Government of **Western Australia**
School Curriculum and Standards Authority

Review of the use of technology in Mathematics education

Prepared for the School Curriculum and Standards Authority, Western Australia

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December 2015

Please cite this document as:

Kissane, B., McConney, A., & Ho, K.F. (2015, December). *Review of the use of technology in Mathematics education and the related use of CAS calculators in external examinations and in post school tertiary education settings*. Perth, WA: School Curriculum and Standards Authority.

ISBN 978 0 7307 2843 6

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Review of the use of technology in Mathematics education and the related use of CAS calculators in external examinations and in post school tertiary education settings

Executive Summary

This research is intended to inform the Mathematics Course Advisory Committee (CAC) of the Western Australian School Curriculum and Standards Authority (SCSA) about appropriate and effective use of digital technologies in Mathematics courses for upper secondary school students and in examinations that contribute to students' Australian Tertiary Admissions Rank (ATAR).

Various sources of information were used to produce an integrated report, drawing on the results from literature review and interviews/discussions with officials and Mathematics education personnel, locally, nationally and internationally, analysis of relevant technologies and surveys of local senior secondary school Mathematics teachers and some Year 12 students. It was agreed that the project would deliver to SCSA:

- A summary of key research related to the use of technology for secondary school Mathematics, particularly related to the use of computer algebra system (CAS) and graphics calculators, and highlighting the role of teachers;
- Results of survey research, canvassing opinions and attitudes of teachers and students regarding the use of technology in senior secondary school Mathematics courses;
- Information gathered from other educational jurisdictions nationally and internationally and universities with respect to the use of technology in examinations;
- Description and analysis of the latest technologies for school Mathematics and how best to integrate these into teaching, learning and assessment;
- Comment on the professional developmental needs of Mathematics teachers to enhance their own and their students' personal confidence and competence in the use of technologies; and
- Advice regarding the use of technology in Mathematics secondary courses and exams.

CAS calculators are described as an extension of graphics calculators, which are in turn an extension of scientific calculators. These technologies have been developed specifically for school mathematics education. Scientific calculators have been used in WA Mathematics courses and external examinations for around 40 years, graphics calculators for around 20 years and CAS calculators for about 8 years.

Research has clearly indicated the pivotal role of teachers in the successful integration of technology into the school Mathematics curriculum. While teachers need support to develop the necessary technological and pedagogical content knowledge that is uniquely associated with the effective use of technology, adequate support has frequently not been provided, so that unrealistic expectations have been made of teachers.

Empirical research summaries have consistently suggested that the use of graphics calculators and CAS calculators by secondary school students can result in improvements in conceptual understanding in mathematics, although the improvements are modest and depend on the extent to which teachers and students make effective classroom use of them. Definitive large-scale studies on the effectiveness of sound use of CAS in secondary schools are not yet available.

In practice, CAS calculators have often been used to replace traditional procedures more than they have been used to enhance students' conceptual understanding. Consistently, research has demonstrated that students do not suffer a decline in by-hand mathematical skills as a result of using technologies of these kinds. Research and careful analysis have highlighted some of the challenges of effective use of CAS in particular, requiring careful consideration of the nature of algebra and calculus especially in both CAS and non-CAS environments, and developing suitable expertise by both students and teachers to integrate the tools appropriately.

Since it has become a common practice for students to be assessed both with and without access to technology when CAS is used, the use of CAS has been recognised as creating special difficulties for the assessment of student learning, especially in timed examinations. In order to provide opportunities to assess discretionary use of technology, test items for which CAS is not helpful are necessary; similarly, to assess effective technological and mathematical competence, test items for which CAS is helpful are also necessary. Finding a suitable balance in practice is recognised by researchers as challenging.

There is a range of practices and no clear professional consensus regarding the use of technologies in senior secondary school mathematics internationally. CAS calculator use is prominent in some European countries and in the USA; graphics calculator use has been common in OECD countries for some years and is integrated into International Baccalaureate courses; some countries, notably some Asian countries, do not permit any use of calculators in high-stakes examinations. There are some developments to use laptop computers as school mathematics tools, to supplement or replace calculator use; these typically provide students with access to computer algebra capabilities at least as powerful as those on CAS calculators.

There is similarly a range of practices within Australia regarding the use of technology for Mathematics. School practices are regarded as closely aligned to examination rules in each state. Some states permit the use of CAS calculators, others expect students to use graphics calculators and one state (NSW) permits students to use only scientific calculators. One state (Victoria) has a small pilot program for a computer-based alternative to calculators, using sophisticated software, including computer algebra. There are also variations among states and internationally on the use of a separate technology-free examination component, on the opportunity for students to take some personal notes to examinations, and on requirements to clear calculator memories for examination purposes. Again, no clear consensus of examination practice is currently observed.

University use of technology for teaching, learning and assessment in mathematics in the early undergraduate years varies internationally. In some countries, use of hand-held technologies typical in schools such as CAS calculators and graphics calculators is common, while in other cases (such as Australia), learning technologies such as calculators are rarely used beyond secondary school. In the case of the five Western Australian universities, neither CAS calculators nor graphics calculators are systematically used for instruction in first year mathematics classes, and technology use in assessment is mostly confined to scientific calculators. This situation is well-known to many local teachers, who often interpret it as an argument against the use of these technologies in school mathematics. Mathematics teachers in local universities are generally unfamiliar with the use of CAS calculators or graphics calculators as learning tools, do not use them for teaching purposes and regard them only as computational devices. In some first year statistics teaching, students with graphics calculators are permitted to use them, including for assessment. Beyond first year, mathematics students are likely to encounter more sophisticated technologies, such as professional computer software. University mathematics teachers do not report substantial unease from students about the lack of use of CAS or graphics calculators.

Both the existing Mathematics syllabuses (concluding with Year 12 in 2015) and the new syllabuses (starting with Year 11 in 2015) explicitly recognise roles for technology. In each case, however, there is very little specific advice and guidance offered to readers to clarify in any detail how that technology might be used for teaching, for learning or for assessment. In particular, there seems to be no substantial advice offered regarding the use of the computer algebra capabilities that distinguish CAS calculators from their predecessors, graphics calculators. While it is recognised that some pedagogical decisions are the prerogative of teachers, it is difficult to see how teachers can understand the extent to which calculators are intended to be used for student learning, rather than merely for assessment, when no systematic advice on this is provided.

No official advice is offered regarding the possible use of technology in school-based assessment, and there is also no advice offered regarding any intended different expectations of students in the calculator-assumed and calculator-free components of external examinations. Similarly, there is almost no advice offered on the extent to which sound use of technology by students ought to be taken into account in allocating grades. In these circumstances, it would be surprising if there were not unease expressed by teachers about the extent of calculator use required or observed in examinations, or an expectation that content needed to be taught twice, once with and once without a calculator.

Study of recent examination papers in mathematics reveals that there are typically few questions that require students to use CAS calculator capabilities for efficient solutions (especially for lower level courses) and that there are also questions for which use of a CAS calculator would be inadvisable or even inappropriate. The appropriate balance between such questions seems to be left to examining panels to determine, as guiding principles seem not to be published. It is clear from some teacher responses and some students' responses that a common understanding of an appropriate balance has not been achieved, and there is a divergence of opinion on what that balance ought to be.

Advice from some recent members of Mathematics examining panels suggests that a balance of calculator use is sought, although panellists interviewed regarded classroom use of the technology for learning as more important than examination use. It is less clear that the CAS capabilities are important for lower level courses. All examiners interviewed report some level of frustration with student use of CAS calculators in examinations, noting that ineffective use (or neglect) is frequently observed by markers, and it is commonly inferred that sound teaching and use of the technology is unevenly distributed amongst teachers.

Examining panellists interviewed would be uneasy about an increase in the level of technology used in Mathematics (such as through the use of computers or tablets in examinations instead of calculators) and generally felt that the level of technology use should either stay the same or be reduced a little. The advantages of a technology at least at the level of a graphics calculator, for learning involving statistics and graphing in particular, suggest that reductions below that level would be problematic. A case for reducing the sophistication of technology expected would be strongest for students in lower level Mathematics courses.

A variety of technologies is available today for mathematics, including calculators of four different levels of sophistication, computers with mathematical software, tablets with mathematical apps and smartphones. While calculators are targeted specifically on mathematics, other technologies are of broader use (but then require significant work and extra resources to be effective for mathematics). The report provides some analysis and description of the advantages and disadvantages of each of these various technologies for learning, teaching and assessment of mathematics.

Costs of technologies were examined; in particular the perceived high cost of CAS calculators was investigated. When compared with the costs of graphics calculators at the time of their introduction to end-of-school examinations in the 1990s and scientific calculators on their introduction in the late 1970s, and after adjusting for CPI changes, CAS calculators are found to be no more expensive than previous technologies and probably a little cheaper. CAS calculators are generally about 10%-20% more expensive than graphics calculators by the same manufacturer.

An online survey of WA senior secondary Mathematics teachers was conducted, with all relevant teachers invited to participate, through general email invitations sent via school principals, consistent with standard SCSA practice. Sufficient time, reminders and publicity were provided so that all relevant teachers with sufficient interest in the matter are assumed to have responded. Responses were obtained from 367 teachers.

Demographic data collected indicate that survey respondents were generally well-experienced with both teaching mathematics and with the use of graphics calculators (including CAS calculators). Substantial numbers of teachers responded from each of the three sectors (Government, Catholic, Independent), although it seems likely that smaller proportions of Government teachers responded than was the case for the other two sectors. Among teacher respondents, most Independent school teachers worked in high SES contexts, most Government and Catholic school teachers worked in average SES contexts, while low SES school contexts were disproportionately represented by Government school teachers. Relatively few teachers in low SES contexts responded to the survey.

Teachers were asked to report on their recent experiences with technology, so that existing courses were the focus, not the new suite of courses that began in Year 11 of 2015. Respondents were asked to select a single course from the existing suite of ATAR Mathematics courses to comment on, which resulted in all courses being chosen, including Specialist Mathematics courses.

Teachers reported that very high proportions of students in all subjects had routine personal access to CAS calculators in class, which was also the case for the three school sectors and for all three levels of school SES, which suggests that the examination expectation for CAS calculator use is consistently achieved. In addition, high levels of access to scientific calculators were reported by all groups. High proportions of teachers expected students to have access to these two technologies at home as well as in class.

Routine student access to laptop computers was reported by about 40% of teachers in each of Independent and Catholic schools, but by only about 20% of teachers in Government schools. Similarly, about 50% of teachers in high SES schools reported that students had access to computers in class, but only about 20% of teachers in average or low SES contexts reported this. These data suggest that there is substantial variation among schools regarding access to technologies more sophisticated than CAS calculators. Student access to tablets was similarly uneven, but relatively small in all subgroups, with the maximum level of access being 12% in the case of average SES school contexts. Although it was rare for students to be expected to use mathematical software on computers or laptops at home, spreadsheets were expected by teachers in about 10-20% of cases (especially in Mathematics 2AB) and the use of websites was expected in around 40% of cases.

Teachers reported on how frequently various technologies were used in lessons, which showed that calculators are the most prominent. While results vary by subject, about half of the teachers report frequent use of CAS or graphics capabilities of calculators in most or all lessons; in comparison scientific calculators are used even more frequently by students in most courses. Very few teachers in any courses reported frequent use (most or all lessons) of other technologies such as computer software, websites, tablets or spreadsheets. Very few teachers reported use of commercial mathematics software (except Microsoft *Excel*), while a few referred to use of some free software such as *GeoGebra*. Similarly, few teachers reported substantial use of mathematical apps on tablets. Teachers reporting use of technologies other than calculators generally did not expect them to be used in assessment.

A wide range of views about the appropriate place of CAS calculators in secondary school was expressed, by both teachers and students. Both positive and negative comments were expressed, suggesting that while some teachers regard the technology as important and helpful for learning, others were concerned that they are unnecessary, unhelpful or inhibiting experimentation with other technologies. Surprisingly few comments were volunteered regarding the specific use of computer algebra capabilities in particular, which are what distinguish CAS calculators from graphics calculators.

Teachers in the survey expressed high levels of personal confidence both in using technology and in supporting student use of technology, with around 40% very confident and a further 50% mostly confident. They reported a range of sources of advice regarding technology use, particularly their colleagues, textbooks, online sources and professional development experiences. Notably, only about 10%-15% of teachers indicated SCSA online materials as a source of advice.

Asked to identify obstacles to their use of technology, about a quarter of teacher respondents indicated time-based concerns as frequent obstacles, including lack of preparation time, lack of class time and a perceived need to teach some topics twice (with and without technology). Only about 1 in 10 respondents indicated that the expense of technology or limited school resources were frequent obstacles.

When teachers were asked to describe the relationships between technology and their chosen courses, there was a consistent and moderately strong view that graphics calculators were sufficient; a slightly weaker and less consistent view indicated that CAS was important for learning, depending on the particular course chosen. There is a strong and consistent view that calculator use in Mathematics is driven by the requirements of ATAR examinations, only mitigated in part by the non-calculator components of examinations.

In most courses (Mathematics 2AB being the exception) there was limited support for the view that a scientific calculator is sufficient for learning mathematics. Teacher responses indicated that scientific calculators are used mostly for numerical computation, rather than for learning purposes, and are easier for students to use than CAS calculators, partly as students are already familiar with them and partly because they are much less sophisticated and most operations are written on the calculator itself, rather than requiring menus. Some teachers noted that many students were restricted to using a scientific calculator in other subjects (such as the sciences), which might inhibit their development of expertise with their CAS calculators. Generally, for each of the six courses, teachers agreed that technology makes mathematics more enjoyable for students and helps them to get a deeper understanding of mathematics than would be possible by hand. Despite these views, a majority of teachers in most subjects agreed that students do not understand mathematics unless they first do it by hand.

Strong majorities of teachers overall and within each of the school sectors did not think that technology should be *increased* in Mathematics examinations (e.g., by allowing computers and tablets with restricted software and no Internet access). Similarly, between 40% and 60% of teachers thought that the use of technology in exams should not be *decreased*, although around 30% thought that technology in exams should be decreased by allowing only scientific calculators, with smaller percentages suggesting that graphics calculators would be sufficient. Overall, a strong majority of teachers prefer that technology in Mathematics courses should stay the same or be reduced, rather than be increased and extended. This view was not the same for all sectors, however, with a slight majority of teachers in high SES schools preferring a reduction, while the plural view of teachers in average and low SES school contexts was for the technology to stay the same. Some teachers in well-resourced schools felt constrained by a need to use CAS calculators, as better alternatives were available, while some teachers in less well-resourced schools suggested that a reduction in technology requirements would lead to reduced student access to technology.

When asked about equity issues associated with the use of CAS technologies, around 80% of teachers in both Catholic and Independent schools reported that there were not equity issues, although teachers in Government schools were more evenly divided on this point. Some responses suggested that differences between teacher expertise and access to professional development were significant threats to equity.

Responses from 522 Year 12 students were spread across a range of courses, but they are not regarded as a representative sample of students. Students reported very high levels of access to CAS calculators, both at school and at home, and also reported high levels of access to a scientific calculator in both places. Reported student access to technologies such as computers, tablets and the Internet was generally better at home than at school.

Generally speaking, students responded positively to the use of CAS calculators, which they reported using regularly in classes, were confident in using, and thought important for their learning and for their examinations. Students also reported that they decided for themselves when to use their calculators, and usually did so either to complete tasks that they couldn't do without their calculator, or which would take too long to do by hand. Across all courses, few students reported that their most frequent use of the calculator was related to experimenting with mathematical ideas and relationships. There were no clear differences between male and female responses to questions regarding calculator use.

In helping SCSA think about possible ways forward, based on the empirical and theoretical findings of this research, the following are suggested:

1. SCSA should continue to encourage teachers to use a range of technologies for teaching and learning mathematics, to suit their interests, school facilities and emerging technologies. Additionally, it will continue to be important to specify a minimum level of technology use in examinations, to maximise coherence in teaching, learning and assessment.

2. In deciding which technologies are approved for examination use, and in particular whether the same technology is used for all ATAR courses, SCSA needs to consider the circumstances of teachers and any anticipated problems associated with approval of different technologies for courses at different levels of sophistication.

3. SCSA needs to develop and publicise a reasoned and clear rationale for the decisions about the way that calculators are expected to be used in the examinations.

4. An important matter for SCSA to consider is how appropriate use of various technologies for learning, teaching and assessment are communicated to those concerned, especially teachers, but also students, examiners and professional development personnel, including teacher educators. While it is recognised that syllabus documents may be constrained to be short, consideration should be given to suitable online mechanisms of providing better advice than is presently available, especially in relation to the use of computer algebra and other capabilities not available on scientific calculators.

Clearly, there will be a continuing need to review the use of technology in Mathematics education and the related use of CAS calculators in teaching, learning and assessment. This project has highlighted several pertinent areas that warrant attention and review, something which SCSA together with schools, universities and other institutions concerned with teacher education and development are well-placed to address.

Authors

Mr Barry Kissane is an Emeritus Associate Professor in Murdoch University's School of Education, having recently retired from full-time employment as a mathematics educator at Murdoch. Over the period from 1985 to 2013, his principal roles at Murdoch were involved with pre-service mathematics teacher education, postgraduate work and research in mathematics education. He spent two years at the University of Chicago, studying and developing text materials for courses that used various technologies in school mathematics, including graphics calculators. He has provided professional development for mathematics teachers and published extensively related to the roles of technology in all levels of school mathematics, including the relationships between technology and examinations in a funded project with Murdoch University colleagues in the late 1990s. He has undertaken leadership roles, including President of the Mathematical Association of WA and the Australian Association of Mathematics Teachers, Dean of the School of Education at Murdoch University, Board Member of the WA College of Teaching and Executive Editor of *The Australian Mathematics Teacher.* He has been invited as a keynote speaker for teachers and researchers related to the use of technology in mathematics education in most states of Australia and in several overseas countries, including invitations to co-chair the technology sections of both the International Congress of Mathematics Education (ICME) and the East Asian Regional Conference on Mathematics Education (EARCOME). His recent funded work includes successful collaborations with Andrew McConney for external evaluation of CSIRO Education's *Maths by Email* initiative and with Marian Kemp to develop books for mathematics teachers and students using scientific and graphics calculators. He served as a member of the Advisory Panel to the National Curriculum Board's development of the national mathematics curriculum.

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Dr Kai Fai Ho is a Lecturer in Mathematics Education at Murdoch University's School of Education, where he has major responsibility for secondary and postgraduate mathematics education, with significant other responsibilities for primary mathematics teacher education. Prior to coming to Australia, Fai was a teacher for many years at the primary, secondary and tertiary levels in Singapore, and also worked and studied in mathematics education in both the UK and the USA. His wide teaching experience includes conducting intervention programs for under-achievers and enrichment programs for high-achievers at the primary level, teaching school mathematics at the secondary level, and teaching engineering science and mathematics at the postgraduate level, including the use of CAS computer programs. Fai's research has involved the study of classroom practices, the mathematics curriculum and the teaching and learning of mathematical problem solving. He has worked with students using CAS calculators in WA secondary courses in a project based at Murdoch's Rockingham campus, and in one of his research projects funded by the Peron Alliance Curriculum and Teaching (PACT) he reviewed the declining trends of students taking up advanced mathematics and studied more closely students from the Rockingham campus who bucked the trend.

Acknowledgements

The research team acknowledges with gratitude the generous support it has received from many people for this project, including the following:

- SCSA officials, especially Malachy Doherty, Anne-Marie Benson and Graham Quelch;

- SCSA leadership, and most particularly the support received from the Authority's CEO Allan Blagaich and Director of Curriculum and Assessment, Robyn Smith;

- The many senior secondary Mathematics teachers and students who responded to the surveys, and especially to those teachers who agreed to provide further detailed responses on various matters;

- Representatives of the Department of Education, Catholic Education Office and Association of Independent Schools WA, for their work to encourage mathematics teachers to respond to the surveys;

- Senior mathematics staff in local universities, including Dr Ian van Loosen, Dr Ryan Admiral, Dr Doug Fletcher, Dr Des Hill, Dr Greg Hine, Dr Steve Richardson, Associate Professor Ute Mueller and several of their colleagues;

- International correspondents including Dr Antonio Quesada, Professor Fou-Lai Lin, Dr Ng Wee Ling, Professor Tai-Yih Tso, Jörg Reddmann, Paavo Heiskanen, Professor Mike Thomas;

- Members of recent WACE Mathematics examiner panels;

- Officers in Australian curriculum authorities, including Dr Antonio Mercurio, Dr David Leigh-Lancaster, Mr Peter Osland and Ms Anna Wethereld.

- Dr Frances Asha, Senior Surveys and Evaluations Officer, Office of Strategy, Policy and Analytics, Murdoch University, for managing the online survey process;

- Ms Gillian Buckingham, Murdoch University for managing administrative processes;

We acknowledge the invaluable contributions of each of these stakeholders to the data analysed for this report. In the final report, nevertheless, any unintended omission of relevant research or data, or misinterpretation of the data gathered, remain the sole responsibility of the authors.

Barry Kissane
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Table of Contents

List of Figures

List of Tables

List of Acronyms

AAMT	Australian Association of Mathematics Teachers
ABS	Australian Bureau of Statistics
ACARA	Australian Curriculum, Assessment and Reporting Authority
ATAR	Australian Tertiary Admissions Rank
ATCM	Asian Technology Conference in Mathematics
BOSTES	Board of Studies, Teaching and Educational Standards (NSW)
CAS	Computer Algebra System
CPI	Consumer Price Index
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DGS	Dynamic Geometry System
GDC	Graphic Display Calculator
GC	Graphics Calculator
GST	Goods and Services Tax
HP	Hewlett-Packard
HSC	Higher Schools Certificate (NSW)
IB	International Baccalaureate
ICT	Information and Communications Technology
MANSW	Mathematical Association of New South Wales
MAT	Mathematics (course)
MAS	Mathematics Specialist (course)
MAWA	Mathematical Association of Western Australia
MEI	Mathematics in Education and Industry
MERGA	Mathematics Education Research Group of Australasia
NAPLAN	National Assessment Program Literacy and Numeracy
NCTM	National Council of Teachers of Mathematics
OECD	Organisation for Economic Co-operation and Development
PISA	Program for International Student Assessment (OECD)
PTK	Pedagogical Technology Knowledge
QCAA	Queensland Curriculum and Assessment Authority
SACE	South Australian Certificate of Education
SAS	Statistical Analysis System

SCSA	School Curriculum and Standards Authority (WA)
SPSS	Statistical Package for the Social Sciences
TI	Texas Instruments
TPACK	Technological Pedagogical Content Knowledge
TIMSS	Trends in International Mathematics and Science Study
VCAA	Victorian Curriculum and Assessment Authority
VCE	Victorian Certificate of Education
WACE	Western Australian Certificate of Education
UWA	University of Western Australia

1. Introduction and overview

The research in this report was contracted to provide a credible report for the Mathematics Course Advisory Committee (CAC) of Western Australia's School Curriculum and Standards Authority (SCSA). The research is intended for CAC's deliberations on advice to the SCSA Board about appropriate and effective use of digital technologies, particularly hand-held technologies, in Mathematics courses for upper secondary school students and in external examinations that contribute to students' Australian Tertiary Admissions Rank (ATAR).

Murdoch University was awarded a contract for this research for $46 000 (including GST), following an open tender process late in 2014. The project was originally expected to be completed by the end of July 2015, but unavoidable delays in the processes associated with ethics approval for the research, and subsequent scheduling of survey work with teachers and students, together with follow-up contact with survey respondents and others led to a mutual agreement extension of the project's timeline until December 2015.

Detailed specifications for the review were as follows:

1. Review available research that relates to the use of digital technologies (CAS calculator technology, in particular) in the teaching, learning and assessment of Mathematics at the senior secondary level – including the impact on the earlier secondary years.

2. Canvas a range of students, parents and educators concerning the use of digital technologies in Mathematics particularly at the senior school level and in examinations.

3. Attempt to establish any links between student performance and teacher competence in facilitating the effective use of digital technologies.

4. Investigate the use of technologies in Mathematics courses and examinations in other jurisdictions and in high performing overseas secondary education systems.

5. Provide a comparison of the mathematical functionality between currently available technologies used in senior school Mathematics, particularly graphics calculators and CAS calculators, and the revised WACE 2015/16 ATAR Mathematics course requirements.

6. Investigate the use of CAS technologies/graphics calculators or their equivalents in post school tertiary courses in WA and interstate.

7. Investigate alternative policies and any associated equity issues identified.

8. Investigate the risk/benefit associated with any changes to existing policy regarding the use of CAS technology in external examinations.

This report is organised into sections as follows: Section 2 comprises brief background description of the development, recent history and some key arguments for the inclusion of technology beyond paper and pencil into school Mathematics, particularly hand-held calculators. The recent deployment of CAS in particular, mostly on hand-held calculators, is also briefly described.

In Section 3, relevant research literature is reviewed and summarised, focusing on available evidence for the use of technology in school Mathematics and the role of the teacher in its implementation.

Section 4 describes the international use of technology in school Mathematics education, paying particular attention to the ways in which such technology is incorporated into examination settings.

Section 5 describes the use of technology in school Mathematics in Australia, highlighting key differences between some states, and noting some recent developments in assessment processes related to the use of calculators.

In Section 6, the use of technology for teaching and assessment purposes in universities is briefly described, including detailed information about the practices in the Mathematics departments of each of the five local universities in Perth.

Section 7 provides an analysis and critique of the ways in which the role of technology use by students has been described in official documents, both for previous and existing Mathematics courses.

In Section 8, an analysis of recent WA senior secondary Mathematics examination practices is provided, based on recent exam papers and reports and on detailed conversations with some members of recent Examiner Panels for Mathematics.

Section 9 provides descriptions and analysis of the main technologies that seem to be relevant to senior secondary Mathematics courses, bearing examinations in mind. Both a variety of calculators, as well as computers, tablets and smartphones are included in this analysis.

Section 10 describes the surveys undertaken, and presents the findings in detail and some interpretation of them. Overall, 367 Mathematics teachers and 522 Year 12 students responded to the surveys. Respondents represented each of the three sectors of education in Western Australia (WA) and provided feedback on the use of technology in the complete range of senior school Mathematics courses for which there is an external examination. This section also includes follow-up information obtained mostly by email from the 68 teacher respondents who agreed to provide further insights into their perspectives and practices on the use of scientific calculators, computers and apps on tablets. This section also reports respondents' views on the various matters canvassed. While most of these were obtained in the teacher and student surveys, some of them were the result of follow-up emails. The purpose of reporting these is to indicate the range of views commonly expressed, rather than to represent faithfully the community opinions on any single matter.

Section 11 summarises the research, drawing on the various sources of data and analysis generated by the project and reporting conclusions regarding the matters of agreed interest to the project. The section also identifies matters for CAC and SCSA to consider regarding the place of technology in senior secondary mathematics course in Western Australia.

The report also includes detailed references consulted and provides appendices that clarify the nature of the survey and other evidence obtained.

2. Background

2.1 Technologies for Mathematics in WA Schools

Since the 1970s, school Mathematics has been influenced by the development of sophisticated technologies, firstly in the form of scientific calculators, which were adopted for use in Mathematics courses and tertiary entrance examinations in WA late in the 1970s, and then in the form of microcomputers. Although microcomputers began to appear in schools from the early 1980s, most commonly in the form of teaching laboratories, their influence on the school Mathematics curriculum was relatively slight. In contrast, the acceptance of scientific calculators as tools for individual students to use, both in classrooms and in high stakes examinations, had some influence on curriculum and teaching practices, most notably reducing the emphasis on by-hand calculation and permitting more realistic data to be used in applications of Mathematics.

This importance of technology changed significantly, however, with the development of graphics calculators from 1985. These were hand-held devices, used by individual students, and included an array of mathematically helpful software, designed to support typical school Mathematics curricula. These were arguably the first examples of what Pea (1987) described as 'cognitive technologies' supporting students in thinking, learning and problem-solving. Early models of graphics calculators included software to draw graphs of functions, evaluate functions numerically, and undertake elementary analyses of statistical data, along with a suite of other mathematical functions. The first examples of these were used for Mathematics in schools and colleges in the USA from 1985 and, by 1992, there were four major companies developing models for school use, and considerable experimentation taking place in Western Australian schools. A paper commissioned by the Secondary Education Authority (Kissane, 1995) outlined the prospects for the use of these in local courses and their use was sanctioned for tertiary entrance courses from 1996. While the principle arguments for their use focused on the possibility of improving the experiences of teaching and learning Mathematics in schools, sanctioning their use in high stakes examinations offered both encouragement for schools to make effective use of them and also an imperative to make necessary adjustments to school curricula. It is now at least twenty years since technology of this kind has been used in WA schools.

A similar process occurred in Victoria around the same time, followed by other Australian locations. In recognition of the significance of this sort of development, the Australian Association of Mathematics Teachers (AAMT), the peak professional body in Australia, conducted its first thematic conference, which was based on the use of this technology by Australian mathematics teachers (Morony & Stephens, 2000) and issued an associated communiqué outlining the potential benefits for school Mathematics in Australia. A comprehensive discussion of the development and significance of graphics calculators is provided in Kissane (2007).

In addition to accumulated professional experience from classrooms, a considerable amount of empirical research into the effects of the use of calculators has been conducted over recent decades, firstly into the effects of the availability and use of scientific calculators and then into the consequences of the use of graphics calculators in school Mathematics. Results from research were consistently positive, so much so that Ronau, Rakes, Bush, Driskell, Niess and Pugalee (2011), summarising the research, suggested that it was now time for mathematics researchers to focus on how best to use technology of these kinds, rather than continuing to study whether its use was advantageous:

> Few areas in mathematics education technology have had such focused attention with such consistent results, yet the issue of whether the use of calculators is a positive addition to the mathematics classroom is still questioned in many areas of the mathematics community, as evidenced by continually repeated studies of the same topic. As a result, we concluded that future practitioner questions about calculator use for mathematics teaching and learning should advance from questions of whether or not they are effective to questions of what effective practices with calculators entail. (p. 2)

Prior to the 1990s, little computer software specifically targeted to Mathematics education was available, the Internet was not a feature of everyday life, and computers were rarely available in usable quantities in schools. Since that time, much has changed in these respects. Major software developments have resulted in new species of software for Mathematics education (dynamic geometry software, such as *Cabri Geometry*, *The Geometer's Sketchpad*, *Cinderella* and – more recently – *GeoGebra*), software for teaching and learning statistics (such as *Fathom* and *Tinkerplots*), multi-purpose software for teachers and students (such as *Autograph*), very powerful computer algebra software for professional mathematicians (such as *Mathematica* and *Maple*) and a new appreciation of educational opportunities of spreadsheet software originally designed for business and accounting purposes, such as Microsoft's *Excel*. Twenty years or so of Internet access have also resulted in innovations designed to support Mathematics education with many websites being developed for educational purposes, together with an environment for professional communication that now relies to a large extent on the Internet.

Recent years have seen an explosion in the developments of digital devices such as tablets and smartphones, along with a deep penetration of these into Australian society. Attempts have been made, and are still being made, to take advantage of these new digital environments for Mathematics, with the development of new products to support learning, as well as the movement of existing products into new environments, and to accommodate them into existing curriculum structures. While it was a commonplace two decades ago, it is now unthinkable that curriculum documents at all levels do not attempt to harness in some way the new opportunities for learning and teaching that are now available.

In the midst of these technology developments along many fronts, graphics calculators were augmented to include symbolic capabilities in addition to their existing suites of numerical, graphical and statistical capabilities. Derived from larger computer algebra systems to fit the smaller spaces of hand-held devices and the less sophisticated audiences of senior secondary school students, these new calculators have also been used in recent years in school Mathematics, both in Western Australia and elsewhere.

In a major study, outlining the relationships between the development of technologies and reform in school mathematics, Heid (1997), a pioneer in the use of computer algebra systems (CAS) for educational purposes, identified four principles that have been frequently invoked when decisions are made regarding technology in mathematics education:

1. student-centered education is valuable and technology is a powerful way to make education more student-centered.
2. giving a student the experience of being a mathematician is valued and technology is thought to provide the opportunities for these experiences.
3. learning will be enhanced by reflection and technology can play a role in promoting reflection.
4. in technology-intensive instruction, that is, instruction that assumes constant student access to technology tools, there is a redefinition of epistemological authority and this realignment is desirable. (pp 8-9)

Principles such as these were likely behind decisions to adopt the use of CAS calculators into the Western Australian Mathematics curricula around a decade ago. This report draws on the experience in Western Australia since that time, mindful of other opportunities to improve teaching and learning through the use of technology, and recognizing the critical role of teachers in the process of interpreting and implementing curricula in an ever-changing and challenging environment.

