2) Cal as Extension/ Mind Expander: the calculator allows me to expand my ideas and to do the work my own way.		.332		.799

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

However, PCA of the Victorian data resulted in the items loading onto four factors instead of three. The rotated matrix table is shown in Table D5. The four factors corresponded to calculator as Master, Servant, Partner and Extension of Self, with some cross-loadings of certain items with an 'adjacent' factor. For example item M1 loaded mainly onto Calculator as Master, with a smaller loading onto Calculator as Servant. When three factors are specified in the PCA, the items loaded similarly to that in the Singaporean data (Table D6). This result supports the theory of the Master, Servant, Partner and Extension of self (MSPE, Goos et al., 2000) framework. The finding that the items from Calculator as Partner and as Extension of Self are combined in the Singaporean data (as compared to separate in the Victorian data) might be because of the relatively lower GC competency in the Singaporean students. It could also be due other factors such as cultural differences. Further investigation using the instrument in different contexts is needed.

Table D6

Factor Analysis of Victorian Data Showing that the Cal_Ma, Cal_Se, and Cal_Co Items loaded onto Three Components

Items	Component		
	1	2	3
(S3) Cal as Servant/ Repetitive Calculations: I use the calculator to look after large calculation and tedious repetitive methods.	.796		
(S2) Cal as Servant/ Efficient Calculations: I use the calculator for calculations because it is faster than working by hand.	.790		
(S1) Cal as Servant/ Reduce Errors in Calculations: I use the calculator for basic calculations because it is more accurate than working by hand.	.682		
(S4) Cal as Servant/ Presentation: I copy the graph on the calculator in my answers because they are more accurate than drawing by hand.	.490		
(E2) Cal as Extension/ Mind Expander: the calculator allows me to expand my ideas and to do the work my own way.		.797	
(P3) Cal as Partner/ Different Perspective: I use the calculator to help me look at the same problem or concept in different ways.		.671	
(P2) Cal as Partner/ Cognitive Load: I use the calculator to help me simplify steps in a complex problem.	.401	.670	
(E1) Cal as Extension/ Freedom: I often use the calculator to explore maths even before the teacher tells me to.		.637	
(P4) Cal as Partner/ Facilitate Understanding: the calculator helps me understand concepts better.		.567	

Items	Component		
	1	2	3
(M2) Cal as Master/ Math Dependence: I usually just follow the steps taught when using the calculator to solve problems, and do not really understand the maths involved.			.845
(M3) Cal as Master/ Unfamiliar Conventions: I find the calculator confusing because it uses different conventions and symbols than normal maths.			.828
(M1) Cal as Master/ Lack of Tech Skills: I do not know why sometimes the calculator does not give me the answer that I want.	.459		.562

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

(3) Analysis of students' reasons for their most preferred social interaction for learning modes

In this section, students' responses for their most preferred social interaction for learning modes (individual, cooperative, or competitive), when studying mathematics and when working with calculators, are analysed and presented. Students' responses were coded and the codes (considered as sub-categories) were aggregated into categories using thematic analysis (Braun & Clarke, 2006). The following are four tables, Tables D7 to D10, which consist of the main categories, sub-categories, and examples. Tables D7 and D8 are analyses of Singaporean students' responses for their preferences when studying mathematics and when working with GCs respectively. Tables D9 and D10 are analyses of Victorian students' responses for their preferences when studying mathematics and when working with CAS calculators respectively. Each table consists of three sub-tables with these headings: studying mathematics/working with calculators Individually, Cooperatively, and Competitively. The percentage of students who most preferred the particular learning mode is indicated in the heading. Each sub-table has rows corresponding to the main categories with sub-categories and examples. The percentages of students' responses coded under each main category, as well as each sub-category, are given. Students' responses may be coded under two different sub-categories (i.e. overlap), and so the sum of the percentages in all the sub-categories for a main category will be either equal or more than the percentage for the category. Similarly, the sum of percentages for all the main categories will be more than 100%.

Table D7

Singaporean Students' Most Preferred Social Interaction Modes when Studying Mathematics: Categories, Subcategories and Examples

Study mathematics INDIVIDUALLY (S'pore: 491 most preferred, N = 361 explained why)	
Main category	*Subcategory and examples*
1. Learning outcomes (60.4%)	1. learn better, concentrate better (57.3%) Able to concentrate and focus better. (student #83)
	2. learn best this way (7.5%) I feel that I make the most progress if I study on my own. (student #292)
2. Learning performance (2.8%)	1. compete with self (2.2%) So that I can arrange my thoughts and understand it slowly. With friends, it's either I don't understand them or they will make me more confuse[d]. I don't really like to compete with my friends because i always prefer to compete with myself (in terms of the previous grades I got.. I will aim to get better grades than the previous grades that I got). (student #757)
	2. prepare for assessment (0.6%) Although cooperating with friends allows more room for "discoveries" but due to the nature that maths is a written paper, at least that is the way now, and hence studying individually allows me to sharpen my skills more effectively. (student # 723)
3. Learning process (33.5%)	1. work at own pace (18.6%) [I] can go at own speed. Especially when I don't understand, I have the chance to try until I can. (student #15)
	2. doing it myself (17.7%) Make out the concepts myself to understand better. (student #54)
	3. need the practice (2.5%) It's about practising...and only when you practise on your own do you know how to do any other similar sums next time (student #331)
	4. do not want to follow friends' schedule or pace (2.2%)

Study mathematics INDIVIDUALLY (S’pore: 491 most preferred, N = 361 explained why)	
Main category	*Subcategory and examples*
	It is more convenient as you do not have to work according to the timeslots of others. (student #442)
4. Learning environment (36.6%)	1. no distractions (31.6%) No room for distraction. (student #17) 2. peaceful and quiet (7.5%) I study more efficiently alone when it's peaceful and quiet. (student #239)
5. Attitudes (13.9%)	1. social pressure when studying with friends (5.0%) [I] can slowly figure out the steps by myself without the pressure of having to perform in front of friends, or being embarrassed in front of them (student #853) 2. I like it (3.9%) I just like it (student #165) 3. stressful when competing with friends (3.0%) Study individually enables me to set my own pace so that I will find it comfortable. Competing with friends may provide a sense of motivation but at the same time, it can ruin friendships or even transforming to a stress that "I am incompetent". Cooperating with friends would provide a collection of ideas, but I would like to discover those ideas myself instead of playing the 'spoon-feeding' game. (student #146) 4. satisfying and enjoyable (2.8%) [Studying alone] provides me the space to think on my own and discover myself (creativity). Also, I like the feeling of satisfaction whenever I am able to solve a tough question (student #438)
6. Peer interaction (17.5%)	1. seek help from teacher (5.8%) or friends (7.2%) when needed So that I can understand it myself. but if I still do not understand I seek help from friends or teachers (student #132) 2. do not want to over-rely on friends (4.7%)

Study mathematics INDIVIDUALLY (S’pore: 491 most preferred, N = 361 explained why)

Main category	*Subcategory and examples*
	I will be able to study at my own pace and to be able to realise the mistake myself instead of always relying on my friends. (student #839)
	3. friends were of no help (4.2%)
	I personally feel that my way of thinking is very different from other people. As such, it will not be conducive that I study with other people as we will just end up confusing ourselves. (student #369)

Study mathematics COOPERATIVELY (S’pore: 376 most preferred, N = 304 explained why)

Main category	*Subcategory and examples*
1. Learning outcomes (41.8%)	1. deepen understanding (13.5%)
	[I] can ask questions when either of us is stuck, and at the same time, deepen understanding on the topic by talking it out (student #154)
	2. clear doubts, mistakes, misconceptions (11.5%)
	Often when I meet with problems or queries or get stuck, I can discuss and learn from my friends or else I won't get anything done. I usually can't spot my own mistakes. (student #315)
	3. learn best this way (personal learning style) (6.6%)
	I work better with people. (student #819)
	4. solve more difficult problems, find new solutions (6.6%)
	Only then can we find a new solution (student #158)
	5. easier, clearer, best (5.9%)
	Answers are easier to get (student #28)

Study mathematics COOPERATIVELY (S’pore: 376 most preferred, N = 304 explained why)

Main category	*Subcategory and examples*
	6. understand better when teaching friends (4.6%) They can help me with the problems that i cannot solve on my own and by helping others i can further consolidate my learning (student # 346)
	7. understand better when explained by friends (3.6%) Formulas and theories seem easier to grasp when explained by friends. (student #553)
	8. can apply what was learnt (2.3%) Confirm what I already know thus helping me to improve and I get to help people. (student # 499)
	9. remember better through discussion (1.6%) Discussion can take place and I can remember what is discussed better. (student # 58)
	10. exposed to more questions (0.7%) I'm exposed to more math questions this way. My friends help me and I help them, so it's a win-win situation. (student #77)
2. Learning performance (8.9%)	1. academically weaker than peers, often get stuck (8.9%) I usually can't get Mathematics on my own, i usually ask my friends for help. (student # 223)2. Prepare for assessment (0.6%)
3. Learning process (29.3%)	1. share answers, knowledge, alternative perspectives and methods of solving problems. (21.7%) We can exchange our answers and methods of doing the sum. In that way both parties would be learning something. (student #407)
	2. immediate, just-in-time help, access to help when needed (7.9%) Can discuss any queries with my friends on the spot when I do not understand certain concepts. (student #444)
4. Learning environment (0%)	
5. Attitudes (15.5%)	1. fun, motivating, encouraging, satisfying (10.9%) It makes me feel happy. This is because i would be really frustrated if i'm stuck in a math question, hence, I really appreciate my friend's help

Study mathematics COOPERATIVELY (S’pore: 376 most preferred, N = 304 explained why)	
Main category	*Subcategory and examples*
	and suggestion to solve the problem as soon as possible. (student # 707) 2. cooperating with friends is easier than asking teacher or studying by myself, less pressure (4.6%) When we study together, at least I can ask my friends anything I don't know how to do and they can teach me, or vice versa. This is good for teachers can't be around all the time, or teachers may scold if they see that I don't understand something which I'm "supposed to understand by now". (student #639) 3. peer pressure keeps me focussed (3.6%) I get easily distracted and i need someone to help keep me focused (student #747)
6. Peer interaction (72.0%)	1. get help from friends, do better with friend’s help (38.5%) They can look out for my mistakes and teach me when I do not understand (student # 192) 2. help / teach each other, peer tutoring (24.0%) We can help each other if we're stuck. (student #451) 3. work together to come up with answer, learn together (5.6%) Working together to solve math problems that i don't know how to do is an effective way of understanding math (student #773) 4. learn from each other, discussions were made (note: vague statements with no details) (7.9%) We can learn from one another. (student #184) It allows room for discussion (student #898) 5. tap one another’s strengths and weaknesses (4.3%) We can help each other as we all having different levels of understanding, strengths and weaknesses. (student #615) 6. selective of friends (must be better in maths), or tutors (3.6%) I'm usually unable to do mathematical sums on my own. Therefore, I prefer to practise maths with my friends who are good at it. (student

Study mathematics COOPERATIVELY (S’pore: 376 most preferred, N = 304 explained why)	
Main category	*Subcategory and examples*
	#849)

Study mathematics COMPETITIVELY (S’pore: 61 most preferred, N = 48 explained why)	
Main category	*Subcategory and examples*
1. Learning outcomes (6.3%)	1. think and concentrate better (6.3%) Motivate me to think better (student #610)
2. Learning performance (12.5%)	1. brings out the best in me, push me to the limits (10.4%) It pushes me to do my best. (student #296) 2. prepares myself for examinations (4.2%) By competing with your friends, it can spur you on to try your best in solving the problems. And at the same time, it would provide the same intensity as what it would be in the exams. (student #335)
3. Learning process (50.0%)	1. study harder, strive for better results (31.3%) Competition makes you strive for even better results (student #31) 2. able to do maths quickly and accurately (12.5%) I will be more motivated to do my math accurately and quickly. (student #506) 3. can gauge improvement, time ourselves (6.3%) [Studying competitively] acts as an gauge to see how much you improved (student #420)
4. Learning environment (0%)	