2.2 The development of CAS in schools

Computer algebra systems (CAS) originally were software programs that enabled high-level algebraic manipulations to be undertaken by computers. Developed from the 1960s on mainframe computers and then also on microcomputers during the 1970s, these programs allowed professionals to obtain exact symbolic answers to questions in algebra and calculus. Although early computer algebra systems were available prior to the development of graphics calculators in 1985, they were generally reserved for research use in universities and required substantial computer systems to operate. However, by the early 1980s, these had become available on small microcomputers and hence more widely accessible. A notable example was *MuMath*, described by Wilf (1982) as the “disk with the college education”, and which was available to teachers in schools and colleges in the US for only $40.

CAS offered an opportunity for students to engage in mathematical activity without having to develop extensive by-hand algebraic skills, which typically dominated the school and undergraduate curriculum in practice. Heid was an early advocate of making educational use of CAS and her doctoral study involved teaching students a calculus course without first developing all of the extensive symbolic manipulative skills traditionally associated with such a course. Heid (1988) engaged students in a traditional college calculus course, making use of a CAS to carry out the necessary routine symbolic manipulations for most of the early parts of the course, while focusing on the concepts and applications of the calculus, and only attending to the traditional calculus skills involving symbolic manipulation late in the course. She found that students taught in this way developed a deeper understanding of the concepts involved than students taught traditionally, and yet performed almost as well on the final examination involving traditional calculus skills (without using a CAS).

Work of this kind, and the increasing availability of CAS to teachers, prompted increasing experimentation at various levels and in different countries, many of which are documented by Heid (1997). Two prominent mathematics educators – pioneers in the use of graphics calculators in schools – raised the matter of CAS use for school mathematics more than twenty years ago (Waits & Demana, 1992), and elaborated two objections. In the first place, CAS was at that stage available only on relatively expensive computers, which were recognised as problematic for all students to access. In the second place, they claimed that it was difficult for students and others to interpret insightfully many of the exact results of CAS manipulations conducted by computers. Despite these objections, they argued that a careful scrutiny of the place of algebraic manipulation in school Mathematics was needed, not only because it frequently played an excessive role, but also because it was not clear how much by-hand competence was needed by students to engage in mathematical work in the real world and to be able to meaningfully use CAS in doing so. Arcavi (1994) offered an insightful analysis into the nature of symbolic manipulation, providing further stimulus for professional reconsideration of the nature of the traditional algebra–calculus sequence common in many countries, and supporting curriculum developers beginning to reconsider traditional emphases.

Although an early graphics calculator (the Hewlett Packard HP-28S) included symbolic manipulation capabilities, the possibility of school Mathematics including some use of CAS first became a reality with the development of a Texas Instruments (TI) graphics calculator (the TI-92) that included significant CAS capabilities. In describing this new tool, Waits and Demana (1996) noted that it overcame their previous objections to CAS and was both affordable and available for students to use in school Mathematics. As it also included some dynamic geometry capabilities, they described it as the first example of a personal hand-held computer for all of secondary Mathematics. Although the calculator was at first prohibited from use in the high-stakes Advanced Placement Calculus examinations in the USA, the reason for this was that it had a QWERTY keyboard, which was prohibited by examination authorities as a potential threat to test security (irrespective of the CAS capabilities); a later version of the TI-92 (called the TI-89) was manufactured by Texas Instruments without the QWERTY keyboard and was subsequently approved for use in those examinations.

In describing the first CAS-capable calculator, Waits and Demana (1996) raised issues that are still relevant today:

> Some traditional paper-and-pencil skills will continue to be necessary for mathematical activities, as will traditional mental-mathematics skills. However, we must also agree to stop spending large portions of our time teaching obsolete paper-and-pencil algebra and calculus manipulations. These obsolete skills must be identified and deemphasized in the curriculum. … The pedagogical thrust should be not to delete traditional topics but to reduce the time spent and change the tools used for these topics. (p. 713)

Other manufacturers produced hand-held calculators with CAS capabilities, designed for a school or lower undergraduate market, and experimentation with their use in Mathematics education continued. By the turn of the century, CAS was available on several different platforms as McMullin (2001) noted, referring to the symbolic manipulations of algebra, trigonometry and calculus that they were capable of doing as ‘Algemetic’. McMullin claimed:

> … symbolic manipulation has been pushed out of its former prominent place in the curriculum. Things continue to change: computer software and calculators can do the symbolic manipulation – the factoring, the solving, the rationalizing–in addition to the graphing. These calculators and software packages are available today, make no mistake about it, they will not go away. The high school curriculum and pedagogy have to change. …

> removing the tediousness associated with symbol manipulation from algebra through calculus. … Algemetic is not all that algebra is, but it is what students spend years learning.” (p. 84)

In a similar vein, but from a background of more experience and research, Heid (2002) suggested that former reservations about the use of CAS in school mathematics no longer were sustainable, especially after the developments of improved CAS-calculators over the previous decade. She argued that CAS ought to be implemented into school curricula and used productively for important purposes, rather than continuing to require students to spend a lot of their school time learning tasks by hand that are effortless for their calculators. In doing so, she used the term CAS to refer not only to the symbolic manipulation capabilities, but also the other capabilities such as numerical, graphical and geometric capabilities that together describe a system.

> The overarching rationale for incorporating CASs into school mathematics is the unprecedented learning opportunities that such use would offer students. Algebra is more than symbolic manipulation; it is interpreting algebraic expressions and using algebraic language to describe real and mathematical worlds, it is understanding and using symbols and it is appreciating structure and using symbolic tools to enhance that appreciation. (2002, p. 664)

Rather than removing symbolic manipulation from the curriculum, Heid argued that CAS offered a number of ways to improve students’ symbolic understanding and competence, and made possible a better balance of skills and concepts in the curriculum. In a later paper, offering a range of examples of how CAS could help students understand ‘big ideas’ in mathematics, she explicitly suggested that CAS is not only about symbolic manipulation: “CAS is a multi-representational tool with symbolic, graphical and numerical capabilities.” (Heid, 2009, p. 541) In a companion paper focused on the middle years of schooling, Hollenbeck and Fey (2009) speculated on the kind of algebra likely to be needed in the future, which they suggest is unlikely to be the same as the past:

> The case for developing students’ proficiency with arithmetic operations and standard algorithms is often justified by the argument that those skills are essential for success in learning algebra. If one thinks about algebra as a collection of syntactic rules for transforming expressions, equations and inequalities into equivalent forms—unaided by tools like spreadsheets, computer algebra systems and graphing utilities—the importance of skill in generalized arithmetic procedures is obvious. However, once again, almost anyone who needs to operate on algebraic expressions, equations and inequalities in technical work will have access to tools that make these tasks routine. (p. 434)

Arguments of these kinds were prominent in the decision to incorporate CAS-capable calculators into the revised Mathematics units constructed by the Curriculum Council of WA in 2008, following ballots by teachers on the matter. To alleviate concerns that the availability of CAS to students would undermine efforts to ensure students acquired appropriate symbolic manipulation and other skills, it was further agreed that formal assessment would include a component for which students were not permitted to use any technology. It was also noted that it seemed likely that future calculators for students (all designed and constructed in other countries) were likely to include a suite of mathematical capabilities to allow access to a range of functionality, including numerical, graphical, symbolic, statistical and geometric, so that a restriction to a non-CAS device might prevent students from accessing the best technologies for learning.

3. Review of research literature

3.1 Use of digital technologies (CAS calculators in particular) in the teaching of mathematics at the senior secondary level – teacher issues

Issues surrounding the use of technology in the mathematics classroom are multi-dimensional and complex. The role of the teacher amidst the challenges of teaching mathematics with digital technologies is evolving (Clark-Wilson *et al*., 2014). Seen in the context of broader ICT developments both within and outside the classroom, the challenges are made more intense with the availability of increasingly sophisticated mathematical, pedagogical and communication tools. Teachers have often expressed support for the use of technology in their teaching (Forgasz, 2006). However the degree and the type of use in their classroom practices differ very widely dependent on conditions such as availability and levels of technical expertise, regarded as critical by Becker (2000). Indeed many factors at play in the teaching-learning process within the classroom may influence teachers integrating technology into their pedagogy. These factors include affective variables such as beliefs, attitudes and confidence, perceptions of the nature of mathematical knowledge and how it should be learned, levels of mathematical content knowledge, and pedagogical content knowledge (Shulman, 1986).

In analysing these factors and gauging teacher readiness for integrating technology into their pedagogy, the literature provides various theoretical frameworks. For example, Drivjers *et al.* (2010) use the theory of instrumental orchestration; and Thomas and Hong (2005a) draw from the notion of Pedagogical Technology Knowledge (PTK) as central to knowing how to teach mathematics with technology. Mishra and Koehler (2006, p.8) highlighted a significant problem with seeing technology "as constituting a separate set of knowledge and skills that has to be learned, and the relationship between these skills and the tried and true basis of teaching (content and pedagogy) is non-existent or considered to be relatively trivial to acquire and implement". They then outlined the central constructs of Technological Pedagogical Content Knowledge (TPACK) and proposed the framework in Figure 1 to theorise about the overlaps of knowledge of subject content, pedagogy and technology.

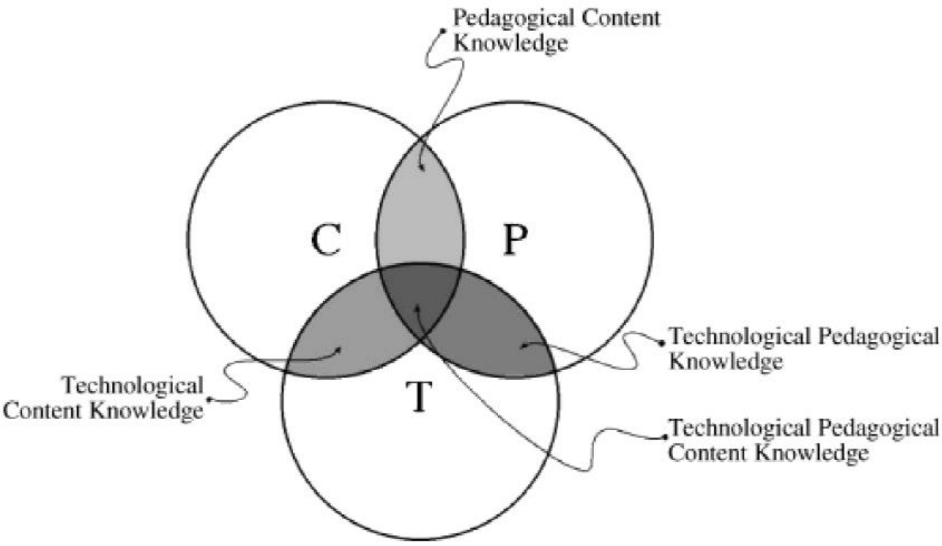


Figure 1. Pedagogical Technological Content Knowledge. The Three Circles, Content, Pedagogy, and Technology, Overlap to Lead to Four More Kinds of Interrelated Knowledge (Mishra & Koehler, 2006, p. 1025).

The elements of the model of most direct relevance to the current project are the Technology Knowledge and its overlaps with Content and Pedagogy. In brief, Technological Content Knowledge (TCK) and Technological Pedagogical Knowledge (TPK) are described as follows:

> TCK is knowledge about the manner in which technology and content are reciprocally related. Although technology constrains the kinds of representations possible, newer technologies often afford newer and more varied representations and greater flexibility in navigating across these representations. Teachers need to know not just the subject matter they teach but also the manner in which the subject matter can be changed by the application of technology.
>
> TPK is knowledge of the existence, components, and capabilities of various technologies as they are used in teaching and learning settings, and conversely, knowing how teaching might change as the result of using particular technologies. (p. 1028)

An example of where TCK can come into play is the use of dynamic geometry software such as *GeoGebra* as a tool for teaching geometry. The software provides a platform with numerous functionalities for users to construct geometric objects, measure lengths and angles, to dynamically change the shapes constructed by 'dragging' points about, to display or animate various geometric properties and relationships instantaneously, etc. TCK would be the knowledge and skills associated with using the technology to mediate the subject matter or the mathematics content. Other examples of TCK include using the graphing capabilities of online software such as *Desmos* (https://www.desmos.com/calculator) and mathematics software such as *Mathematica* and *Maple.*

Significant in the use of digital technologies in the teaching of mathematics is the notion of TPACK. Mishra and Koehler (2006) describe it as:

> the basis of good teaching with technology and requires an understanding of the representation of concepts using technologies; pedagogical techniques that use technologies in constructive ways to teach content; knowledge of what makes concepts difficult or easy to learn and how technology can help redress some of the problems that students face; knowledge of students' prior knowledge and theories of epistemology; and knowledge of how technologies can be used to build on existing knowledge and to develop new epistemologies or strengthen old ones. (p. 1029)

In other words, for a teacher to consider using the CAS calculator and other digital technologies as a significant part of her mathematics classroom practice, then some degree of TPACK is necessary. Thomas and Hong (2005) made a similar argument about the importance of teachers having some degree of PTK.

As noted earlier, functionalities afforded by digital technologies change the nature of teaching and learning using representations not available prior to such technologies. Significantly, functionalities like graphing, spreadsheets, dynamic geometry and computer algebra system are packed into CAS calculators giving the user an immediate access in a single hand-held device. These open up many opportunities, both functional and pedagogical, for the teacher at several levels. The following map by Pierce and Stacey (2010, p. 6) provides an overview of the pedagogical opportunities afforded.

There are three levels of pedagogical opportunities, namely the *tasks* which teachers set for their students, the *classroom* interaction and the *subject* (that is an area of mathematics) being taught. The expanded pedagogical opportunities are underpinned by functional opportunities afforded by technologies such as the CAS calculator. An underlying feature is the *outsourcing* of some of the technical aspects of mathematics allowing teachers to focus more on enhancing student learning tasks.

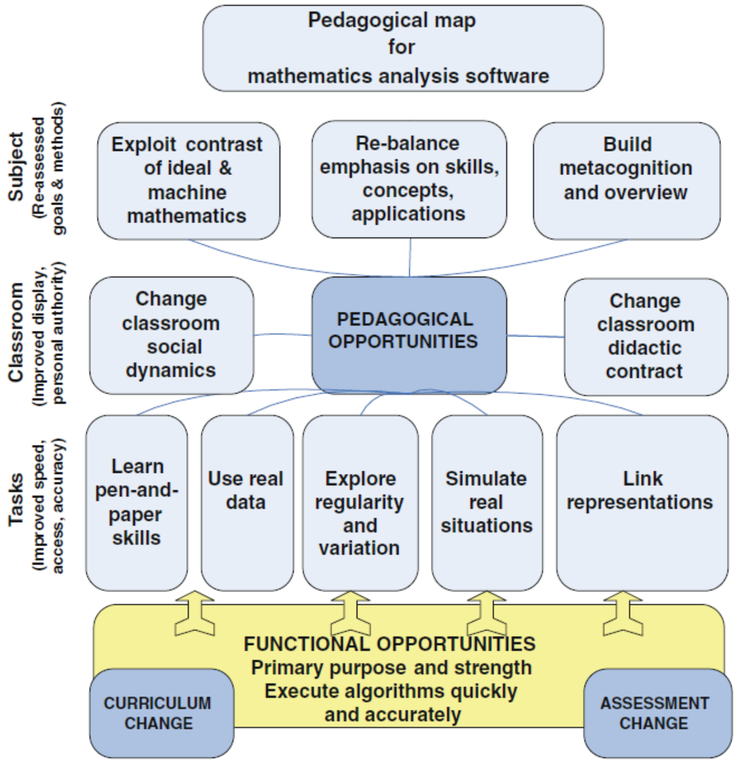


Figure 2. Pedagogical map for mathematics analysis software (Pierce & Stacey, 2010, p. 6).

While it is clear there are many pedagogical opportunities afforded by appropriate use of digital technologies, it is by no means a straightforward matter when it comes to whether or not teachers take these opportunities and integrate them into their classroom practices. Goos and Bennison (2008) noted in their review of research that the integration of technology into classroom practice remains marginal in many countries. Further there are huge challenges for teachers as pointed out by Healy and Lagrange (2010, p. 288):

> Modifying teaching practices to include new tools is no mean feat for teachers. In addition to mastering the various possibilities for doing mathematics offered by different digital tools, they are also faced with the need to rethink a number of classroom management issues, adapt their teaching styles to include new forms of interactions–with students, between students and between students and mathematical ideas–take a more prominent role in designing learning activities for their students and confront a range of epistemic issues… It is not surprising then that the

> process of orchestrating technology-integrated mathematics learning is neither a spontaneous nor rapid one.

Researchers have sought to identify the factors influencing teachers' use or non-use of technology for teaching (see for example Forgasz, 2006; Zbiek & Hollebrands, 2008; Pierce & Ball, 2009). Heid *et al.* (2013, p. 630) summarise these factors that either promote or inhibit teachers' abilities to use technology as:

> previous experience in using technology, time, opportunities to learn, professional development, access to technology, availability of classroom teaching materials, support from colleagues and school administration, pressures of curriculum and assessment requirements and technical supports.

The professional development factor to enhance teachers' preparedness to use technology in teaching-learning situations within classrooms is pivotal. In a large-scale survey of Queensland secondary mathematics teachers, Bennison and Goos (2010) found that participation in technology-related professional development was crucial in whether and how technology was used in classrooms. Participants gained confidence in using technology and became more convinced that it supports students' learning of mathematics. On the other hand, the lack of time and limited access to resources inhibited many. In addition, the study also found "teachers' lack of skill and confidence and their uncertainty about the benefits of technology for students' mathematical learning were also important factors that discouraged greater use" (*ibid.*, p. 33).

It should be noted that professional development for teachers is not monolithic. According to Clark-Wilson *et al.* (2014, p. 10), professional development

> encompasses a wide range of individual and collaborative activities across a broad range of structured and informal opportunities, which are constrained by country-specific and cultural boundaries and expectations. Central to all of these activities lies the development of a teacher's mathematical, pedagogical and technological knowledge and practice.

In other words, the importance of effective professional development to facilitate teachers' development of TPACK or PTK is underscored.

In their meta-analysis of 43 studies chosen from over 180 research reports, Burrill *et al.* (2002) found that "simply providing teachers with information about how the technology functions is not likely to result in effective integration in the classroom. Substantial professional development and support is necessary for teachers to make informed decisions about how to best use handheld technology in their classrooms." Notably Waits and Demana (2000), in drawing from their decades of experience, argued that teachers cannot be expected to make fundamental changes in their teaching without adequate, ongoing support. The changes have "to come from within the teaching profession and be supported both from within and from without" and that "changing practice is full of local issues that must be dealt with at that level." Further, they argued for turning the professional development activities over "to practising teachers who had succeeded in embedding the appropriate use of calculators into their own practices" and that on a large scale, "*it takes practiced teachers to change the practice of teachers*" (p. 53, emphasis in original).

Digital technologies, CAS calculators in particular, have indeed changed the way mathematics is taught and the way students learn (Waits & Demana, 2000; Kieran & Drijvers, 2006; Heid, Thomas & Zbiek, 2013). According to Waits and Demana (2000), the general view was that before computers and calculators, students needed to spend time mastering and becoming fluent and proficient in using paper-and-pencil computational and manipulative techniques, but that "today much of this time can be spent on developing deeper conceptual understanding and valuable critical-thinking and problem-solving skills" (*ibid.,* p. 56).

Notwithstanding the promise and the potential there is considerable uncertainty about the role of technology in the teaching and learning of mathematics, particularly the issue of changing the relation between technical skills and conceptual understanding. Kieran and Drijvers (2005, p. 205) noted that "it is often not clear how the use of technological tools relates to the required paper-and-pencil skills" both from the students' perspective as well as the teachers' standpoint. Further, researchers "have difficulty in providing evidence of improved learning with technological means, as well as in understanding the influence of technology on learning."

Amidst the many challenges of integrating technology into mathematics, many education systems have taken this activity on board in varying degrees, no doubt with the expectation that it will bring about intended learning outcomes. There is also acknowledgment of the pivotal role teachers play. Current research suggests a broad need for teachers to know some levels of TPACK or TPK to teach in a CAS environment, and supports the view that there is still much to be done in terms of teachers' professional development and system-wide support.

3.2. Use of digital technologies (CAS calculators in particular) in the learning of mathematics at the senior secondary level

Arguments for the use digital technologies in school mathematics have focussed on its potential capacity to help students learn mathematics in engaging ways, opening avenues that allow them to tackle problems grounded in the real world and broadening the range and scope of mathematical exploration and investigation. It enhances visualisation and support student understanding of mathematical concepts. Proponents believe that students would thereby achieve *better* learning outcomes. Many empirical studies have been conducted over the years to see if there is evidence to bear such arguments out. Several reviews appear to suggest some positive effects. For example, Burrill *et al* (2002) through their meta-analysis of 43 studies from a field of over 180 research reports about the use of handheld graphing technology at the secondary level, found that the graphics calculator can be an important factor in assisting students develop a better understanding of mathematical concepts. Significantly, they also found that students who used CAS calculators were "better able to apply calculus concepts than those without that experience." In addition, "no significant differences in procedural skills were found between students who used handheld graphing technology and those who do not", indicating that "extensive use of the technology does not necessarily interfere with students' acquisition of skills" (p. v).

In another review, Rakes *et al.* (2010) examined 82 studies about methods of instructional improvement in algebra. They grouped the studies using five categories namely implementation of new curricula, technology-based curricula, instructional strategies, manipulatives, and technology tools. They found statistically significant positive effect size averages in each of the five categories, underscoring the importance of technology-related factors. In another meta-analysis, Cheung and Slavin (2011) examined 74 studies and concluded that: "Educational technology is making a modest difference in learning of mathematics. It is a help, but not a breakthrough" (p. 20).

There is a growing body of studies illustrating how technologies can potentially be used to enhance learning and teaching; for example in areas of algebra (Zeller & Barzel, 2010; Heid, Thomas & Zbiek, 2013), mathematical modelling (Berry, 2002; Williams & Goos, 2013), geometry (Sinclair & Yurita, 2008; Sinclair & Robutti, 2013), functions (Abu-Naja, 2008) and statistics (Biehler *et al.*, 2013). More specifically with reference to the use of CAS, Heid, Thomas and Zbiek (2013, p. 597) highlighted major areas such as "new explorations of mathematical invariants, active linking of dynamic representations, engagement with real data, and simulations of real and mathematical relationships."

But is the case for using CAS in classrooms convincing enough? In drawing implications from research about CAS in mathematics instruction Heid (2002, p. 587) pointed out: "The fact that using CASs in mathematics instruction does no harm to students' symbolic-manipulation skills, however, is hardly a persuasive reason to incorporate CAS use into mathematics instruction. Unless an improvement occurs in some aspect of mathematics learning, the argument for change is not compelling." While the numerous studies cited above appear to support the view that integrating appropriate use of technologies into the classrooms holds much promise, a study by Weigand and Weller (2001) reported no evidence of a *better* understanding of functions by a group of students using CAS compared to students working with pencil and paper.

Furthermore, the integration is by no means a straightforward matter as noted in the previous section. From the students' perspective, Drijvers (2000, 2002) highlighted various obstacles and constraints that stand in the way of learning mathematics in a CAS environment. Based on his observations he noted the following non-exhaustive list of obstacles (2002, p. 222):

(1) *The difference between the algebraic representations provided by the CAS and those students expect and conceive as 'simple'.* This concerns difficulties in recognizing that, for example, -(x – 12), given by the CAS, is equivalent to 12 – x, that the student had in mind, or that $\sqrt{\frac{s}{4}}$ equals $\frac{1}{2}\sqrt{s}$. Recognizing equivalent expressions is a central issue in algebra, and still is when working in a computer algebra environment.

(2) *The difference between numerical and algebraic calculations and the implicit way the CAS deals with this difference*. For many students $\sqrt{2}$ is not a real answer: they consider 1.41 as the ultimate result. They do not really understand the difference in status of the two answers: $\sqrt{2}$ 'still has some algebra in it', whereas 1.41 is purely numerical. The CAS is not always clear about this difference in status

(3) *The flexible conception of variables and parameters that using a CAS requires*. In a computer algebra environment 'all letters are equal', to paraphrase Orwell. However, in a specific problem context the variables have different meanings and roles, such as the role of unknown, parameter or changing quantity. The meaning and the role of the letter are 'in the eye of the beholder'. Working efficiently with a CAS requires that one deals flexibly with the roles of the variables involved and with the context-bound meanings they may have outside the software and the abstract way of dealing with them within the software.

(4) *The tendency to accept only numerical solutions and not algebraic solutions.* Students often are not satisfied with answers such as $x = ½ s - ½ v$. In the end they want to know what value x stands for. This is called the 'expected answer obstacle'.
(5) *The limitations of the CAS, and the difficulty in providing algebraic strategies to help the CAS to overcome these limitations.* Sometimes, as in the example in the introduction, there is no direct command to perform a task, or the CAS is unable to carry it out without any help from the user. In such cases, cooperation between users' expertise and CAS capacities is needed to find a result.
(6) *The inability to decide when and how computer algebra can be useful.* Experienced users know what the CAS can be used for, and how to let it work for them in a certain problem situation. Novice users however don't have this sense of what can be reasonably expected from the tool.
(7) *The black box character of the CAS.* Usually the CAS provides no insight in the way it obtains its results. This means that students are often unable to verify the procedure. To them, the CAS has a black box character. Students may feel uncomfortable with this, as they are 'at the mercy of' a hardly controllable engine.

A framework that some researchers have drawn on for understanding the learning process and the difficulties of effective use of technology is the theory of instrumentation (Lagrange, 1999a & 1999b; Artigue, 2002; Drijvers, 2002; Trouche, 2005). Accordingly artefacts such as CAS calculators become instruments of value in both pragmatic and epistemic sense for a user through a process called *instrumental genesis*. This process works in two directions (Artigue, 2002, p. 250):

> Firstly, it is directed towards the artefact, loading it progressively with potentialities, and eventually transforming it for specific uses; this is called the *instrumentalisation* of the artefact. Secondly, instrumental genesis is directed towards the subject, leading to the development or appropriation of schemes of instrumented action which progressively take shape as techniques that permit an effective response to given tasks. The latter direction is properly called *instrumentation*.

The theoretical framework of instrument genesis draws out the underlying complexity involved in using technologies in the learning of mathematics. Each user has to go through the process of working out the role CAS plays in their learning, deciding when CAS could be used and when a task might be better done by hand, and how to balance the two (Thomas, Monaghan & Pierce, 2004). Clearly it would require time and effort for both the student and the teacher to learn to use digital technologies, including CAS calculators, in appropriate ways before *expecting* improvement in some aspects of mathematics learning.

Another significant area in researching the use of technology in the learning mathematics concerns student attitudes and behaviours. Schmidt (2010) surveyed more than 2600 German students about their attitudes towards their use of CAS calculators and found those who are better in mathematics tend to feel that they benefitted more from the use of CAS calculators. Her research also revealed that while there was not much of a gender effect, male students have considerably less problems working with the CAS calculator and use it a lot more in other lessons than female students.

In another study of effects of attitudes and behaviours on learning mathematics with computer tools Reed, Drijvers and Kirschner (2009) found that improvements in conceptual understanding can be predicted from student attitudes towards mathematics and mathematical computer tools. They suggested that "student attitudes towards mathematics and mathematical computer tools have a moderate impact on the extent to which intended learning outcomes of using such a tool are realised, in terms of both improved insight into the targeted mathematical concepts and technically and conceptually correct use of tool techniques" (p. 12). To promote learning with mathematical computer tools, they recommended "improving student attitudes, raising levels of goal-oriented learning behaviours, and giving sufficient opportunity for constructing new mathematical knowledge from acquired tool mastery" (p. 12).

Another critical research question when implementing the use of CAS in classrooms is: "How does CAS use influence student conceptualisation?" (Thomas, Monaghan, & Pierce, 2004, p. 166). As noted earlier, the use of digital technologies including the CAS calculator holds much promise in expanding students learning opportunities, opening up avenues for investigation and exploration. How does the promise hold out in real classrooms? Some research (e.g. Thomas & Hong 2004, 2005b) would suggest that the focus of CAS use in secondary mathematics was not so much about investigating or exploring mathematical concepts but rather procedural applications such as checking of work done by-hand. It appears that the promise is often not realised. In another research study, Pierce *et al*. (2010) pointed to differences between what teachers and students saw in classrooms where hand-held technologies were used. While there were some advantages to be gleaned from the use of technology, there were mismatches between the students and the teachers' conceptions – "Students saw technology skills as the main point of the lesson, but the teachers saw the lesson as primarily teaching mathematics" (*ibid.*, p. 683). The teaching of mathematics and of technology skills have quite different characteristics and these differences add to the complexity students have to grapple with using digital technologies to help them learn mathematics.

3.3 Use of hand-held calculators with or without CAS and assessment

The functional and pedagogical opportunities afforded by hand-held calculators and their impact on assessment have been widely researched. In a meta-analysis of 54 research studies to determine the effects of calculators on student achievement and attitude levels, Ellington (2003, p. 433) found that "students' operational skills and problem-solving skills improved when calculators were an integral part of testing and instruction." In addition, "calculator use did not hinder the development of mathematical skills", and "students using calculators had better attitudes toward mathematics than their non-calculator counterparts."

In another meta-analysis, Ellington (2006) examined 42 studies comparing the effects of graphing calculators on student achievement and attitude levels, covering middle and high school mathematics as well as first-year undergraduate calculus. She found that when graphing calculators were included in instruction but not in the testing process, they neither help nor hinder students' development of skills in applying mathematical formulas and procedures, and their overall achievement. However, when graphics calculators were included in both testing and instruction, students benefitted in their development of mathematical skills and their overall achievement. They performed significantly better on achievement tests than students taught without access to graphing calculators. The meta-analysis also revealed that the graphing calculator has had a positive effect on students' attitudes towards mathematics.

Schmidt, Köhler and Moldenhauer (2009) reported the effects the use of CAS calculators had on the performance in mathematics of grade 11 students in Germany, following a lifting of restrictions on the use of technology in mathematics education in 2002. The tests consisted of a large number of short questions testing primarily basic mathematical skills, administered over a period of five years. Students in both CAS and non-CAS groups had to work without any kind of calculator. In 70% of the cases CAS students performed noticeably better, and in the remaining 30% cases they performed as well as, non-CAS students. The positive effect on student performance is more pronounced for the advanced course than for the basic course.

A number of studies have suggested improvement and better test results for students exposed to functional and pedagogical opportunities afforded by CAS. For example an experimental study by Lyublinskaya and Tournaki (2011) found that students taught with CAS calculators outperformed those taught with a graphics calculator. In Australia, an action research study by Driver (2012) found some evidence to suggest that the use of a CAS calculator both in class and in exams made a positive impact on students' achievement and that there was greater improvement in learning when the CAS calculator was introduced in Year 10 rather than Year 11. Interestingly a small-scale study by Ng *et al* (2005) of Singapore's 17-year-old junior college students' attitudes towards CAS and achievement in mathematics found no significant difference between the treatment group which used CAS calculator and the control group which used the graphics calculator. Notwithstanding, their results indicated that appropriate use of CAS in classrooms can improve students' attitudes.

A common concern about using CAS calculators in class and in assessment is that students would lose their traditional 'by-hand' skills. Leigh-Lancaster, Les and Evans (2011) reported that facility with traditional 'by-hand' skills as measured by mean score data on a VCAA technology free exam 1 for 2006-2009 consistently indicates that in general the mathematical methods (CAS) cohort perform at least as well as the Mathematical methods (non-CAS) cohort on related questions. In particular for 2009 the distribution of student scores for each cohort across the full range of marks show that at the top end, the performance of the two cohorts is essentially the same; at the bottom end, the performance of the Mathematical Methods (CAS) cohort tends to be better, while across the range of marks the Mathematical Methods (CAS) cohort consistently achieves a slightly higher score that the non-CAS group.

So these results suggest that in the main calculator use compared with non-use has either positive or at worst neutral effects on students' abilities and that the use of CAS does not lead to reduced procedural skills.

The increasing availability of technology and its use in mathematics changes quite profoundly the way mathematics is assessed. In their review of technology and assessment in mathematics, Stacey and Wiliam (2013) pointed out that "current assessment practices are struggling to keep pace with the use of technology for doing and teaching mathematics, particularly for senior students" (p. 721). More specifically in assessing mathematics changed by technology, there are fundamental issues about what mathematics is valued, how it should be taught and how it should be assessed. They drew from the USA's National Research Council Mathematical Sciences Education Board (1993) conceptual guide for assessment:

- *The mathematics principle:* Assessment should reflect the mathematics that is most important for students to learn.
- *The learning principle:* Assessment should enhance mathematics learning and support good instructional practice.
- *The equity principle:* Assessment should support *every* student's opportunity to learn important mathematics. (p. 1)

Summarising Drijvers (2009)'s study on the use of mathematically-able software (principally graphics calculator and CAS calculators) in ten European countries, Stacey and Wiliams noted there were four policies: "technology not allowed; technology allowed but with examination questions designed so that it is of minimal use; technology allowed and useful in solving questions but without any reward for such work; and technology use allowed and rewarded in at least some components of the assessment." Accordingly, the ten countries were probably "moving towards consensus on the policies allowing the use of technology: (a) including some questions where it is definitely useful, and (b) ensuring pen-and-paper algebra/calculus skills are tested in some way, either by not rewarding certain technology-assisted work, or by including a special component of assessment without technology" (p. 20).