Study mathematics COMPETITIVELY (S’pore: 61 most preferred, N = 48 explained why)	
Main category	*Subcategory and examples*
5. Attitudes (62.5%)	1. fun, motivating (43.8%) Competition pushes one to his limits for the motivation of doing better (student #137) 2. I like it, don’t like to lose, like to beat others (14.6%) I don't like to lose. (student #282) 3. makes maths interesting, meaningful (12.5%) That would be my main motivation to study math. Interest in math does not come naturally to me. (student #133) 4. sense of accomplishment (6.3%) Personally, competition motivates me to study harder and to push myself so that I can win my friends and makes me feel a sense of accomplishment satisfied with myself, unlike studying individually which doesn't gives me the same sense. (student #124)
6. Peer interaction (6.3%)	1. compare with those better than me (6.3%) For example Saravanan, who is a Maths expert and by getting the answer b4 [before] him, [it] give[s] me a great sense of achievement (student #840)

Table D8

Singaporean Students' Most Preferred Social Interaction Modes when Working with GC: Categories, Subcategories and Examples

Work with GC INDIVIDUALLY (S'pore: 292 most preferred, N = 200 explained why)	
Main category	*Subcategory and examples*
1. Learning outcomes (31.5%)	1. learn better, concentrate better (28.5%) Much easier because I can focus better (student #360) 2. learn best this way (3.5%) I learn best when I explore the uses of the GC on my own with little guidance or help. (student #292)
2. Learning performance (4.5%)	1. prepare for assessment (3.5%) During exams, I won't be able to get any help from my friends. So it's better to train and learn to use GC on my own. (student #764)
3. Learning process (23.5%)	1. explore on my own (13.0%) It allows me to learn about the functions on my own, which then allows me remember the functions of certain buttons. (student #94) 2. work at own pace (9.0%) I can take my time to explore different functions of GC (student #749) 3. I can go faster (3.0%) I can figure out the steps faster. (student #112) 4. need the practice (1.5%) I would be able to fully learn and practise the functions of the GC at my own pace when doing it by myself. (student #665)
4. Learning environment	1. no distractions (7.0%)

Work with GC INDIVIDUALLY (S'pore: 292 most preferred, N = 200 explained why)	
Main category	*Subcategory and examples*
(9.5%)	No distractions. (student #341)
	2. peace and quiet (2.5%)
	The quiet and peaceful environment is very important to me as i am thinking of the ways to use the GC to solve the problem sums. (student #651)
5. Attitudes (10.0%)	1. I like it (4.0%)
	I like it. (student #417); I like to figure it out on my own. (student #831)
	2. satisfying and fun (3.0%)
	Its fun to explore GC on my own (student #424)
	3. social pressure of working with friends (2.0%)
	[Be]cause can click randomly and not being laughed at by friends for not knowing certain functions (student #544)
	4. I am confident enough to work with GC on my own (1.5%)
	I can figure things out myself pretty easily!! (student #750)
6. Peer interaction	1. less confusing, friends are of no help (6.5%)
(12.5%)	Sometimes cooperating with my friends can make it even more confusing (student #492)
	2. ask friends if I don't understand (3.0%)
	You can learn a lot of things from friends, as well as explore new stuff that the teacher does not cover in the syllabus (student #339)
	3. don't want to be too reliant on friends (3.0%)
	I want to know how to use the GC and not rely on my friends (student #276)

Work with GC INDIVIDUALLY (S’pore: 292 most preferred, N = 200 explained why)

Main category	*Subcategory and examples*
7. Technology (22.5%)	1. GC is a personal device, cannot be shared (6.5%) GC is a PERSONAL calculating device. it is irritating to discuss with friends about how to use a GC (student #551) Kinda hard to 'collectively' use a GC (student #759)
	2. it is easier to use GC individually (5.5%) There's nothing to compete with using the GC, since it just helps you in solving math questions, thus it would be easier to use the GC individually. (student #335)
	3. do not understand how to work with GC cooperatively or competitively (5.5%) Sorry I don’t know what you mean by compete with friends in using GC. I don’t know how it is possible to compete with people in using the GC unless its something like fastest fingers first, which I think is quite silly. cooperating with others only if I don’t know how to use the GC (student #275)
	4. Enough clear instructions that I can do it alone (4.5%) My definition of studying on my own is to read instructions and press the GC, so this is better for me because I like following printed instructions that I know are correct, and this gives me security. (student #193) The instructions given are generally sufficient for competent usage of the GC. (student #292)
	5. I have my own way of using GC; different people have different ways of using GC (3.0%) We all have different methods of using the GC, I find that I use it differently from most of my classmates and so it is just weird to do GC stuff with them. By the way your question is rather awkward, how does one really compete with the GC... (student #390)

Work with GC INDIVIDUALLY (S’pore: 292 most preferred, N = 200 explained why)

Main category	*Subcategory and examples*
	I don't get confused with my friends' methods, especially after I'm used to my own ways after being taught by the teacher. (student #826)
	6. GC is too complicated to discuss with friends (1.0%)
	GC has too many details to discuss with my friends. (student #98)

Work with GC COOPERATIVELY (S’pore: 595 most preferred, N = 452 explained why)

Main category	*Subcategory and examples*
1. Learning outcomes (36.7%)	1. clear doubts, spot mistakes, misconceptions, check answers and GC steps (20.1%)
	I might have missed out certain steps and my friends can identify them for me. (student # 433)
	2. clearer, best (5.5%)
	Its better and easier to figure out how to use the GC (student #938)
	3. learn how to use GC best this way (personal learning style) (4.0%)
	The GC is a new concept which I find easier to understand by discussing with friends sometimes. (student #621)
	4. solve more difficult problems, find new or best or most efficient solution, discover new things (3.1%, N = 14)
	Cooperating with friends to use the GC enables me to discover new things more easily (student #671)
	5. remember better, friends remind me of the steps (2.7%)
	If I do not know how to work the GC I can always ask my friends. also, if they do not know, I can explain and this helps me in remembering how to

Work with GC COOPERATIVELY (S'pore: 595 most preferred, N = 452 explained why)	
Main category	*Subcategory and examples*
	work the GC even better (student #773)
	6. clearer, I understand better because it's explained by my friends (2.0%)
	Steps are often easier to understand when taught by friends (student #188)
	7. deepen understanding (1.8%)
	[I] can understand better through sharing of knowledge (student #111)
	8. solve faster, easier, better results (0.9%)
	We can teach each other how to call out specific symbols and programmes if we are unsure. Hence, making the task of solving a maths question easier. (student #959)
	9. I understand better when I teach my friends, I benefit when helping friends (0.9%)
	I explored the GC more than my peers - so I am able to teach them how to do stuff. (student #611)
2. Learning performance (7.1%)	1. I am weaker than my peers in GC skills, I often get stuck, I need a lot of help (7.1%)
	Because I usually need a lot of help when it comes down to using the GC.. (student #74)
3. Learning process (21.9%)	1. share ideas, knowledge, perspectives (9.1%)
	Share knowledge/methods about the use of GC. (student #935)
	2. help when you are stuck, when there is a problem (6.9%)
	So that I can ask them if I can't find the answer. (student #470)
	3. immediate just-in-time help, saves time, learn faster (6.2%)

Work with GC COOPERATIVELY (S'pore: 595 most preferred, N = 452 explained why)

Main category	*Subcategory and examples*
	If I don't know or am unsure on how to use it, I can immediately consult my friends and they can teach me. (student #467)
4. Learning environment (0%)	
5. Attitudes (12.4%)	1. fun, motivating, encouraging (7.3%) As for GC, it's more fun and enjoyable to discover it with other people. And there is not much competitiveness in terms of GC usage. (student #730) 2. easier than asking teacher or using GC by myself (2.7%) Sometimes, I find GC a bit confusing due to so many different functions and buttons. So it is easier for me to ask my friends or discover how to approach a question together. (student #557) 3. I am not confident in using GC (1.5%) [I] need their help alot because I'm not too sure and confident of my GC abilities. (student #212) 4. too lazy to do it myself (1.1%) Too lazy to figure it out myself. (student #552)
6. Peer interaction (68.1%)	1. get help from friends, do better with friends' help (40.0%) I can ask my friends to help me out. (student #3) 2. help each other (16.8%) This is because we can all help one another to learn about the functions of the GC! (student #25)

Work with GC COOPERATIVELY (S’pore: 595 most preferred, N = 452 explained why)	
Main category	*Subcategory and examples*
	3. learn from each other, two heads better than one (8.4%) More brains are better than one; in case I have trouble using a function in the GC, my friends may help me. (student #290)
	4. work together to come up with answer, learn together (4.2%) It is more interesting to work with friends, and discover the different functions together. (student #222)
	5. tap one another’s strengths and weaknesses (4.2%) Sometimes they know how to work the GC in the areas I don't know and vice versa, this way we can help each other to better know how to use the GC. (student #495)
	6. selective of friends (must be better at GC) (0.7%) [I] learn about the GC from those who knows how to use it (student #472)
7. Technology (29.9%)	1. learn from friends how to use the GC functions, explore together (28.5%) When I cooperate with my friends, I can ask for help if I do not know what to press in the GC (student #561)
	2. GC is complicated (2.2%) Learning to use the GC is like teaching my grandmother to use the world wide web. The numerous options to each category, different modes plus all the hidden tricks is very very complicating. (student #34)
	3. GC is different from pen-paper (0.9%) Using the GC is complicated. when I'm stuck at solving by the GC, my friends can help me to continue with the next step as GC only have one or two ways to solve. this is unlike solving math manually, when i can use all my math concepts to go around the problems when i'm stuck (student #400)

Work with GC COMPETITIVELY (S’pore: 19 most preferred, N = 12 explained why)

Main category	*Subcategory and examples*
Learning outcomes (8.3%)	1. think and concentrate better (8.3%)
	Motivate me to think better (student #610)
Learning performance (0%)	
Learning process (50.0%)	1. study harder, strive for better results (25.0%)
	It spurs me on to do better (student #716)
	2. can gauge improvement, time ourselves (16.7%)
	Fun to see who gets it first, and can test our timings (student #639)
	3. able to do maths quickly, accurately (8.3%)
	We can come out with interesting ideas or the shortest shortcut to solve a problem (student #13)
Learning environment (0%)	
Attitudes (50.0%)	1. fun and motivating (50.0%,)
	Extra motivation. (student #378)
	2. sense of accomplishment (8.3%)
	Again, a sense of accomplishment and motivation will be triggered by competition. (student #124)
Peer Interaction (0%)	
Technology (0%)	

Table D9

Victorian Students' Most Preferred Social Interaction Modes when Studying Mathematics: Categories, Subcategories and Examples

Study mathematics INDIVIDUALLY (Vic: 67 most preferred, N = 48 explained why)	
Main category	*Subcategory and examples*
1. Learning outcomes (54.2%)	1. learn better, concentrate better (33.3%) There is quiet and my thoughts can run clearly through my head without interuptions. It allows me to find my own mistakes, correct them and learn from them, so ultimately i am learning more from myself which is more beneficial.. (student #177) 2. get more work done (22.9%) When I'm on my own I feel I can understand the work I'm doing better and get more work done (student #166) 3. understand more thoroughly (4.2%) I like to study on my own because I can go at my own pace and understand concepts thoroughly before moving on. (student #145)
2. Learning performance (2.1%)	1. compete with self (2.1%) My class is very competitive and i dont like that. i like to do my personal best and not be competing all the time, hence why i like to study by myself (student #49)
3. Learning process (33.3%)	1. work at own pace (12.5%) [I prefer to study mathematics individually so] then there is no competition and I can go at my own pace (student #168) 2. doing it myself (18.8%) It helps me to think independently. (student #68) 3. get more practice (6.3%)

Study mathematics INDIVIDUALLY (Vic: 67 most preferred, N = 48 explained why)	
Main category	*Subcategory and examples*
	I get to work at my own pace and get more practice trying to work out to problem. (student #90)
4. Learning environment (45.8%)	1. no distractions (43.8%) I often get distracted when working with friends, so for me personally, I prefer working on my own (student #169)
	2. peaceful and quiet (10.4%) I get the most work done when I’m not distracted and can work in a quiet place (student #92)
5. Attitudes (16.7%)	1. social pressure when studying with friends (10.4%) I find that it is often good to spend some time alone playing around without the pressure of needing to get things right the first time. (student #37)
	2. stressful when competing with friends (4.2%) My class is very competitive and I don’t like that. I like to do my personal best and not be competing all the time, hence why I like to study by myself (student #49)
	3. satisfying and enjoyable (2.1%) I like the satisfaction of being able to work out something on my own rather than "cheating" by sharing with someone else (student #60)
6. Peer interaction (10.4%)	1. seek help from teacher (2.1%) or friends (6.3%) when needed I can usually work out the maths problems by myself, if not I will then ask a teacher or sometimes a friend. (student #107)
	2. friends were of no help (6.3%) I find it easier to get the work done if i am by myself and in a quiet environment rather than with friends that may distract. Also if the friend is at a different level than i am it can be quite irritating and can slow down the study. (student #115)

Study mathematics COOPERATIVELY (Vic: 45 most preferred, N = 36 explained why)

Main category	*Subcategory and examples*
1. Learning outcomes (38.9%)	1. deepen understanding (13.9%) I find that it really helps me understand things, and help others understand them. Ideas can be communicated in a much more.. Well, understandable way by my peers rather than my teacher. (student #11)
	2. clear doubts, mistakes, misconceptions (8.3%) I often require my friends to explain a concept to me/show me how to do it, and receive affirmation that my answers are correct before attempting on my own (student #123)
	3. easier, clearer, best (8.3%) It's easier to work together and make sure you both have the right answer and remind each other about the steps that are involved than struggling by yourself (student #10)
	4. understand better when teaching friends (5.6%)
	5. understand better when explained by friends (5.6%) You can learn more by trying to teach your friends a concept if they do not understand it and also if you need help they can usually explain it in a way which I can understand (student #128)
	6. remember better through discussion (5.6%) Helping others makes myself feel good, dispensing what you know also helps the information sink into your memory much better. (student # 51)

Study mathematics COOPERATIVELY (Vic: 45 most preferred, N = 36 explained why)	
Main category	*Subcategory and examples*
	7. learn best this way (personal learning style) (2.8%) I'm extroverted and prefer to work with people and if I require help, I have quick access to other people. (student #86) 8. solve more difficult problems, find new solutions (2.8%) We can help each other out… and work through the problems together consolidate our own skills and learn new ones from them. Provides help and support. It makes me feel confident as they are in the same position as me (student #167)
2. Learning performance (2.8%)	1. academically weaker than peers, often get stuck (2.8%) I'm bad at studying by myself. I get distracted, procrastinate. If I'm with a friend, they don't even have to be doing the same thing as me, just their presence is helpful. (student #119)
3. Learning process (30.6%)	1. share answers, knowledge, alternative perspectives and methods of solving problems. (25.0%) So if I have trouble I can compare answers with friends and understand how they worked it out. (student #151) 2. immediate, just-in-time help, access to help when needed (5.6%) Multiple brains are better than one, we all do our own work, but when people need help on particular questions, we are able to help each other, making sure not to do all the work for that person, but allowing each other to still learn. (student #56)
4. Learning environment (0%)	
5. Attitudes (16.7%)	1. fun, motivating, encouraging, satisfying (13.9%)

Study mathematics COOPERATIVELY (Vic: 45 most preferred, N = 36 explained why)	
Main category	*Subcategory and examples*
	Do the working by myself, and then compare answers, and when stuck, ask for help. It's therefore fun, as well as understanding the procedure myself. (student # 83) 2. distract from boring maths (2.8%) Because my friends distract me from the boring maths that I took only because further maths clashed with all the subjects i had chosen to take. (student #149)
6. Peer interaction (69.4%)	1. get help from friends, do better with friend's help (33.3%) I often require my friends to explain a concept to me/show me how to do it, and receive affirmation that my answers are correct before attempting on my own (student # 123) 2. help / teach each other, peer tutoring (30.6%) You can help each other if one person gets stuck. (student #165) 3. work together to come up with answer, learn together (8.3%) I like to do it with otehrs because if i have something wrong or if i'm doing it differently to others, we can cooperate with eachother and find a solution. (student #41) 4. tap one another's strengths and weaknesses (8.3%) I'm extroverted and prefer to work with people and if I require help, I have quick access to other people. Also, different people have different strengths and so when we work together we are more capable. (student #615)

Study mathematics COMPETITIVELY (Vic: 15 most preferred, N = 13 explained why)	
Main category	*Subcategory and examples*
1. Learning outcomes (23.1%)	1. learn best this way, my learning style (23.1%) I learn well when I'm trying to do something quickly and logically, but only informal competition in the study room, not classroom competitions. (student #1) I'm a very competitive person (student #610)
2. Learning performance (15.4%)	1. brings out the best in me, push me to the limits (15.4%) Puts pressure on me to top my class, and because of this I am averaging 96% for my tests so far, and the funny thing about that is it's a VCE subject. (student #114)
3. Learning process (7.7%)	able to do maths quickly and accurately (7.7%) I like competition because it drives me to solve problems faster. If I don't understand a concept, I ask a friend or a teacher and try to make up the lost ground. (student #70)
4. Learning environment (0%)	
5. Attitudes (61.5%)	fun, motivating (38.5%) Competing against friends involves many aspects which I appreciate. First of all, you're still having fun with friends, yet learning (and possibly doing homework) at the same time. Given that you're with friends, it makes [studying] the subject a lot more pleasant (student #7) I like it, don't like to lose, like to beat others (15.4%)

Study mathematics COMPETITIVELY (Vic: 15 most preferred, N = 13 explained why)	
Main category	*Subcategory and examples*
	'cause I always win. :). (student #21)
	makes maths interesting, meaningful (7.7%)
	To see who's better. Gives me a reason [to study]. (student #54)
6. Peer interaction (15.4%)	help one another (7.7%)
	It’s fun. me and my mate always fight over who gets the correct answer and if one of us gets it wrong we explain to each other how we got it right then we look at the mistakes the other person made and laugh at it because it’s usually stupid! (student #5)
	friends help when I’m stuck (7.7%)
	Higher motivation and friends are able to help out when I get stuck (student #24)

Table D10

Victorian Students' Most Preferred Social Interaction Modes when Working with CAS Calculators: Categories, Subcategories and Examples

Work with CAS calculators INDIVIDUALLY (Vic: 52 most preferred, N = 36 explained why)	
Main category	*Subcategory and examples*
1. Learning outcomes (47.2%)	1. learn better, concentrate better (30.6%) I find it easier to concentrate. (student #138) 2. learn best this way (5.6%) it is more productive for me. (student #110) 3. responsible for own learning (5.6%) I know everything if learnt is my own. i.e. if I learnt something wrong it isn't because a friend had taught me the wrong thing. (student #90) 4. remember steps better (2.8%) I seem to remember the steps more easily if I am playing around with it myself; pressing the buttons and seeing what the results are. (student #57)
2. Learning performance (0.0%)	
3. Learning process (22.5%)	1. work at own pace (11.1%) learn at different pace to peers. (student #49) 2. I can go faster, more efficient (8.3%) Because I can do maths more quickly on my own. (student #74) 3. explore on my own (2.8%)

Work with CAS calculators INDIVIDUALLY (Vic: 52 most preferred, N = 36 explained why)	
Main category	*Subcategory and examples*
	I like to explore and figure things out for myself. If I need assistance, then I will often ask a friend or a teacher. (student #107)
4. Learning environment (13.5%)	1. no distractions (11.1%)
	I am easily distracted by other people. (student #172)
	2. peace and quiet (2.8%)
	Aplace which has more than a [one] person is too noisy. It is better to do it alone, quietly. (student #81)
5. Attitudes (11.1%)	1. satisfying and fun (5.6%)
	I get intrigued by some of the things I stumble upon. (student #45)
	2. I like it (2.8%)
	I like to explore and figure things out for myself. If I need assistance, then I will often ask a friend or a teacher. (student #107)
	3. I am confident enough to work with calculator on my own (2.8%)
	The calculator steps are not that hard to understand, I can do it on my own; otherwise I would prefer talking to the teacher than my friends. (student #155)
6. Peer interaction (19.4%)	1. ask teachers if I don’t understand (8.3%)
	The calculator steps are not that hard to understand, I can do it on my own; otherwise I would prefer talking to the teacher than my friends. (student #155)
	2. don’t want to be too reliant on friends (8.3%)
	It’s easier and can be more organised, you don’t have to rely on others (student #115)

Work with CAS calculators INDIVIDUALLY (Vic: 52 most preferred, N = 36 explained why)	
Main category	*Subcategory and examples*
	3. ask friends if I don't understand (5.6%) I take in the concepts better, I may ask my friends for help but it becomes disruptive to be asked every 2 minutes by a friend for help. (student #137)
7. Technology (13.9%)	1. Calculator is a personal device, cannot be shared (5.6%) Only one person can really use a calculator at a time (student #10) Due to the nature of the calculator, if others are working with you they do not necessarily have to do any work on their own calculators but just look off yours. This causes them to not actually learn the methods. (student #7) 2. Calculator is not hard so I can do it alone (2.8%) The calculator steps are not that hard to understand, I can do it on my own; otherwise I would prefer talking to the teacher than my friends. (student #155) 5. I have my own way of using the calculator, different people have different ways of using calculators (2.8%) It's not the sort of thing that you can really work together with because everyone uses the calculator differently to solve equations. (student #37) 6. Depending on situation (2.8%) When I am learning new functions on the calculator I find it helpful to learn with others. However when I am using the calculator for task which I have already learnt I prefer to work by myself. (student #159)

Work with calculators COOPERATIVELY (Vic: 62 most preferred, N = 46 explained why)

Main category	*Subcategory and examples*
1. Learning outcomes (45.7%)	1. clear doubts, spot mistakes, misconceptions, check answers and GC steps (21.7%)
	If I get the wrong answer I won’t know what I did wrong unless my friend can show me what I did or didn't do. (student # 152)
	2. deepen understanding (6.5%)
	When i'm doing it with my friends i feel i understand it better (student #166)
	3. solve more difficult problems, find new or best or most efficient solution, discover new things (6.5%)
	As all my friends have different knowledge of the calculator, we all learn new ways to work out a problem using the calculator (student #169)
	4. clearer, I understand better because it’s explained by my friends (6.5%)
	They can usually explain it to me, in 'english' terms so I understand it. (student #122)
	5. remember better, friends remind me of the steps (2.2%)
	We can discuss the process and if I have mistakes, friends can tell me what's wrong and next time I will remember. (student #139)
	6. I understand better when I teach my friends, I benefit when helping friends (2.2%)
	Some friends are more technologically inclined than others. When we work together, we can help each other work out how to work with the calculator. Teaching others also helps improve oneself's skills. (student #86)
2. Learning performance (2.2%)	1. I am weaker than my peers in GC skills, I often get stuck, I need a lot of help (2.2%)
	I do not know how to use the calculator, so when I’m stuck on a question, my friends help me. (student #50)
3. Learning process (37.0%)	1. share ideas, knowledge, perspectives (23.9%)
	We can help each other try to understand all the different symbols and notation that the calculator uses. (student #128)

Work with calculators COOPERATIVELY (Vic: 62 most preferred, N = 46 explained why)	
Main category	*Subcategory and examples*
	2. help when you are stuck, when there is a problem (15.2%) They can help me out if I get stuck. (student #116)
4. Learning environment (0%)	
5. Attitudes (15.2%)	1. easier than asking teacher or using calculator by myself (4.3%) It’s easier when we work it out together. (student #87)
	2. I am not confident in using the calculator (4.3%) Because I do not really understand how to use the calculator properly, so my friends are able to explain it for me (student #117)
	3. fun, motivating, encouraging (2.2%) So I can check whether my answer corresponds with theirs, even though this may not be correct it gives me confidence if we share the same answer. (student #154)
	4. I like it, hate other modes (2.2%) I hate competition, and I hate being by myself. Simple solution. (student #119)
	5. less pressure (2.2%) Most people aren’t that comfortable with using calculators so bouncing ideas off each other often helps and you don’t feel like it's just you who doesn’t understand the concept. (student #158)
	6. I don’t like mathematics (2.2%) Because my friends are awesome and maths sucks like hell. (student #149)

Work with calculators COOPERATIVELY (Vic: 62 most preferred, N = 46 explained why)