At the end of their review, Stacey and Wiliams (2013) reiterated:

> Technology, including dynamic geometry, spreadsheets, and calculators, enables students to explore mathematical ideas for themselves formulating and testing and resolving hypotheses, so some assessment with technology needs to be without time pressure so that students can show these abilities. Similarly, some extended assessment can look at the whole modelling cycle, from formulating a problem mathematically, to solving it and interpreting the results; a process which technology assists at a number of points. Since technology takes over much of the routine work of solving, even examinations now need to look beyond assessing a narrow bandwidth of mathematical activity… Designing good assessments with technology also needs to pay attention to equity…it is important that use of technology in class or in assessment does not operate to limit further the achievement of socially and economically disadvantaged students. (p.748)

The use of technology in assessment should bear these pertinent points in mind.

4. International use of technology in mathematics education

In recent years, comparisons have been regularly made between Australian educational performance and practices in relation to those in other countries. The most prominent form of this comparison has been through the medium of international assessments, periodically conducted and in which Australia has always been a prominent participant, and recently undertaken leadership roles. In the case of mathematics, the two major tests have been the Program for International Student Assessment (PISA) and the Trends in International Mathematics and Science Study (TIMSS). As a result of these exercises, each of which involves careful test construction and reliable assessments, quasi-league tables comparing the overall performances of countries have been developed, and have exerted considerable influence on policymakers in many countries, including Australia. The findings of these international assessment programs have resulted in a new rhetoric of countries as ‘high-achieving’ or ‘high-performing’ and various attempts to emulate best educational practices from one country to another. As an illustration of this perspective, in the Request for Quote specifications for the present project, SCSA has referred to an expectation that the project will “investigate the use of technologies in mathematics courses and examinations in other jurisdictions and in *high performing* overseas secondary education systems” (italics added).

International comparisons have long been understood to be problematic, however. In the present case, caution is needed to recognise some of the complexities. In the first place, neither PISA nor TIMSS provides direct information regarding senior secondary schools, the main focus of the present investigation. PISA tests involve 15-year old students, most of whom are in 10^{th} grade in OECD countries, while TIMSS involves students in 4^{th} grade and 8^{th} grade in a wider range of countries. PISA is a test of *mathematical literacy*, concerned with the application of mathematics learned in school, and intentionally decouples its cognitive assessments from any particular country’s curriculum. TIMSS involves more conventional school mathematics material, as taught in many countries’ curricula, but at a level well below senior secondary schooling, which is the major focus of this report. Unavoidably, tests are translated into various languages, and involve samples of mathematical tasks that align differently with what is taught well in different countries. A recent analysis by Buckingham (2012) urged caution in over-interpretation of international comparisons, describing in some detail significant differences between the small, homogenous, highly equitable nation of Finland and the large, diverse and inequitable nation of Australia. Finland is regularly described as a high-performing country because of its ranking on PISA tests, but care is needed to interpret the underlying factors associated with such rankings.

Criticisms of the use of PISA, in particular, for international comparisons were foregrounded by Carnoy (2015) in a recent review. Although countries are compared on the basis of national scores on PISA tests, and the rankings then used to compare national educational policies, according to Carnoy account is not taken of the differential family academic resources involved, which differ considerably between countries. After adjusting for these differences, students in some countries have made substantial gains that are not reflected in the PISA comparison data published. Carnoy also reports criticisms of the validity of the tests themselves and the ways in which they have been used. Of note is the use of Shanghai data (excluding some lower-achieving groups in Shanghai), although there are substantial other Chinese data that would lead to different conclusions regarding Chinese education.

Similarly, in a recent published address, Leung (2014) also urged caution in interpretation of international comparisons resulting from TIMSS. Prominent in international rankings on TIMSS and hence prominent in designations of 'high-performing' countries are several East Asian countries, especially Japan, Korea, Singapore, Chinese Taipei and Hong Kong. Leung describes a number of significant differences between these and other countries, including the strong influence of the Confucian Heritage Culture on student performance. As Leung notes, East Asian cultural practices likely give rise to high student performance include a strong emphasis on the importance of education and expectations on students, a culture of examinations, a belief in effort, a stress on practice and memorization and the virtue of modesty. These cultural practices have resulted in massive financial investment by parents and time investment by their children in out-of-school education in some cases, most notably in *juku* in Japan and *hagwon* in Korea, but do not necessarily result in students valuing mathematics, or wishing to pursue it beyond a minimum level to succeed in University entrance (for example). For example, Carnoy notes:

> [T]here is no doubt that a high percentage of students in these countries spend a considerable amount of time during their middle school and high school years in cram schools/courses in addition to studying for tests and completing other work for "regular" school. Families invest major resources in extra instruction. Amazingly, this is rarely mentioned when discussing whether such behavior or levels of investment are broadly transferable to other societies. (2015, p. 21)

Similarly, Buckingham (2012, p. 1) makes the observation that, "Students in high-performing territories such as Shanghai, Hong Kong and Singapore are subjected to punishing study schedules that Australian families would consider excessive."

Despite such critique and advisable caution that needs to be exercised in generalizing or inferring from the findings of international assessment programs like PISA or TIMSS, we nonetheless are also sympathetic to the view that there are valuable educational lessons to be learned using international comparisons based on large-scale, high quality data. As eloquently articulated more than 50 years ago by Arthur Foshay (1962):

> If custom and law define what is educationally allowable within a nation, the educational systems beyond one's national boundaries suggest what is educationally possible. The field of comparative education exists to examine these possibilities. (p. 7)

In other words, it is well known that there are important limitations with any international, or indeed domestic, large scale comparison. The task and the trick, however, is to not get stuck on all the various reasons why such comparisons are problematic, but rather to ask ourselves in reasonable ways, what can be learned from others, just as we would do for other fields of endeavor. For example, both Leung (2014) and Buckingham (2012) have observed that high-performing countries on PISA and TIMSS typically value education highly and invest heavily in teacher education and professional development. In addition, as a cultural value, many of the high-performing countries stress the importance of personal effort, rather than an assumed ability, in order to succeed. Is there something of value to be learned here?

The extent to which countries are 'high-performing' can be assessed in other ways, which are also quite problematic. Other possibilities include comparisons of national performance on the International Mathematical Olympiad, or on comparisons of national success at the highest levels of scholarship in mathematics, notably the Fields Medal for young mathematicians (less than 40 years of age) or the Abel Prize for Mathematics.

The connections between these measures and schooling for ‘typical’ students at the end of secondary school are unlikely to be persuasive, however. In the first place, success at the International Mathematical Olympiads is generally a result of exceptional talent, nurtured by special programs to support an extremely small elite group of young students to engage in high level mathematical thinking of the kind needed to address the questions asked. Questions are typically concerned with pure mathematics, with standards of mathematical reasoning well beyond standard high school curricula and likely to prove significantly difficult for many mathematics undergraduates. In addition, in the present context, no technology such as computers or calculators (including CAS-calculators) is used in Olympiads and hence in the Olympiad training programs conducted. For these reasons, it seems unwise to make links between the use of technology in schools with the extent to which a particular country performs highly on such a measure.

Similarly, links between the elite measures of high performance are problematic, not the least of reasons for which are that award winners are designated as being associated with their working address rather than their birth and secondary schooling address. Good examples are Terence Tao, born and raised in Australia, but listed as a US winner in 2006, because of his affiliation with UCLA in the USA and Maryam Mirzakhani, born and raised in Iran, but also listed as a US winner in 2014, because of her affiliation with Stanford University in the USA (Wikipedia, 2015). In any event, such exceptional people rarely undergo ‘normal’ schooling and it would seem unwise to use such comparisons for the present purpose. Notwithstanding these sorts of reservations, it is still of interest to compare approaches to the use of technology in mathematics education in various countries, including ‘high-performing’ countries, in part to determine the direction of curricular and instructional practices and philosophies elsewhere, but perhaps not with the intention of expecting that these practices *alone* are substantial contributors to a country’s status on a high-performing checklist.

A good summary of developments in the use of CAS in school mathematics up to 2009 in various countries was compiled by Leigh-Lancaster (2009) and hosted online on the international site of the organization, Computer Algebra in Mathematics Education. This summary demonstrated a range of practices at that time regarding the use of CAS in examinations (as well as a range of practices in examinations generally). Countries actively expecting or permitting CAS use in some school examinations towards the end of the school years included Scandinavian countries (Denmark, Norway and Sweden), other European countries (France, Austria and Switzerland), the USA (Advanced Placement examinations in Calculus and Statistics), New Zealand and Canada (Ontario). In some cases, the use of CAS was recognised because schools or other smaller divisions than the whole country, made their own decisions regarding assessment, rather than assessment being conducted externally.

In some countries, the use of CAS is regarded as appropriate in courses at high levels, but not at lower levels. New Zealand is a good case in point, with the New Zealand Qualifications Authority (2015) publishing a list of approved scientific and graphics calculators for use in all mathematics examinations, and a separate addendum to the list with nominated CAS-calculators permitted for some specified courses at the highest levels. All calculators used in examinations are required to be reset to their default states, and teachers or examination supervisors permitted to check and reset calculators brought to the examinations.

Other countries not listed in Leigh-Lancaster's table have since adopted some use of CAS calculators in school examinations. A good example is Finland, which recently permitted the use of CAS calculators in matriculation examinations in mathematics, but which will change the mathematics examination structure in 2016 to also include a component without technology, in addition to the two components for which a CAS calculator is permitted (and expected). An additional and significant change has been flagged, however, to digitalise the matriculation examinations (in all subjects, not only mathematics) starting in 2016. The mathematics examinations will be the last ones to undergo this transformation, scheduled for 2019. Students will undertake mathematics examinations with their own devices, which will include specified CAS software (such as that presently available on hand-held devices), but will prohibit access to personal data or to the Internet. Examinations will be entirely digital, with student scripts saved to Ministry of Education servers via the Internet connection at their school (Palovaara, 2014).

Finer details of the new Finnish computer-based arrangements are not yet available (and little information is likely to be available in English), and sample examination papers have not been published. It seems that students will use their own computers (with the assistance of schools when they do not have a personal computer), and will be responsible for equipping it with appropriate software in the case of in-school examinations. The external examinations will apparently take place online via a process that will prevent students from accessing their own software or the Internet (except for material directly related to the examination paper itself). Students will generally purchase their own CAS calculators and would typically purchase (in addition to the hand-held device) computer versions of the relevant emulator software for use on their computers (Heiskanen, 2015).

It appears that the Finnish examination process from 2019 will provide students with access to substantial software online, standardised to provide each student with access to the same resources. This suite of available resources for mathematics is not yet finally determined, but it is already clear that it will include software versions of major CAS calculators (such as CASIO *Classpad* and *TI-Nspire*), *GeoGebra*, a spreadsheet, and document production software for word processing (such as *Free Office*) and image processing (such as *GIMP*). These resources will be provided and maintained by the examination authorities. It seems likely, but it has also not yet been determined, that students will be permitted to take their CAS calculators with them to the examination, presumably to use together with the relevant emulation software, should they find that more convenient. In the online examinations, students will be expected to construct their answers in extended responses, making use of the CAS and other software where appropriate, rather than selecting answers, as in a multiple-choice test; once they have finished, their constructed responses will be automatically uploaded to the Matriculation Examinations Board for marking, using mechanisms that are not yet clear. (Heiskanen, 2015). Importantly for this review, it seems that the change to online assessment will continue to make substantial use of the CAS calculator capabilities presently used by Finnish students.

In the United States of America, external assessment of upper secondary school mathematics is mostly conducted on a national level, rather than a state level. For the present purpose, three kinds of examinations are relevant. The Scholastic Aptitude Test (SAT) and the American College Test (ACT) have been widely used for many years by universities as part of a tertiary entrance process, assessing aspects of readiness for college study, and are significant for students seeking financial support or scholarships. Different universities make use of these tests, so it is not unusual for students to take both, depending on their intended college preferences. The ACT measures achievement related to high school curricula, such as Mathematics, while the SAT measures general verbal and quantitative reasoning. The College Board's Mathematics achievement tests (at two levels) are used by some universities to help students choose undergraduate courses appropriate to their backgrounds. There are also Advanced Placement courses, also conducted by the College Board, which allow students who are successful in the corresponding examinations to received credit in the form of advanced standing in many universities for successful high-level studies in calculus and statistics courses conducted in schools; in addition, high-level performance is taken into account by universities making decisions about financial support and scholarships.

For the present purpose, the Advanced Placement courses are those most similar to the more sophisticated mathematics courses in Australian upper secondary schools, which routinely address many aspects of calculus. The Advanced Placement courses have encouraged and permitted the use of sophisticated calculators, including graphics calculators, for more than two decades now, and have regularly updated their calculator examination policy to include new technologies over that time. The College Board has been concerned that students have extensive access to suitable technology over the course of their studies and reflects that concern in its requirements for calculator use on the associated examinations. There are two aspects to this concern. In the first place, the Board requires students to have access to a *minimal* level of technology, reflected with the requirement that students' calculators are able to:

- Plot the graph of a function within an arbitrary viewing window
- Find the zeros of functions (solve equations numerically)
- Numerically calculate the derivative of a function
- Numerically calculate the value of a definite integral (College Board, 2015b)

In addition, students are not permitted to bring a non-graphing scientific calculator into the examinations with them (as this would clearly fall below the first minimum specification above). The College Board policy includes a published list of acceptable calculators, noting explicitly those that exceed the minimum mathematical requirements (College Board, 2015b). This list presently includes and thus sanctions the use of calculators with CAS capabilities from all three of the major manufacturers (CASIO, Hewlett-Packard and Texas Instruments).

The second concern of the College Board is that technology not be used to threaten test security in any way, so the policy prohibits the use of computers and those calculators with Internet or Bluetooth capabilities or with a capacity to record or reproduce text efficiently (such as a QWERTY keyboard – hardwired or virtual - or a stylus operation). The following statement makes this concern explicit:

> Calculator memories will not be cleared. Students are allowed to bring to the exam calculators containing whatever programs they want. Students must not use calculator memories to take test materials out of the room. Students that attempt to remove test materials from the room by any method will have their exam grades invalidated. (College Board, 2015b)

Part of the rationale of not clearing memories is to ensure that students with relatively unsophisticated calculators can install a suitable calculator program to increase the calculator capability.

Perusal of the list of approved calculators makes it clear that the use of CAS is regarded as an acceptable part of mathematics at this level, provided test security is not compromised. For example, the Texas Instruments TI-92 calculator, which includes a QWERTY keyboard and substantial CAS capabilities was first made available commercially in the mid-1990s, is not approved for examination use; however, the same company's TI-89 CAS calculator that has essentially the same mathematical capabilities, but without a QWERTY keyboard, is approved for examination use. The College Board table notes that those students with a Sharp EL-9600 calculator (which can be operated by a stylus) is approved, but students are not permitted to bring the stylus with them to the examination. Other modern devices, such as the CASIO *ClassPad* series are not approved, as they are both stylus-driven and include (virtual) QWERTY keyboards. It is notable that calculators without a QWERTY keyboard (such as a TI-89 or a *TI-Nspire*) can still be used to generate text in the examination, but somewhat less efficiently than those with a keyboard, and hence are regarded as acceptable for examination use.

While students are expected to make appropriate use of the technology (including CAS calculators) in Advanced Placement examinations, they are required to provide suitable reasons and methods for their mathematical conclusions, rather than merely relying on reproducing calculations from a screen. In addition, some parts of the examination papers are technology-free, in both multiple-choice and free response sections, requiring students to demonstrate that they have adequate competence without calculator use. Other Advanced Placement courses, such as those for Statistics and for various Sciences, have similar requirements for calculators, and routinely refer to the same calculus-based calculator policy, with suitable additional advice relating to the specific courses. Essentially, however, the use of CAS-calculators is permitted in all of these Advanced Placement courses in the USA.

The requirements for calculator use on the less sophisticated national Mathematics examinations conducted by the College Board are similar to those for the Advanced Placement examinations, and the similar list of approved calculators, with similar exclusions, is published and routinely updated (College Board, 2015a). Thus, this list also includes most modern calculators that have CAS capabilities, and excludes those with QWERTY keyboards and stylus operation. Although students are permitted either a scientific or graphics calculator, they are advised to use a graphics calculator instead of a scientific calculator for Mathematics. In the case of the SAT, students can also use a scientific or graphics calculator in the Mathematics section, but are not advised whether one of these is preferred. Significantly, College Board subject tests other than those for Mathematics (such as those in the science disciplines) do not presently permit students to use graphics calculators.

The widely-used American College Test (ACT) for Mathematics similarly has a set of calculator policies, which make it clear that both scientific and graphics calculators are approved for use in examinations, although students are not permitted to use a calculator with inbuilt or downloaded CAS functionalities. Consequently, examples of prohibited calculators are listed by the American College Testing Program (2015a). In a separate section, further detail is provided regarding the CAS prohibitions, which also include a prohibition of a Press-To-Test facility that is available on some calculators to temporarily disable some calculator capabilities; calculators are only approved for use if the CAS elements have been removed altogether from the device (American College Testing Program 2015b).

In the present context, care is needed to interpret the US situation and compare it with local practices. In particular, the two major external college entrance tests (the SAT and the ACT) are typically taken by relatively young students, in their Junior Year of high school (i.e., in the eleventh grade), as part of a college admission process that generally takes a long time, so that the materials tested are generally not of a high level of mathematical sophistication and students are advised that it is not necessary to use a calculator to complete the tests. This is in stark contrast to the Advanced Placement examinations, which are at a significantly higher mathematical level, are taken by more experienced students and calculator accessibility and competence are regarded as essential.

In general terms, 'high-performing' Asian countries have been slower to integrate technologies into school Mathematics than have major western countries. For example, in both Japan and (South) Korea, senior secondary schooling is significantly affected by high-stakes assessments used for university entrance at the end of secondary school, and each country has a very significant out-of-school private coaching environment for students for that purpose. With fierce competition for limited places in the most highly regarded universities, the examinations exert a dominant influence on the experience of schooling. At present, it seems that the Japanese curriculum is most heavily influenced by pure mathematicians, and that routine use of technology by students is rare (Fujii, 2015). In the case of Korea, while the curriculum appears to encourage the use of technology for teaching and learning, Hew and Jeong (2013) have noted that the use of technology in senior secondary textbooks is generally at a relatively low level conceptual level, with teachers needing much more help to integrate the technology into teaching. The examinations do not permit the use of any forms of technology in both countries, so that it seems likely that there are limited incentives for teachers to help students use technology for learning.

In Taiwan, similarly, Mathematics curriculum in recent years has encouraged the use of various technologies in school, provided students have already learned the necessary mathematics. Thus calculators and computers are regarded as appropriate devices to save time, but only after students have learned how to understand the necessary calculations, graphing skills, statistics, etc. Anecdotally, there has been increasing use of technology in schools, particularly personal computers, *iPads* and smartphones (with mathematics apps on them), and of software such as *GeoGebra*, but evidence on the extent of use is not available. However, the official examinations at various levels (including in particular the tertiary entrance level), which exert a dominant influence on schools and society, prohibit the use of any technology except pen and paper (Tso, 2015). Similarly, within universities, while some teachers reportedly use software such as *Matlab* and *Maple* to support lectures and to design assignments and exams, it is rare for such software to be used by students in formal assessment (Tso, 2015). In describing the Taiwanese situation, Tso (2015) offered a personal view:

> As for external examinations, [university] entrance examinations in particular, the use of any kind of calculators during the examinations is forbidden. I believe the main reason for such policy is based on fairness. Two possible factors may impede the achievement of fairness if calculators are allowed during examinations, one is related to the device itself, and the other is related to the students' skill in using the device.
>
> Regarding the device, because there are nearly three hundred thousand students taking the entrance examinations at the same time each year in Taiwan, it would be difficult to control the devices being brought

> into the examination settings. When various types of devices with different functions are used during the examination, it would be nearly impossible to control the fairness of the examination.
>
> As for the students' skill in using the device, some argue that the students' proficiency of device usage may have an impact on their ability to answer the questions in the examination, which may deliver biased results that were caused by factors not relevant to the level of mathematics proficiency itself, and thus create a possible fairness problem.
>
> Fairness is a basic requirement and top priority demanded in external examinations in Taiwan, especially in the major entrance examinations. These major examinations also attract a great deal of attention from the society. Therefore, in order to guarantee fairness, it is important that students are tested on and only on their understanding, ability, and skills in mathematics, and any action against this concept would be prohibited, which is why calculators are forbidden in all external examinations.

Despite the strong influence of external examinations in Asian countries, it is clear that there are changes taking place in some Asian countries regarding technology use, often in a phased way. In Singapore, for example, graphics calculators were first permitted in tertiary entrance level examinations from 2002 to 2006 when students who sat for the Further Mathematics examinations at the advanced level (pre-university level, or Year 11 and 12) were allowed to use graphics calculators, provided they did not have CAS capabilities. Further Mathematics courses were intended for only the strongest students; students who took the next level courses, Mathematics, were not permitted to use graphics calculators in their examinations. In addition, Further Mathematics examinations were designed to be calculator neutral, so that students who did not use a graphics calculator would not be disadvantaged. Typically, students who studied Further Mathematics also studied the lower level Mathematics subject.

Following this initial implementation of graphics calculators, a revised Singapore mathematics curriculum for pre-university level students was implemented in 2006, and is still in use. Students now take either Higher 1 (H1) Mathematics or Higher 2 (H2) Mathematics, where H2 Mathematics is a subject taken by the majority of pre-university students while H1 Mathematics is taken by students who are less mathematically inclined. The use of graphics calculators is expected and assumed for both subjects in all assessments including national examinations. Unlike the original arrangement for Further Mathematics, examination papers are set with the assumption that candidates will have access to graphics calculators and are proficient in solving problems with the aid of graphics calculators under conditions of a timed examination. The use of CAS calculators continues to not be permitted in these examinations, however (Kissane, Ng & Springer, 2015). A further recent developmental change has been the inclusion of scientific calculators into the Singapore school curriculum from the final years of the primary school.

In European countries, there is a diversity of practices regarding the use of technology in curricula and in examinations. A good recent source of information is a review conducted for the International Baccalaureate Organisation (Drijvers, Monaghan, Thomas & Trouche, 2014). The IB courses in mathematics are not publicly available for scrutiny, but at present the senior level courses require students to make extensive use of a graphics calculator that does not have CAS capabilities, including use in some examinations. The review provides a useful summary of the state of affairs regarding the use of technology in the curricula of various countries, including England, the Netherlands and France. (An interesting aspect of this review is the inclusion of the official position, alongside commentary regarding the extent to which the official position reflects what is actually occurring in various countries, which is a clear indication that the questions of interest are in various states of transition, in addition to the well-known differences between official and implemented curricula).

While the situation in England is complicated by the existence of a number of different examination boards, and modularity of courses, it seems that for A-level examinations, used for tertiary entrance, students are permitted to use a graphics calculator or a scientific calculator, but not a CAS calculator, except for some examinations in Pure Mathematics, which do not permit the use of technology. The use of computers in examinations is generally prohibited (Drijvers et al, 2014, p.67). A significant and recent exception concerns a new examination managed by the Mathematics in Education and Industry (MEI) group, and which expects students to use a computer, with CAS software installed (particularly the *TI-Nspire*, but alternatives such as a *GeoGebra*, *Maple* and CASIO *Classpad* software are acceptable), along with *Autograph* and Microsoft *Excel* (Mathematics in Education and Industry, 2015). The MEI examination also permits students to have a graphics calculator, in addition to their computer.

In the Netherlands, final examinations for some time have permitted students to use specified graphics calculators, for which the memories are not cleared, but the use of CAS calculators is prohibited. Although other technologies are becoming available in schools, such as computers and tablets, the review team's assessment is that a conservative trend at present makes it unlikely that these will become more prominent in the near future, especially for assessment (Drijvers et al, 2014, pp.89-90).

Different practices have evolved in France, in which there is an increasing emphasis on ICT generally, reflected in Mathematics in particular (Drijvers et al, 2014, pp 74-76). At present CAS calculators are permitted for use in *baccalaureát* Mathematics examinations, as well as graphics and scientific calculators. Although there is a climate of change towards greater use of ICT evident, and official support of various kinds, it seems that changing the practices of schools and teachers is recognised as an unavoidably slower project that requires particular support and that the use of the calculators is restricted in practice to computational purposes (Drijvers et al, 2014, p. 72).

In Germany, the situation is different again, as (similar to Australia), there is a collection of sixteen independent states, each of which has its own curriculum and examinations structures, making it difficult to generalise. An early report (Fothe & Greefrath, 2007) indicated diverse approaches to the use of technology at that time to the *Abitur* examinations conducted independently in each state at the end of secondary school for tertiary entrance purposes. Thus, at that time, all but three of the states permitted students to use CAS calculators in examinations and many permitted the use of graphics calculators, which some regarded as obligatory. However, some states regarded only scientific calculators as obligatory. Considerable attention was also paid to the use of dynamic geometry software and spreadsheets in schools, although not in examinations. Since that time, there have been further changes in various directions, as individual states have engaged in experimentation, but with no single national picture emerging.

In summary, it seems reasonable to conclude that there is no clear consensus evident internationally on how to incorporate technology into secondary school mathematics, including all-important examinations in mathematics at the end of the secondary school years. Nor is there a consensus view on the appropriateness, or otherwise, of the use of CAS at the school level. The situation is complicated by the rapid increase and penetration of digital technologies into societies, arguably at a faster rate than school systems, examination authorities or teachers can readily accommodate. Despite the lack of a consensus view, it seems reasonable to conclude that there is a general trend internationally to increase (rather than decrease) the extent to which the use of technology is recognised as an intrinsic part of school, as it is now an intrinsic part of society. Finding an achievable balance between changing too rapidly and changing too slowly, changing too little and changing too much, especially in diverse societies, is an ongoing struggle in most countries.

5. Australian use of technology in school mathematics education

Australian states are responsible for their own curriculum and its assessment. Consequently, a diversity of approaches has been taken in mathematics curricula for Years 11 and 12 as far as technology is concerned. Recent developments of senior secondary Australian Curriculum for Years 11-12 have increased the extent to which curricula are similar, at least in some ways, but the effects of examinations on curricula are such that significant differences exist, reflected in differing specifications regarding the use of technology in examinations.

Senior mathematics curricula in Australian states and territories are now potentially informed by the Australian Senior Secondary Mathematics curriculum, although responsibility for the structure and organization of courses and the mechanisms for integration of national content and achievement standards remains a matter for the individual authorities. While some states and territories commenced implementation of integrated courses in 2014, others are still determining the nature and extent of integration (ACARA, 2015a). Given the jurisdictional differences in both the number and nature of mathematics courses for Years 11 and 12, it seems unlikely that there will be a uniform national approach in the near future.

Each of the four nationally developed senior secondary mathematics courses includes, as one of its stated aims, the development of the "capacity to choose and use technology appropriately and efficiently", although the particular technologies involved differ from course to course, and are not described in detail in documentation online. Thus, there is no direct reference to particular technologies such as CAS, computer software, graphics calculators or scientific calculators in the documentation, as decisions regarding these are left to individual authorities to determine.

The likely role and significance of technology differs from course to course, as might be expected. The four Australian Curriculum courses, *Specialist Mathematics*, *Mathematical Methods*, *General Mathematics* and *Essential Mathematics* all include the same statement acknowledging the role of technology:

> It is assumed that students will be taught the Senior Secondary Australian Curriculum: Mathematics subjects with an extensive range of technological applications and techniques. If appropriately used, these have the potential to enhance the teaching and learning of mathematics. However, students also need to continue to develop skills that do not depend on technology. The ability to be able to choose when or when not to use some form of technology and to be able to work flexibly with technology are important skills in these subjects. (ACARA, 2015b, paragraph 13)

In addition, the Achievement Standards include a reference to the use of technologies; at the highest level of A, a student:

> uses digital technologies effectively to graph, display and organise mathematical information to solve a range of routine and non-routine problems in a variety of contexts. (ACARA, 2015c)

(For the least sophisticated course, *Essential Mathematics*, the expectation for graphing above is omitted, however.) In addition to the specific course expectations, the General

Capability of ICT is to be addressed in senior secondary mathematics courses, as noted in the official descriptions online such as the following for *Mathematical Methods*:

> In the senior years students use ICT both to develop theoretical mathematical understanding and to apply mathematical knowledge to a range of problems. They use software aligned with areas of work and society with which they may be involved such as for statistical analysis, algorithm generation, data representation and manipulation, and complex calculation. They use digital tools to make connections between mathematical theory, practice and application; for example, to use data, to address problems, and to operate systems in authentic situations. (ACARA, 2015d, paragraph 4)

The process of revising senior secondary courses with a view to integrating aspects of the national courses is still underway in various jurisdictions. However, the present courses in different jurisdictions offer insight into the ways in which technologies have been incorporated, and in which CAS in particular is regarded. Some illustrations of points on a spectrum of technology emphasis in senior secondary mathematics are outlined below.

5.1 Western Australia

The existing suite of senior mathematics courses in Western Australia is offered for the final time (as Year 12 courses only) in 2015, with a new suite of courses being introduced (starting in Year 11) in 2015. The existing suite of courses began in 2009 and was first examined in 2010. Units within the Mathematics course are offered in a series of three stages of increasing sophistication, while units in the Mathematics Specialist course are all at Stage 3; students undertaking Mathematics Specialist units also undertake companion Mathematics units at Stage 3. Students undertake external examinations at various levels, depending on which sequence of units they have undertaken. For ATAR purposes, only students in Stages 2 and 3 undertake external examinations.

Prior to the existing suite of units, from 1997 until 2009, students had chosen one or two of a set of three Mathematics units in Year 11 and then one or two of a set of three Year 12 Mathematics units with different content and sophistication. All sequences of courses over Years 11 and 12 were expected to involve consistent use of technology, which was assumed to comprise minimally the regular use of a suitable graphics calculator. Consequently, coherent with the design of the courses, examinations were conducted under the expectation that students would have access to a suitable graphics calculator (and a scientific calculator if desired). Only graphics calculators that did not have CAS capabilities were acceptable in the examinations. A suite of calculator models was publicised and maintained to make explicit which calculator models were acceptable. Students were not obliged to clear calculator memories for the examinations.

When the existing courses were being developed, a consultative process with schools was undertaken. One part of the consultation was with respect to the level of technology that would be assumed to be available to students in the courses, and consequently also in the examinations. An explicit ballot of schools was undertaken regarding the use of CAS in the courses, and thus in the associated examinations. The majority opinion was that a change from graphics calculators to more sophisticated technology that also included CAS was appropriate and the courses were accordingly designed on that assumption. Apart from a change in the level of acceptable technology, the courses included an associated change to include two separately timed components in the external examinations, one of which was to be calculator-free, and the other calculator assumed, in the ratio of 1:2. Thus, since the examinations for the existing courses in 2010, CAS has been routinely used in senior secondary Mathematics and Specialist Mathematics ATAR courses at Stage 3 and at most of the courses at Stage 2. The exception has been courses at the lowest levels of Stage 2 (that is Mathematics 2A and 2B), which do not involve any study of calculus and for which a graphics calculator has been regarded as sufficient and assumed to be available to students in examinations (although a CAS calculator has been permitted, should students choose to use one.) Students have been permitted to take up to three CAS calculators, graphics calculators or scientific calculators into the exam room. They have not been required to clear memories of their calculators for examination purposes. Any brands or models of CAS calculators have been permitted for examination use.

From 2015, a new suite of six senior secondary courses has been developed, following consideration of student needs, existing courses and the nationally developed courses. Four of these courses have similar names and broadly similar content to the national courses, with the three most sophisticated courses (Mathematics Specialist, Mathematics Methods and Mathematics Applications) leading to ATAR scores. The new courses have begun in 2015 and these three courses will be examined in 2016 for the first time. As far as the use of technology is concerned, the new courses assume similar levels of technology throughout the teaching and learning processes, as for the existing suite of courses (which are phasing out and have been examined in 2015 for the last time). In brief, it is assumed that students will have access to and use a variety of technologies, with the use of CAS calculators still assumed in future examinations, as for the existing suite of courses. As for the existing courses, external examinations involve two separately timed components, one of which is calculator-free and the other of which is calculator-assumed. Also as previously, there are essentially no restrictions on calculator brands or models regarded as acceptable for examination purposes in the three ATAR mathematics courses.

It is of interest to note also that courses in areas other than mathematics do not permit either graphics calculators or CAS calculators to be used in external examinations, although a number of courses permit and expect students to have a scientific calculator available to them.