Main category	*Subcategory and examples*
6. Peer interaction (67.4%)	1. get help from friends, do better with friends’ help (26.1%)
	They show me what I have done wrong. (student #104)
	2. help each other (21.7%)
	We can help each other to figure out what we need to do, and ensure that we are all on the right track by comparing our answers. (student #76)
	3. work together to come up with answer, learn together (13.0%)
	Sharing ideas and how to work the calculator by learning together. (student #51)
	4. tap one another’s strengths and weaknesses (6.5%)
	Friends have often learnt different ways or shortcuts for using the CAS calculator, which we can show each other for a broader understanding. (student #75)
	5. learn from each other, two heads better than one (4.3%)
	Two or more minds are better than one. (student #118)
7. Technology (32.6%)	1. learn from friends how to use the calculator functions, explore together (15.2%)
	If there is a concept on the calculator that we don't understand we can work together to find the answer. (student #102)
	2. CAS calculator is complicated, confusing (10.9%)
	At times, using calculators are confusing. (student #24)
	3. some friends are more technologically inclined (6.5%)
	Some friends are more technologically inclined than others. When we work together, we can help each other work out how to work with the

Work with calculators COOPERATIVELY (Vic: 62 most preferred, N = 46 explained why)	
Main category	*Subcategory and examples*
	calculator. Teaching others also helps improve oneself's skills. (student #86) 4. troubleshoot for one another (4.3%) It allows us to work out different ways of achieving desired goals, or we can troubleshoot each other's calculations to help determine where they are wrong (in the case that the calculator does not give the answer expected). (student #39) 5. prefer not to use CAS calculator (2.2%) I prefer not to use the CAS, so I like to learn quickly. (student #70)

Work with calculators COMPETITIVELY (Vic: 4 most preferred, N = 2 explained why)	
Main category	*Subcategory and examples*
1. Learning outcomes (0.0%)	
2. Learning performance (0%)	
3. Learning process (0.0%)	
4. Learning environment (0%)	
5. Attitudes (100%)	1. fun and motivating (50%) It's more fun. (student #124) 2. I like it, don't like to lose, like to beat others (50%) I always win. :) (student #21)

Work with calculators COMPETITIVELY (Vic: 4 most preferred, N = 2 explained why)	
Main category	*Subcategory and examples*
6. Peer Interaction (0%)	
7. Technology (0%)	

Chi-square test results for investigating gender differences in students' general VARK preferences. No significant differences were found.

S'pore: ($\chi^2_{\text{Visual}}(1,964) = 0.133$, $p = 0.715$; $\chi^2_{\text{Aural}}(1,964) = 0.636$, $p = 0.425$; $\chi^2_{\text{Read/Write}}(1,964) = 0.155$, $p = 0.694$; $\chi^2_{\text{Kinesthetic}}(1,964) = 1.815$, $p = 0.178$)

Vic: ($\chi^2_{\text{Visual}}(1,142) = 0.557$, $p = 0.456$; $\chi^2_{\text{Aural}}(1,142) = 0.528$, $p = 0.467$; $\chi^2_{\text{Read/Write}}(1,142) = 1.421$, $p = 0.233$; $\chi^2_{\text{Kinesthetic}}(1,142) = 0.063$, $p = 0.801$)

Table D11

Singaporean Students' Reasons for Most Preferred Social Interaction Preferences when Studying Mathematics: Summary of Percentages of Categories between Males and Females

	Individually		Cooperatively		Competitively	
	Females N = 236	Males N = 125	Females N = 203	Males N = 101	Females N = 21	Males N = 27
Learning outcomes	60.2%	60.8%	42.9%	39.6%	4.8%	7.4%
Learning performance	0.8%	6.4%	9.4%	7.9%	14.3%	0.0%
Learning process	34.3%	32.0%	32.5%	22.8%	42.9%	55.6%
Learning environment	39.0%	32.0%	0.0%	0.0%	0.0%	0.0%
Attitudes	12.7%	16.0%	12.3%	21.8%	61.9%	63.0%
Peer Interaction	17.4%	17.6%	74.9%	66.3%	9.5%	3.7%

Note: those percentages with a difference of about 10% or higher between females and males were highlighted.

Table D12

Singaporean Students' Reasons for Most Preferred Social Interaction Preferences when Working with GCs: Summary of Percentages of Categories between Males and Females

	Individually		Cooperatively		Competitively	
	Females N = 121	Males N = 79	Females N = 313	Males N = 139	Females N = 6	Males N = 6
Learning outcomes	31.4%	31.6%	39.0%	31.7%	16.7%	0.0%
Learning performance	3.3%	3.8%	7.7%	5.8%	0.0%	0.0%
Learning process	26.4%	19.0%	17.9%	30.9%	50.0%	50.0%
Learning environment	9.9%	8.9%	0.0%	0.0%	0.0%	0.0%
Attitudes	12.4%	6.3%	12.3%	12.2%	50.0%	50.0%
Peer Interaction	13.2%	11.4%	70.9%	61.9%	0.0%	0.0%
Technology	22.3%	22.8%	31.6%	25.9%	0.0%	0.0%

Note: those percentages with a difference of about 10% or higher between females and males were highlighted.

Table D13

Victorian Students' Reasons for Most Preferred Social Interaction Preferences when Studying Mathematics: Summary of Percentages of Categories between Males and Females

	Individually		Cooperatively		Competitively	
	Females N = 44	Males N = 4	Females N = 27	Males N = 9	Females N = 6	Males N = 7
Learning outcomes	59.1% (N = 26)	0.0%	33.3% (N = 9)	55.6% (N = 5)	50.0% (N = 3)	0.0%
Learning performance	2.3% (N = 1)	0.0%	3.7% (N = 1)	0.0%	0.0%	28.6% (N = 2)
Learning process	29.5% (N = 13)	75.0% (N = 3)	33.3% (N = 9)	22.2% (N = 2)	0.0%	14.3% (N = 1)
Learning environment	47.7% (N = 21)	25.0% (N = 1)	0.0%	0.0%	0.0%	0.0%
Attitudes	15.9% (N = 7)	25.0% (N = 1)	18.5% (N = 5)	11.1% (N = 1)	66.7% (N = 4)	57.1% (N = 4)
Peer Interaction	11.4% (N = 5)	0.0%	74.1% (N = 20)	55.6% (N = 5)	33.3% (N = 2)	0.0% (N = 0)

Table D14

Victorian Students' Reasons for Most Preferred Social Interaction Preferences when Working with CAS Calculators: Summary of Percentages of Categories between Males and Females

	Individually		Cooperatively		Competitively	
	Females N = 29	Males N = 7	Females N = 35	Males N = 11	Females N = 1	Males N = 1
Learning outcomes	55.2% (N = 16)	14.3% (N = 1)	54.3% (N = 19)	18.2% (N = 2)	0.0%	0.0%
Learning performance	0.0%	0.0%	2.9% (N = 1)	0.0%	0.0%	0.0%
Learning process	20.7% (N = 6)	28.6% (N = 2)	37.1% (N = 13)	36.4% (N = 4)	0.0%	0.0%
Learning environment	17.2% (N = 5)	0.0%	0.0%	0.0%	0.0%	0.0%
Attitudes	10.3% (N = 3)	14.3% (N = 1)	20.0% (N = 7)	0.0%	100% (N = 1)	100% (N = 1)
Peer Interaction	20.7% (N = 6)	14.3% (N = 1	68.6% (N = 24)	63.6% (N = 7)	0.0%	0.0%
Technology	10.3% (N = 3)	28.6% (N = 2)	28.6% (N = 10)	45.5% (N = 5)	0.0%	0.0%

(4) Analysis of students' VARK preferences

Table D15

Cross-Tabulation of Students' VARK Preferences by Gender and Region

Region				Gender		Total
				Female	Male	
Singapore	Visual	non-Visual	Count	338	204	542
			Expected Count	340.7	201.3	542.0
			% within Gender	55.8%	57.0%	56.2%
			% of Total	35.1%	21.2%	56.2%
		Visual	Count	268	154	422
			Expected Count	265.3	156.7	422.0
			% within Gender	44.2%	43.0%	43.8%
			% of Total	27.8%	16.0%	43.8%
	Total		Count	606	358	964
			Expected Count	606.0	358.0	964.0
			% of Total	62.9%	37.1%	100.0%
Victoria	Visual	non-Visual	Count	83	23	106
			Expected Count	81.4	24.6	106.0
			% within Gender	76.1%	69.7%	74.6%
			% of Total	58.5%	16.2%	74.6%
		Visual	Count	26	10	36
			Expected Count	27.6	8.4	36.0
			% within Gender	23.9%	30.3%	25.4%
			% of Total	18.3%	7.0%	25.4%
	Total		Count	109	33	142
			Expected Count	109.0	33.0	142.0
			% of Total	76.8%	23.2%	100.0%
Singapore	Aural	non-Aural	Count	331	205	536
			Expected Count	336.9	199.1	536.0
			% within Gender	54.6%	57.3%	55.6%
			% of Total	34.3%	21.3%	55.6%
		Aural	Count	275	153	428
			Expected Count	269.1	158.9	428.0
			% within Gender	45.4%	42.7%	44.4%
			% of Total	28.5%	15.9%	44.4%
	Total		Count	606	358	964
			Expected Count	606.0	358.0	964.0
			% of Total	62.9%	37.1%	100.0%
Victoria	Aural	non-Aural	Count	65	22	87
			Expected Count	66.8	20.2	87.0
			% within Gender	59.6%	66.7%	61.3%
			% of Total	45.8%	15.5%	61.3%
		Aural	Count	44	11	55
			Expected Count	42.2	12.8	55.0
			% within Gender	40.4%	33.3%	38.7%
			% of Total	31.0%	7.7%	38.7%
	Total		Count	109	33	142
			Expected Count	109.0	33.0	142.0
			% of Total	76.8%	23.2%	100.0%

Region				Gender		Total
				Female	Male	
Singapore	Read/Write	non-Read/ Write	Count	412	239	651
			Expected Count	409.2	241.8	651.0
			% within Gender	68.0%	66.8%	67.5%
			% of Total	42.7%	24.8%	67.5%
		Read/Write	Count	194	119	313
			Expected Count	196.8	116.2	313.0
			% within Gender	32.0%	33.2%	32.5%
			% of Total	20.1%	12.3%	32.5%
	Total		Count	606	358	964
			Expected Count	606.0	358.0	964.0
			% of Total	62.9%	37.1%	100.0%
Victoria	Read/Write	non-Read/ Write	Count	31	13	44
			Expected Count	33.8	10.2	44.0
			% within Gender	28.4%	39.4%	31.0%
			% of Total	21.8%	9.2%	31.0%
		Read/Write	Count	78	20	98
			Expected Count	75.2	22.8	98.0
			% within Gender	71.6%	60.6%	69.0%
			% of Total	54.9%	14.1%	69.0%
	Total		Count	109	33	142
			Expected Count	109.0	33.0	142.0
			% of Total	76.8%	23.2%	100.0%
Singapore	Kinesthetic	non-Kinesthetic	Count	533	304	837
			Expected Count	526.2	310.8	837.0
			% within Gender	88.0%	84.9%	86.8%
			% of Total	55.3%	31.5%	86.8%
		Kinesthetic	Count	73	54	127
			Expected Count	79.8	47.2	127.0
			% within Gender	12.0%	15.1%	13.2%
			% of Total	7.6%	5.6%	13.2%
	Total		Count	606	358	964
			Expected Count	606.0	358.0	964.0
			% of Total	62.9%	37.1%	100.0%
Victoria	Kinesthetic	non-Kinesthetic	Count	101	31	132
			Expected Count	101.3	30.7	132.0
			% within Gender	92.7%	93.9%	93.0%
			% of Total	71.1%	21.8%	93.0%
		Kinesthetic	Count	8	2	10
			Expected Count	7.7	2.3	10.0
			% within Gender	7.3%	6.1%	7.0%
			% of Total	5.6%	1.4%	7.0%
	Total		Count	109	33	142
			Expected Count	109.0	33.0	142.0
			% of Total	76.8%	23.2%	100.0%

Table D16

Pearson Chi-Square Values and Significant Levels for VARK Frequencies by Gender and Region

Mode	Singapore	Victoria
Visual	χ^2 (1, N = 964) = 0.133, p = 0.715	χ^2 (1, N = 142) = 0.557, p = 0.456
Aural	χ^2 (1, N = 964) = 0.636, p = 0.425	χ^2 (1, N = 142) = 0.528, p = 0.467
Read/Write	χ^2 (1, N = 964) = 0.155, p = 0.694	χ^2 (1, N = 142) = 1.421, p = 0.233
Kinesthetic	χ^2 (1, N = 964) = 1.815, p = 0.178	χ^2 (1, N = 142) = 0.063, p = 0.801