5.2 New South Wales

At one extreme of the spectrum of Australian jurisdictions regarding the use of technology in external assessment is the state of New South Wales, which expects schools and teachers and students to use computers and calculators for the sake of relevance and student interest but currently does not permit technology more powerful than a scientific calculator to be used in the Higher School Certificate (HSC) examinations. The Board regards the use of technology in teaching and learning as a matter of implementation for schools to decide, and observes that it has no role in making implementation strategies compulsory (Board of Studies NSW, 1997, p. 11). Teachers will make decisions based on the circumstances of their school and other factors. The HSC calculus-based courses, the most sophisticated Mathematics courses offered in NSW, are essentially the same as previous courses, first devised in the 1980s and renamed in the late 1990s for the revision of the HSC. The broad outcomes listed for the calculus-based courses (Board of Studies Teaching and Educational Standards NSW, 2015a) make no reference to technology of any kind, although there are some references within the course syllabuses themselves, including an aim of "An appreciation of appropriate uses of technology, including calculators and computers" (Board of Studies NSW, 1997, p. 7). In addition, when referring to the role of materials in learning mathematics, two implications are drawn regarding technology, neither of which can be interpreted as statements encouraging the use of technology in mathematics:

- The availability of technological equipment, such as calculators and computers, does not reduce the need for mathematical understanding or the need for competence.
- Some concepts and skills will need to receive greater emphasis with the introduction of calculators and computers, e.g. place value and decimal concepts; skills of approximation and estimation. (Board of Studies NSW, 1997, p. 8)

In considering NSW, it should be noted that the calculus-based courses underwent a substantial process of revision, resulting in a new suite of courses subsequently endorsed by the NSW Board of Studies in 2009. However, these courses were not implemented, because of the impending Australian Curriculum in the senior secondary years, as a result of national work by ACARA. The course development process did not reach the point of detailing technology requirements for the associated HSC examinations (Osland, 2015).

The capabilities of the calculators currently permitted for examination use are specified by the Board of Studies Teaching and Educational Standards NSW (2015b), through a process of designating some models as approved for examination use and identifying a substantial list of features of calculator use prohibited for examination purposes. Typically, the models approved have minimal capabilities, so that many scientific calculators in manufacture today and available for purchase in Australia or overseas are not permitted for examination use, as they would exceed the permitted capabilities.

Until its most recent revision, one of the senior secondary school courses in NSW (*General Mathematics*) permitted the use of graphics calculators in HSC examinations, but this permission was recently removed; the course concerned was relatively unsophisticated, mathematically speaking, compared with the NSW mathematics calculus-based courses, and the features offered by graphics calculators were not expected for examination use or for regular classroom experiences. In addition, feedback from schools and teachers indicated that a range of technology platforms other than graphics calculators was being used within this course (Osland, 2015). In the revised courses (New South Wales Board of Studies Teaching and Educational Standards, 2015c), it is noted that technology is an important part of learning, but decisions are made by teachers regarding the details of technologies:

> The appropriateness, viability and level of use of different types of technology in the learning and teaching of courses within the Mathematics Key Learning Area are decisions for students, teachers and schools. However, the use of technology is encouraged in the learning and teaching, and school-based assessment, where appropriate, of courses within the learning area. … The courses provide a range of opportunities for the use of calculators and computer software packages in learning and teaching. This includes opportunities to utilise the graphing functions and financial and statistical capabilities of calculators, spreadsheets, and dynamic geometry and statistics software packages. (p. 16)

The current NSW senior Mathematics calculus-based courses are notably different from those in other Australian states in that they do not include significant study of statistics and they do include significant study of formal geometry (which was frequently diminished in significance in other states over recent decades to make space for statistical studies, regarded with increasing importance). As statistics is an aspect of mathematics for which technology is universally regarded as essential, and geometry is an aspect of mathematics for which technology support has only recently been available to school mathematics, it is possible that the current nature of the NSW curriculum has given rise to less interest in technologies, such as graphics calculators, that have been very well received in other states. Given that the use of graphics calculators is currently prohibited for examination use in NSW, however, it is of no surprise that there is no specific reference to computer algebra or CAS in any of its curriculum documents.

NSW teachers are less likely to have personal knowledge of sophisticated calculators in school mathematics, as their use is optional in the curriculum and prohibited in the HSC examinations. However, a recent survey of more than 1000 secondary mathematics teachers conducted by the Mathematical Association of New South Wales (2013) found considerable support for a change to the assessment requirements regarding calculators:

> In what appears to be a significant shift in opinion among the mathematics education community, there is now clear support for incorporating technology into the HSC Examinations. It should be noted that 20% of respondents have experience teaching mathematics in a jurisdiction where students are permitted to use handheld technology beyond a scientific calculator. (p. 17)

While 53% of respondents supported a change to include more sophisticated calculators in examinations, only 16% disagreed. The substantial group of neutral respondents (31%) is presumably mostly explained by inexperience with the technologies concerned. Elsewhere (2013, p. 24), the report noted that there would be a good case for examinations with and without technology to be considered in NSW, as in other states, and drew attention to issues regarding the use of CAS.

5.3 South Australia

In contrast to the NSW Higher School Certificate, the South Australian Certificate of Education (SACE) has permitted and expected electronic technology (including graphics calculators in particular) to be used in external Mathematics examinations since 2001, and the SACE Board issues regular advice on the specifications that must be met by the calculators, as well as suggested models that meet those specifications. Scientific calculators of any kind are permitted, but CAS calculators are specifically prohibited from examination use. The memory of graphics calculators is not required to be cleared for examination use (but the memory is not to be used to install a CAS), although the memory of scientific calculators has been required to be cleared (SACE Board of South Australia, 2015a).

These provisions have recently been reconsidered, with a new suite of four senior Mathematics courses undergoing an online consultative process with teachers, with a view to implementation in Year 11 from 2016. The four proposed courses all include provisions for an external examination that contributes 30% of students' assessment, with the remaining 70% to be determined by school-based components. In the external examinations, graphics calculators (and scientific calculators) are expected to be used by students. As with the existing courses, detailed specifications are provided regarding these, and the use of CAS or an attached memory device, continues to be explicitly prohibited. Part of the consultation process with teachers involved the consideration of a two-part examination, in which one of the parts would be conducted without access to electronic technology. (At present, examinations are not divided in this way.) The proposed weighting of the two parts differed a little between the various courses and was part of the consultation process.

The proposals for the new courses arise in part from the work of a large reference group, including representatives from schools, universities and elsewhere, so that the role of technology (including prohibitions regarding CAS in particular) can be regarded as a consensus position of this group, and there is no appetite evident for including CAS in the near future (Mercurio, 2015). The new courses no longer refer to a requirement for the memory of scientific calculators to be cleared.

Interestingly, the SACE Board has permitted the use of computers as an alternative to graphics calculators for Mathematics, since the introduction of graphics calculators into the external examinations, with various conditions exercised to limit the software accessed and ensure that the examination room does not permit students see the work of other students. Internet access and hard-drive access are effectively disabled. However, very few schools have taken advantage of this provision, which is regarded as too problematic in practical terms at the school level (Mercurio, 2015).

Both the existing and the proposed new SACE courses emphasise the need for students to "make discerning use of electronic technology", and substantial corresponding advice is offered to teachers regarding the use of technology for teaching and learning purposes. In making links between school and work, a qualified recognition of the place of technology is made: "Although the use of information technology has changed the nature of the mathematical skills required, it has not reduced the need for mathematics." (SACE Board of South Australia, 2015b p.4). The learning requirements for *Mathematical Methods*, for example, include an expectation that students will "make informed and critical use of electronic technology to provide numerical results and graphical representations" (SACE Board of South Australia, 2015b p.7). It is clear from this statement, and elsewhere in the specifications for electronic technology, that access to CAS is not regarded as an appropriate component of the electronic technology to be used by students in external assessment.

The proposed new courses describe in some detail the school-based components of assessment, which include investigation tasks in each of the three most sophisticated courses (and practical reports in *Essential Mathematics*, the least sophisticated course). These tasks are worth 20% of the overall mark in *Specialist Mathematics* and *Mathematical Methods*, and 25% in *General Mathematics*. The descriptions of these tasks are broad, and decisions about suitable tasks are made at the school level; however, the proposed courses indicate that students are encouraged to use a variety of mathematical and other software (e.g., computer algebra systems, spreadsheets, statistical packages) to enhance their investigation and evidence of technological skill is regarded as an important consideration (Mercurio, 2015). The appropriate technology used for an investigation would depend of course on the details of the investigation itself, but it is clear that the use of CAS is not prohibited in these tasks, where it is relevant and available, although it is not permitted for use in the external examinations setting, and there is no apparent appetite to change this. It seems likely that the extent to which CAS is used, if at all, will depend in large part on available school facilities and teacher preferences.

The consultation process, around the middle of 2015, revealed that many teachers in SA were uneasy about a change towards having an examination with and without the use of technology, as they were unconvinced that this would advance the aim of developing student discernment in the use of calculating devices. Other teachers were uneasy about the proposal for different reasons, including uncertainties regarding what would be assessed with and without calculators. As a consequence, a decision was made to continue with the previous practices of permitting the use of graphics calculators (and scientific calculators) in external mathematics examinations. However, one of the six 'skills and applications tasks' for the school assessment component (worth 70% of the total in SA) will now be done without the use of calculators. The Mathematics Learning Area Group was strong in their belief that students should be trained with and without calculators; that what is being tested was not 'mere calculations' but the basis for mathematical thinking (Mercurio, 2015).

5.4 Victoria

At the other extreme from NSW is the state of Victoria, which has permitted and broadened the use of CAS calculators in the Victorian Certificate of Education (VCE) examinations for almost a decade and which has recently begun to experiment with the use of computers in some mathematics examinations. The present situation is similar to that in Western Australia, in which a choice from a range of specified graphics CAS calculators are expected to be used by most students in both classroom experience and assessment, including external examinations. Further, students are expected to access the full range of capabilities of calculators, so there is no requirement for memories to be cleared for examination purposes. In addition, however, some early work is being done in some pilot schools involving students using CAS software on computers, as an alternative to CAS calculators (Victorian Certificate of Education, 2015a). This work is consistent with the provision of a license to all government schools in Victoria to use *Mathematica* and *Wolfram Alpha*, related software packages with very sophisticated CAS capabilities. Section 9 of this report also refers briefly to this pilot work.

The Victorian experience suggests that in the wider community, both private and government organisations generally expect employees to make use of mathematically capable software wherever it is appropriate, which has in part motivated the continued development of the use of CAS and other software in schools (Leigh-Lancaster, 2015). In that vein, the recently released Study Design for VCE mathematics courses for 2016-2108 makes it clear that technology is expected to be part of the mathematical experience and also part of the assessment environment for students at all levels, with the inclusion in each unit of the broad statement, "The use of numerical, graphical, geometric, symbolic and statistical functionality of technology for teaching and learning mathematics, for working mathematically, and in related assessment, is to be incorporated through each unit as applicable" rather than with precise details of which particular device (such as calculator models or CAS functionalities) might be used to provide appropriate technology for students (Victorian Curriculum and Assessment Authority, 2015b, p. 12). In that sense, the advice is intended to be 'platform-agnostic'. In addition, to develop and maintain an environment for learning and for mathematical activity that is more natural and less artificial, and appropriate to typical 21st century working environments, students are permitted to take a 'bound reference' to the technology-permitted examination with them, in the form of a textbook or lecture pad with their own annotations (Leigh-Lancaster, 2015). As for Western Australia, courses also include a technology-free examination, as reassurance that students can demonstrate appropriate mathematical achievement without either technology or notes for support.

The use of technology to support symbolic work is made explicit and prominent in the outcomes for the new Victorian courses. For all courses beyond the most elementary, one of only three course outcomes refers explicitly to the use of a suite of mathematically relevant technologies (Victorian Certificate of Education, 2015b):

> Outcome 3: On completion of this unit the student should be able to select and use numerical, graphical, symbolic and statistical functionalities of technology to develop mathematical ideas, produce results and carry out analysis in situations requiring problem-solving, modelling or investigative techniques or approaches. (p. 29)

The elaborations of key knowledge and skills associated with this outcome make it clear that the appropriate use of symbolic representations with technology is a routine and pervasive part of senior secondary mathematics courses, without naming the technology (as CAS) or identifying the platform (such as a hand-held device or computer software).

5.5 Queensland

Unlike the other states, for many years Queensland has not used an external examination to accredit mathematics achievement at the end of year 12 for tertiary entrance purposes. Instead, a process of state-wide school-based moderation has been used, managed by the Queensland Curriculum and Assessment Authority (QCAA, 2015a). Schools are responsible for their own assessment procedures, which are expected to provide credible evidence against the standards associated with each course. The procedures are defended in a series of school moderation activities, which ensure that comparability between schools is maintained. These processes allow schools to make independent decisions regarding the use of technology that align with the various course expectations as well as the preferences of individual schools and their communities, in contrast to other states, where decisions regarding the use of technology are generally heavily influenced by the details of examination requirements at the end of secondary school. Queensland students receive an OP (Overall Position) score, which is used for tertiary entrance purposes, following a scaling process undertaken by the QCAA, using school-based assessment information and a state-wide Queensland Core Skills test.

At present, as far as technology is concerned, a minimum course requirement for students in the two stronger mathematics courses in Queensland, Mathematics B and Mathematics C, is regular access to and frequent use of a graphics calculator, while the lowest level course, Mathematics A requires only a scientific calculator to be included. Although schools are responsible for their own programmes of teaching and assessment, the use of technology in assessment is not regarded as optional in QCAA courses. For example, the syllabus for Mathematics C (QCAA, 2014) identifies the use of technology as a key competency and notes:

> A range of technological tools must be used in the learning and assessment experiences offered in this course. This ranges from pen and paper, measuring instruments and tables, through to higher technologies such as computers and graphing calculators, including those that allow for algebraic manipulations. The minimum level of higher technology appropriate for the teaching of this course is a graphing calculator. (p. 6)

In describing the place of technology in the course, the syllabus further notes:

> The minimum level of higher technology appropriate for the teaching of this course is a graphing calculator. While student ownership of graphing calculators is not a requirement, *regular and frequent student access* to appropriate technology is necessary to enable students to develop the full range of skills required for successful problem solving during their course of study. Use of graphing calculators or computers will significantly enhance the learning outcomes of this syllabus. (p. 8)

Alternatives to calculators are encouraged, depending on the preferences and circumstances of individual schools. The Mathematics C syllabus allows schools to choose whether or not to use CAS versions of graphics calculators:

> To meet the requirements of this syllabus, schools should consider the use of:
> - general purpose computer software that can be used for mathematics teaching and learning, e.g. spreadsheeting software
> - computer software designed for mathematics teaching and learning, e.g. dynamic graphing software, dynamic geometry software
> - hand held (calculator) technologies designed for mathematics teaching and learning, e.g. graphics calculators with and without algebraic manipulation or dynamic geometry facilities. (p. 9)

Both the Mathematics B and Mathematics C syllabuses (each of which includes calculus studies) have similar technology expectations and suggestions, which provide a requirement for graphics calculators to be integrated into the courses, and for the possibility of CAS calculator use, while the Mathematics A syllabus has less sophisticated expectations.

The major structural element in the moderation processes used for assessment in Queensland is the Standards outlined by the syllabuses. Each of the syllabuses makes explicit reference in its standards to the selection and use of technology by students, so that assessment procedures at schools will be regarded as unacceptable unless they provide suitable evidence regarding that standard. Schools are reminded of the need for a suitable balance in syllabuses, such as the reminder in the case of Mathematics C:

> Complete dependence on calculator and computer technologies at the expense of students demonstrating algebraic facility may not satisfy syllabus requirements for *Knowledge and procedures.* (p. 9)

The assessment requirements in Queensland do not prevent schools from using forms of technology other than calculators in assessing subjects like Mathematics B and Mathematics C. Yet it seems that the technology used in practice is either a graphics calculator or a CAS calculator. Even schools in which students have good access to computers and tablets for learning purposes do not make use of them for assessment purposes, as it is regarded as too difficult to avoid security and comparability issues associated with Internet access (Wethereld, 2015).

Although the overwhelming majority of students in Queensland receive QCAA assessments via the schools-based moderation processes, it should also be noted for completeness that a small number of students undertake QCAA-administered examinations in both Mathematics B and Mathematics A (but not in Mathematics C). These are typically students who are not associated with a school, including adults studying externally (QCAA, 2015b).

The courses are similar to those offered in schools, so that the minimum requirement for technology in Mathematics B is a graphics calculator, as for the regular course. The examinations for Mathematics B allow and expect students to use a graphics calculator, but prohibit the use of a CAS calculator.

At present, there are expectations that senior school assessment in Queensland will change in the next few years, to include an external examination process, following a recent review and Ministerial decision (QCAA, 2015c). A series of examination trials for some aspects of five selected subjects will be conducted in 2016 and it is expected that a system of external examinations will be in place for students starting year 11 in 2018 and completing their studies in 2019. Details for the trials were recently announced (QCAA, 2015d). In the trial examination in 2016 for (Year 11) Mathematics B, students will be expected to use an approved graphics calculator, but not a CAS calculator, similar to the present arrangements for external examinations for Mathematics B. In addition, calculator memories are to be cleared of add-in applications or programs prior to the exam; calculators will be checked by exam supervisors. Of further interest is the use of online delivery and response for two of the trial examinations (in Geography and Modern History, but not Mathematics B). In addition, candidates will be permitted to use a similar calculator to that approved for Mathematics B in the trial examinations in each of Geography and Chemistry, with the same conditions of clearing memories in place.

5.6 Summary

Overall, these brief descriptions of the curriculum practices regarding technology use in senior secondary school mathematics in various Australian states, as for the earlier descriptions of practices internationally, highlight the lack of a consensus view on some key issues. Furthermore, it seems clear that changing circumstances regarding the availability of technology in schools, and more widely, make it unlikely that a national consensus will emerge in the near future. While the national curriculum work related to mathematics will have an effect on both the nature and content of senior secondary courses in each jurisdiction, jurisdictional differences seem likely to persist, at least for the next few years. These differences are manifested in a number of ways with respect to technology expectations for external examinations, including the acceptability (or otherwise) of CAS and graphics capabilities on calculators, the use (or otherwise) of a technology-free component, requirements (or a lack of them) to clear calculator memories, restrictions on the number and nature of calculators, provisions for students to take supporting materials into examinations, and recently the possibility of examinations being conducted on computers equipped with powerful mathematical software. In addition to differences in examinations, jurisdictions differ in the extent to which school-based assessment is used to construct ATAR scores, and the mechanisms through which that assessment is constrained and moderated, including the extent to which (if at all) assessment incorporating the use of technology is expected and structured. Less evident from external scrutiny, but arguably no less significant, are jurisdictional practices for supporting classroom teachers to make effective use of the technologies regarded as acceptable for particular courses in the complex processes of teaching and learning, in addition to supporting their effective use in assessment, as well as encouraging teachers to adapt to continually changing technology circumstances and facilities in individual schools. While such diversity might be regarded as problematic, it ought not be regarded as surprising in the circumstances of rapid technological change that characterises Australian society in the early years of the 21st century.

6. Use of technology for mathematics in universities

6.1 Background

Australian universities are autonomous institutions, setting their own standards and practices, so that there is a diversity of approaches regarding the use of technology for learning mathematics. In general terms, it appears that decisions about the use of technology tend to be made at the individual unit level, rather than policies being decided across an institution or a department. There is also a diversity of kinds of undergraduate mathematics courses, sometimes in a range of faculties, which makes it difficult to see a bigger picture.

To access the use of technology for mathematics teaching, learning and assessment in Australian universities, Kemp (2012) surveyed mathematics departments at 38 Australian universities, and obtained responses from 28 of them; some of the responses were incomplete, unfortunately, and it needs to be recognised that many responses report individual rather than collective practices, as just noted. Kemp's survey asked about the technologies used by students for learning mathematics, and separately for statistics, and also sought information about the technology that was permitted for examination use. It was clear from the responses that calculators were a less prominent tool in universities than in schools, with about 30% of respondents reporting some use of graphics calculators (some with a CAS) in mathematics learning environments, while seven responses reported that graphics calculators were permitted in examinations. In 16 cases, students were permitted to use non-programmable calculators in their mathematics exams. In the case of undergraduate statistics, a little more use of graphics calculators was reported in units, but there was also a more pronounced use of statistical software as well.

Kemp, Kissane and Fletcher (2013) drew on these data (and further data from one university) to describe discontinuities experienced by students entering universities in Australia after a secondary school mathematics experience that involved considerable use of both graphics calculators and CAS calculators. They noted that few university staff reported extensive personal knowledge of graphics or CAS calculators, or claimed to use them regularly, so that part of the discontinuity observed might have been related to limited staff experience with technologies that are less powerful than those in regular professional use. It appeared that students who used graphics calculators, including CAS calculators, for learning purposes were more likely to be left to their own devices to do so than was the case in school, where it was more likely that most students had the same calculator, which was also used regularly by the teacher in class. In short, it seems that, even when the use of graphics calculators (including CAS calculators) is tolerated in either teaching or assessment in university Mathematics courses, integration of the technology into the unit concerned is mostly left to the students, not the teacher.

Kemp's survey of university mathematics departments and the university survey (of unit coordinators across a range of areas, not only mathematics) suggested that a common view was that calculators were significant only for computational purposes, and few volunteered the view that they might be helpful for student learning of mathematics. Although a suitable question was not explicitly asked, there did not seem to be a clear distinction made by staff between technology designed to support students *learning* mathematics and professional technology designed for professional users of mathematics for their *working* purposes; of necessity, undergraduate students are usually located somewhere between these two purposes. Nor was it clear that survey respondents had a good sense of the range of capabilities of typical modern calculators, such as those used by students in school. As an illustration, staff expressed unease about the storage of information in calculators, partly as a justification for the prohibitions on programmable calculators in examinations, yet few specific examples were offered of where this was likely to be problematic for assessment (Kemp, Kissane & Fletcher, 2013).

By comparison with Australia, the situation in the USA seems quite different. Given the assessment regimes used in the USA, such as the SAT Subject tests and the Advanced Placement examinations described earlier, it is not surprising that most mathematics students in the undergraduate years in the USA have a graphics calculator, and many have a version that includes a CAS capability. Consequently, many undergraduate mathematics courses, especially at the introductory levels, routinely include graphics calculators in both teaching and assessment practices. A recent (and continuing) project of the Mathematical Association of America entitled the *National Study of Calculus 1* is a useful source of information regarding this matter, based on work with a large sample of students from a range of institutions. In describing the place of graphics calculators and CAS, Bressoud (2013) distinguished institutions involved as ‘research’, ‘undergraduate’, ‘masters’ or ‘two-year’, depending on the highest degree in mathematics offered, noting some differences among these.

Bressoud noted that almost all *Calculus 1* students reported having using graphics calculators in school exams at least some of the time, while more than half of the students were allowed to use CAS-calculators at least some of the time, suggesting that about half of the students taking *Calculus 1* have had previous access to such calculators. In their study of *Calculus 1*, it seemed that around 20-30% of students were permitted to use a CAS calculator in college exams, with a higher percentage allowed to use graphics calculators in exams. It was noteworthy that graphics calculators were less prominent at the research universities than the other three categories (Bressoud, 2013).

When documenting instructor decisions regarding calculator use in *Calculus 1* exams, Bressoud noted large numbers of instructors who allow, but do not require graphics calculators in exams, and differences between institutional types. For example, at research universities, 26% of instructors require the use of some kind of technology, and a further 25% allow, but do not require the use of some sort of technology. The figures are generally smaller for the case of CAS calculators, and there is generally less acceptance of the use of technology at research universities than others. In summarizing a complex situation, Bressoud (2013) noted:

> We see a pattern of very heavy use of graphing calculators in high schools, driven no doubt by the fact that students are expected to use them for certain sections of the Advanced Placement Calculus exams. They are still the dominant technology at colleges and universities, but there the use is likely to be voluntary as required. This implies that in many colleges and universities, questions are posed in such a way that graphing calculators confer little or no advantage. The use of graphing calculators at the post-secondary level varies tremendously by type of institution. Yet even at the research universities, over half of the instructors allow the use of graphing calculators for at least some portion of their exams. (para. 13)

It is not clear from Bressoud's report as to the extent to which graphics calculators used have CAS capabilities, in part because the study also examined student use of other forms of CAS (on computers).

6.2 Technology use in Western Australian universities

In order to investigate the nature and extent of the use of CAS calculators and other hand-held technologies into university practices, informal meetings were arranged with relevant mathematics staff in the five local universities in Perth. While decisions about the use of technology in teaching and learning early undergraduate mathematics are typically made by individual unit coordinators, there is sufficient commonality amongst staff to allow pictures of typical practice to emerge, as summarised below.

6.2.1 Curtin University

First year mathematics units at Curtin University serve a range of audiences, and are regarded as a form of service teaching, rather than being restricted to mathematics and statistics majors. Many of the students are studying courses in Engineering or Business. Technology is regarded as an important part of the courses concerned, and recognised in Graduate Attribute statements. In some calculus-based units, students undertake a required series of workshops using *Maple* over the course of the year to become a little familiar with the concept of a computer algebra system. These workshops include an assessment component in the laboratories using the software. Similarly, in statistics units, students are expected to use computer software such as SPSS or SAS, in University laboratories, although these would not be typically used in assessment. Some units (such as actuarial units) may also use Microsoft *Excel*. Students are asked to interpret some computer output in some assessments, but not to actually use the software in the assessment.

Students are generally not permitted to use CAS calculators and graphics calculators brought from school for formal assessment purposes, such as tests and examinations. Assessments are usually crafted to minimise the need for computation, but students sometimes might need to have access to a scientific calculator for this purpose, although even then it is not regarded as necessary for a powerful scientific calculator to be used. Accordingly, at the start of their course, all students taking Mathematics units are issued by the University with an inexpensive scientific calculator with basic features for this purpose (Hewlett Packard HP-10S+), thus providing assurance of uniformity and calculator capabilities. Because the calculators are inexpensive, occasional problems with loss, malfunction or breakage are not significant.

A major concern of mathematics staff is for students to understand the mathematical ideas involved in units, so there is an emphasis on students completing by hand common procedures (such as evaluating a definite integral or solving an equation) and providing the associated reasoning, showing all necessary working. It is felt that a calculator that produces an answer too readily would undermine this encouragement to understand procedures. Similarly, a graphics calculator may not be a useful device for students who do not use it carefully to include all necessary parts of a graph on the screen (such as the apex of a parabola).

Calculators are interpreted entirely as instruments to obtain a numerical answer, and not regarded by staff as potential learning tools for students, so it seems unlikely that there is a reservoir of experience in the school at using sophisticated calculators for either teaching or learning purposes. So, decisions to not encourage or permit the use of graphics or CAS calculators were made consistent with staff concerns, rather than staff history. In addition to concerns about calculators undermining student learning, concerns had been expressed about potential misuse of calculator storage (e.g., to store notes), and potential inequities associated with some students having a calculator with more functionality than another. The prospect of conducting dual examinations (with and without technology) was regarded as impractical given the examination scheduling issues involved, although had not really been discussed at length, given the disinterest amongst staff towards calculators.

Instruction on efficient or effective (scientific) calculator use is not routinely provided to students, as this is mostly regarded as a matter for students themselves to deal with, should they wish. While some (very few) staff may have a personal graphics or CAS calculator, they would rarely use it and it would be most unlikely for it to be used in teaching situations. It seems unlikely that staff in the school would have significant expertise with CAS calculator use. It is noted that some textbooks used in this area often come from US publishers, and so routinely provide exercises and tasks for graphics calculator use, but these are not regarded as an important part of the units, and students are not directed to deal with them. In addition, there is a growing reluctance to assign textbooks for student purchase, in part because of their cost.

While coordinators generally have some level of authority to make decisions regarding the content of units, including any use of technology, in this case the decisions about calculator use were made by the Head of the Department. Staff members appear quite comfortable with the position taken, although there is a spectrum of opinion and practice evident, from "lenient" (in a statistics unit, where use of existing student graphics calculators in class – not for assessment – was regarded as an appropriate use of an available resource) to "strict" (in a calculus-based unit, where no use of calculators at all was permitted, and students were given a printed set of formulae, rather than being expected to construct their own). There has been some discussion in the School of Mathematics and Statistics about changing from an allocated calculator to the use of an approved list (as at UWA), but a decision on the matter has not yet been taken.

A wide range of students is involved, including recent school graduates, mature-age students and international students. While recent school graduates may have CAS calculators or graphics calculators, this is unlikely to be the case for either mature-age or international students. There does not seem to be significant concern or any signs of resentment amongst students about limited use of calculators brought from school, although it is not uncommon for some student unease to be expressed at the start of a new year (van Loosen, 2015).

6.2.2 Edith Cowan University

The bulk of the early undergraduate mathematics teaching at Edith Cowan University is service teaching for various departments at the University, and there are different practices in place for units focusing on statistics (e.g., those for the Health Sciences) and calculus-based units (such as those for Engineering).

In the case of first year statistics units, students are expected to become competent with SPSS, generally using campus licenses on campus computers. They undertake an assessment of their use of SPSS either in a campus laboratory or at home, and formal examinations generally include an expectation that they interpret SPSS printouts (although do not involve students using the software on a computer or tablet in the examination). In addition, students are permitted to use their graphics or CAS calculators, which generally have significant statistics functionality, in formal assessment, including examinations. Students are not expected to purchase calculators of these kinds if they do not already have one (which is the case for the considerable number of mature age and international students), but are free to use their existing calculator if they wish. It is generally expected that their calculator use will not confer an extra advantage over students who have a less powerful calculator, such as a scientific calculator. Students taking these courses are spread throughout the university, rather than being concentrated in the mathematics area, so the units are widely regarded as service teaching to meet general needs for statistics in other programs. Students in these courses have diverse backgrounds and interests. Teaching staff are generally unfamiliar with CAS or graphics calculators and hence are unlikely to be able to help students who need help.

The situation is different in the case of Engineering and other students taking calculus-based units in first year. Although unit coordinators generally make decisions for their own units, student use of calculators is discouraged generally in Engineering (which includes Mathematics courses, which are located in the School of Engineering), following a decision by the Head of School a few years ago. Some University staff (including some Physics and Engineering staff) had expressed concern about students using high-end CAS calculators to store notes and thus have an advantage over other students. It was easier not to use calculators at all than to deal with perceived problems of this kind. There was also some enthusiasm for adopting policies similar to those in use in Schools of Engineering at other local universities. As a result, teaching staff typically use software relevant to their field of expertise and teaching and rarely use CAS or graphics calculators. While students do not generally use technology in examinations, students enrolled in a mathematics major or a mathematics education major, and thus in small classes (e.g., *Timeseries Forecasting*) are sometimes required to use software like *SPSS* or *Excel* in exams.

Students taking calculus-based units in first year, including Engineering students, are generally not permitted to use either graphics or CAS calculators in formal assessments, but are mostly restricted to using one of four specified scientific calculators. The list of approved calculators is the responsibility of the Engineering School, but is likely to be adhered to for students in other schools as well; a small list is preferred, as it allows examination invigilation to be handled easily. One purpose of the list is to ensure that students have access to a calculator that has a minimal functionality. Efforts are made in assessments to not ask questions that would require more sophisticated computation than is readily accessible on the prescribed calculators; for example, small integers may be used in examples and a cubic function with integral factors would be preferred, to facilitate integration or root finding.

Calculators and computers play a very limited role in teaching (which is generally restricted to large group teaching for economic reasons), and mathematical software (such as graphing software) is not widely used in classes. Some first year classes include MATLAB® being used for demonstrations by the teacher in large group classes, but it is no longer possible to use this software in regular computer laboratory classes, because of a limited number of licenses available at the University. Students would not normally be offered systematic help in class in using their calculators, unless they sought help from a staff member. It seems clear that calculators are regarded by staff as devices whose purpose is restricted to answering computational questions, and are not regarded as devices that might help students learn mathematics or teachers teach mathematics.

The decision to disallow use of graphics calculators and CAS calculators is generally supported by staff, most of whom would not normally make use of such technologies themselves, and would be apprehensive about the significant course and assessment changes that would be required if the situation were to be changed. The staff has considered the position of the Engineering faculty on this matter, and is generally comfortable with it. The prospects for change would be further limited by the costs that would be needed for non-school leavers to acquire more sophisticated calculators. In some cases, this has dissuaded staff from continuing to use CAS calculators, as it has been too difficult to do so in a large group, that likely includes many who have not brought a calculator from school recently. At an earlier time, and with a smaller class, different arrangements could be made to use the calculators for teaching as well as assessment. More importantly perhaps, at the first year level, staff continues to be concerned for students to understand well the mathematical ideas involved at this level and to develop sufficient by-hand algebraic competence. Some staff perceive that observed students' weaknesses could be a consequence of the prior reliance on calculators; in fact, however, it appears anecdotally that similar weaknesses are evident when students have not been using graphics and CAS calculators.

After first year, it is more likely that students will engage with mathematical software in their studies; for example, students in their second year are expected to use MATLAB®, relying on University laboratory facilities and licenses. A few years ago, teaching in a linear algebra course routinely used CAS calculators, but this has become too difficult to do since class sizes became much larger (around 200 students) and it became too hard to attain uniformity of calculator access and use. It was not possible to mandate the purchase of a particular calculator and students used an assortment of calculators from their school experience. In addition, classes are quite heterogeneous in other senses, with a mixture of recent school graduates, mature age students and international students involved. While some operations (such as matrix reduction) are efficiently handled by calculators, it is not possible to guarantee that all students have access to a suitable calculator, and hence they have faded from student use, although they are still sometimes used by the teacher of a large class for demonstration purposes. Microsoft *Excel* is used in some courses, and it would usually be expected that students have personal access to this at home, as well as at university. However, students are not permitted to use a computer in their examinations, so it would not be expected that *Excel* would be used in exams. In general, there seems to be few significant complaints from Engineering students and other students in calculus-based courses who have brought CAS calculators or graphics calculators from recent school experience and been prevented from using them in assessments (Richardson, 2015).

6.2.3 Murdoch University

First year calculus-based and discrete mathematics units at Murdoch University serve a range of audiences, and are regarded as a form of service teaching, rather than being restricted to mathematics and statistics majors. While calculator technology might have been appropriate ten or so years ago, staff at Murdoch University have generally moved on, and have a greater focus on software likely to be expected of university graduates, such as *SPSS* or Microsoft *Excel*. Staff do not typically use a CAS calculator or graphics calculator themselves, are hence are not much interested in them, nor have much experience with them, but are more likely to use more sophisticated computer software relevant to mathematics.

Typically, students are permitted to use a scientific calculator in formal assessment (such as examinations), but other forms of technology are not used in examinations. Exams are written in such a way as to avoid a need for technology use, although it is a common practice for students to be expected to interpret technology outputs (such as *SPSS* statistics printouts) in exams, as evidence that they have developed competence with interpreting them and with associated mathematical ideas. Individual coordinators make their own decisions regarding the use of technology in their units, although commonly discuss their preferences informally with colleagues. Students are neither permitted nor encouraged to use CAS calculators and graphics calculators brought from school for formal assessment purposes, such as tests and examinations. They are expected and sometimes may need to have access to a scientific calculator in these situations, although it is not regarded as necessary for a powerful scientific calculator to be used. The most likely use of the calculator will be for arithmetical purposes, so students without a calculator are advised to buy an inexpensive model. In these circumstances, calculators would rarely be used in teaching, although some small group teaching takes place in computer laboratories, where computers and software are used. Students are not expected to purchase their own copies of the software, but are permitted to use University licensed versions on campus.

In general, there is a focus in first year units on students understanding mathematical ideas and reasoning; since calculators are mostly interpreted by staff as devices that produce 'answers', either numeric (in the case of graphics calculators) or symbolic (in the case of CAS calculators); they are regarded as not likely to be helpful for students to understand the mathematics involved. There is an emphasis on students completing by hand common procedures (such as evaluating a definite integral or solving an equation) and providing the associated reasoning, showing all necessary working. It is felt that a calculator that produces an answer too readily will undermine this encouragement to understand procedures. It is recognised that students with high-end calculators may make use of them at home (e.g., for checking), but they are still expected to develop expertise in showing all of their reasoning by hand.

Students are neither actively encouraged nor supported to use CAS or graphics calculators they may have brought from school. A wide range of students is involved, including recent school graduates, mature-age students and international students. While recent school graduates may have CAS calculators or graphics calculators, this is unlikely to be the case for either mature-age or international students, who would not routinely have had access to such devices. Instruction on efficient or effective CAS calculator use is not routinely provided to students, as this is regarded as a matter for students themselves to deal with, should they wish. While some staff members have a graphics calculator, they rarely use it and it would not be used in teaching situations. It is noted that the textbooks used in this area often come from US publishers, and so routinely provide exercises and tasks for calculator use, but these are not regarded as an important part of the units, and students are not directed to deal with them. Similarly, students are not assigned tasks that require graphics or CAS calculator use or encouraged to use them.

A persistent concern of teaching staff is that students often have limited algebraic skills, and it is thought to be unlikely that a CAS calculator would be helpful to improve these; indeed, it is thought more likely that such a calculator may encourage students to get the result without trying to understand its origins. As an illustration, staff would be uneasy about use of a calculator result that showed $\sqrt{12} = 2\sqrt{3}$ but did not show the intermediate steps. Some tasks on assignments are designed to discourage graphics calculator use (such as matrix multiplication when some matrix elements are variables, which would not be accessible to graphics calculators – although they would be within the capabilities of CAS calculators).

Previously, graphics calculators have been used in some Mathematics units, but changes were made a few years ago, partly in response to changed practices at the University regarding the specification of allowable calculator models. In the past, students have sometimes been seen to have a limited understanding of some aspects of mathematics, as a result of poor use of graphics calculators. For example, some students have thought that the graph of a cubic function might consist of three straight lines, and sketched it accordingly, presumably because of poor choice of scales for a graphics calculator. While this seems likely to be the result of poor use of the graphics calculator, and presumably ineffective instruction on using it well, students with graphics calculators have sometimes been thought to have gained little benefit from their earlier use, further discouraging staff from making use of them.

The situation in introductory statistics units is a little different. The principal first year statistics unit serves a range of audiences, with about 750 enrolments per year, almost all of whom are not mathematics and statistics majors. Hence this unit is an important part of the service teaching responsibilities of the Mathematics and Statistics area. In contrast to the calculus-based and discrete mathematics units, students are encouraged and permitted to use any calculator they already own, including CAS calculators and graphics calculators brought from school. This use extends to use in formal assessment, including end of semester examinations. The statistical capabilities of the calculators are regarded as useful for the content of first year statistics units, although insufficient for some purposes (such as handling large data sets or developing expertise with industry software like *SPSS*). CAS is not regarded as of particular significance, because it is not likely to impact upon the substantive content of statistics units at this level.

Students are expected to develop expertise with the statistical package *SPSS* in certain defined areas, and commonly expected to interpret *SPSS* output in formal assessments such as examinations. They are also expected to make use of Microsoft *Excel* for some purposes, typically with larger data sets. The University has site licenses for this software, with some small-group classes conducted in computer laboratories. Although many students purchase a 6-month license for *SPSS* software, which provides them with home access, they are not required to do so, so that other students are restricted to on-campus use of the software. *SPSS* is routinely used in large group teaching.

A wide range of students is involved, including recent school graduates, mature-age students and international students, and it is neither practical nor defensible to ask students to purchase a high-end calculator to allow uniformity of use; the high price of the calculators is a factor in this practice. Rather, the spirit is to make good use of any hand-held technology students already have. Those without sophisticated calculators are expected to purchase their own scientific calculator, and it is made clear to them that this will be sufficient for their calculating needs in assessment situations.

Instruction on CAS calculator use is not routinely provided, as there is a diversity of student ownership and use. Help with calculator use is available to students on request, however, as the staff member concerned has the relevant expertise with various calculators, although it is rare for these to be formally used in teaching. A statistics teaching staff member has observed that students typically come from school with a limited understanding of unbiased standard deviations, because the school curriculum does not carefully distinguish sample and population variances; in addition, the notation for standard deviation on some advanced calculators is regarded as inferior.

Although unit coordinators are personally responsible for and make decisions regarding which technologies are permitted in units, they would generally discuss their preferences with colleagues. In this case, while many staff members are not positively inclined to calculator use, the nature of the statistics units and personal experience of the staff member with calculators may account for the differences between this introductory statistics unit and other first year mathematics units There do not seem to be concerns amongst students regarding these various practices regarding calculators, and teaching staff are not aware of any signs of resentment amongst students about limited use of calculators brought from school or disparities of calculator ownership and use (Admiraal, 2015).

6.2.4 University of Notre Dame Australia

There are relatively few mathematics units taught at Notre Dame (and students seeking an undergraduate major in mathematics typically also complete units at other institutions in addition to their Notre Dame studies). However, there is a suite of four mathematics units taught to intending secondary teachers, the principal purpose of which is to ensure that students have a strong and confident grasp of all the mathematics taught at school up to at least the end of the more demanding units at Year 12. One of the units also has a focus on mathematics education in parallel to the mathematics content. Some students not intending to become secondary teachers also take some of these units. A major emphasis of the units is introductory calculus, building on algebra and trigonometry, although other mathematical content (such as statistics, geometry and vectors) is also included. Another statistics unit is also taught for students in other faculties.

Students typically already own both CAS calculators and scientific calculators from their experience as school students, and these are used by students and staff whenever appropriate in the four units. Students have a variety of models, depending on their school experience. The focus of the units is to learn mathematics thoroughly, in order to be an effective teacher, and developing expertise with these technologies is regarded as important for the students. It has been observed that the textbooks used (college level texts from the US) frequently refer to the use of graphics calculators in the body of the text as well as in tasks assigned to students. It seems to not be uncommon for some students to have a poor grasp of how to use their CAS calculators effectively (or have forgotten how to do so) at the beginning of their studies, so that suitable individual help is offered when needed. The staff member concerned has their own CAS calculators as well as experience with using them. A CAS calculator emulator is sometimes used for teaching purposes. In addition to graphics calculator features, such as computation and graphing, CAS features are sometimes used (e.g., to seek general rather than particular results for problems or investigations). The statistics unit makes us of both *SPSS* and also graphics calculators at times.

For assignments, students are encouraged to use whatever technology suits the problems at hand, including CAS functionalities, but the mid-semester and end of semester exams permit students to use only a scientific calculator. In addition, students are permitted to refer to a formula book, based on the textbooks used. The exams are constructed so that use of a CAS is unnecessary, in order to gauge students' understanding of the mathematical concepts involved. Decisions about the use of technology for teaching and assessment are made by individual teachers, although units are formally approved before being offered.

The use of technology is regarded as very important for these units, especially with the focus on the preparation of teachers for teaching local courses. Students are generally positive about the use of technology, although some are at first a little uneasy because of the length of time since they last used their calculators (Hine, 2015).

6.2.5 The University of Western Australia

Undergraduate degree structures at The University of Western Australia have changed recently, but this has not directly impacted on the use of technology in first year Mathematics units. The bulk of first year mathematics teaching conducted by the School of Mathematics and Statistics is concerned with service teaching, especially for Engineering, Science and Business students. Only a small cohort of students undertake mathematics majors.

Students have access to a large computer laboratory, and make use of this with a commercial software package in their own time to develop mathematical skills in a systematic way. Their work on this contributes to their assessment in units. Students in statistics units are expected to make use of an open source statistics package, *R*, and are taught how to use the relevant aspects of the software.

Graphics calculators were prohibited in formal assessment many years ago, and consequently CAS calculators are also effectively prohibited from use in assessment. Consequently, it seems that neither of these is used for teaching purposes by staff and their use for learning purposes by students is not directly supported or encouraged.

Students who wish to use calculators in invigilated assessments (such as quizzes, mid-term and end-of-term examinations) are permitted to use only a nominated calculator from an official UWA list of calculators. The mechanism for this process involves students having an official sticker placed on their personal calculator to facilitate exam invigilation. The list is adjusted regularly as new calculators are brought to light, and includes both very recent models and some that are museum pieces. Details of the UWA policy, including the present version of the list of approved calculators, are available online (University of Western Australia, 2015). The list of permitted calculators expressly excludes calculators that are programmable or have a graphics display, or Bluetooth connectivity. The list identifies some scientific calculators that do not meet these specifications (essentially because they are programmable). While the list necessarily excludes both graphics and CAS calculators, it contains an extensive set of other calculators, mostly scientific calculators. Students have a free choice of calculator for assessment purposes, and it seems that advice on this choice is not formally provided (such as to ensure a minimum functionality or advise of a maximum functionality). The list includes calculators over a very wide range, from those intended for junior primary students (such as the Texas Instruments TI-10 that does not automatically handle decimal numbers, assuming children have not yet encountered them) to sophisticated calculators with a wide range of inbuilt capabilities (such as the CASIO fx-991 ES, which includes some functionality for bivariate data analysis, function tabulation, equation solving, matrices, vectors, complex numbers, series summation and numerical calculus) to specialist financial calculators (such as the Texas Instruments BA-II, which has a full suite of standard financial functions, presumably of particular interest to Business students).

Students are not offered help with calculators, which are regarded entirely as personal tools, and it would be very rare for staff to use calculators of any kind in their teaching. Some students bring their scientific calculators to classes, but this is not common. As graphics calculators have not been permitted for use in assessment for many years, few staff, if any, have personal experience of using them or a good knowledge of the capabilities of modern machines. (Exceptions might be staff members who have been involved in Year 12 Mathematics examining panels.) Consequently, there is no apparent encouragement from staff for any change to the present policies regarding calculator use, and the matter is not part of routine faculty discussions. To some extent, assessments are designed to avoid the need for calculators (e.g., by using small integers rather than awkward data or by using variables instead of numbers) so that students would not be expected to make much use of calculators in assessments and hence the different functionalities of different calculators would not be of concern.

While staff members have some measure of autonomy over individual units, this does not extend to variations on the place of calculators, and the list of approved calculators is applied for all Mathematics units in accordance with the University policy. The rationale for the calculator policy seems to have been lost in time, presumably because it has been in place for some time and is no longer actively discussed as a matter of significance. It is thought to have arisen from unease about students becoming reliant on their calculators without understanding the mathematics involved in reaching results without assistance, and possibly reflects a concern about the use of the memories of some graphics calculators to store notes or formulae for reference in exams. An additional concern might have been the disparities in functionality amongst different models of graphics calculators, conferring an advantage to some students over others (although this would be surprising in view of the range of functionalities of the present list of approved calculators). It seems clear that the calculators are universally regarded by staff as devices to generate answers to computational questions, and are not at all regarded as tools to support either teaching or learning mathematics at this level. It seems unlikely that the policy has arisen from staff experiences with teaching students at UWA in classes with graphics or CAS calculators.

In later years, after the first year of study, students are supported and expected to use some mathematical software, such as *Maple*, MATLAB® and *Mathematica*, dependent in part on staff interests. Similarly students studying statistics units are expected to use statistical packages in later years.

There does not seem to be any discussion or concern amongst students about disparities of calculator ownership and use, or unease expressed about not being permitted to use their CAS calculators in their studies. While it is possible that some students might be using their school calculators at home (not in formal assessments), this too is not a matter of discussion or concern among staff (Hill, 2015).

6.3 Summary

Overall, there is a consistent pattern at local universities in WA regarding the place of CAS calculators and graphics calculators. Essentially, these are regarded as computational devices, and are not regarded as tools that might be used for either teaching or learning. Although there are doubtless some staff in universities with some experience in their use, there are very few of these it seems, and it is likely that very few university staff are aware of the capabilities or educational purposes of CAS calculators or the less sophisticated graphics calculators, as they have not been part of their environment for some time. In addition, the major means of staff becoming personally familiar with CAS calculators seems likely to be for participation in Mathematics Examining panels for ATAR courses, where the focus is on assessment and not directly on teaching and learning.

While sophisticated mathematical software is used, it seems more likely that this is the case beyond first year, with the notable exception of statistics. Even when software is used, it is not used in formal assessment, most likely because of the difficulties of large-scale assessments involving computers. Similar to the case for CAS calculators, it does not seem that technology such as computer software or apps on tablets are prominent in first year teaching, which is often dominated by large group lectures, because of substantial class sizes and considerable service teaching for a range of courses across the campus.

Although there are clearly many differences between the contexts of tertiary and secondary schooling, it is clear from comments of teachers and students that the local university practices exert a considerable influence on opinions about the place of CAS calculators in schools, as highlighted later in this report.

7. Communicating the role of technology

There has been a great deal of professional interest and activity in the use of technology in Mathematics education over the past two or three decades. This interest has been stimulated by, and in turn has stimulated, a variety of specialised manifestations of technology that have found their ways into school mathematics. (Current examples of these are described briefly in Section 9 of this report.) In this section, attention is focused on how the use of these technologies intended by the developers of the WA curricula is communicated and actualised, to address the project brief regarding the functionality of currently available technologies used in senior school mathematics, particularly graphics calculators and CAS calculators, and the WACE course requirements.

While the use of a term like 'calculator' makes it clear that a device is claimed to be helpful for undertaking calculations, the place of technology in school mathematics has generally been intended to be considerably broader than mere calculation. For example, a much-quoted Technology Principle has been proposed and used to underpin other work by the National Council of Teachers of Mathematics (NCTM) in the USA:

> **Technology Principle.** Technology is essential in teaching and learning mathematics; it influences the mathematics that is taught and enhances students' learning. (NCTM, 2000)

This overarching principle is one of six principles developed by the NCTM to frame school mathematics, and has been frequently referenced and elaborated in discussions of technology in other countries, not only in the USA. The Technology Principle makes explicit that technology is intended to provide much more than a mere means of computation, but is expected to be of assistance to students learning mathematics and teachers teaching mathematics, as well as being taken into account in making decisions regarding which aspects of mathematics are worthy of attention, emphasis and time in the curriculum. Similarly, the AAMT communiqué in 2000 regarding graphics calculators focused on the learning opportunities:

> The use of graphics calculators enhances student learning and addresses important issues of equity and relevance of school mathematics to the wider world. There is a compelling case for the advantages offered to students who use graphics calculators when learning mathematics. They are empowering learning tools, and their effective use in Australia's classrooms is to be highly recommended. (2000, p. 2)

With calculators in particular in mind, Kissane and Kemp (2014) elaborated a four-part model for their educational use, claiming that processes of representation, computation, exploration and verification were involved. More recently, Kissane (2015a) used this model to illustrate how scientific calculators in particular might be incorporated into an educational program. While computation is clearly one of the ways in which calculators might be regarded as beneficial, much of the popular discourse around the role of calculators in schools has focused entirely on that aspect, and not on other educationally productive uses, as Kissane (2015b) argued, claiming that the calculator is better regarded as a tool for learning mathematics instead of being restricted to numerical computation.

As for other curriculum jurisdictions in Australia and elsewhere, it seems likely that technology is expected by curriculum developers to play multiple roles in senior school Western Australian mathematics curricula, and to have had some influence in deciding questions of which topics are important and how to balance them. The mechanism for making explicit the roles of technology involves references in the official curriculum documents and supporting materials. To illustrate the approaches taken in WA to communicate the role of technology, an analysis of an existing and a new course was undertaken. The *Rationale* for the existing Mathematics course (School Curriculum and Standards Authority, 2015a) includes the following reference to technology, highlighting that it has been a source of influence in course design:

> This Mathematics course has a greater emphasis on pattern recognition, recursion, mathematical reasoning, modelling, and the use of technology, in keeping with recent trends in mathematics education, and in response to the growing impact of computers and technology. (p. 2)

The three outcomes specified for the course do not make explicit reference to the use of technology, presumably on the assumption that it is embedded or implied in the outcome statements. There is only a single reference to technology in the *Course Content*; this reference is shown in the following extract from the *Number and algebra* strand:

> Also, an understanding of the meaning, use and connections between arithmetic operations and the ability to use and interpret mental, written and technology-based calculations efficiently are required. (p. 4)

The *Tools and procedures* strands refer to technology in three separate places. In *Forms and representations*, reference is made to choosing a suitable means of dealing with procedures in the following extract:

> Appropriate methods are expected to be chosen from an array of symbolic, numerical, graphical or technology-based algorithms. (p. 4)

The remaining two aspects of *Tools and procedures* make several references to the use of technology. In the first place, the *Algorithms* component, reproduced here in its entirety, recognises that some computations might involve technology, so that students ought to develop associated expertise with these:

> **Algorithms.** Computations involving number, data, algebra and calculus need to be performed with facility, reliability and accuracy. Suitable algorithms must be chosen from a collection of symbolic, numerical, graphical or technology-based algorithms. Decisions are needed regarding whether results ought to be numerical or symbolic, and the level of precision or generality required. Tools and procedures are chosen to be consistent with these decisions. (p. 5)

The final component of *Tools and procedures* refers explicitly to technology, and, unlike previous references, appears to suggest that technology might involve more than computation.

> **Technology.** Technology of various kinds (spreadsheets, calculators, computer algebra systems, dedicated and dynamic mathematics software, interactive whiteboards and the internet) can *support students to investigate, generate, create and explore mathematical ideas.* Once selected for use, such technology should be used deliberately, carefully, and frequently. Decisions about the appropriate presentation of results must be considered. These decisions help to influence the optimal use of technologies. The internet is an increasingly important resource that allows students to access mathematically significant information and visually rich dynamic demonstrations of many ideas in this course. (p. 5, italics added)

The details of the units in the Mathematics course make brief and occasional references to technology. (These units are abbreviated by SCSA and here for convenience, so that Unit 2B of the Mathematics course is referred to as 2BMAT.) Many of these refer specifically to calculation in the Unit Description, such as the following in 2BMAT (and in other Stage 2 and Stage 3 units in this course):

> They use mental and written methods and technologies where appropriate. (p. 36)

Some specific technology uses are referred to in Unit Content, such as the following in the Finance section of 3AMAT

> 1.5.1: use, construct and interpret spreadsheets for making financial decisions. (p. 46)

References to technology are made in probability and statistics content, such as the following from 2DMAT:

> 3.1.1: plan and conduct simulations using technology-based random number generators (p. 43)

and the following from 3ABMAT:

> 3.1.1: determine Pearson's correlation coefficient *r* using a calculator

There are some references to graphing also, such as the following from 2DMAT:

> 1.2.1: use technology to graph $y = ax^3 + bx^2 + cx + d$. (p. 42)

While there are some references of the above kinds to technology, there seem to be very few references or suggestions regarding what students or teachers might actually do with the technology, beyond using it for computation; there are very few examples such as those above referring to simulations and to spreadsheeting. In particular, there do not seem to be any specific references in the units themselves to the additional capabilities provided by the change several years ago in Western Australian ATAR courses from the use of graphics calculators to CAS calculators, which provide capabilities for symbolic work generally, for generalisation and for exact representations of mathematical objects such as integrals and solutions to equations.

There are guidelines for the school-based assessment for each unit, referring to the balance between Response and Investigation assessment types. These do not seem to make any reference to the student use of technology in general (or CAS calculators in particular), and hence do not convey a sense that technology is thought to be appropriate for such assessment. While there might be an implied reference to technology in the Response section (with the well-known distinction between computation with and without technology), there seems to be little advice in the Investigation section to indicate that technology might have a role to play in extended investigations away from the unavoidable time-strictures of tests and examinations. Two possible roles include the use of the calculators (or other forms of technology) for extended mathematical modelling of real-world contexts or for extended investigation of mathematical concepts and problems involving generalisations with symbolic algebra or calculus.

The course also describes the external examinations, making reference to the calculator-free and calculator-assumed sections, but does not elaborate how these might be different, beyond the presence or otherwise of a calculator. Surprisingly, no advice seems to be offered regarding the rationale for students to take up to three calculators with them to the calculator-assumed examinations, nor to the general purpose of permitting the calculators to be used. Presumably, it is assumed that teachers will understand the role of the CAS calculators via some other (unspecified) source, including of course a study of previous examination papers, examiner reports and, of course, colleagues.

Finally, the Grade Descriptions in the Mathematics course (School Curriculum and Standards Authority, 2015a, pp. 65-79) make very few references to the use of technology, so that it is not clear how student expertise with technology is intended to contribute to the determination of their grades. There are some references to (routine) use of a calculator for computational purposes, such as, for a grade of C in Mathematics 3AB:

> using a calculator to produce a mean or standard deviation from a set of data. (p. 77)

References to use of technology are mostly at lower grades, to indicate defective practices, however, such as the following for a grade of D in Mathematics 3CD:

> Uses technology to evaluate an integral but gives only the answer. Enters data correctly into a calculator but tends to give numerical answers without working. (p. 79)

There seem to be remarkably few references to use of technology at grades A and B for any of the units in this course. The singular exception seems to be for a grade of B for Mathematics 2CD:

> Uses a calculator appropriately for calculation, statistics, algebra and graphing. (p. 74)

It would seem reasonable from the grade descriptions to infer that higher grades for the units in this course might be awarded irrespective of the extent to which students made good use of the technology they were using, although it seems unlikely that this is the intention of the curriculum.

The SCSA online portal provides further detailed advice on the Course for teachers (but not for others), including resource lists, scope and sequence suggestions and assessment support of various kinds. Taken as a whole, while there are occasional uses of calculators (for computational purposes) referred to in the additional materials, there does not seem to be significant advice to teachers regarding ways in which technology might support the teaching and learning program generally. There are scant references, for example, to the intended roles to be played by the CAS facilities that are assumed to be available to students throughout the course (beyond Mathematics 2AB). Overall, it would seem reasonable for teachers to infer, from the lack of explicit advice otherwise, that the principle role of the CAS calculators in the Mathematics course up to 2015 is to undertake computations. While this is unlikely to be the case, it is not clear how teachers might be expected to reach other conclusions.

The revised courses that began in 2015 for examination at the end of 2016 can be scrutinised in a similar way, in order to discern how the role of technology is communicated to teachers (and others). To illustrate this, the Mathematics Specialist course for Year 12 was analysed. The course is taken in conjunction with Mathematics Methods (the only such ATAR course combination for dual enrolment), but is here examined separately. The course has clearly been constructed to be consistent with the Australian National Curriculum developments for senior secondary school, referred to earlier in this report, and there is thus considerable overlap with the ACARA course. A recent critique of the corresponding F-10 Australian Curriculum: Mathematics by Goos (2012) noted the overarching questions regarding the place of technology:

> Digital technologies have been available in school mathematics classrooms since the introduction of simple four function calculators in the 1970s. Since then, computers equipped with increasingly sophisticated software, graphics calculators that have evolved into “all-purpose” hand-held devices integrating graphical, symbolic manipulation, statistical and dynamic geometry packages, and web-based applications offering virtual learning environments have promised to change the mathematics teaching and learning landscape. But what should be the role of digital technologies in school mathematics? Is technology meant to help students “get the answer” more quickly and accurately, or to improve the way they learn mathematics? (p. 1)

The *Rationale* for the new Mathematics Specialist course makes no explicit reference at all to the use of technology. While it is possible to interpret aspects of the rationale from a perspective of technology (such as assuming that current real-world modelling and problem solving might involve the use of technology, or that rigorous arguments and proofs might be considered with the support of CAS in mind), such interpretations are left entirely to the reader.

The course has a series of six aims (identical to those in the corresponding ACARA course document), one of which refers explicitly to the use of technology:

- capacity to choose and use technology appropriately (p. 3)

The other five aims seem relatively easy to extract from the stated rationale, while this technology aim seems to demand an inferential leap on behalf of readers, because of the lack of any explicit reference to technology in the rationale.

The other five aims make no mention of technology (presumably because one of the aims specifically refers to technology), but careful readers might recognise that achieving the aims might nonetheless involve appropriate use of technology, including in particular CAS calculators, at least sometimes. For example, consider the four aims below, in which key phrases have been emphasised for a brief analysis:

- ability to *solve applied problems* using concepts and techniques drawn from combinatorics, geometry, trigonometry, complex numbers, vectors, matrices, calculus and statistics
- reasoning in mathematical and statistical contexts and *interpretation of mathematical and statistical information*, including ascertaining the reasonableness of solutions to problems
- capacity to *communicate in a concise and systematic manner* using appropriate mathematical and statistical language
- ability to *construct proofs*. (p. 3, italics added)

The solution of applied problems at this level will sometimes involve high-level use of technology to represent problems mathematically and to resolve them with technological support, e.g., through the setting up and solving of a differential equation. A CAS calculator might provide various kinds of statistical information, such as a confidence interval, which requires adequate interpretation to demonstrate statistical reasoning. Communication in a technological environment, such as through use of a CAS calculator, will frequently require students to interpret information on the calculator and represent it in conventional ways, which often differ from calculator representations. Proofs can be constructed in part through the use of symbolic manipulation capabilities of CAS calculators (such as expanding, combining and factorizing expressions), which have to be decided upon, executed, interpreted and re-written into conventional forms of proof. All these sorts of interpretations, however, are reliant upon the reader recognizing the connections between the technology that is assumed to be available and the aims that are sought; they are not explicit in the document.

The new year-long Mathematics Specialist course involves two units (Units 3 and 4), which are clearly based on the ACARA senior secondary mathematics curriculum units. The units themselves are described in brief on page 4, but there is no reference to the use of technology in the descriptions. However, a separate part of the overview of the courses refers specifically to the use of technology, both for teaching and learning and also with respect to student capabilities, with and without technology:

> **Role of technology.** It is assumed that students will have access to an extensive range of technological applications and techniques. If appropriately used, these have the potential to enhance the teaching and learning of mathematics. However, students also need to continue to develop skills that do not depend on technology. *The ability to be able to choose when or when not to use some form of technology and to be able to work flexibly with technology are important skills in this course.* (p. 5, italics added.)

The General Capability of ICT from ACARA is also recognised in the new course:

> **Information and communication technology capability.** Students use information and communication technology (ICT) both to develop theoretical

> mathematical understanding and to apply mathematical knowledge to a range of problems. They use software aligned with areas of work and society with which they may be involved, such as for statistical analysis, generation of algorithms, manipulation and complex calculation. They use digital tools to make connections between mathematical theory, practice and application; for example, to use data, to address problems, and to operate systems in authentic situations. (p. 5)

Notably, neither of these two statements about technology refers to specific technologies, such as those to do with graphing, CAS or spreadsheets, except for the clear reference to statistical software.

In each of the two units in this course for Year 12, the overall Unit Descriptions make a clear reference to the use of technology for computational purposes:

> Access to technology to support the computational aspects of these topics is assumed. (p. 8, p. 11)

It is not entirely clear what this statement might mean in some cases, however. For example, while using a graphics calculator to evaluate a definite integral would certainly be regarded as a 'computational' act, it is not clear whether using a CAS calculator to evaluate an indefinite integral would be regarded as 'computational' and hence fit within this overall assumption regarding access to technology. While precise definitions and distinctions between terms will no doubt be contested, reference to *Wikipedia* (2015) suggests that at least some would regard the terms 'computation' and 'calculation' as different:

> **Computation** is any type of calculation that follows a well-defined model understood and expressed as, for example, an algorithm, or a protocol.

Elsewhere, *Wikipedia* suggests that 'calculation' generally involves numbers, and is regarded as relatively unsophisticated process, while computation is a broader term. Indeed, some conventional mathematics dictionaries would use the term 'computation' essentially to refer to what computers do:

> **Computation**. *n* 1. A calculation, especially of a number or a value from given information by use of an algorithm. 2. Any step-wise calculation, especially one that could be followed by a suitably programmed computer. **(**Borowski & Borwein, 1999, p. 101)

In that case, determining that a particular integral was sought would not be regarded as computational, while actually evaluating the integral, including the case of an indefinite integral via a CAS calculator, would be regarded as a computation, with the calculator having been programmed for such a purpose. Leaving semantics aside, the standard procedures involved with methods of integration in Topic 4.1, for example, might well be regarded as following well-defined algorithms, so that it is not immediately clear whether or not, or to what extent, CAS facilities are expected to be involved.

The detailed specification of the Unit Content for the two units in Year 12 Mathematics Specialist comprise 59 separate items, arranged over six different topics. In only the following four cases is there a clear statement (or inference in the case of three of the four) that technology might be involved in some way:

> 4.1.7 use technology with numerical integration (p. 12)
> 4.3.2 simulate repeated random sampling, from a variety of distributions and a range of sample sizes to illustrate properties of the distribution of $\overline{X}$ … (p. 12)
> 4.3.3 simulate repeated random sampling, from a variety of distributions and a range of sample sizes, to illustrate the approximate standard normality … (p. 12)
> 4.3.6 use simulation to illustrate variations in confidence intervals between samples and to show that most but not all confidence intervals contain μ (p. 12)

While it seems clear that suitable technology, including a CAS calculator in particular, might be appropriate for many of the other 55 separate items, and it is further likely that it is intended for teaching or learning (or both), given the earlier statements and the technology aim, these inferences seem to be left to the reader.

The specifications of the School-based assessment for the course are entirely silent on the possibility, or expectation, of the use of technology (including CAS calculators) in the three types of assessment referred to (i.e., response, investigation, examination). It is surprising that the potential for using CAS or other technologies for student investigations is not mentioned as a possibility (at least), and also surprising that references to the examination components make no mention of technology either. (Yet it seems that teachers routinely include a calculator-free and a calculator-assumed component in school assessments, to mirror external assessments, presumably).