(5) Point-Biserial correlations between VARK preferences and the other variables

Table D17

Point-Biserial Correlations between VARK Preferences and the Other Variables

	Gender	MSR	CalSR	CK-DA	SK-SA	Ma_Indv	Ma_Coop	Ma_Comp	Cal_Indv	Cal_Coop	Cal_Comp	Cal_Enj	Cal_Conf	Cal_Ma	Cal_Se	Cal-Co
Singapore																
Visual	-.012	-.002	.053	.047	-.059	.031	.043	.018	.044	.041	.091**	.062	.021	-.017	-.001	.046
Aural	-.026	-.068*	-.056	-.065*	.037	-.024	.034	-.006	-.064	.024	-.109**	-.079*	-.066*	-.014	.008	-.085**
Read/Write	.013	-.025	-.024	-.016	.108**	.038	-.111**	.019	.067*	-.023	.007	-.028	-.020	.011	-.073*	-.049
Kinesthetic	.043	.033	.011	.010	-.046	-.046	.075*	.010	.014	.005	.053	.019	-.011	-.009	.008	.000
Victoria																
Visual	.063	-.092	-.010	-.110	-.029	-.084	-.151	.107	.024	-.101	.121	.018	.042	.063	-.012	-.031
Aural	-.061	.090	.025	.053	.045	-.055	.156	.079	-.045	.088	.103	.096	-.005	.098	.101	.089
Read/Write	-.100	-.010	-.025	.088	.190*	.294**	-.099	-.001	.169	-.032	-.009	-.081	.012	-.139	.062	.045
Kinesthetic	-.021	-.056	.023	-.093	.005	-.089	.073	.076	-.057	.026	-.005	-.045	-.048	.076	-.111	-.096

* $p<0.05$ ** $p<0.01$ *** $p< 0.001$

It can be seen that the correlations were non-significant or weak ($r < 0.3$).

(6) Point-Biserial correlations between social interaction for learning preferences and the other variables

Table D18

Point-Biserial Correlations between Social Interaction for Learning Preferences (Studying Mathematics and Working with Calculators) and the Other Variables

	Ma_Coop	Ma_Comp	Cal_Indv	Cal_Coop	Cal_Comp	V	A	R	K	Gender	MSR	CalSR	CK-DA	SK-SA	Cal_Enj	Cal_Conf	Cal_Ma	Cal_Se	Cal_Co
Singapore																			
Ma_Indv	-.070*	-.004	.190**	.018	-.045	.031	-.024	.038	-.046	-.057	.087**	.012	.130**	-.050	.015	.010	-.034	-.064	.077*
Ma_Coop		-.080*	-.010	.378**	.049	.043	.034	-.111**	.075*	-.053	-.056	-.014	-.048	.054	.060	.013	-.019	.000	.030
Ma_Comp			-.006	-.005	.438**	.018	-.006	.019	.010	.193**	.193**	.090**	.223**	-.075*	.026	.043	-.006	-.031	.125**
Cal_Indv				-.036	.113**	.044	-.064	.067*	.014	.021	.074*	.269**	.045	-.065*	.328**	.293**	-.222**	.092**	.250**
Cal_Coop					.059	.041	.024	-.023	.005	-.058	-.018	-.031	.001	.085*	.041	.005	.012	-.014	.056
Cal_Comp						.091**	-.109**	.007	.053	.138**	.142**	.226**	.188**	-.017	.203**	.181**	-.041	.025	.217**
Victoria																			
Ma_Indv	-.018	.015	.344**	.123	.100	-.084	-.055	.294**	-.089	-.126	.098	-.009	.180*	.105	.044	-.058	-.042	.202*	.167
Ma_Coop		.069	.038	.580**	.050	-.151	.156	-.099	.073	.024	.002	-.107	-.023	.050	-.062	-.144	.040	.123	-.032
Ma_Comp			.098	.139	.513**	.107	.079	-.001	.076	.261**	.243**	.225*	.093	-.063	-.048	.073	-.117	-.165	.150
Cal_Indv				-.079	.102	.024	-.045	.169	-.057	.025	.132	.183*	.200*	-.040	.229*	.314**	-.209*	.092	.291**
Cal_Coop					.049	-.101	.088	-.032	.026	-.086	-.055	-.115	-.051	.134	.035	-.095	.050	.151	-.039
Cal_Comp						.121	.103	-.009	-.005	.182*	.161	.052	.018	.041	.036	-.023	-.011	-.085	.091

* $p<0.05$ ** $p<0.01$ *** $p< 0.001$

Note: Significant correlations were highlighted: Blue (weak, r between 0.1 and 0.3), Yellow (moderate, r between 0.3 and 0.5), Green (strong, r>0.5).

It can be seen in Table A33 that most of the correlations were non-significant or weak ($r < 0.3$, highlighted in Blue). The social interaction for learning preferences were mainly correlated with one another (e.g., preference for studying mathematics individually [Ma_Indv] correlated to preference for working individually with calculators [Cal_Indv]). The preference for working with calculators individually is moderately with calculator enjoyment [Cal_Enj] (S'pore: $r = 0.328$, Vic: $r = 0.229$) and calculator confidence [Cal_Conf] (S'pore: $r = 0.293$, Vic: $r = 0.314$).

Appendix E: Analyses of Part 2 of the study

(1) Students' survey data with respect to gender

	Hajah	**Nuru**	**RuiGang**	**Michelle**	**Stephanie**	**Sulleh**	**Asyraff**	**Amira**	**Umah**
Class	*Science H2Maths*	*Science H2Maths*	*BlendH2 Maths*	*BlendH2 Maths*	*BlendH2 Maths*	*ArtsH1Maths*	*ArtsH1Maths*	*ArtsH1Maths*	*ArtsH1Maths*
Gender	Male	Female	Male	Female	Female	Male	Male	Female	Female
MSR	3 Average	3 Average	3 Average	4 Good	2 Below Average	Left blank	1 Weak	1 Weak	4 = Good
CalSR	3 Average	3 Average	3 Average	4 Good	3 Average	3 Average	3 Average	1 Weak	4 = Good
General VARK preference	Aural (V = 0, A = 5, R = 0, K = 2)	Aural (V = 3, A = 4, R = 2, K = 1)	Aural (V = 2, A = 3, R = 2, K = 0)	Visual (V = 6, A = 3, R = 1, K = 2)	Read-Write (V = 2, A = 2, R = 5, K = 3)	Aural + Read-Write (V = 0, A = 3, R = 3, K = 1)	Visual (V = 5, A = 3, R = 4, K = 2)	VAR multimodal (V = 2, A = 2, R = 2, K = 1)	Visual (V = 6, A = 3, R = 5, K = 0)
Most preferred method of learning how to use the GC (Cal VARK)	(i) try out the steps on the GC the same time I see a demonstration, hear an explanation, or read the	b) see steps friends show me on the GC	Left Blank	(i) try out the steps on the GC the same time I see a demonstration, hear an explanation, or read the	(i) try out the steps on the GC the same time I see a demonstration, hear an explanation, or read the	c) refer to GC screen shown on notes, textbooks or manual	(h) make my own notes.	(i) try out the steps on the GC the same time I see a demonstration, hear an explanation, or read the	(a) see my teacher's demonstration in class

	Hajah	**Nuru**	**RuiGang**	**Michelle**	**Stephanie**	**Sulleh**	**Asyraff**	**Amira**	**Umah**
Class	*Science H2Maths*	*Science H2Maths*	*BlendH2 Maths*	*BlendH2 Maths*	*BlendH2 Maths*	*ArtsH1Maths*	*ArtsH1Maths*	*ArtsH1Maths*	*ArtsH1Maths*
	instructions.			instructions.	instructions.			instructions.	
Least preferred method of learning how to use the GC	(h) make my own notes	(f) listen to a teacher who reads out the steps given in notes, textbooks or manual.	Left Blank.	(c) look at the GC screen captures in notes, textbooks or manual. Note: Not consistent with her VARK preference – Visual.	(j) try the buttons out and play around with the GC.	(j) try the buttons out and play around with the GC.	(c) look at GC captures in notes, textbooks or manual. Note: Not consistent with his VARK preference - Visual.	(j) try the buttons out and play around with the GC.	(d) discuss answers with my friends.
CK	13/3 = 4.33	13/3 = 4.33	11/3 = 3.66	12/3 = 4	9/3 = 3	9/3 = 3	13/3 = 4.33	6/3 = 2	12/3 = 4
SK	12/3 = 4	11/3 = 3.66	7/3 = 2.33	12/3 = 4	11/3 = 3.67	14/3 = 4.67	12/3 = 4	14/3 = 4.67	14/3 = 4.67
DA	14/4=3.5	11/4=2.75	13/4=3.25	14/4=3.5	11/4=2.75	8/4=2	11/4=2.75	4/4=1	12/3=4*
SA	13/4 = 3.25	11/4 = 2.75	16/4 = 4	12/4 = 3	15/4 = 3.75	12/4 = 3	13/4 = 3.25	14/4 = 3.5	16/4 = 4

* Except one item missing: "As I am reading, I try to relate new concepts and ideas to what I already know about the topic". Hence, the average of 3 items instead of 4 items was used.

	Hajah	**Nuru**	**RuiGang**	**Michelle**	**Stephanie**	**Sulleh**	**Asyraff**	**Amira**	**Umah**
Class	*Science H2Maths*	*Science H2Maths*	*BlendH2 Maths*	*BlendH2 Maths*	*BlendH2 Maths*	*ArtsH1Maths*	*ArtsH1Maths*	*ArtsH1Maths*	*ArtsH1Maths*
CK-DA	27/7 = 3.85	24/7 = 3.43	24/7 = 3.43	26/7 = 3.71	20/7 = 2.86	17/7 = 2.43	24/7 = 3.43	10/7 = 1.43	24/6 = 4
SK-SA	25/7 = 3.57	22/7 = 3.14	23/7 = 3.29	24/7 = 3.43	26/7 = 3.71	26/7 = 3.71	25/7 = 3.57	28/7 = 4	30/7 = 4.29
Ma_Indv	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes
Ma_Coop	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Ma_Comp	No	No	No	No	No	No	Yes	No	Yes
Ma_Social	"Cooperate with friends. The problem can be solved faster and things that we do not know, my friend might know and vice versa."	Individually "Study on my own. I am able to find out my own capability from how much I have learnt in school, and during tutorials."	Individually "Study on my own. There are lesser distraction as compared to the second option, and lesser stress as compared to the last option."	Study individually on my own. "I can concentrate better and focus is there".	"Cooperate with friends as they can teach me whatever I don't know, vice versa."	Cooperate with friends. "They can help out on sums that I can't do on my own".	Cooperate with friends. "They can help me if I get stuck. Easier to ask also.".	Cooperate with friends. "Friends can assist in my learning when I'm in doubt".	Individually. "Able to concentrate more."
Cal_Indv	Yes	No	Yes	Yes	Yes	Yes	Yes	No	Yes
Cal_Coop	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No

	Hajah	**Nuru**	**RuiGang**	**Michelle**	**Stephanie**	**Sulleh**	**Asyraff**	**Amira**	**Umah**
Class	*Science H2Maths*	*Science H2Maths*	*BlendH2 Maths*	*BlendH2 Maths*	*BlendH2 Maths*	*ArtsH1Maths*	*ArtsH1Maths*	*ArtsH1Maths*	*ArtsH1Maths*
Cal_Comp	No	No	No	No	No	No	No	No	Yes
Cal_ Social	"Cooperate with friends. Can learn from each other."	"Cooperate with friends. I learn more when my friends show me the step by step way of finding the answer using the GC."	"First option [individually]. I don't see a need for the last two options."	Cooperate. "They might have new insights or shortcuts to get the answers."	Individually. "It is more efficient."	Cooperate. "If I miss a step, they can tell me what I need to do, or did wrong."	Cooperate. "It's easier to learn than learning (it) yourself."	Cooperate. "Friends can assist and help me when I go wrong."	Individually. "I am able to concentrate on my own."
Cal_Enj	5 Strongly Agree	3 Neutral	3 Neutral	3 Neutral	4 Agree	3 Neutral	4 Agree	3 Neutral	5 Strongly Agree
Cal_Conf	5 Strongly Agree	3 Neutral	4 Agree	3 Neutral	3 Neutral	3 Neutral	3 Neutral	3 Neutral	5 Strongly Agree
Cal_Ma	12/3 = 4	8/3 = 2.66	9/3 = 3	10/3 = 3.33	10/3 = 3.33	10/3 = 3.33	10/3 = 3.33	11/3 = 3.67	10/3 = 3.33
Cal_Se	18/4 = 4.5	20/4 = 5	12/4 = 3	19/4 = 4.75	15/4 = 3.75	19/4 = 4.75	15/4 = 3.75	19/4 = 4.75	14/4 = 3.5
Cal_Co	21/5 = 4.2	17/5 = 3.4	16/5 = 3.2	16/5 = 3.2	14/5 = 2.8	9/5 = 1.8	15/5 = 3	5/5 = 1	25/5 = 5

	Hajah	**Nuru**	**RuiGang**	**Michelle**	**Stephanie**	**Sulleh**	**Asyraff**	**Amira**	**Umah**
Class	*Science H2Maths*	*Science H2Maths*	*BlendH2 Maths*	*BlendH2 Maths*	*BlendH2 Maths*	*ArtsH1Maths*	*ArtsH1Maths*	*ArtsH1Maths*	*ArtsH1Maths*
What do you like most about using GC in maths classes?	"It shortens the process of doing calculations which are tough and complicating. It can help solve the toughest of problems as well."	"It would be useful to find the final answer."	"For statistical calculations."	Helps you in getting your answer fast! And accurately (via the store function)	Getting answers swiftly	That I don't need to draw out the graphs myself.	"Learning new stuff for calculations.	"It is quite an amusing instrument."	You will get it once you start practising.