Similarly, there are course requirements regarding what is expected of an assessment outline on page 14 of the Course document, but there is no reference of any kind in the specifications to a possible role (or a suitable balance) of the use of any technology, including CAS calculators. Given the well-known difficulties and constraints of external (and internal) examinations, it is surprising in this case that one of the requirements for the assessment outline does not specifically refer to students making sound use of technology, at least for an extended investigation task. Overall, it is not clear how school-based assessment can expect to provide insight on the extent to which students have achieved the specified aim regarding the choice and use of technology, if there is no reference at all to technology in the associated framework.

The Examination design brief (p. 17) refers to the two exam sections, as calculator-free and calculator-assumed, and makes it clear that up to three calculators are permitted in the latter. It is surprising that no advice is offered regarding the three calculators, beyond their meeting the WACE approved specifications, including why as many as three calculators are permitted, and for what purpose(s) the calculators are expected to be used. For example, although there is a statement that candidates are assumed to have a calculator with CAS capabilities, no advice is offered regarding whether they might anticipate some examination questions for which the use of such a calculator is necessary, and no advice is offered regarding the extent that the CAS calculator will not be necessary for all items. Nor are candidates given advice to the effect that a scientific calculator might be insufficient for some examination questions.

While such matters might be handled by folklore, by word of mouth or by inspecting similar recent examination papers, it is surprising that specific guidance of these kinds is not provided for candidates, teachers, examiners and others. While it might not be appropriate to include advice of these kinds in the syllabus document itself, in the interests of brevity, it is surprising that it is not available in an easily located place.

Finally, the Course is completed by some official Grade descriptions, intended to help teachers allocate and students interpret grades for the course. As with the earlier example of the *Mathematics* courses for 2015, these are almost completely devoid of any explicit references to the use of technology. The single exception is the following statement included as part of one of the five criteria for a grade of D to be awarded:

> Uses a calculator appropriately for straightforward calculations, algebra and graphing. (p. 20)

The Syllabus document is supported by other materials online via a portal, accessible only to authorised people, such as registered teachers. These include a course outline, sample assessment outline, sample assessment tasks and examination materials. The sample assessment tasks offered are directed at the content items 4.3.1 and 4.3.2, the latter of which is observed above to be one of the few examples of a reference (at least, an implied reference) to technology in the unit content. While the task seems appropriate, and makes good use of various technologies, the choice of tasks might unwittingly give the impression that technology is only appropriate when the unit content specifically implies it, and thus unwittingly suggest that most parts of the unit do not expect students to use technology. In the circumstances, it would have been prudent to offer at least another example (in addition) for which the technology had not been so evident in the associated unit content items.
The sample examination provided includes both a calculator-free and a calculator-assumed section, although with different weights than the external examination. The use of different weights is appropriate to model the fact that teachers can determine appropriate proportions in the school-based assessment and are not required to keep the same weighting as the exam. It is not clear where and how the students might use (or not use) their CAS calculators in the calculator-assumed component, however. It would be helpful, in terms of advising teachers, to make explicit comments about these sorts of matters, to ensure that the example was used to good effect.

Overall, it appears on the surface that the intentions of the syllabus regarding technology in general, and CAS calculators in particular, are difficult to discern from the published syllabus documents, both for the previous courses (exemplified by *Mathematics* for 2015) and the new courses (exemplified by *Mathematics Specialist* for 2016). Although experienced teachers might well be more likely to read successfully between the lines, it seems unlikely that new teachers could determine the course intentions regarding technology from what is published, and even less likely that students or their parents would be able to do so. Importantly, it is not clear how other groups, such as potential textbook authors, professional development providers, examining panels or teacher educators could use the published materials to understand well the intentions regarding technology in general, and CAS calculators in particular (exaggerated for these groups as they do not have routine access to the secure online portal).

To examine further this matter, some published materials developed for the existing Mathematics Specialist course (concluding in 2015) were considered. While textbooks and other materials inevitably reflect individual writing styles and pedagogical preferences of the authors, they also reveal interpretations of the syllabus and hence provide insight into the clarity and consistency with which the syllabus has communicated its intentions. In addition, of course, published materials are likely to be used as a guide to interpret the syllabus by both teachers and their students. As far as technology in this course is concerned, the explicit statement at the front of the course syllabus (similar to that for the Mathematics course described earlier) offers the most guidance:

> **Technology.** Technology of various kinds (spreadsheets, calculators, computer algebra systems, dedicated and dynamic mathematics software, interactive whiteboards and the internet) can support the investigation, generation, creation and exploration of mathematical ideas. Once selected for use, such technology should be used carefully, and frequently. Decisions about the appropriate presentation of results are made. These decisions affect the technology chosen and help to influence its optimal use. (p. 5)

Four textbooks (Sadler, 2008, 2009) constitute a popular series that was specifically developed locally for the WA course. These do not contain an explicit statement for readers regarding the significance of CAS calculators (or the other forms of technology referred to above), so that students and teachers need to infer this for themselves from the texts. Although the texts refer periodically to a distinction between exact and approximate values, this is not done with reference to CAS calculators (in which such a distinction is a key part of the CAS). The texts do not use actual CAS calculator screens, but instead use schematic versions of them (to accommodate differences between calculator models, presumably). The texts regularly refer to the importance of students developing mathematical arguments by hand (without using a calculator), and often refer to the possibility of verifying a by-hand method on a calculator or highlighting that there are alternative methods available via a calculator. Sometimes (but rarely) the text in the books makes use of a calculator in developing a new idea or procedure. There are some references to the possible use of computer algebra (such as to factor, expand, solve and integrate in various places), but overall there are very few of these.

Technologies other than calculators are not referred to in the series. Most of the (many) exercises and problems in the series are quite short; in some places, students are recommended to complete exercises by hand and with the calculator, but are rarely offered advice on how to choose which of these is appropriate. There are some longer investigation tasks and extension activities, some of which refer to possible uses of calculators, and which might serve as models for activity of that kind to teachers or students. On balance, although the author seems to have reflected the content of the syllabus well and offered interesting tasks to students and help for teachers to understand and to sequence the material, the series does not provide significantly more guidance as far as the place of CAS calculators is concerned than is available in the syllabus itself. While many of these aspects might well be a consequence of writing style, and interpreting the syllabus is not the responsibility of the author, it seems that teachers and students who needed more help in understanding the intended place of the technology in the syllabus would not find these texts very helpful for that purpose.

A different kind of resource material was developed for Mathematics Specialist 3CD by Williams and Williams (2011). This text is in the form of a workbook comprising a large collection of examination questions from Western Australia, Victoria and New South Wales, as well as projected examination questions constructed by the editors. The clear and explicit intention of the text is to support students in preparing for the examinations in this course. Accordingly, all the questions are grouped into course topics and classified as Calculator-Free or Calculator-Assumed, consistent with the examination practice for this course. In addition to the questions, the text provides worked solutions for all questions. The text offers specific advice to students regarding the use of CAS calculators in particular:

> It is the advice of the editors to attempt as much as possible from each question without the use of a CAS calculator and then to use the CAS calculator to verify answers where appropriate. (2011, frontispiece)

It is not clear whether this advice is a pedagogical preference of the authors, general advice for examinations or an interpretation of the intention of the syllabus, but it seems likely that it will be regarded in the latter way by many of the users of the text. Throughout the set of solutions, comprising some 30 pages, there is only one explicit reference to a CAS calculator (on p. 203, for finding an angle between two vectors), eight explicit references to graphics calculators (on pp. 229-230, all in a single module concerned with transition matrices) and two references to an unspecified kind of calculator (one on p. 214, to find a numerical solution to a quadratic equation, and one on p. 220 to evaluate i^i, both of which could be done on either a graphics or a CAS calculator, but not on a scientific calculator). Although there are many examination questions that are marked as Calculator-Assumed and which could be answered via the use of computer algebra commands, in none of these is that possibility mentioned; this may of course be faithful to the advice above to answer questions without the CAS calculator. There are many other places where numerical results would have been obtained using calculators, but no mention is made of how this was done. There seemed to be no explicit use of computer algebra in the solutions. In many places, numerical calculations had been undertaken without reference to how this was done. Overall, it seems unlikely that students or teachers would find this resource helpful for deciding either when or how to make use of a CAS calculator in the examinations for this course.

A similar text (with the same publisher) by Lee (2010) is also in the form of a workbook constructed to support student preparation for the Mathematics Specialist 3CD examinations. As for the previous text, questions are grouped into topics and classified as Calculator-Free or Calculator-Assumed, and a complete set of solutions is provided. Unlike the previous text, many of the worked solutions provide calculator screen dumps that show readers (students, but possibly also teachers) some ways in which a CAS calculator might be used for many of the Calculator-Assumed questions, providing that the students were using the same (unnamed) calculator as the author. Many of these screen dumps show the use of computer algebra commands to solve equations symbolically (e.g., p. 150), differentiate or integrate functions (e.g., p. 193), manipulate expressions (e.g., p. 225), and so on. In many cases (but not all), both CAS solutions and non-CAS solutions are provided (e.g., p. 145), but generally without any advice on which of these might be preferable. In many cases, Calculator-Assumed questions are solved without recourse to a CAS calculator (e.g., p. 160) and in many other cases, CAS calculator solutions are provided without a corresponding non-CAS solution (e.g., p. 195). Overall, it seems unlikely that students would readily discern how or why decisions to use or to not use a CAS calculator were made in compiling the solutions, although this is clearly stated in the syllabus as a key aspect of the use of technology generally and, by implication, is important for the examination.

It is important to recognise that the authors of these three sets of materials might well have sound reasons for the decisions that they made regarding what was included and what was omitted. (For example, the two sets of examination practice questions might have been written in order to provoke a discussion amongst students as to which approaches to the use of their CAS calculators might be appropriate.) However, the three interpretations are so different from each other regarding the roles of CAS calculators that it is difficult to not conclude instead that the syllabus in question has not been described with sufficient clarity for authors to develop supporting materials of these kinds in line with the intentions for this course.

In conclusion, neither the extent to which technology might be expected to play a significant part in the teaching and learning of the courses nor the extent to which students are expected to develop competence with the judicious use of a range of technologies (including CAS calculators) are clear in the previous courses or the new courses, based on the sampling of materials chosen for analysis. Whilst it might be argued that it is the role of the teacher to decide how they will teach, including how they will make use of technologies of various kinds, taking into account their local circumstances and their own preferences and pedagogies, it seems optimistic in this case to expect that teachers will interpret the intentions of the curriculum with respect to the use of CAS calculators (in particular), without some further guidance. In observing and critiquing the ways in which the use of technology had been incorporated into the F-10 Australian Curriculum: Mathematics, Goos (2012) noted the limitations of curriculum documents regarding pedagogy:

> To be fair, it is unrealistic to expect a curriculum document to transform *classroom interactions* (the second level of Pierce and Stacey's framework), since this remains in the realm of pedagogy. (p. 150).

While there might be issues related to clarity and pedagogy for teachers, it is not clear how students might reasonably be expected to appreciate the level of expertise they are expected to acquire with CAS calculators, and for what purposes, without more explicit reference to this in the official materials. There are also similar risks that those developing textbooks or other kinds of supportive materials for teachers or for students (such as examination preparation materials) may misunderstand the intended roles of CAS calculators without more explicit help and further examples. In the same way, it is not clear how examining panels are expected to interpret the intended role of the CAS calculators, and reflect that role appropriately, in the Calculator-Assumed components of examinations, given the relative paucity of detailed guidance on this point in the official materials.

It seems that the most likely reasons for these problems are SCSA preferences to offer relatively succinct documents and, in the case of the new course, to match similar course offerings elsewhere in Australia. However, a case could be made that the intentions of the curriculum developers, especially with respect to the place of technology, and any intended balance of by-hand and calculator methods, might have become lost a little in the process. Mechanisms to make the technology intentions more explicit and to provide more extensive guidance and examples – especially for those who might need them – would seem to be worth pursuing.

8. Analysis of recent WA mathematics examination practices

8.1 Present practices

A major aspect of Mathematics courses, both in Western Australia and elsewhere, is their assessment. High-stakes assessment is widely understood to have significant effects on both teaching and learning, so that a major issue for SCSA and similar bodies concerns the extent to which teaching, learning and assessment are consistent with each other. According to the syllabus documents and WACE practices, assessment in Mathematics courses includes both a school-based component and an external examination component. In this section, the focus is on the examination component.

Formal examinations for Mathematics courses conducted by SCSA exert considerable influence on perceptions about mathematics, including the relevance of technology. Thus, since the introduction of CAS calculators in WA in 2009, the final examinations have included a component in which students are allowed to use their calculators (consistent with the assumed classroom practice of making judicious use of calculators) as well as a component in which calculators are prohibited (to stress the importance of students also being able to undertake mathematical work without the aid of technology). Anecdotally, it seems that schools typically mimic this structure in their own test and examination practices, increasing its importance. The details of which particular calculators can be used are published by SCSA.

Students are permitted to use up to three calculators of their own choice in external examinations. While these might include both a CAS calculator and a scientific calculator, as well as possibly another model of CAS calculator, advice does not seem to be published on the rationale for this practice, as noted in the previous section of this report. Presumably, it is regarded as a mechanism for ensuring that students who were concerned about different capabilities of different CAS calculators could have access to the capabilities of their choice, although it seems unlikely that many students would be inclined to purchase a second CAS calculator and master its operating system, given opinions about the expense of the calculators and the difficulties of using them. It is also possible that a multiplicity of models is permitted to insure against catastrophic breakdown in an examination, although students are expected to have replacement batteries on hand if necessary. There does not seem to be systematic information available about the extent to which students in fact choose to take three calculators into examinations, although there is widespread anecdotal advice that students commonly take both a CAS calculator and a scientific calculator to exams.

Although it is clear that calculators are not permitted to be used in the calculator-free section of the examination, there is no expectation that calculators *must* be used in the calculator-allowed section. In analysing this issue when graphics calculators were first prominent in Australian schools, in the early 1990s, Kemp, Kissane and Bradley (1995) identified some general principles and issues associated with calculator use. Kemp, Kissane and Bradley (1996) accordingly developed a typology of calculator use, recognising that sometimes calculators should be used, at other times they should not be used and at still other times, students might be expected to exercise a personal preference. Students need to learn to make the necessary distinctions and to become discerning users of technology. Thus, it would not be appropriate for an examination with technology to consist entirely of questions for which the technology was essential.

Recent examination papers and their marking guides were studied to see the extent to which CAS calculators were used appropriately by students and apparently expected by examiners. Examiners' reports following examinations sometimes comment explicitly on the extent to which students made judicious or competent use of their calculators, or otherwise. These reports are compiled by the chairs of the relevant examining panels, following advice from the teachers who are employed to mark the papers and discussions amongst panellists and markers.

It is clear from studying recent papers, their marking guides and associated reports that, while CAS calculators are permitted for use in the calculator-assumed mathematics examinations (although not expected to be used in lower level examinations such as Mathematics 2AB), the use of the computer algebra aspects is neither expected nor necessary in many questions. In some cases, use of a CAS calculator would be desirable, or sensible, although the nature of the courses concerned is that students could address questions without using their calculator (albeit sometimes inefficiently). A CAS calculator includes graphical, statistical and numerical capabilities, and these non-symbolic (i.e., graphics calculator) capabilities are more likely to be important for answering examination questions; again, there are typically alternatives to using calculators (again, frequently inefficient for completing a timed exam). A CAS calculator also includes the numerical computation capabilities typically found on scientific calculators, and these too are important for answering many exam questions requiring a numerical answer.

In general terms, and unsurprisingly, the use of the computer algebra functionality of CAS calculators is more likely to be appropriate for higher level exams (such as those for Specialist Mathematics 3CD) than for lower level exams (such as those for Mathematics 2CD). Minimally, graphics calculator capabilities are needed for exams involving a significant statistics component. Some calculations (such as vector operations) can be handled by CAS calculator capabilities or graphics calculator capabilities, depending on the models, or could be completed by a student using a scientific calculator or even mentally (since typically the numbers used are integers). In these senses, the exams clearly allow students an opportunity to choose a suitable technology, including no technology at all, to support their thinking with a particular task.

8.2 Views of examining panels

At the research team's request, SCSA invited members of recent examining panels to contact the team directly to offer advice and perspectives on the significance and use of CAS calculators for the examinations, recognizing that panellists would be able to reflect a body of informed and expert opinion on the actual practice of CAS calculators in examinations, both designing exams and managing the marking processes. Following a reasonable period, this invitation was repeated, but there was no implied obligation or expectation of panellists to contribute advice. Five examiners agreed to discuss in detail a range of issues with the research team and were promised anonymity in doing so, consistent with long-standing SCSA practices related to external examinations. Accordingly, the observations which follow have been constructed to maintain their anonymity, mindful that they are a small sample from a small group of experts.

The five panellists together have a wide range of experiences in various roles over recent years, as Panellists, Chief Examiners and Independent Reviewers of various Mathematics examination papers, including papers covering both Mathematics and Specialist Mathematics courses, at both Stages 2 and 3. Although examining panels do not comprise only teachers, the five panellists who accepted the invitation were all experienced school teachers, and had substantial experience teaching with CAS calculators in their schools, typically across a range of senior secondary courses. Typically, they also had considerable experience teaching with graphics calculators as well, before CAS calculators were sanctioned for use. (However, in any given year, panellists teaching a particular mathematics course are not permitted to act as an Examiner or Independent Reviewer for the course.)

Detailed individual interviews were conducted by telephone, following which written summaries of panellist opinions were compiled and formally accepted as a faithful record, following further discussion. The topics discussed in the interviews are noted in the Appendix to this report.

Panellists were first asked about their views on the place of technology in the particular mathematics subject concerned. Three panellists noted that the significance is about learning mathematics:

> *The key role is to enhance learning. Calculators should be regarded principally as learning tools.*
>
> *Very important as a classroom learning tool, and provides a capacity to solve previously inaccessible problems. Provides potential to address realistic problems. Important as a teaching tool for demonstrating key features of mathematical situations via projectors.*
>
> *CAS calculators are a fantastic tool for efficiently handling arithmetic and are excellent learning tools for students. Some mathematical operations are handled very efficiently by CAS calculators (in this case, CASIO Classpads); examples include finding turning points for optimization by setting a derivative to zero and solving; evaluating dot products. Mathematics is always involved in setting up the calculator to solve problems, and understanding what is going on, but the tedious procedures can then be handled well by technology.*

The other two panellists noted that the place of CAS calculators in particular in lower level Mathematics courses was less appropriate:

> *Students in this particular course are relatively weak in mathematics, and need a working technology to support them. To an extent, the course is designed for some reliance on technology; however, it is doubtful whether they need a very sophisticated technology like a CAS calculator. In general, students need to encounter technology in their mathematics courses, partly as a preparation for a later life that will include technology in many forms.*
>
> *The course is not especially related to technologies like CAS calculators, as it is a relatively low level course, and there is a substantial 'tail' in the cohort.*

Panellists were asked about the extent to which CAS in particular (i.e., symbolic algebra and calculus, not just graphs, tables, numerical solutions and data analysis) were important for the course in question. To a predictable extent, responses depended in part on the levels of the courses being considered. Indeed, one panellist noted:

> *Inclusion of CAS questions in lower level courses is a bit forced, "gimmicky", perhaps for the sake of doing so rather than for more profound reasons.*

On the other hand, with higher level courses in mind, panellists suggested that CAS was more important:

> *Very important, allowing students to apply their understanding, which is often expressed in symbolic terms.*

> *Valuable, as it potentially allows a focus on the formulation of problems, which might then be solved using CAS capabilities.*

Two of the panellists responded to this issue by indicating that concerns were evident about the extent to which students receive sufficient support from their teachers to use the CAS aspects well:

> *It depends on the learning process, to some extent. The CAS calculators (including the CAS elements) could play a more prominent role in learning than they seem to do. I suspect that many teachers do not take full advantage of the possibilities so that CAS is not really used to advantage for learning purposes.*

> *While there are certainly opportunities for CAS use, the impression from the exams annually is that many students don't get much support to take advantage of these, so examining panels are not sure that teachers are using it much. If the technology is available, it would seem appropriate for students to use it judiciously, yet it is not uncommon for students to do things longhand (and incorrectly), when a CAS calculator could do the tasks more quickly and efficiently (and accurately).*

Panellists were asked whether there were particular difficulties associated with setting and marking exam questions. In the calculator-free sections of the exams, it is clear that there are no difficulties experienced. The following responses reflect this position:

> *No problems observed here. Questions test the fundamental ideas and procedures, which is regarded by panels as a good idea.*

> *No particular problems. This is well-understood territory now after a few years of operation.*

> *Strong endorsement of the need for this section, in part as it encourages students to develop adequate expertise without technology. Mostly used to deal with less sophisticated procedures, easy numbers, etc.*

One panellist offered a different view, however:

> *No problems reported, although the preference would be to not have a calculator-free section in school and external exams, in part because they are messy to deal with and place extra burdens on marking (such as matching papers, reporting results, etc). If CAS is involved (rather than, say, graphics or scientific calculators), the calculator-free section is needed, but the previous arrangement with graphics calculators, for which there was only one exam, is preferred. There is no perception that the calculator-free section has made the course more difficult for students.*

Regarding the calculator-assumed papers, panellists did not report problems associated with different calculator models:

> *CAS is not regarded as problematic from the perspective of examiners for these units. Examining panels are aware of various CAS models and check carefully, as instructed, that questions are relevant to all models.*

> *No particular difficulties noted; the panel feels that it can write 'normal' questions and is comfortable with students using their CAS calculators to answer them if they choose. They tend to not write questions that can only be attempted sensibly through CAS use.*

> *Panellists tend to have no difficulties being aware of CAS calculator capabilities, including those of different models, perhaps because they are mostly teachers. (In earlier times, some tertiary people were less familiar with the details of CAS calculators, however.)*

On the question of the extent to which students used CAS in the exams, panellists offered some useful insights:

> *Students may prefer to use by-hand methods instead of CAS in many cases, and there are also consistent reports that many students don't seem to use their CAS devices well, inferred to be in part because of limited help from teachers.*

> *Although questions with very few marks (such as a single mark for an algebraic simplification) might sensibly be done by students on their CAS calculators, many students do not detect the implicit advice of the marks and choose to complete questions by hand instead.*

> *The calculators can handle routine things, and ensure that it doesn't take too long to reach answers. If students can use the calculators to reach a desired endpoint efficiently, then they should be helped and encouraged to do so.*

Similarly, panellists reflected on a variety of experiences and some tensions of including examination questions that required CAS use in exams, and did not all have the same views:

> *Examiners should not set a question solely to get students to use their calculators: it's a learning tool, mostly. … Students should not be excessively penalised for not using their CAS well.*

> *We are aware of criticisms from teachers that the lack of questions requiring sophisticated CAS use suggests that the CAS calculators are not in fact needed by students. Examining Panels have struggled with the dilemmas in this respect.*
>
> *A panel has perceived a reluctance by SCSA to permit more sophisticated uses of technology in exams, lest differences between schools be too apparent. Not all questions require CAS (which is unproblematic), but SCSA seems uneasy about examiners anticipating a high level of expertise with CAS.*
>
> *The anticipated emphasis on formulation of problems – a major real skill required in high level mathematics – has not really occurred in exams, partly because of unavoidable exam constraints.*
>
> *Issues of paper balance, mean scores and disagreements of what is and is not on the syllabus have been problematic with panels. (E.g., good questions that all panellists and the independent reviewer have agreed were OK have been vetoed 'higher up' as not being on the syllabus.)*
>
> *Panels have been reluctant to include questions that require CAS use, in part because it is recognized by reviewers and others that there is differential access to sound CAS use, as it appears that many teachers do not make good use of the technology. Consequently, a reliance on CAS would be seen as an equity issue to an extent, and questions of that kind are likely to be rejected by reviewers.*
>
> *There is a perception that SCSA is wary of negative feedback, so that questions likely to be interpreted as too demanding, or focusing too heavily on CAS which is not well supported by teachers, are discouraged in case they result in negative discussion or even embarrassment to the Authority.*

Such comments make it clear that examining panels are often treading a difficult path between various extremes as far as CAS and other calculator use on exams is concerned, and are conscious that the balance between insufficient and excessive use of technology is both hard to find and unlikely to be agreed upon by all concerned groups simultaneously. There is a risk, if exams require too much technical expertise with calculators, that teachers and others will be concerned that mathematics has become less important than the technology use. Alternatively, if the exams can be completed well without using the power of the calculators (notably the CAS capabilities), teachers and others may claim that the technology is unnecessary. The comments also clearly indicate that there are no clear guidelines in place regarding questions of balance, consistent with the observations previously made in Section 7.

Panellists were also asked to comment on the practice of allowing students to take two pages of personal notes into the exams. This practice began when graphics calculators were first introduced into exams in the mid-1990s, partly to permit students to take instructions for their calculator into the exam (as calculator manuals were prohibited) and partly to compensate for differences between early graphics calculator models, some of which had a text storage facility. It seems that it has not been systematically discussed since that time, however, and it also seems (as noted in Section 7) that no rationale or other detailed advice regarding the practice seems to be published officially. Again, there was some divergence of opinion amongst the panellists interviewed:

> *Given that students have formula sheets, it's no longer clear what purpose is served by the notes. Notes are not used in other Year 12 subjects. Students who write out good notes for themselves learned from the experience, but tend to not use them in exams. There is little to be gained, however from students copying other students' notes, as some weaker students are inclined to do.*

> *I'm not sure these are a good idea: many students don't seem to put much effort into them, and they may even contain errors. I am not sure that they are widely used effectively, and would not be concerned if they were reduced to a single page (both sides) or even removed altogether.*

> *Notes have morphed into inappropriate uses, such as showing type examples anticipated to be on the paper. To some extent, some sorts of questions are inevitable on a paper (especially if it sticks to the syllabus and is not too hard), and students using notes to avoid learning the mathematics but relying on a standard example is a serious problem. It is also a problem for examiners.*

> *While it is often valuable for students to make their own notes, on balance it seems that many students misuse the concept, so that it is not clear why it has been persisted with. I have an impression that the bulk of teachers would disapprove of removal of the notes feature, perhaps because they encouraged its (mis)use?*

> *Notes are not regarded as problematic; the panel doesn't really give this much attention. The main benefit to students is in constructing the notes for themselves. The Formula Sheets provided are already quite comprehensive.*

> *I would prefer that notes were better used by students, and am concerned that some students seem to use them to pre-empt examination questions and solutions. I would not be concerned if notes were no longer permitted.*

Examiner reports for recent exams often draw attention to concerns expressed by markers about students' use of their CAS calculators. Accordingly, panellists were asked to comment on the impressions by markers recently of the nature and extent of student use of calculators in examinations, some of which are referred to above. Despite their diversity of experiences and the range of courses concerned, there was considerable unanimity among panellists on this matter, with all reporting perceptions of (large groups of) markers that there is considerable variation amongst teachers in helping students to use their CAS calculators judiciously and effectively:

> *This is a big issue, often discussed by markers and examiners: have students been educated by their teachers to use the calculators well (e.g., to annotate a diagram they get from the calculator) or just to write down an answer?*

> *Too many students do not seem to use their CAS calculators efficiently or well, and the likely reason is the ways in which teachers make use of them and the extent to which they help students to do so well.*
>
> *Do new teachers get sufficient help with this? In addition, many teachers are teaching mathematics out of field these days, and are not confident themselves with sound use of technology, it seems. Help is needed to address these teacher-related problems.*
>
> *It is clear that some students don't make good use of their CAS calculators, possibly because their teachers do not support them well enough to do so. Some 'switched-on' teachers will both use the technology well for teaching, promote its use for learning and give their students tips on sound use; students without such a teacher are disadvantaged in comparison.*
>
> *As noted regularly in annual Examiners' Reports, markers and examiners are unconvinced that students use their calculators well. It seems that, overall, students make less use of their calculators in exams than is expected. It is not unusual for lower level Maths courses to be taught by relatively inexperienced teachers, who may themselves be unfamiliar with sound calculator use or perhaps are less confident than might be expected with the technology; this might account in part for the limited student use of CAS.*
>
> *We have strong impressions of variation amongst teachers in the extent to which they make effective use of the technology; it is not a level playing-field as far as teachers are concerned. Too many students lack suitable level of competence with their calculators, which is perceived to be a teacher problem.*
>
> *Feedback from markers, reported in Examiners' Reports, often suggests that students use their calculators inefficiently, or don't use them at all, even when they would be very helpful. An inference is often made by markers that students have not been well taught to use their calculators judiciously and efficiently.*

Panellists were asked whether they see risks or benefits associated with a change of policy on the use of calculators in exams, including the possibility of permitting the use of only graphics calculators or scientific calculators (instead of CAS calculators) or even extending the allowable technology to more sophisticated devices such as computers. The five panellists offered different perspectives and insights on the issue, depending in part on the levels of courses being considered:

> *There are always risks and benefits, but there have been so many changes in recent years that changes to technology do not carry especially heavy risks. Changing to a graphics calculator would not be a big risk, although it would be unfortunate for some of the strongest students, who would be more limited by such a change (although it is noted that other technologies such as computers etc. in some schools would be available). A change to*

> *permitting only a scientific calculator would be too big a change and would diminish the mathematical opportunities in the course too much.*
>
> *I don't think there are strong risks or benefits associated with changes to calculator policy. A benefit of not allowing CAS calculators might be a return to a single exam paper rather than the double papers as at present. Even if calculators were removed from examination use, they could still be used in class teaching, although I recognize that in practice many classes would emulate the examination requirements, so that removal from exams might also involve removal from classrooms. There would not be too many risks associated with having different calculator expectations for courses at different levels, say CAS calculators for higher level courses, but not lower level courses.*
>
> *Teachers are weary of changes, especially these past few years. So further changes are unlikely to be welcome. I like the idea and the practice of the calculator free section (which wasn't there with graphics calculators). Teachers have generally accepted this, so there would be risks if it were now removed, and there was a return to a single exam (with a graphics calculator). Further changes may even lead to teachers leaving (e.g., retiring) more quickly, unwilling to cope with new changes?*
>
> *Any risks or benefits would depend on the actual changes made. For example, if exams allowed further technology use (such as tablets, the Internet or smartphones), there would be risks in maintaining equity and it would be problematic to compare students' performances reliably. A 'retrograde' step (such as permitting only scientific calculators) would carry even more risks, however, and increase the likelihood that students were not being prepared for their futures, which will include many technologies routinely. There are risks if technology does so much for students that the fundamentals of mathematics get neglected, although the calculator-free component addresses this risk to an extent; this is true for any calculator and the CAS element appears to be the scapegoat when it really isn't the major contributor to this concern.*
>
> *Although I am very impressed with the learning potentials of CAS calculators, I would be happy for CAS calculators to be no longer used in exams. I would like the capabilities to be available in classrooms, but I am uneasy about their availability in exams. There may be some risks if changes were made, so that staff needed to re-do investigations, etc, which assumed a certain level of technology.*

Finally, the panellists were asked to provide their personal views on the extent to which technology should be included in the courses in which they had been involved, including their examinations, and other related insights. Each was asked to choose between technology use in the course being reduced in importance, staying about the same or increased and extended. Although they are not a random sample of experienced and senior teachers, the views of the examination panellists' highlight a range of issues echoed elsewhere in this study:

Stay about the same: Pressures to increase technology use will continue (e.g., iPads, the Internet, ...) although we are not yet ready to do that practically, at least in a large state-wide examination system. Today's students need to be immersed in technologies, because they will live and work in a world that includes many technologies; mathematics courses that did not embrace technology would not serve them well. We still have an antiquated examination system that does not provide us with good information about real life, where people solving problems would have access to resources, the Internet, etc., although I recognise that it is difficult to provide a secure and fair state-wide examination system that reflects real life well.

Somewhere between reduced in importance and staying about the same: Not increased in importance, however through the use of laptops, which would open a Pandora's Box of problems, and be likely to exaggerate teacher differences even further. Schools need very substantial facilities to cope with updates/software maintenance/hardware maintenance etc. … a 24 hour help-desk. While some schools are adequately resourced, many are not: the haves and the have nots. There would be significant PD needs as well. I have the impression that the quality of [teacher] *candidates has been declining recently, inevitably as the quality of the teaching force has been declining in recent years. Declining teacher expertise is a major problem. Examining panels are criticized for low mean scores, but the real problem is that the students as a group are less capable than previously, not that the papers are too hard.*

Somewhere between reduced in importance and staying about the same: Although scientific calculators might be used for many calculations, more sophisticated calculators (such as graphics calculators and CAS calculators) provided significant help with statistics and with graphing. There is strong appeal in the visual nature of technologies for teaching purposes, as distinct from student learning purposes, especially as projectors are now common in classrooms. I am not sure whether more recent calculators with strong computation capabilities (but without graphing, CAS or statistical graphing) would be sufficient, but I am not convinced that CAS access is important for less sophisticated units; the most important features of calculators (in addition to calculating answers) are related to statistics and to graphing, not to the CAS elements.

Stay about the same: I am comfortable with the status quo, mostly. Computers are fine to use in classes, but it would not be wise to do so in timed exams; there are big risks of students wasting lots of time, apart from issues of controlling the context and keeping things equitable between students. Some people lap up new technologies, while others are less inclined to do so.

Stay about the same: I have heard of (but not used) advanced scientific calculators with many computational capabilities, which could be used instead of CAS calculators, although the lack of access to a graphics screen would be problematic for both graphing and statistics. I would not want the *access to technology overall to be any less than at present, but I feel that the technology can be better used and doesn't need to include CAS calculators. Most schools and students these days have access to laptops/iPad/apps of various kinds, which offer many opportunities.*

8.3 Issues for consideration

Taken overall, it seems that while the insights of the examining panel members who agreed to provide advice to the research team do not argue strongly for a change to the status quo regarding technology use in examinations, there are some issues that seem worthy of further investigation with the new suite of mathematics courses in mind. At present, the new ATAR mathematics courses have similar assessment structures as the existing Stage 2 and Stage 3 courses, but an exploration of some of the existing issues may be advisable. These include:

(i) whether it is appropriate for different technology requirements to be made for courses at different levels, such as expecting CAS calculators for the most sophisticated courses and less sophisticated calculators for less sophisticated courses. On the surface, this might seem sensible, but it may create practical problems in schools for teachers teaching a range of courses and needing to develop proficiency with several devices, and for students moving from courses at one level to those of another level;

(ii) whether there should be a directive of some kind for examining panels to include a range of questions in exams, from those requiring sophisticated and high-level use of technology to those for which technology is unhelpful. A consideration of a principle that both over-use and under-use of technology are inappropriate and would lead to an inherent penalty of some kind might be undertaken;

(iii) whether the case for students bringing in two pages of A4 notes warrants re-investigation, in the light of the experiences of examination panels over recent years; to date, this issue seems not to have been systematically studied, nor teacher opinions canvassed on it;

(iv) whether and why it is appropriate for students to be permitted (and thus, encouraged) to bring several calculators with them to examinations; on the face of it, this would seem to open an equity issue, as those students who can afford to have more than one CAS calculator would seem to have an advantage. In addition, the practice of permitting students to use their scientific calculator as well as their graphics calculator or CAS calculator may well inhibit any motivation to develop expertise with the more sophisticated device.

(v) how teachers can best be supported to help students to make effective use of the technology expected to be used in courses and in their examination; it is not clear that there is an appropriate mechanism for this at present, although it seems to have been a regular concern expressed by examiners and markers of examinations for some years now.

(vi) to what extent the assessment practices in the school context should be the same as those in the (timed) external examinations; at present, it seems that the examinations are used to moderate in-school assessments, thus discouraging schools to undertake innovative assessments, such as extended projects, that might be able to encourage better student use of technologies such as CAS calculators, as well perhaps as other technologies available in a particular school, but not permitted in an examination.

(vii) preliminary study of the prospects and feasibility of computer-based testing in mathematics (but not restricted to unsophisticated response selection testing such as multiple choice or completion items, which are unlikely to be positively regarded by teachers) for which there are some trials taking place in Australia and internationally; while it is clearly too early to contemplate such a change, preliminary work might be undertaken in the near future.

9. Overview of alternative learning technologies

One of the motivations for this project is to provide an up-to-date accounting of the availability of a variety of technologies to support the teaching and learning of mathematics in schools. This variety has become increasingly evident in recent years and advice on how widespread its use is was sought from the surveys of both teachers and students. In this section, a brief description of the alternatives known to be in common use is provided, together with their apparent main advantages and disadvantages for school use. While the technology used in mathematics examinations is usually tightly controlled, in the interests of both clarity and equity, there are no constraints imposed on the technology used in classrooms or at home. As a consequence, some students have access to a variety of forms of technology for learning and for doing mathematics, dependent in part on the decisions made at a school and by their teachers, as well as by their family's financial resources.

Although indicative prices are given for some of these technologies, in order to provide a sense of scale, it needs to be noted that prices vary substantially in practice for a range of reasons. These include market forces, volume discounting, regular developmental changes, exchange rate fluctuations and differences in the mechanisms for technology devices to be purchased. Retail purchases tend to be more expensive than those organised via schools, but there can be differences between prices at schools as well, as there are commercial arrangements between firms managing school booklist purchases and the schools themselves that may result in variations for various purposes, as well as competitive pricing amongst calculator dealers.

9.1 Scientific calculators

Scientific calculators have been in widespread use in Western Australian schools since their introduction in the late 1970s, after they had become more affordable to school students. As Kissane (2001) noted, their adoption resulted in earlier technologies for arithmetical calculation (such as table books, logarithms and slide rules) being superseded and, during the 1980s, they were officially recognised in curricula nationwide as important tools for students.

While various models have slightly different sets of capabilities, modern scientific calculators cost about $30 and typically handle arithmetic computations, previously tabulated values (such as trigonometric and logarithmic functions), univariate and bivariate statistical calculations, fractions and decimals, roots and powers of numbers, scientific notation where necessary, (pseudo-) random numbers and combinatorics. Some current models provide other features as well, including the solution of simultaneous linear equations, representation of surds and operations with complex numbers. In recent years, scientific calculators have become easier to use, with syntax similar to everyday mathematical syntax and displays with more than one line. Generally, since scientific calculators are manufactured for educational use, it is possible for computer emulators to be obtained, to support their use for teaching in classrooms. To an extent, for reasons of economy of scale, scientific calculators typically used in Australian schools often tend to be those approved by the NSW Board of Studies, which presently would not permit students to access certain features possibly regarded as helpful by teachers (such as the numerical solution of equations, tabulation of functions and use of surds).

The principal arguments in favour of the use of scientific calculators are that they are relatively inexpensive and are likely to be purchased by students early in the secondary years, so that students are comfortable with their use by the time they reach senior secondary school. When students need to complete a numerical calculation, a scientific calculator is convenient and familiar and thus likely to be efficient. In addition, in some senior secondary school subjects, notably the science subjects, students are restricted to using a scientific calculator in their WACE exams.

The principal arguments against a focus on scientific calculators is that they are mostly limited to numerical computational purposes, and hence are less likely to be used as learning tools for mathematics. These limitations arise from the restricted suite of mathematical capabilities in the calculators and, critically, by the lack of a graphics screen (to permit the display of visual information, such as a graph of a function, a statistical display or a geometric object) or the easy display of several lines of text.

9.2 Advanced scientific calculators

In recent years, some scientific calculators with a much wider suite of mathematical capabilities have been developed, although they are not as widely used within Australia as are less sophisticated models. The major calculator manufacturers (CASIO, Hewlett-Packard, Sharp and Texas Instruments) all manufacture advanced scientific calculators, with varying functionalities. These include CASIO's fx-991ES PLUS series, Hewlett-Packard's HP-35S, Sharp's EL-506X and Texas Instruments' TI-36X PRO, all of which are available in Australia, but rarely used in schools. The extra capabilities involved mimic many of those found on graphics calculators, including computation related to equations, matrices, vectors, complex numbers, numerical calculus, function tabulation, series, logarithms to various bases, various probability distributions and spreadsheets; of course there are variations in the suite of capabilities amongst the various models. In general, these calculators are more complicated to use than are standard scientific calculators, in part because it is not possible for the large number of calculator functions to be accessed directly on the keyboard, and so a menu structure of some kind is necessary.

Advanced scientific calculators significantly lack a graphics screen, but otherwise have mathematical capabilities that reflect many of the computational elements of mathematics in stronger senior secondary courses. (They might, in fact, be regarded as similar to graphics calculators, without the benefits provided by a graphics screen.) They would seem to offer more opportunities for learning than less sophisticated scientific calculators, in part because of their wider suite of capabilities, and because they are less restricted to being used solely for computation. Emulator versions are generally available for teaching purposes. Examples and a further analysis of the significance of advanced scientific calculators are provided in Kissane and Kemp (2013). Extensive examples for current models are available from Kissane (2015c) and Kissane & Kemp (2014).

The principal argument in favour of advanced scientific calculators is that they seem to offer a broader range of computations than regular scientific calculators, and so are more likely to be useful when only a computational result is sought. Importantly, the range of mathematical capabilities in theory offers a greater possibility that they would support conceptual development, rather than be restricted to computation. Although likely to be more expensive than regular scientific calculators, it is difficult to determine their typical price in Australia unless they were routinely available. They are likely to be less expensive than graphics calculators or CAS calculators, however, and a useful rule of thumb is that they would be likely to cost around two to three times as much as a regular scientific calculator, with of course variations within and between competing brands.

The principal argument against the adoption of advanced scientific calculators is that they do not have a graphics screen, and thus are limited in key areas of mathematics, including importantly the use of functions in algebra, trigonometry and calculus, the use of geometry and the analysis and visual representation of statistical data. These substantial limitations may in fact discourage their use in practice for purposes beyond computation. Less importantly, were students to change from the use of a familiar scientific calculator in lower secondary school to an advanced scientific calculator in senior secondary school, they would need to learn how to operate the new device. As the question has not been discussed, it is not clear whether calculators of these kinds would be permitted for use in science and other non-mathematics subjects.

9.3 Graphics calculators

Graphics calculators have been available to schools for almost thirty years now, and can be seen in hindsight as a natural development of scientific calculators, but with superior capacity to explore and represent key mathematical ideas encountered in the secondary school. Where a principal purpose of scientific calculators has often been to undertake numerical calculation, graphics calculators have become prominent in school mathematics internationally because of their capacity to support student learning of mathematics, in addition to handling the numerical computation associated with secondary school (Kissane, 2007).

Although these are sometimes described as ‘graphing’ calculators, such a term is limiting as it suggests that the key feature is a capacity for graphing functions; the addition of a graphics screen to a scientific calculator has allowed for graphs of functions, but also for graphical displays of statistical data and geometric objects to be reproduced and manipulated to support student learning. (Indeed, in recent years a common term to describe this technology is a *graphics display calculator*, abbreviated to GDC by, for example, the International Baccalaureate Organisation, to avoid thinking of them solely as graph-generation devices.) The larger screens of graphics calculators (compared with those of scientific calculators) have allowed for several lines of text to be included, so that other representations of mathematical ideas are also supported, such as tables of values, statistical data, matrices, vectors, systems of equations and spreadsheets. Similarly, the availability of several lines of text facilitates the construction and use of calculator programs, for a variety of purposes. Graphics calculators might, in fact, be regarded as similar to CAS calculators, but without the symbolic manipulation capabilities of the latter. Graphics calculators were developed primarily to support the teaching and learning of school (and early undergraduate) mathematics, rather than for use by professionals in quantitative environments, and are arguably the first technology targeted for that purpose. They have been routinely used in senior secondary schools throughout Australia, with the exception of New South Wales, for around 20 years now. Because they have been in common use for a good deal of time internationally, there is now a body of research on their educational use, most of which suggests that they have been used beneficially for a range of purposes (as noted in Section 3 of this report).

The principal arguments for graphics calculators revolve around their capacity to support students to represent and then explore a wide range of mathematical ideas of importance in secondary school. By their nature, graphics calculators include the computational capabilities of scientific calculators, and generally significantly more, so that it is not necessary to have both; these computational capabilities render some kinds of mathematical work more manageable, most notably statistical analysis, mathematical modelling and the understanding of functions.

The main arguments against the use of graphics calculators have been that they are regarded as too expensive for some students (modern examples cost between $170 and $190), that they might discourage students from understanding mathematics (by using them without fully understanding the mathematics involved), that they are more limited than computers and, perhaps ironically, that they are insufficiently powerful to be tools for professionals, and thus not widely used in universities.

9.4 CAS calculators

A natural development of graphics calculators involved the provision of a symbolic capacity, in addition to the graphical, numerical and statistical capacities routinely provided on various models. As noted in Section 2 of this report, Computer Algebra Systems (CAS) first appeared on mainframe computers and then personal computers in the 1970s, while powerful computer software such as *Mathematica* and *Maple* have become commonplace in professional settings in the past twenty years. While the computer algebra systems developed for calculators, from the late 1980s, are very much less powerful than full-blown professional systems, their target of school mathematics makes clear that relatively unsophisticated systems are sufficient to meet likely needs. Modern CAS calculators typically provide all the capabilities of graphics calculators; in addition they permit users to undertake elementary algebraic representation and manipulation, mostly typical of school algebra and trigonometry, as well as to undertake differentiation, integration and solutions of elementary differential equations, typical of school calculus courses. CAS calculators thus enable general solutions to equations and indefinite integrals to be determined, rather than being restricted to numerical work (as are graphics calculators).

Importantly, CAS calculators have provided a suite of capabilities, consciously designed to meet many of the learning and computational needs of mathematics students in the senior secondary years, in a single, portable device. Recently, CAS calculators, as well as providing symbolic capabilities, have typically also provided superior representations for students than their graphics calculator predecessors, with larger, higher resolution and coloured screens and sufficient memory to store information. In the circumstances, it is not surprising that both teachers and students commonly refer to a CAS calculator, even when they are not making use of the particular algebraic capabilities that distinguish the device from its predecessors. In effect, they might frequently use the device as a graphics calculator, such as focussing on statistical analysis, numerical equation solving or graph generation.

The main arguments in favour of CAS calculators have been related to their comprehensive coverage of the learning needs of mathematics students, with sufficient graphical, symbolic, numerical and statistical capabilities in a single device to be adapted to most parts of most senior secondary mathematics courses. Additional arguments have been about the quality of the devices themselves, especially their screens and the integrated nature of their various functionalities. By their nature, CAS calculators include all of the capabilities of graphics calculators, so that it is not necessary for students to have both (at least from the same manufacturer) or to have a scientific calculator. As there are only a few manufacturers of

CAS calculators, it is manageable for examining panels to understand well all of their capabilities.

The main arguments against CAS calculators have been related to their price (typically between $210 and $220 at present, about 10-15% more than graphics calculators), to concerns that they might discourage students from understanding mathematics (by using them without fully understanding the mathematics involved), to their complexity of use (which seems to be partly related to their wide range of functionalities and hence the need to use menus of some kind), and to their limitations compared with computers and specialised mathematical software. In addition, their limited use in early undergraduate mathematics teaching and assessment is also regarded as a counter argument by some.

9.5 Computers

While it is still possible for students to use stand-alone computers, or even computer laboratories, for mathematics, the impracticalities of these have meant that in recent years laptop computers have become the preferred mechanism for students to access computers in mathematics classes. The most likely mechanism is a whole-school program in which students purchase their own laptop, with direction from the school. In some schools, too, Federal-government sponsored computers for senior secondary students are significant resources. In some cases, schools have available a portable collection of laptop computers that can be accessed by a class relatively easily (e.g., on a trolley). Many schools have adequate WiFi networks, so that laptop computers can also be used to access the Internet as well as local materials, including centrally housed software.

Computer software for mathematics continues to be problematic. Good commercial software for school use tends to be relatively scarce and relatively expensive, with a site license often beyond the budgets of mathematics departments, but individual copies of software are too expensive for schools to require all students to purchase. Thus, very few schools seem to have made use of the best commercial school mathematical software of recent years such as *Geometer's SketchPad*, *Cabri Geometry*, *Cabri3D*, *Fathom*, *TinkerPlots* and *Autograph*. A significant exception is Microsoft *Excel*, which, while certainly not designed for education, has been used often enough for mathematics purposes for there to be examples of sound use, and the software is commonly bundled with computers or school site licenses and thus does not require additional purchase. Some years ago, the computer software *Derive*, a computer algebra system, was used in some countries (notably Austria) in schools. Recently the professional level mathematical software *Mathematica*, a very sophisticated software environment that includes programming and computer algebra capabilities, has been used in some Victorian schools, through the purchase of site licenses in a trial project.

In addition to software directed at schools, it is possible for schools to make use of commercial software originally designed for a professional audience. Probably the best local example is the recent Victorian use of Wolfram Research's *Mathematica* (Wolfram.org, 2015), a high-end mathematics software package (with a full suite of computer algebra capabilities) designed for working professionals in mathematics, science and related areas, and thus generally an expensive package, together with other software products from the same company. This software is available via a state-wide site license for students in years 7-12 in government schools in Victoria (Bauling, 2015). In addition, the Victorian Curriculum and Assessment Authority (2015c) has conducted trials of the use of this software in volunteer schools for the Mathematics Methods (CAS) course in Victoria over recent years.

In addition to using the software for purposes of teaching and learning, students in the trial use the software on their computers for formal assessment purposes in the course at the end of Year 12. *Mathematica* is used to deliver the paper electronically, and students construct their responses using the software and then transmit them online. The trials require significant school-based resources, as well as suitable teachers, and generally involve students working with the software well before starting the Mathematical Methods (CAS) course in Year 11, in part to ensure that students are not disadvantaged by the high-stakes nature of the course (Bauling, 2015). The trials are taking place without a need for the students to purchase the software, which is made available via the site license, but such an arrangement may be more problematic should the project proceed beyond a trial stage. Students need good access to sufficient computing resources to run the software, but this can include a tablet. While it is valuable for these trials to be taking place, and the results of the trials will be of wide interest, *Mathematica* is regarded by some as challenging for many beginners, and it seems unlikely that a result of the trial will be a suggestion that it has broad use across senior secondary school mathematics, but is likely to be of high relevance to the most sophisticated students. However, others have a different view, and the result of the trails and the experience will cast light on such questions. The scaling up of work of this kind from a small group of trial schools to a whole state, may prove to be problematic, but again it is too early to tell. Nonetheless, work of this kind is worthy of attention, and the experiences of the trial will be informative over the next few years.

The use of computers as the basis for the mathematics curriculum, especially based on *Mathematica* and its derivatives, is argued by computerbasedmath.org in a well-developed case (Computer-based Math, 2015). The essential argument for this more radical proposition is that the mathematics curriculum typically evident in countries like Australia is insufficient for future needs of individuals or wider society, since so much of the focus is on hand computation that is better carried out by machines, and workplaces have become increasingly computerised. In describing what it regards as the problem with today's mathematics curriculum, the organisation notes:

> It's 80% a different subject from what is required. Why? Because computers mechanized computation beyond previous imagination and do calculating really well. Today's math education spends 80% of the curriculum time gaining expertise in hand–calculation methods and algebraic manipulation. The curriculum is ordered by the difficulty of the skills necessary to complete the calculation, rather than the difficulty of understanding the complexity of the topic. (para. 6)

The focus of the alternative CBM curriculum proposed is problem solving, under the assumption that computers (including versions of *Mathematica*) are available to all:

> The CBM curriculum is unique in assuming computers by default, and so avoiding the need to learn most of the complex hand–calculation skills that were vital to our predecessors. The CBM curriculum has been written from core guiding principles that firmly focus on the needs of learners for jobs and everyday life in the near future. (para. 7)
>
> The new curriculum is problem centered versus the traditional mechanics–centered curriculum, so students are taught to solve problems using the tools available to them, rather than learning isolated, out–of–context skills, like

> completing a long division problem or calculating standard deviation. In today's curriculum, computers are mainly used to assist in the teaching of hand–calculation techniques. (para. 9)

These arguments are well presented online and the organization has developed materials to implement them in schools, making use of *Mathematica* and associated software. Such developments merit close consideration, although it is difficult to see circumstances in which such a radical and paradigmatic change might be implemented on a wide scale in Western Australia at the present time; the Victorian work in doing so in a more limited way has merit, as noted above. Amongst the reasons for such a position are:

- Assumptions about access to suitable technology access by students; while becoming more realistic in some schools, the wide range of school and personal resources in WA make universal use problematic at present. Schools that are struggling with perceived inequities in the case of calculators would presumably encounter even more significant problems in a computer-based curriculum.

- Assumptions about teacher expertise and associated professional development needs; again, there is a wide range of needs, with some schools likely to find such a curriculum manageable, and others struggling significantly.

- Mechanisms for development, approval and implementation of SCSA mathematics courses, including their relationship with national courses; recent changes have already begun to be implemented, and realistic timeframes for further changes – especially on the scale proposed by CBM personnel – would need to be considered.

- Issues of assessment, both within schools and in external examinations; while the trial Victorian work indicates that these might be manageable in the right circumstances, considerable work would be needed to effect this, rendered difficult by a teacher workforce that is tired of change.

- The apparent reluctance of universities to embrace much more primitive hand-held technologies, described in some detail in Section 6, would seem to render even more problematic a significant escalation in the extent to which technology was seen as foundational to the school mathematics curriculum. While the school curriculum ought to be seen differently from tertiary curricula, existing concerns about gaps between the two would be exaggerated by moves in this direction.

- While there are clearly some mathematics teachers enthusiastic about increasing the connections between school mathematics and technology, there would seem to be a significantly larger group of different orientations, as revealed in survey responses in the next section.

None of these are arguments for a lack of Western Australian attention to such developments, or even arguments against some active trialling of them in local schools, but it seems on balance unlikely that all of these issues will dissipate sufficiently in the near future for more than a watching brief to be maintained. Indeed, Conrad Wolfram, a key international advocate for the CBM position, has suggested that the project may be a 25-year venture.

An alternative to commercial software is 'free' software, the most popular example of which is *GeoGebra*, which was originally a dynamic geometry package like *Geometer's SketchPad* and *Cabri Geometry*, but in recent years has included developments in both statistics and CAS. Originally developed with grant money (from the National Science Foundation in the US), *GeoGebra* is not sold commercially (although apparently recovers some of its costs from commercial uses), with the consequence that it has had very limited resources for software development (such as new features, adapting to new operating systems, etc.), research to improve its features or even routine maintenance (such as repairing bugs) or targeted professional development support. While these limitations probably don't interfere with low-level use of the software, they seem likely to become increasingly problematic in time. Regrettably, the availability of 'free' software has undermined the development of other commercial software, which requires significant resources for survival and improvement, so that the outlook for good free software for school mathematics is at best limited. It now seems less likely than previously that good commercial mathematics software will be developed, and consequently schools rarely have a budget for that purpose. Some free software is available for mathematics beyond secondary school level, such as *SageMath* (SageMath.org, 2015), which is seen by its developers as an alternative to high-end commercial software such as *Mathematica.*

The main advantages of computers with educational software are that computers are much more powerful and adaptable than calculators and have larger screens. This is the case with sophisticated mathematics software like *Mathematica*, which can be used for examinations as well as classroom learning, at least in theory. As noted earlier, computers can also run software in the form of CAS calculators, so essentially can reproduce the capabilities of CAS calculators, and yet do many other useful things as well. Laptop computers provide a number of other benefits to students, in other aspects of their schooling, as they can also be used for a wide variety of purposes, including accessing school networks and other Internet sites, as well as using soft copies of textbooks. Increasingly, publishers have offered online materials in support of their textbooks for computer access.

The main disadvantages of computers are that they are significantly more expensive to purchase than calculators, and generally require significantly more resources for effective use, as software needs to be purchased, or adapted and teachers need to be supported. Typically, a variety of software programs is needed, to meet the needs of various parts of the curriculum, requiring both students and teachers to be competent with several different systems. Computers need regular maintenance, for both hardware and software, so that substantial investments in IT infrastructure are required, in addition to the costs of the devices themselves. At present, computers are rarely used in external (or internal) assessment, as it is too difficult or expensive to ensure equity of access, comparability of computer software and hardware and guaranteed telecommunications security. (Although some work in these areas is taking place, such as the Victorian use of *Mathematica* and the Finnish use of a variety of software online, each described briefly elsewhere in this report.) Using computers as the foundation for the mathematics curriculum does not seem a realistic proposition at present in Western Australia, although that might change over time. While significantly more powerful and versatile than calculators, computers connected to the Internet can also be a significant distraction for many adolescents, drawn to social media and entertainment sites.

9.6 Tablets (with specialist apps)

Tablets are a recent species of computer that have proved to be popular for many everyday uses. Typically, they provide users with an opportunity to run a variety of software applications (apps), allow Internet access and offer a touch-screen user interface. Tablets offer more limited opportunities for computing than do conventional computers, so that some features are unavailable (notably interactive websites that require *Java* or *Flash*) and some software does not operate on some tablets because of machine limitations. Recently, it has become easier for tablets to be projected for whole class use, although this is not the case for less expensive tablets. The most powerful tablets (such as Apple *iPads* or Samsung *Galaxies*) are the most robust, and provide access to the largest range of apps, but are also the most expensive, typically costing several times as much as a CAS calculator and more than low-end laptop computers. Less expensive tablets are also available, costing around the same price as a CAS calculator, although these do not seem to be designed to withstand sustained educational use. Like computers, tablets provide large, high resolution screens, which can effectively present complex information well. Some devices used by schools effectively function as both laptops and tablets; examples include Microsoft's *Surface Pro* and Toshiba's *Ultrabook*. So the distinction between computers and tablets is perhaps blurred in such cases. For assessment purposes, especially assessment involving production of answers (as distinct from responding to selection items, such as multiple-choice items), tablets are still regarded as problematic. While Internet capabilities can be temporarily turned off (as now happens routinely on aircraft), they can generally be easily turned back on again by a user, as tablets have been designed in part to facilitate Internet access.

The main advantages of tablets are similar to those of computers, with high quality screens, operated by touch with versatile uses in mathematics and elsewhere in the school curriculum. They are typically smaller and lighter than laptop computers, and thus more portable; for this reason, they are potentially useful as textbooks, with manufacturers often producing e-versions of printed texts, literally reducing the burden on student backpacks (and backs!). Tablets can be used conveniently to access the Internet (sometimes with software restrictions, however) and can access versions of some mathematical software online. As for computers, tablets are multi-purpose devices, not restricted to mathematics, and typically contain a variety of applications such as music, photography and entertainment, so they will have uses elsewhere in the school as well as in mathematics.

The main disadvantages of tablets are similar to those of computers too, with substantially more costs to purchase the devices and to provide an environment for using them. In addition, there is much less high quality educational software available – very few of the thousands of apps produced seem to have been developed by education professionals. The longevity of tablets is difficult to determine, but battery life may be less than is required of a school device, with battery replacement being very expensive. While it is possible to obtain tablets with data plans, it is more likely that tablets require a WiFi service for Internet access. As for computers, tablets also have significant potential for distraction of adolescents: indeed, the attraction of tablets is their capacity to engage the user in a wide variety of activities, many of which might be regarded as a distraction from learning mathematics.

9.7 Smartphones (with specialist apps)

The distinction between tablets and recent models of smartphones is becoming blurred, so that it might now be reasonable to regard a modern smartphone as a tablet that has a telephonic capability. Although there are other platforms, the major two operating systems of Android and iOS seem to account for the bulk of sales and anecdotally to be most popular amongst adolescents, and high-end models now have most of the capabilities of tablets, referred to above. Prices vary considerably, but typically smartphones cost several times as much as a CAS calculator. Although phones can be purchased outright, it seems to be typical in WA for users to purchase phones on a phone and data plan, which build the cost of the device into the plan over 24-month installments. In a fiercely competitive market, it is difficult to generalise about prices, but popular phones cost around two to four times as much as a CAS calculator, while typical 24-month bundles with phones, phone calls, messages and data cost around five to eight times the cost of a CAS calculator. Their smaller size makes some of the more mathematically useful apps difficult to use, as they require fine touches with fingers, and some apps that work on a tablet will not work on a smaller device for other reasons (such as *GeoGebra* and *TI-Nspire*).

The main advantages of smartphones are similar to those of tablets, albeit with limitations associated with screen size. Unlike tablets, smartphones often have Internet access, and so are not restricted to WiFi. A clear advantage is that many students seem to already have a smartphone, and are familiar with its use for many personal purposes. Recent smartphones have become larger, and can almost be regarded as small tablets.

The disadvantages of smartphones would seem to be substantial. A major disadvantage is their price, likely in practice to be several times as much as a CAS calculator, so that it is clearly unlikely that they would be purchased specifically for mathematical use. Their functionality for mathematics is considerably less than that of tablets, computers and CAS calculators, with limited likelihood that they could be projected in a classroom or printed from. Their independent Internet access is likely to be regarded as a risk rather than a benefit in schools, which often take steps to prevent students accessing undesirable content. The prospect of students communicating or accessing the Internet via smartphones suggests that they are unlikely to be welcome in formal assessment in the near future. Although, like tablets and computers, Internet and telecommunications access can be disabled on the device, smartphones have been consciously designed for people to reconnect them quickly and easily (and surreptitiously). Many schools have reached a view that the educational disadvantages overwhelm the advantages of smartphones, and have banned their use at school, mindful of their significant potential for distraction through the use of social media, messaging, photography and music or even because of concerns about malpractice (such as cyber-bullying) although it is not clear that these bans are always successful or how well enforced they are, with an adolescent population in which the devices are extremely popular.

9.8 Internet

The use of the Internet for education purposes has increased significantly in recent years, and there are now many opportunities for both mathematics students and teachers to access helpful material of various kinds. A typology of the possibilities is described in Kissane (2009), recognizing that both students and teachers of mathematics can use the Internet in important educational ways. Increasingly, schools have provided Wi-Fi capabilities so that students can access the Internet in class (provided they have a suitable device) and it is now becoming increasingly common for students to have good Internet access at home as well, although of course there are still substantial differences between both schools and communities in these respects. The development and gradual roll-out of the Australian National Broadband Network can be expected to improve both the nature and extent of access to the Internet for educational purposes. Internet access provides a ‘real-world’ opportunity for classrooms, allowing students to engage with actual examples of mathematics; unfortunately, they are also able to engage with many other varieties of materials online, not all of which are helpful for mathematics lessons. In many schools, a local Intranet serves important purposes, including administrative purposes, and allows ready access by students to suitable material for learning. It seems likely that the Internet is regarded mostly as a supplement to typical classroom experiences in mathematics, rather than being integrated within it, although there is of course variation in that regard, dependent mostly on the teacher. Increasingly, publishers are providing support for materials via the Internet and commercial companies have developed software of various kinds to support students: two popular Australian examples are *Mathletics* and *HOTMaths*. In addition to commercial products, online materials of various kinds relevant to mathematics have been well-used by teachers and students, including software like *Desmos* and *GeoGebra*, instructional sites like *Khan Academy* and general purpose repositories like *You-Tube*. While opinions differ on the quality of some of these materials, they do at least provide alternatives for students to support their learning.

The main advantage of the Internet is that it can provide a wide range of experiences for students learning mathematics that are not regularly available in class. While it is difficult to develop high quality materials, so that teacher guidance is important for efficient use, there are many opportunities opened up to students by Internet access, both at school and at home. Each of the WA senior mathematics courses offers teachers selected web links to support the courses.

The main disadvantages of the Internet are connected with its vast size and scope, so that, while there are many valuable materials, there are many materials of inferior quality and even materials from which parents and teachers would like to shield their students (and in schools at least, often take steps to do so.) So, while the Internet can be used to good effect, especially with a conscientious, informed and capable teacher, it can also be used poorly (such as for cyber-bullying, pornography, plagiarism) or can waste a lot of valuable mathematics learning time (such as social media, gaming and entertainment purposes). Providing and maintaining adequate Internet access in schools can also be expensive, although the cost of doing so in schools is rarely the responsibility of the mathematics department directly. In addition, Internet access can be very helpful for some purposes and very problematic for others (such as using computers and tablets in formal assessment, when Internet access can threaten both the validity and the authenticity of a student’s work).

9.9 Costs of technology

The costs of technology are significant and give rise to the possibilities of difficulties for some students, when family resources are limited; in addition, schools have differential access to technology resources, and some students might study mathematics under financial constraints of both their family and their school circumstances. Regular comments from teachers and others regarding the costs of technology make it clear that the costs are problematic for some students and there are risks of inequities. (Of course, it needs to be recognised that there are many inequities in Australia in addition to difficulties in providing technologies for mathematics education, and, indeed, Australia is recognised as having a significant and growing problem in this regard generally.)

Comment is often made informally regarding the costs of CAS calculators, which are regarded as increasingly expensive by some, perhaps in part because they are regarded as somewhat more expensive than graphics calculators (the technology that they effectively replaced in examinations several years ago in WA). (This impression is possibly exaggerated by the purchase cost of CAS calculators typically exceeding $200, which might for some be regarded as a hurdle when the first digit has changed from 1 to 2). Accordingly, a brief examination of purchase prices of calculators was undertaken.

To see whether the extent to which the price of calculators is increasing, prices of typical graphics calculators in 1998 were obtained via a large calculator sales company. The year 1998 was chosen as it was shortly after the introduction of graphics calculators into TEE courses in Western Australia. Although there were variations between manufacturers, a typical price (including taxes) at that time for a high-end graphics calculator was about $160. The Australian Bureau of Statistics (2015) hosts an online calculator for the purpose of comparing the monetary value of goods over time in Australia; this calculator is regarded as authoritative because the official data regarding the CPI are obtained and managed by the ABS, and the same data are used by the Australian Taxation Office. The equivalent in 2015 to $160 in 1998 after taking account of Consumer Price Index (CPI) changes since that time is $256, well beyond the cost of a top end graphics calculator in 2015, which generally cost less than $200 at this time. It is also more than the cost of typical high-end CAS calculators in 2015. Given that current models of graphics calculators are substantial improvements on 1998 models (e.g., with colour screens and more functionality), the fact that they have *declined* in price, relative to the price in 1998, seems to be not widely appreciated. Nor is it recognised that a CAS calculator in 2015 costs less in real terms than did a graphics calculator in 1998.