	Hajah	**Nuru**	**RuiGang**	**Michelle**	**Stephanie**	**Sulleh**	**Asyraff**	**Amira**	**Umah**
Class	*Science H2Maths*	*Science H2Maths*	*BlendH2 Maths*	*BlendH2 Maths*	*BlendH2 Maths*	*ArtsH1Maths*	*ArtsH1Maths*	*ArtsH1Maths*	*ArtsH1Maths*
What do you dislike most about using GC in maths classes?	A wrong input and the whole equation may become wrong, and it may show the wrong value. Hence, the GC is as good as it gets as long as the user uses it correctly and types in the correct input.	It would be quite confusing, as it would involve multi-tasking in class (e.g. listening to the teacher, understanding, copy down the answer etc.)	RK left answer blank.	Must pay close attention in class in order to get the GC commands right. Also, there are certain limitations to the work of the GC.	Too many commands to remember	I cool with it.	“Solving difficult problems”.	“It confuses me at times when I could not catch up with the teacher”.	Can be complicated at times.

(2) Sample transcript: Hajah from ScienceH2Maths Class

The interviews were transcribed ad verbatim. The speech patterns were informal and contained hesitations, false starts, and Singaporean colloquialisms. Square brackets were used to add researcher comments in order to make the meaning clearer in the written text form (as compared to speech). Unclear words were followed by question marks. At the start of every interview, preamble such as the purpose of the study, anonymity and confidentiality of the data and security of the kept data were explained to the participants. The consent of participants was also sought. The transcript from the interview with Hajah is presented as a sample without the preamble. All the interviews were conducted by the researcher.

Int [Interviewer]: Ok. Hajah can you tell me three words to describe mathematics? Like what does mathematics mean to you? Three adjectives to describe maths.

Hajah: I'd say maths would be rather… it's interesting, because basically we tend to, though certain things [you] may not [be able to] apply in future, we get to actually know things that will, that might or might not help us, so it's kind of new to us you see, every… when we graduate from primary school to secondary school it changes, it's kind of new to us, every time we learn a new maths topic, so it's kind of interesting to be looking forward to something new, so I'm… I find it quite interesting. Another thing would be sometimes it might get complicated. Maths being a rather tough subject, because we know that some people might not be able to do maths as well as others, but I'm rather ok with it, because maths has always been, had had been a weak point in my life, but once I had actually gone for this er primary school tuition I kinda got a lot of confidence from it, then I'm, now I'm very, I'm very, trying to enjoy maths as much as I can, so I find maths very interesting too, complicated sometimes, and the last thing would be… maths is … hmm… it's a tough one… er… maths is rather…. …. …. Basically maths deals with a lot of numbers, so… how do I put it then… … … oh maths is pretty repetitive, I kind of realise, because basically what we learn earlier is kind of being mentioned over and over again in most lectures, so basically it trying to show us that, what we learn at the start, will definitely be keeping, will be applied inevitably in every topic, so basically the base of the mathematics education, we learn that in primary school, is rather important for you to keep (??) and (??), so maths is rather repetitive in that way, that's what I believe.

Int: sorry, can you give an example? I can't quite [get it], when you said it's been mentioned again and again…

Hajah: hmm, mentioned again and again mean that er… certain things like the… like… trigonometry. You have a certain way of differentiating and integrating it, so there is no other way to get an answer to that question, so when it comes to certain differential equations as well, or when it comes to integration, when you apply integration, like in graphs, you have to keep repeating the same thing, the same differentiation formula, so in that meaning, I mean it's repetitive, ya, that's about it.

Int: ok. that's interesting. It's… reminds me of what I hear in the lecture, Mrs [Patricia] Chan or Ms [Candice] Ang said that "Oh you've learnt this in secondary school", (Hajah: ya) is that what you meant?

Hajah: yes, exactly. That too. Because basically like I said earlier, it's, you need to know your base before you come to an advanced level you see, so more or less any topic, I mean, we would have predicted already that it would have required the application of our secondary school work, but we, I never really realised that it isn't much different. Because basically when we took our Additional Mathematics back in our secondary school, it's not much different. We only have a few, we only are learning statistics now, which is completely new to us, and otherwise differentiation is pretty similar, apart from the fact that we are learning how to differentiate and integrate cosine inverse sine inverse, and we learn the double angle formula in trigo, otherwise the things like graphs, binomial, you know, maybe partial fractions is pretty new. Graphs, binomial and transformation, erm, functions, our system of linear equations. So basically it's, it is kind of repetitive in that way, what we learnt back then is being repeated back now, only certain things that are new to us. so that's why I feel it's pretty much the same thing we are learning over the past, maybe now, past three years, ya. Three years that I have learnt so far.

Int: Three years. Ya. And then… and three years, you mentioned?

Hajah: ya, since secondary three. So Sec 3 [and] Sec 4 [Years 9 and 10], and J1 [Year 11] and this is my fourth year.

Int: ok. and then just now you mentioned about the mathematics being complicated and then you said that previously you had some, is it some problems or something, in primary school?

Hajah: basically what happened was when I was in primary school I really didn’t have a liking for maths, but I, I did, didn’t do that bad actually, used to get band 2s [Achievement bands: band 1 (highest) to band 4 (lowest)], but you know, as [because of] parents’ expectations you wanted to do higher you see, so.. what .. I was sent to [have] tuition, and actually it didn’t really help much, I already know that I know what I know, I can’t really learn extra, so it’s that I still keep on getting band 2, and kinda really got them mad. So there is one point of time where I actually stooped to a level where I got to band 3, then that really made them go wild, so it’s kind of… it was kind of tough for me at that point of time. So when it came to primary 6, being the judgement year, because you need to go a good secondary school you see, so I had, I went for two maths tuition in fact. Tried to make me good, make me better. So from band 3 when I got my band 3 grade, when I was in mid-year, when it came to prelims back in PSLE then I actually went straight into band 1, so it kind of did help, so I realised that Wow, it is still possible, you know in fact, that if you are really understand why it is not possible to score an A when… when… between an A grade and a B grade the difference is only 5 marks, so I really tried, and ever since then I have been really, erm, tried to excel in maths as much as I can. I really enjoy maths nowadays, not that I find it very tough nowadays, but when I look back in the past [school bell ringing, so voice was not clear] I do more than… I actually went a difficult path through mathematics, so that’s kind of complicated to me, ya.

Int: ya. Ok. So it’s more of like attending the tuition and then learning on your own, and then making it to the band 1 band. That sort of like…

Hajah: that motivated me, and more or less it actually gives me confidence. Basically what I lacked when I did my maths papers when I did revision at home was that, I was scared maybe whether my answer will be wrong or not. But then when I went for these tuition classes more or less it gave me the confidence to just give it a shot, you know, whatever the thing is, you just have to do it. There is no point in leaving out marks when you know that if you have done it, and even if you think it was wrong, but it went right, you will have got extra marks. Instead of leaving out marks, instead of leaving questions blank, just attempt it, it might end up being [???]… That gave me confidence as well. Ever since then, since secondary school onwards I have really tried my best to excel in maths, then it kind of happened in sec 3 where Additional Mathematics was kind of [like] German to me. It was, how to say, it was rather torrid time, that the whole year was, for maths… I mean there were E Maths [Elementary Mathematics] and A Maths, the Additional Maths was rather tough, E Maths I was fine with it, the Additional Maths was rather tough because it was rather new. So when I kept learning it, I went to secondary 4 and there was this awesome teacher that taught me A Maths that I was very grateful for that. So she again gave me the confidence. I actually lacked a lot back then. I mean, It was actually worse that my primary school days. And when I went to that year, she just kept on made us practise practise practise practise, so I thought “Wow, same teacher lah, what’s the difference” so from what she actually provided us was that she gave us one to one sessions where she really analyse our problems and told us what are we lacking, and she actually caught my point straightaway that I was lacking in confidence. She knows that if I really attempted the question, and I would get it correct, but I’m just scared that I might get it wrong. So most of the time I just won’t do it. So she saw the problem and she said “just attempt, just attempt”, and then it came back to me that that was exactly what happened back then. It was my judgement year as well. And now it’s again my O level year, so I can’t mess up again. So now back to now A levels, but now I’m rather fine, because I don’t really see that, see maths as a problem now. I see that maths is probably my best subject right now, ya. So I’m kind of grateful for that, I think I went past too many torrid times already, so I’m kind of, like more or less understand that for maths, you just need the confidence and just attempt it even though if you get it wrong, then just get it wrong. If you get it right, then that proof that you know, that you understand.

Int: oh ok. so then how do you study maths then?

Hajah: I do questions actually. To be honest with you what happened was that er. My past J1 [Year 11] and J2 [Year 12], I didn’t really, how to say, I didn’t really do a lot of questions, so when it came to exam times I just read notes. I just read my notes. It actually did helped, to an extent, but it is not as good as doing questions and preparing yourself you see, so ... though you know your formulas, and when a certain type of question comes out, you wouldn't know to apply it or not. And that kind of application only comes with experience when you are doing the questions, you see, so that kind of was bad for me. I'm still doing the same thing now, I'm still only revising lecture notes that's what happened to my prelim 1 as well, but now I'm, now because the school is giving us extra practice then I'm kind of getting the hang of doing more maths instead of just revising notes, and ya, I guess I only read lecture notes, I don't really do much, unless I am forced to, otherwise, you see. Because when we go [to] tuition we are actually forced to do questions, but then when you study on your own, it's your own liberty to do whatever you want to do you see, so, I never have the liking to do questions much. I just thought that maybe reading notes would actually help. And just looking at the examples would be rather sufficient. But after my prelim 1 [school-based preliminary examination during mid academic year] I kind of realised that it is rather not lah. You have to really need the practice, if not, certain types of questions would not, would be quite ancient to you, so you need to practise in order to get the hang of the certain topics, topics like er, how to say er… one very good topic of practising would be your… summation [of series]. Because summation itself it's rather complicated, because it can deal with, though the formulas the methods is rather simple, the numbers they give you, the numbers they give you is rather crazy you see, so, it only come, those kinds of topic you really really must practise so that we can get confidence in doing them. It's not really like, you read the lecture notes and it will definitely come out like that. There have to be variations to it, if not life would be too simplistic. So ya, so more or less I realise that practice makes perfect, it's not just reading.

Int: ok. then when you say you just read the lecture notes right? Did you really just read? As in like take, put it in front of you and just look through? How did you read?

Hajah: how do I read? Ya actually that really got the hang of me as well [meaning he hasn't thought about how he read], I really … er… what I would do is that I would, ya, like you said I will just read the lecture notes, and I will actually will look at the examples. The examples to me will be like, more or less explain everything that I have just read. So to me when I look at examples I see how I did it before. Because usually when we are in lecture we don't really see what we are doing, we just copy blindly. And it's up to us to go back home to really analyse what we are doing. So, but that's not what I do, I only do it only a few weeks, maybe few days before the exams, so … it's kind of tough, but it is rather helpful, because I know what kind of, what the question will be asking for. For example when I was learning partial fractions back then I really didn't look at the questions, the examples much. So when you actually give the explanations [in the lecture notes] it was like kind of, "ok wow, like how am I supposed to apply this" you see. But when it comes to the examples, they rather show you how you can do this, so it's good that the examples are there but it's still not good, it still doesn't come as good as practising. That bit I know.

Int: ok. So when you talk about being in the lecture and blindly copying right? So how do you find the lectures?

Hajah: Lectures are good. Lectures are very good. I really, very really enjoy the lectures because it doesn't, it don't really do it too fast. It goes according to pace, I mean to me it is according to pace. And what I would do is that let's say the lecturer just finished one question, and maybe I finished earlier because I've already got my point, I've already got the point from her. I just keep on doing and doing and I realised that what the questions, most questions would ask the exact same thing. So in that way I more or less can presume and predict what might this, what this topic might be asking. Now let's say it comes down to differentiation. Or… when it comes down to applications to differentiation, you know when it comes down to differentiating to find out dv dx , dv dt, it is the same thing, rate of change, maxima, minima. They are going to ask the same thing over and over again, so more or less by doing them beforehand, before the lecturer goes through we are actually are practising in a way, and instead of like er how do you do it, and instead of going there, and just blindly copying, what the lecturer is actually gonna, what, I mean he will actually give the answer, I mean he or she, we cannot bang on that only, we have to really try out the examples that they give, because these examples are rather helpful, to me, to certain people, I really find them very helpful. Because to a person like me I don't really practise much, so when I get these simple simple practices I'll rather do them.

Int: so you did the questions before you go to the lecture?

Hajah: ya, I always will do the questions before I go to the lecture, that’s my, I can say that that’s my plus point.

Int: oh. Ok. that means you do those questions that the previous lecture tells you to do, or? Do you just look through to see what is next?

Hajah: ya, I just keeps doing and doing and doing, let’s say certain things, because certain things like when last year, they will give us blank screens between the lectures, so we really wouldn’t know what to copy down, but this year I really noticed that most of the lectures they are all, they already have given all the points, so it is rather easy to just keep on going and going with the flow. Last year, that was one, I find it quite a defect, because they put blanks at the important points, and we really do not know how what they are going to try to say. You see, that’s. I know their motive is to try to make us think. Which is true, I find that there is nothing wrong, but for those students who actually wanna you know, just go for it, you know, just want to give it a shot, it kind of holds them back. So that was one problem for me last year. But this year I’m, I managed to overcome that problem and just keep do it.

Int: oh, so that means you do, you try the questions so that when you go to the lecture you will actually listen, because you sort of tried the questions already?

Hajah: ya. Yes.

Int: are you able to do those questions, because you said you keep trying?

Hajah: ya I did.

Int: so some you can, but not all, is it?

Hajah: ya, only the last few, because basically the last few ones will be rather tough, but I managed to get through them some times. There will be certain parts where it might hit [a wall??], you know, you do not know actually, plus and plus doesn’t go together really [???], usually I have those kinds of problems, you see, but it can be easily managed because the lecturer usually goes through them, so in that way I know that I'm falling back on something. So ya. That's about it.

Int: then can you explain about the copying blindly, because then I can't quite understand what you meant by, because on one hand sometimes you do say that you do copy blindly, but on the other hand you also mentioned about trying it before. It's ok to be … you know…

Hajah: basically I mean I don't do it every time you see, I don't really. I only do it when I have the time, so but it comes to the lecture, you know sometimes, you never prepare your work. Then there has to be a, there comes a circumstance where I would definitely have to copy blindly you see, so that's what I meant. But most of the time, as much as I can, I will really try to do the maths, because usually I really like, rather like maths more than anything else, any other subjects, so I find maths very interesting.

Int: ok, then what about copying with understanding? I mean like you could also have not prepared but yet you can still copy with understanding? (Hajah: true, it's true). I mean does that happen?

Hajah: ya, basically when I copy sometimes blindly, but just because… what will happen is that er, we'll just go to lecture, they'll just give us the example, and we are supposed to do it, and sometimes I just won't do because maybe I'm very tired or something, then when we go through the answer I'll just copy blindly. But when it comes to, when I get into the mood during the lecture, it just goes on, when it comes to the next example, and that's when I will do the next example, before the lecturer gives us the answers. I never really, how to say… copy blindly because I don't know how to do them. I actually copy blindly because I never really tried it. You see. So that's… but if I do copy, I actually copy with understanding, as much as I can. Because.. if you do not understand what you are copying, you wouldn't know how to apply it to the next example, so it is rather important that you know, you copy with understanding. So ya. True.

Int: it's ok to you know, to be frank. And explain yourself a bit more, then I can understand what you meant.

Hajah: uh-huh.

Int: ok, now maybe I ask you more about using graphing calculators. So erm. Can you tell me also again, three adjectives or words to describe how you use the graphing calculators?

Hajah: One is definitely efficient. One is definitely it comes in handy every time, the graphing calculator I mean, can be applied for nearly every topic, as far as I know, so it's very very, how do you put it… it's like a buddy to me. It's like my second, it's like my tool for maths you know, like everyone has their own superpower, for me for mathematics that will be…

Int: everybody has their own…?

Hajah: I mean every subject they have their own, how do I say, it's like er … plus minus right? For mathematics it's definitely the graphics calculator, it's only the graphics calculator in fact. So without the GC it's being, I can't, I cannot imagine how our seniors would have done it, really! It's rather tough. Because certain topics like statistics, especially statistics, I'd. you just have to go to the application, just have to press it, and just have to type it inside the answer will come out. You don't have to actually had to do the original, the long method, which oh-wow, which really happen might take forever… Is one thing that always gets me thinking. It's rather tough. But then again with the introduction of the graphic calculator, it has actually led to the questions becoming more tougher, because it is easier to do the questions right, so when one goes down you have to balance it with something else. That we understand. And the last thing definitely about the calculator is that it, it just … it's like er… how do I put it… GC… it not only helps for our maths, it actually helps for many other subjects as well. Physics, for example, ya. Physics. Because we have physics, physics basically is related to mathematics in a way, so when it comes to certain topics like kinematics and .. because they require equations, circular motion require equations, so when it comes to solving for unknowns, our graphics calculator has the best in that, we have our own applications specifically for it. So ya in a way it can, it's rather, there's a word for it, I can't remember, ya, it's rather versatile, it can be used for anything, you know, it can be used for any circumstance, any subjects anything, so … it's versatile, efficient and it's handy at anytime anywhere anyplace.

Int: ok, wow, so what does your physics teacher say about that?

Hajah: ya, I mean he doesn't really, he always expects us to have our graphics calculator always with us instead of having normal calculator, because our GC actually helps us to speed things up faster, because when we are using certain normal calculators where we do not have applications like solving polynomial equations, solving simultaneous equations, solving fractions, solving binomial. It's rather hard. It takes time. Because this sort of things it is rather time consuming. It's not really easy, and you could, do make a mistake when you are doing it manually, see. But with the calculator it is more or less confirmed ninety-nine point nine percent confirmed that you will get it right. So it is rather important that we do have a graphic calculator in class as our physics teacher had told us before. I mean there are people, that are still rather keen to use their previous calculators, casio model, ya. The casio model, so. I mean I did use it once, and nowadays when I start using graphic calculator and when I go back to that [scientific calculator], it's like, I kind of forgot, it's like it's past me already, I'm more or less, er keyed… programmed, I'm more or less programmed to keep using the graphics calculator now, it's like I only know how to use that calculator and nothing else. Ya.

Int: ok. so that means like, can I use that analogy of like using calculator like using your handphone, like you can, you know… (laughs)

Hajah: ya, you could, ya, there's nothing wrong with.. ya you could, actually it's true, ya, I mean… your calculator, when you are in junior college, your calculator is like your second, it is like your next pencilbox you see, your pencilbox is where you keep your stationery, your calculator is the next thing, that has to be on your table. I mean apart from your, your, what do you say, your GP [General Paper, a subject that focuses on language and literacy], your economics, even your economics might require [GC], your GP, your mother-tongue, your project work or everything else, for many other subjects, you would require the graphic calculator, so it is rather important that we have our GC with us every time. Even if that day doesn't really require the need of it, it's rather, it's good to have it, because certain… if you do not know when the need would arise you see, so it’s better to keep it with you at all times. I mean, I’m not really saying that you should always keep your graphic calculator, you can actually use any other calculator. But it is better to use your graphic calculator because you know that certain things that a normal calculator cannot do it a graphic calculator can do. Plotting graphs, because you are doing physics you definitely need to plot graphs, your Chemistry. For Chemistry we have this ionic equilibrium which uses a lot of calculations, we have our chemical equilibrium which uses a lot of calculations, we have our … basically our whole physical chemistry requires a lot of calculations as well, so we, it is rather important, so I kind of don’t see any need for, don’t see reason why people shouldn’t not should not bring it (???), I find it kind of important to bring it everyday.

Int: ya. Ok. because the calculator is something that you only started to pick up in JC1, so you think that of the time that you started using the graphing calculator. How did you learn how to use the calculator, you know, so proficiently?

Hajah: oh. I actually didn’t in fact. What I would do is, I would just try. (Int: ok). I really did not read the manual, neither would I read, because you know the maths lecture notes, they actually tell you how to key in stuff I actually wouldn’t know how to do that as well, I mean certain things they teach us this year then I realised “wow, you can actually do it” . But how I did was that I just kept on trying certain, try the new functions myself to see what is possible what is not possible. And I came to more or less soon realise that, that I know that what this graphics calculator <u>can</u> do, and what it <u>can’t</u> do. (Hajah’s emphasis). So that’s how I did. I didn’t really learn it from other people, I didn’t really learn it from the manual, I just kept on trying [it] myself. I didn’t really have many help trying to do it as well. So that is…

Int: so did you refer to the notes also?

Hajah: hmm, I, at first I didn’t understand what the notes was trying to say. I really thought that was just additional page, you know, just trying to tell us something else, something extra information. I really didn’t know it was actually helping us. Ya. So I really never knew until I came to realise that “wow, it’s been there all along and I really messed up”. But ok lah, for now, since I’ve already found out, so just… okay…

Int: so if you were to repeat it again, I mean like, let’s say, you know, were to, or maybe to give advice to the teacher, about next year for students like you, how, what kind of advice would you give to the teacher, on how to teach, how to use the graphing calculator, what is the best way?

Hajah: ok. I mean being a student I know that reading is rather, how to say this, we do not really like reading you see. Because when it comes to reading the manual especially, it really, you have, we are the kind of people nowadays that really do not like to read things, we like to do things, you see. So we do not, we rather, I still have the manual at home, it is still untouched, when I see it I really go like “woah, ok, fine, I don’t really need you anymore” but actually, since I rather know that our teenage people really don’t like reading much, so what teachers could do or should do, or maybe they might do, is that they can have a lesson, you know before starting most of the tutorials, like before your first topic, before you start doing your first topic tutorials, you actually can go through your function with them. Personally. Because they need to know for themselves what the calculator might posses. So it is rather important that they know what are the functions available to them, so that they themselves could figure it out even if they don’t want to read the manual. Basically the teacher could just provide the stepping stones for them to just climb on and on and on. So they really should have maybe the starting, the starting, the first lesson they have, before, or the first time they ever…

Int: lecture or tutorial?

Hajah: tutorial. I mean lecture is fine, there’s nothing wrong. But lecture people may, they, ok. being a student I rather know this, but usually when it comes to lectures people really don’t, when it comes to simple things like, ya, calculators, who really wants to listen to these people, you know. Like ??? they are going to teach us how this calculator is going, it’s no big deal???. When it go to tutorial class, they actually have to stay there, they can’t do anything else, they are under the teacher’s supervision, so more or less they have to listen to you, so I think maybe the tutorial lessons will be better than the lectures.

Int: ok, so when you say going through, how do you imagine the teachers going through?

Hajah: like how they actually have. You know how they actually go through in the lecture? They have their own function in the laptop you see, so they can actually teach you, they go through one by one, what can each apps do, what program, what's in the catalogue, you know, what's the Varsity [variable], how do you find out where's your binom cdf pdf, and ya, things like that, how did you get your exponential form, how do you get your ln form, how do you get your brackets, how you get your L1 L2, how do you type words in your calculator, because you need to, I mean it's rather neat, this simple simple things they learn, right, they more or less might remember. So when it comes to the topic which requires it they know, "oh here, our calculator has this kind of functions, so might as well use it, don't have to really crack your brain and do, use the method that has been mentioned there". So ya, at least one lesson at the start of [the year], or maybe can stretch it into two, if you can't cover everything in one day. But one lesson should be more than enough I guess, because there's nothing much. Our calculator just posses 6 options. Six apps, which is required for us, programs which is nothing, we have our Varsity, we have the catalogue, we have all these, so we need to know, just need to show, there's only 3 buttons, when we use???… that's really important. The rest they can figure out for themselves, so more or less ya…

Int: ok.

Hajah: it should be enough. Or even if it's going to take half a lesson, it's not going to take long.

Int: ok, so. Ok. I'm trying to imagine it here. So it will be the teacher showing the, on the computer, the graphing calculator. Like showing what buttons and what functions, then what would the students be doing?

Hajah: they would have their calculator with them, so they would actually have to go through exactly. They will have to do the same thing. The teacher will actually give them some dummy values, so that they could try out and actually solve for the answer. So more or less they know how to use it, instead of knowing where it is. So those kind of things is possible. The thing is that every student must bring [the GC], so it's up to them as well, to actually follow the teacher's instruction and bring it as well, because I mean, it is rather expensive, so you might be in a need to… have the trouble buying it.

So it’s rather you inform the teacher as soon as possible so that they can actually help you do something about it.

Because it is like a pen-pal, I mean it’s not say pen-pal, it’s like a pal. Your calculator is really very very important to you, as far as I know, because it’s experience lah, when you go through the two years you realised how much you’ve come to because of just the calculator, so more or less I know, ya, it is rather important that they <u>need</u> (Hajah’s emphasis) to know what’s inside. I mean certain things I didn’t know until this year itself, so I kind of realise that this thing should be, it’s one problem that I had, I mean probably be a few more students that might have the same problems as me, I can’t guarantee??? them don’t do well, so…

Int: ok and then just now you also mentioned that you didn’t really learn from somebody else, you know, from asking friends or whatever, but you learn more on like, doing it yourself and trying to find out the functions and playing around with the calculator.

Hajah: hmm, ya.

Int: maybe now I go back to mathematics, do you actually study with your friends, or you study on your own.

Hajah: ya I do both actually. Because I have a friend, he is Ashraf, and he lives near my house, he’s not very close from me, I mean not very far from me, he’s not very far from me. And we actually meet almost every weekend, in fact every day after we go back we just sit down and do work. We don’t really do anything else. We find it rather effective because we can speed up things, by doing alone you are actually just to yourself, certain things you might not know you wouldn’t know how to do it. But when you are with your friends, certain things that he might not know you might know, certain things you might not know he might know, so we both we just sometimes we just have to share and then just have to do things, I mean our answers might tend to be the same, but more or less we actually did our work so, I find it that, I find studying together is more efficient than studying alone.

Int: is it for mathematics, or other subjects?

Hajah: every subject, more or less, I think. Apart from your GP and your economics I mean. Those kind of things require a lot of writing and content, those things really do really require the ?? way of two students I mean, those are not necessary. Your physics, chemistry, maths, your 3 H2, which is rather, I mean, it's not easy to just remember everything at one shot, because there's so much content that you need to know you see, so basically certain things you might have forgotten, he might have remembered???, so it is good. But the thing about studying with two people, there is a down side to it as well, certain things like you might don't feel like studying, but just like talk to him, playing or slacking with him. So there is a down side to it so it is up to us to actually have the mental discipline to do stuff, which we rather not ???

Int: ok. I think one last question I wanted to ask, because it take up quite some time already, although I mean thanks for much for being so forthcoming with your answers.

Hajah: not a problem.

Int: because I noticed that in class, there are quite a lot of times that when the teacher asked some questions as she writes on the board, you know. And then I noticed that you all would sort of like, answer. Like she says, er… I can't remember already (laughs), and then you all would just answer, or add on or complete the sentence for her, that kind of thing.

Hajah: ya.

Int: so did you notice it? (laughs)

Hajah: ya. Ya. (laughs) I mean I find it quite natural lah, it just happens, it just comes out, you really do not know, I mean to me naturally when the teacher like, does something, I just naturally comes out of me to actually try to, complete what she does, sort of follow along, and then follow what she is doing, so I, so more or less I know, sort of show that I know the understanding. Because some students they do not know they just keep it quiet. So we still wouldn't know whether they understand or not. It's up to them to voice out their own opinion saying that “madam I still don’t understand what you are trying to say” so ya, in a way it is good, I find it very good lah. I mean our class as far as I know it’s very open about things they do, things they say, things they don’t understand. They aren’t shy to show. It’s rather good, because I also sometimes kind of like, think that “ok, I’m the only guy that doesn’t know, everyone else knows what, how am I going to do this” but because I see that my classmates really do not, they really find it appreciative that we are asking questions, so I’m finding this also, it’s rather cool that we actually do this as well and there’s nothing wrong with it, I feel that there’s nothing wrong.

Int: hmm.. ok. ya

Hajah: I mean certain teachers might not like it because we shout, one thing is that we are making noise, another thing is that they do like repetition of the things they are saying, so … *smack lips* [can’t help it gesture] I’m not saying that they do not like it lah, they find it rather irritating, so far most of my teachers are okay with it, and I’m okay with it, so, so. And I don’t really have the opportunity to feel that the teacher didn’t like what I am trying to do, so… ya.

Int: oh, can you say that again?... never

Hajah: I never really have the opportunity to feel that kind of, like the teacher scolding you back because you are actually trying to answer the questions, I never really had that kind of thing before, so…

Int: ya ya ya. So that means the teacher is comfortable with…

Hajah: ya. Most of the teachers I had are really comfortable with, what we do, what I do, so okay I’m fine with it.

Int: ok. so is there anything that you feel that you know you are being, stifled, like you wanted to do something but maybe the teacher didn’t follow up on that, have a different style, doesn’t match?

Hajah: I feel that my current maths lesson is fantastic and I, our teacher is pretty cool you see, so certain things like, we really really want, when it comes to maths lesson right, we really look forward to it, as a class. We don’t really like [say] “aw man, it’s maths!” (Int: laughs) you know certain subjects we feel like that, there’s nothing wrong, but it’s because when it comes to maths, we know our teacher is pretty cool you see, the things she teaches, the things she says. She’s rather quick and when she teaches she teaches with such clarity. So it’s... We can grasp it very fast, we don’t really have to stumble upon any of the dead blocks along the way, so ya. I, I really, there’s nothing that my teacher has done so far that has make us feel this way. So it’s quite cool. Ya. I mean in fact having two teachers in our class now has made things even better, because now that one teacher can teach, the other teacher can actually walk around to answer our doubts, because sometimes when the teacher is teaching they do not like being interrupted halfway. So with the aid of another teacher at the back you know that you can actually ask that teacher, and you are not interrupting the class at the same time, so it’s cool you see. That’s one good thing which they did to try to make our maths classes more comprehensible, more efficient, more fun, and ya.

Int: but do they have different styles and?

Hajah: no! I mean okay, they have contrasting styles it’s true, because, but both teachers are experienced in their fields, so there’s nothing wrong. To us what I feel is that the teachers are teaching us what they know and they are better at it than anyone else, you see, so no matter how contrasting their style may be, they are still doing the same thing. So there’s nothing wrong. I mean if you do not understand her style, then go to the other teacher and listen to her, because she will definitely know what this teacher is teaching, let’s say, vice versa if you don’t like the other teacher, then just go to the other teacher! So there’s nothing wrong, it’s quite cool. It’s good to have two teachers in class because two different styles, certain, you yourself wouldn’t know which style you are preferring, you are preferred to you see, so ya.

Int: ok. ya. Actually I wanted to ask which style are you, do you prefer? Hajah: ah…

Int: I mean not being a choice between the two teachers, but more of like which styles suits you better.

Hajah: I kind of find both results in the same thing, I really don’t see any difference in their styles. I mean the teacher is very good, and the other is very experienced in their fields, and they have been through a lot of A level years, so they are ok, I’m very cool with them, as long as they are teaching us what they know, and I’m fine with it. Because the way they teach is very good, I’m very gifted to actually, our class is actually very very gifted to have this kind of teachers, teachers like this. Because at the start of last year, our teacher is pregnant, so we didn’t really have this foundation, like when it came to partial fractions, binomials and AP GP [Arithmetric and Geometric Progression] and summation, we really didn’t know anything. She only came back around April, so that’s when we actually started learning everything again you see. So, when she came back she actually made the teaching very fast, efficient, and we actually understand very fast. I mean for me I always have trouble with summation, so it’s actually my fault it’s not her fault, you see I actually managed to, thing that we learn over 3 months, she managed to actually cover in 1 month. So it’s very good you know, we really, it’s very good to say that our teacher is very comfortable and so good in what they do, so. It also gives us the confidence you know, like our teachers teaching us so many good things, they already know so much stuff, so we can just go for it you see. So given the content as well. They don’t have different styles, they teach the same way, so I find that, ya.

Int: so thanks, I think you have to go for your sessions [classes] already.

Appendix F: List of Publications Arising from the Study

Book chapter

Tan, H. (2012). Senior secondary mathematics students in Singapore: Attitudes towards and engagement with the graphics calculator. In P. W. K. Chan (Ed.), *Asia Pacific education: Diversity, challenges and changes*. Victoria, Aus: Monash University Publishing.

Peer-refeerred

Tan, H. (2009). Development of an instrument for ways of using graphic calculators: Preliminary findings. In R. Hunter, B. Bicknell, & T. Burgess (Eds.), *Crossing divides.* (Proceedings of the 32nd annual conference of the Mathematics Education Research Group of Australasia, pp. 531-538). Palmerston North, NZ: MERGA.

Tan, H., & Forgasz, H. (2011). Students' ways of using handheld calculators in Singapore and Australia: Technology as master, servant, partner and extension of self. In J. Clark, B. Kissane, J. Mousley, T. Spencer & S. Thornton (Eds.), *Mathematics: Traditions and [new] practices* (Proceedings of the 34th annual conference of the Mathematics Education Research Group of Australasia and the Australian Association of Mathematics Teachers, pp. 728-735). Adelaide: AAMT and MERGA.

Tan, H. (2012). Students' ways of knowing and learning mathematics and their ways of interacting with advanced calculators. In J. Dindyal, L. P. Cheng, & S. F. Ng (Eds.), *Mathematics education: Expanding horizons,* (Proceedings of the 35th annual conference of the Mathematics Education Research Group of Australasia, eBook, pp. 704-711). Singappore: MERGA, Inc.

Tan, H., Forgasz, H., Leder, G., & McLeod, A. (2012). Survey recruitment using Facebook: Three studies. Proceedings of the 2012 International Conference on Internet Studies (NETs2012), August 17-19, 2012, Bangkok, Thailand. http://www.internet-studies.org/

Non peer-referred

Tan, H. (2010). Recruitment of participants using Facebook. Paper presented at the *Contemporary approaches to research in mathematics, science, health and environmental education symposium*, Deakin University, Melbourne, 25–26 November, 2010. Retrieved Jan 14, 2011, from http://www.deakin.edu.au/arts-ed/efi/conferences/car-2010/

Tan, H. (2010). Singaporean senior secondary students' ways of using graphics calculators. In L. Sparrow, B. Kissane, & C. Hurst (Eds.), *Shaping the Future of Mathematics Education,* Proceedings of the 33rd annual conference of the Mathematics Education Research Group of Australasia held at John Curtin College of the Arts, Fremantle, 3-7 July 2010.

Tan, H. (2012, to be presented). *Gender and graphics calculators in the Singaporean senior secondary context*. In Leder, G. (Chair), The gender divide in STEM and

English: Has anything changed? Symposium to be conducted at the 2012 joint International Conference of the Australian Association for Research in Education (AARE) and the Asia Pacifiic Education Research Association (APERA), 6-12 December 2012, Sydney, Australia.