Similarly, the relatively small disparity between the cost of graphics calculators and CAS calculators is not widely recognised (quite possibly because teachers and others are rarely engaged in comparing prices). Yet the cost of a CAS calculator is typically 10%-20% more than a graphics calculator from the same manufacturer. When CAS calculators were first introduced, teachers were aware that the additional cost to purchase a CAS calculator, instead of a graphics calculator was relatively small, but the passage of time has possibly made it harder to appreciate this.

Comparisons of calculator costs can be made with earlier calculators as well in this way. Thus, when scientific calculators were first used in senior secondary school external examinations in Mathematics in WA late in the 1970s, they were (understandably) regarded as expensive, although their costs were regarded as manageable for students and their families and the mathematical benefits were regarded as sufficiently important to justify the costs. For example, Kissane (2006, p. 5) reports a teacher's 1977 observation that a scientific calculator with rudimentary bivariate statistics capabilities could be purchased at that time for $40; the teacher's observation was made to support his argument that the technology was affordable to schools. Using the ABS online calculator, the equivalent cost in 2015 is $210, which is around the cost of a CAS calculator in 2015. Thus, while the cost of the technology over that period has stayed about the same in equivalent terms, the functionality of the calculator available for a similar cost has massively increased.

While the costs of high-end calculators are decreasing, and not in fact increasing, relative to CPI, they still represent significant investments for some families. In that case, there would seem to be some disadvantages to purchasing them at the start of Year 11, since that means students will use them only for the final two of their six secondary school years. Many schools seem to start using them at the start of Year 10, and others even at the start of Year 9, which gives students more opportunities to use the technology for learning and also might reduce the need to teach students how to use their calculators at the same time as they are starting senior secondary school. This would require some level of comfort with using only some parts of the device in the lower secondary years, as the levels of mathematical sophistication are lower than they are in senior secondary school. There is also a risk that some students might choose to discontinue studying senior mathematics or elect to follow lower-level courses, so that more substantial mathematical capabilities might not be needed in senior secondary years in such cases.

An additional aspect to the cost of technology for mathematics is that it is restricted to use in mathematics, as distinct from other technologies (such as laptops, tablets and smartphones), which are used in a number of aspects of school (and life). While there are some advantages to being restricted to one area, most notably the minimization of the distractions that are often of concern with the other devices, the lack of acceptability of graphics calculators and CAS calculators in other quantitative subjects, notably science and social science subjects, is unfortunate. It is not clear how carefully the decisions were made in other subject areas, and the strength of the arguments involved, but many students of mathematics would be able to make good use of their CAS calculators or graphics calculators in other subjects, both for handling computation and for dealing with real data, were they permitted to do so. As well as making good use of the calculator purchased for mathematics, they would also be likely to improve their capabilities with the sensible use of the calculators if they were to use them more widely. Such use would of course have implications for teachers of other subjects, however.

Other costs of technology in schools are usually hidden, such as the costs of providing the human and physical infrastructure needed for the use of tablets and a wireless network in a school; as these costs are not borne directly by students or their families, they tend not to be recognised as costs. Finally, the costs of CAS calculators are typically not spread over time, in the way that other significant costs of schooling for late adolescence are. For example, a student completing a double maths option in Years 11 and 12 will generally need to spend significantly more on textbooks than on their CAS calculators (as textbooks also have become more expensive after CPI increases are factored in), but will not do so in a single purchase at the beginning of a school year. Similarly, as noted above, many students have smartphones, but pay for them on a monthly plan rather than a single purchase.

10. Surveys

A major purpose of this research project is to gather information on the way in which technology is presently being used in teaching and learning mathematics in Western Australian secondary schools at present, and to evaluate the appropriateness and effectiveness of that use. To this end surveys of both teachers and students were undertaken. In this section both the methodology employed and the results of the surveys are presented.

10.1 Methodology

To understand current school practices and perspectives, online surveys of mathematics teachers and some Year 12 mathematics students were undertaken. Survey questions were initially designed by the Project Team, following broad advice from SCSA, with final versions of the survey jointly agreed by SCSA and the Project Team. The survey instruments used are provided in Appendices 1 and 2, although the actual survey items were presented in an online format and thus not identical in appearance to these.

Recognising that many mathematics teachers in the senior years teach more than one mathematics course in Years 11 and 12, respondents were invited to choose a single course with which they had significant recent experience in teaching, as a basis for their response. A principal reason for asking respondents to choose only one course was to limit the time required for an individual response, as it is widely recognised that surveys that require extensive time inevitability suffer various forms of survey fatigue, with consequent effects on the value of the responses.

Although a new suite of mathematics courses has been implemented from the start of Year 11 of 2015, the survey focuses on the suite of existing courses that will finish in 2015 as these are the courses that teachers have had significant experience teaching in recent years, and for which information about examinations is also available. It was agreed between the project team and SCSA that it would be inappropriate to seek considered advice from teachers regarding new courses that had only just been initiated in schools and for which experience was thus unavoidably limited.

The intention was that all recent teachers of senior secondary mathematics courses be invited to respond, in order to obtain an accurate reflection of practices and perspectives. Detailed information on this population was not readily accessible to the project in the time available, and circumstances did not permit an individual request to be sent to each member of the population. Instead, information about the survey, and invitations to participate, were sent to all secondary schools associated with SCSA, via the standard and long-standing practice of communicating directly and officially with the school administration. It is recognised that such processes are less efficient in some settings than others, for internal structural reasons related to the size of the school or the mechanism by which requests of this kind are passed from the administration to the Mathematics Department and then to individual teachers.

Advice about the survey and encouragement to participate was provided independently within the three education sectors (Government, Independent and Catholic). In addition, the email list of the Mathematical Association of Western Australia was used to advise members of the survey and encourage them to respond. Reminder emails were also sent to schools by SCSA before the survey was closed, encouraging the widest response possible.

While it is expected that this process would result in all mathematics teachers becoming aware of the request over the period of slightly more than four weeks for which the surveys were available, it is recognised that the sample of respondents is necessarily a volitional sample, and that there is a range of reasons for teachers electing to not participate, including time pressures for other activities and personal disinterest in the issues involved.

Resources and time did not permit a wide survey of students and parents, but student perspectives were sought survey, which relied upon teachers drawing it to their students' notice. Again, to ensure that the student responses were based on significant experience, only Year 12 students were invited to participate; it is expected that these students have had at least one year's experience of learning senior mathematics, and thus have some experience using associated technologies. Teachers were requested to bring the survey to the attention of their own students, all of whom were eligible to participate. It is recognised that the number of students responses will depend both on receiving the information about the survey from their teacher and also volunteering to complete it, so it is unwise to regard the sample as random or representative. Nonetheless, it might be expected that survey responses would provide some indication of the kinds of issues of concern to students at large.

10.2 Survey findings for teachers

10.2.1 How many Mathematics teachers responded to this survey? Who are they and where do they teach?

In all, as shown in Table 1, 367 teachers responded to this survey. Of these 87 (24%) teach in Government secondary schools, 62 (17%) teach in Catholic schools and 118 (32%) teach in Independent high schools. However, as shown in Figure 3, a smaller number of teachers (268) actually completed the survey (i.e., responded to all questions), including demographic questions on gender, teaching experience, qualifications, school sector and the like.

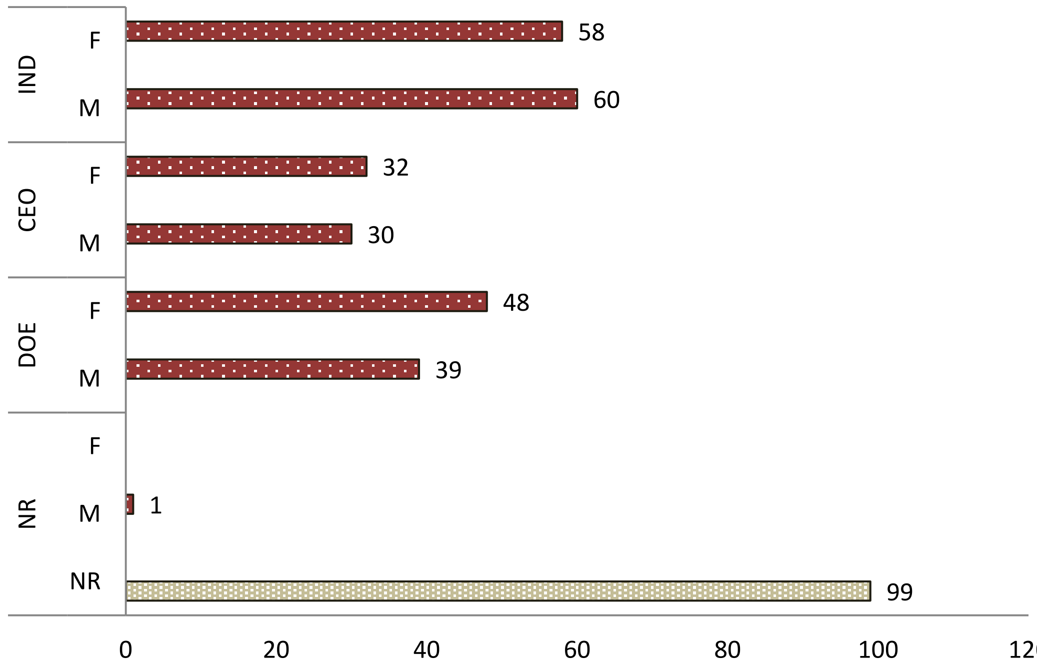
Table 1. Overall number of teacher respondents, by school sector and gender.

		Gender				
		NR	Male	Female	Total	% of sample
School Sector	NR	99	1	0	100	27%
	DOE	0	39	48	87	24%
	CEO	0	30	32	62	17%
	IND	0	60	58	118	32%
Total		99	130	138	367	100%

Note. NR = not reported; DOE = Government schools; CEO = Catholic Education Office (Catholic schools); IND = Independent schools.

Our best estimate, obtained directly from SCSA, is that there are about 620 teachers of upper secondary Mathematics courses (Years 11 and 12) across the three school sectors in Western Australia. All of these teachers were invited, via email from SCSA, to participate in the survey. That 367 teachers responded implies a response rate of 59%. However, if the more conservative number of 268 teacher respondents who completed all items on the survey is used, the response rate falls to 43%.

This more conservative response rate suggests that for a population of 620 teachers, we can be 95% confident that any point estimate provided by this analysis would have a confidence interval of 4.5 points. For example, if 50% of teacher respondents agreed that the use of CAS calculators in ATAR Maths exams should stay the same, we can be 95% confident that the true percentage of teachers in the population who hold this view is between 45.5% and 54.5%. This of course assumes that the sample of respondents is chosen entirely at random, which is not the case here. Although we endeavoured to ensure that every member of the population had an equal opportunity to respond, the heavy participation by some schools and the non-participation by others, suggests that this intention was not fulfilled. Nevertheless, these estimates of confidence level and interval provide useful guides for judging the descriptive statistics provided by this analysis.



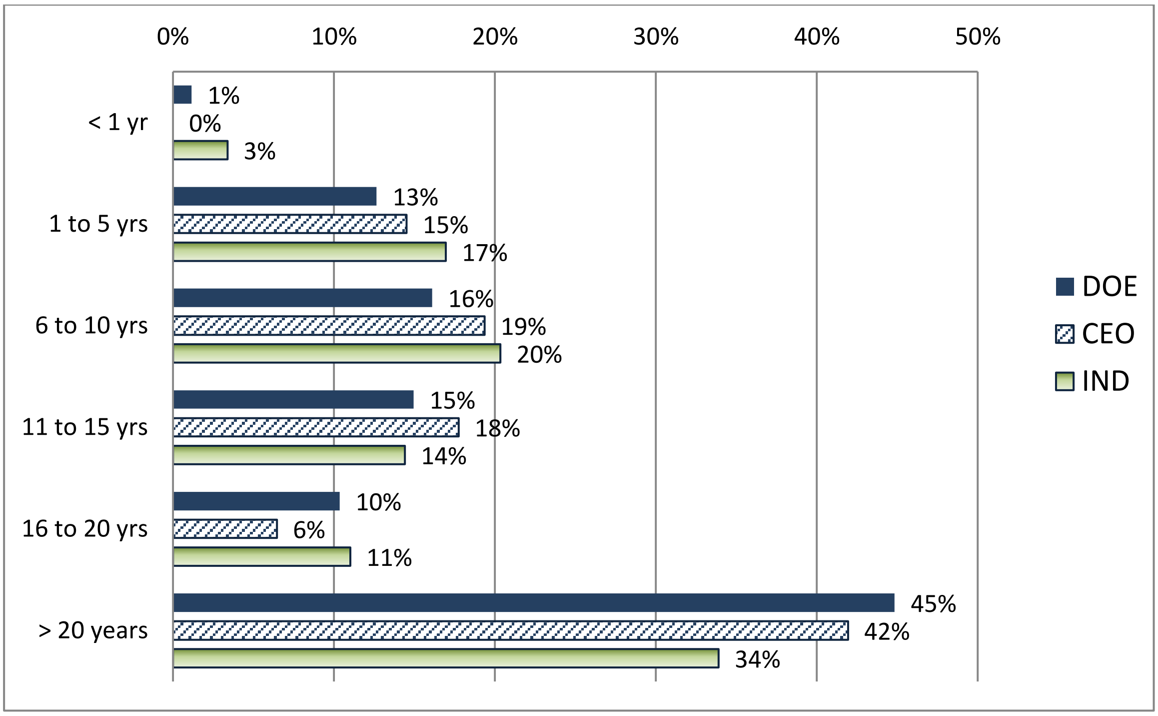
	NR			DOE		CEO		IND	
	NR	M	F	M	F	M	F	M	F
Finished		1		39	48	30	32	60	58
Did not finish	99								

Note. NR = not reported. F = female, M = male.

Figure 3. Number of teacher respondents who "finished" the survey, by school sector and gender.

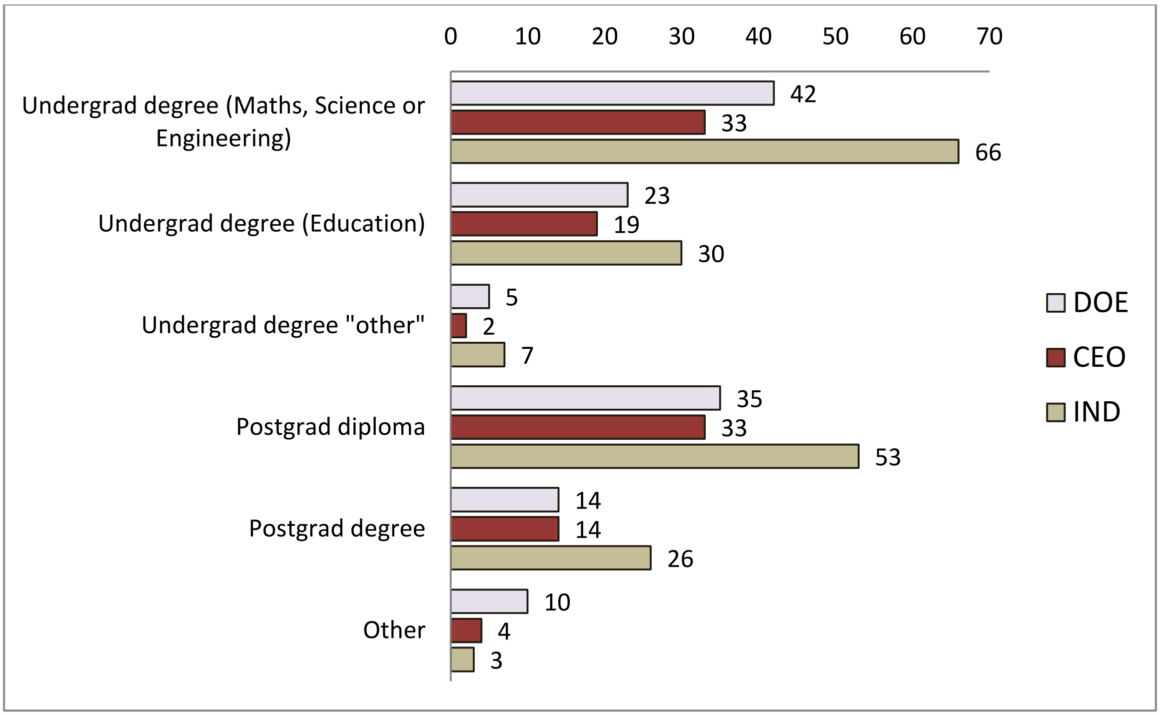
Figure 4 portrays teacher respondents' levels of experience teaching Maths in WA schools. Teacher survey respondents who did not report school sector (n = 99) are excluded from this chart. As shown, a plurality of Maths teachers in each sector hold significant levels of teaching experience in WA schools. For Independent school teachers, 45% reported 16 or more years of teaching experience in WA schools; similarly, 48% of Catholic school teacher respondents and 55% of Government school teacher respondents hold 16 or more years' experience. On the other end of the experience spectrum, 20% of Independent school respondents hold 5 or less years' experience; 15% of Catholic school teacher respondents and 14% of Government school teacher respondents hold similar levels of experience in WA high schools. Overall, one can assuredly say that the respondents for this survey are well experienced Maths teachers, with majorities in each sector experienced teaching with both CAS calculators over their entire time of use in WA and graphics calculators before their introduction.

Figure 5 indicates the tertiary qualifications held by teacher respondents. In response to this set of items, 99 out of 367 teachers did not indicate qualification or school sector. Of those who responded, 66 of 118 (56%) teachers in Independent schools reported holding an undergraduate degree with a major in Mathematics, Science or Engineering. Similar proportions of Maths teachers in Government (48%) and Catholic high schools (53%) hold similar undergraduate degrees. Likewise, 53 of 118 (45%) of Independent school Maths teachers hold a post-graduate diploma as compared to 35 of 87 Government school teachers (40%) and 33 of 62 Catholic school teachers(53%), responding to this survey.



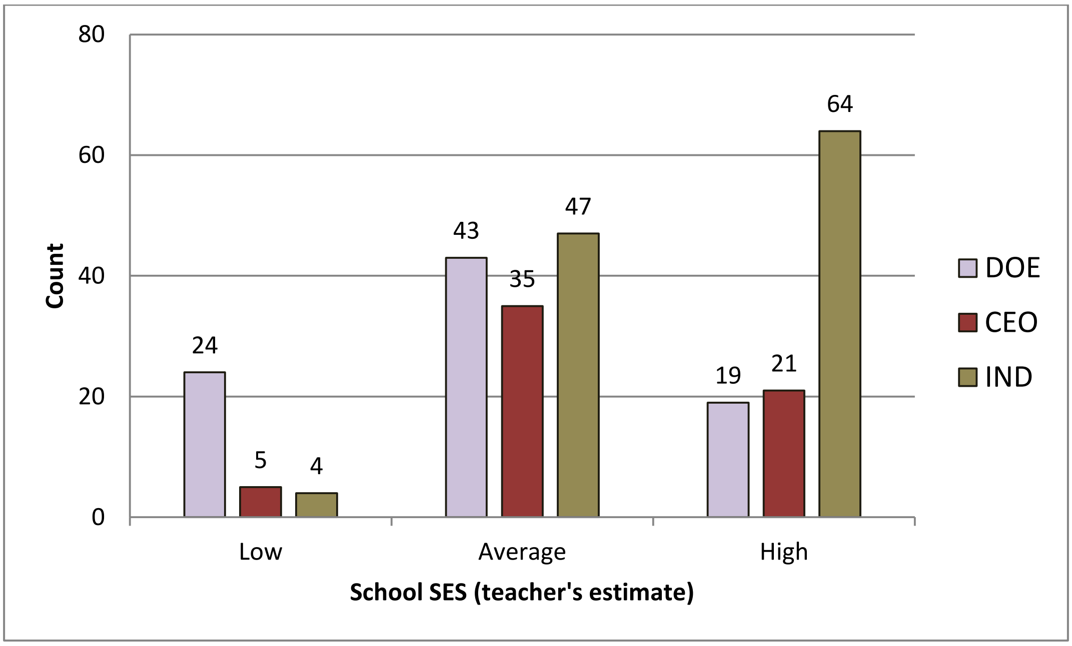
Note. N = 267; percentages are for levels of experience *within* each sector; DOE = Government schools; CEO = Catholic schools; IND = Independent schools.

Figure 4. Teacher respondents' levels of experience, by school sector.



Note. Teachers may hold more than one qualification.

Figure 5. Teacher respondents' tertiary qualifications, by school sector.



Note. N = 262 (i.e., 105 respondents did not indicate school sector or SES).

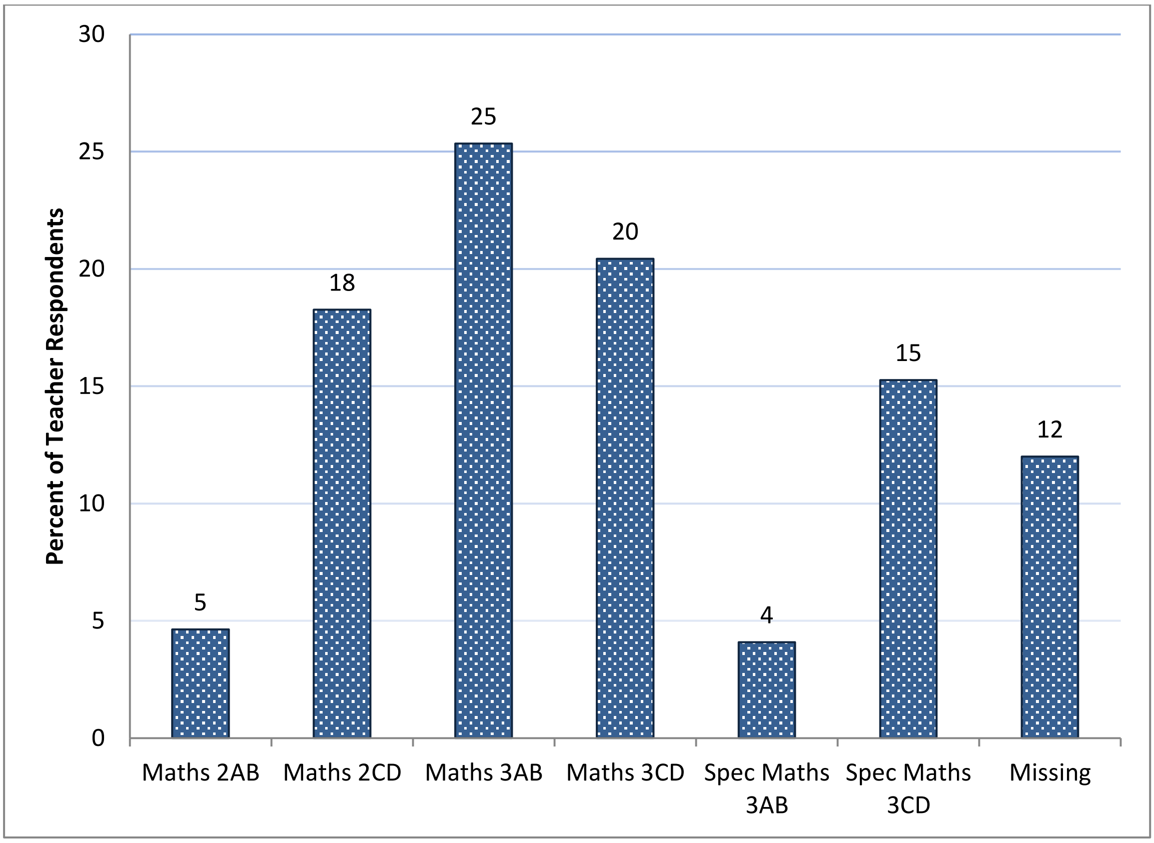
Figure 6. Teacher respondents by school sector and school SES (estimated by teachers).

As detailed in Table 1, teachers from the Independent sector form the largest group, making 32% of all who responded. Of these, as shown in Figure 6, 64 (54%) teach at "high SES" schools, and 47 (40%) teach in schools teachers characterised as "average SES". In contrast, of the 62 respondents teaching Maths in Catholic schools, 21 (34%) report working in high SES schools, and a further 35 (56%) in average SES schools. Of the 87 teacher respondents in Government schools, only 19 (22%) report teaching in high SES schools, about half (49%)

teach in average SES schools, and another quarter teach in schools that they characterise as "low SES". Thus, among the teachers responding to this survey, most Independent school teachers work in high SES contexts. In contrast most Government and Catholic school Maths teachers work in average SES contexts, and low SES contexts are disproportionately represented by Government school teachers. Similarly, high SES school contexts are disproportionately represented by teachers in Independent schools.

10.2.2 On which senior secondary (ATAR) Mathematics courses did teachers choose to report?

To reduce the time required, respondents were asked to select a single course on which to report, even if they were experienced in teaching several courses. As shown in Figure 7, a plurality (45%) of the 323 teachers who selected a single course chose to base their responses to the survey on Mathematics 3AB or 3CD. A further 67 teachers (18% of the sample) based their responses on their experiences in Maths 2CD, and a similar proportion on Specialist Maths 3CD (15%). Forty-four teachers, or 12% of the sample, did not indicate a choice of a Maths course.

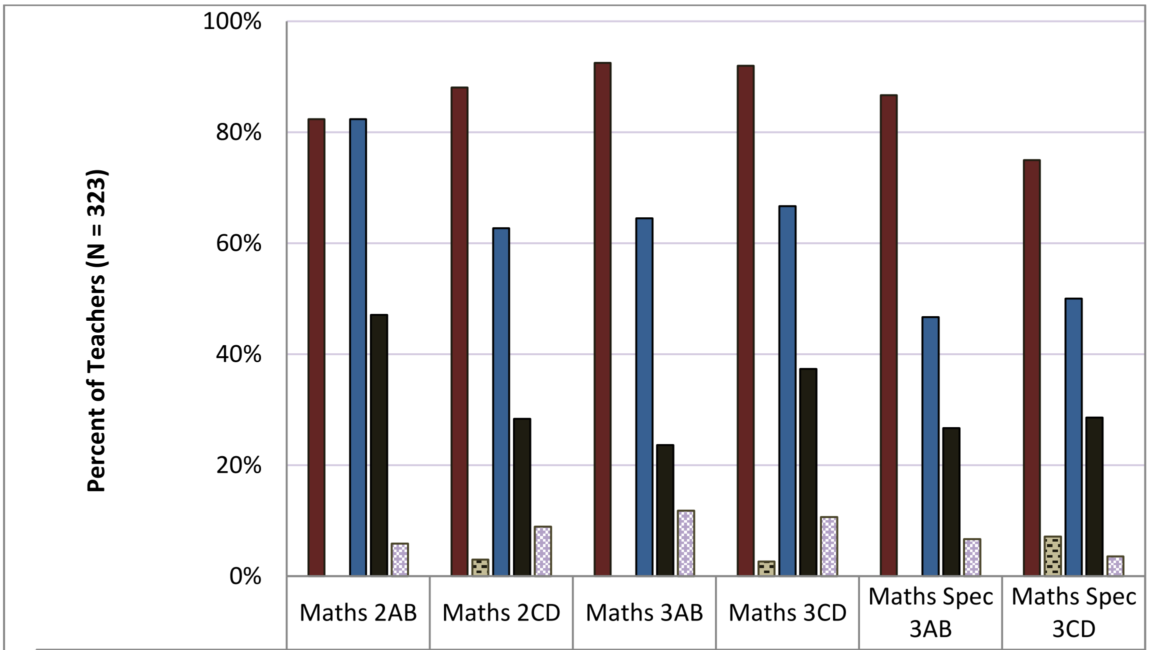


Note. N = 367.

Figure 7. Senior secondary Mathematics courses about which teacher respondents reported.

10.2.3 To what types of technology do students have "routine personal access" at school and at home?

To examine students' classroom access to various technologies, teachers were asked: *To which of the following technologies do your students have routine personal access (in your chosen mathematics class)?* According to these Maths teachers, students have routine access to a variety of technologies in support of their learning. As shown in Figure 8a, the most ubiquitous type of technology to which students have routine access is the CAS calculator. For example, in Maths 2AB, 82% of teachers report routine student access to CAS calculators; in Maths Specialist 3AB, 87% of teachers report routine student access to CAS calculators. Teachers also reported relatively strong routine student access to scientific calculators, although this varied more by course than did access to CAS calculators. For example, about half of the teachers reporting on Maths Specialist 3AB indicated students' routine access to scientific calculators in comparison to 8 of 10 teachers reporting on Maths 2AB.

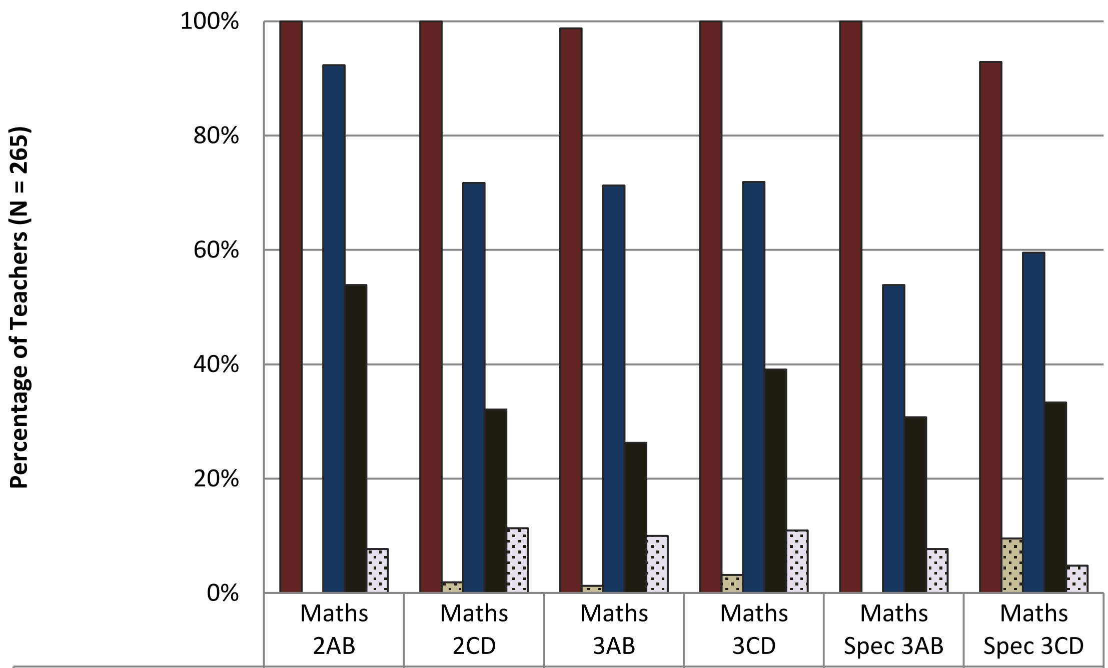


	Maths 2AB	Maths 2CD	Maths 3AB	Maths 3CD	Maths Spec 3AB	Maths Spec 3CD
CAS Calculator	82%	88%	92%	92%	87%	75%
Graphics Calculator	0%	3%	0%	3%	0%	7%
Scientific Calculator	82%	63%	65%	67%	47%	50%
Notebook/Laptop	47%	28%	24%	37%	27%	29%
Tablet	6%	9%	12%	11%	7%	4%

Figure 8a. Types of technology to which students have "routine personal access" in class, as reported by teachers (N = 323).

It should be noted here that Figure 8a provides the summarised responses for 323 teachers (all teachers who indicated a choice of Maths course on which to base their survey responses). It is likely, however, that not all of these teachers actively responded to the survey items about routine student access to various types of technology. Therefore, Figure 8b is also offered; these results consider only those 265 teachers who completed enough of the survey to have identified their school sector (an item asked late in the survey). Considering this more restricted sample of teacher respondents, all of whom participated fully in the survey, CAS and scientific calculators continue to be the most common forms of technology to which students are reported to have routine classroom access. For this more restricted sample, across the Maths courses chosen, between 93% and 100% of teachers indicate routine in-class access to CAS calculators for their students.

Further, Figure 9 examines whether students' classroom access to various forms of technology varies by school sector. Of the 268 respondents who provided school sector information, similarly high proportions across the three school sectors reported that their students have routine access to CAS calculators. Somewhat smaller but nevertheless relatively equal proportions of teachers across the three sectors reported routine student access to scientific calculators. The two types of technology for which there are notable teacher-reported differences in routine access across the three sectors are notebooks/laptops and tablets. For these two types of technology, about twice the fraction of Independent and Catholic school teachers as compared to Government school teachers report routine in-class access for their students in Mathematics.

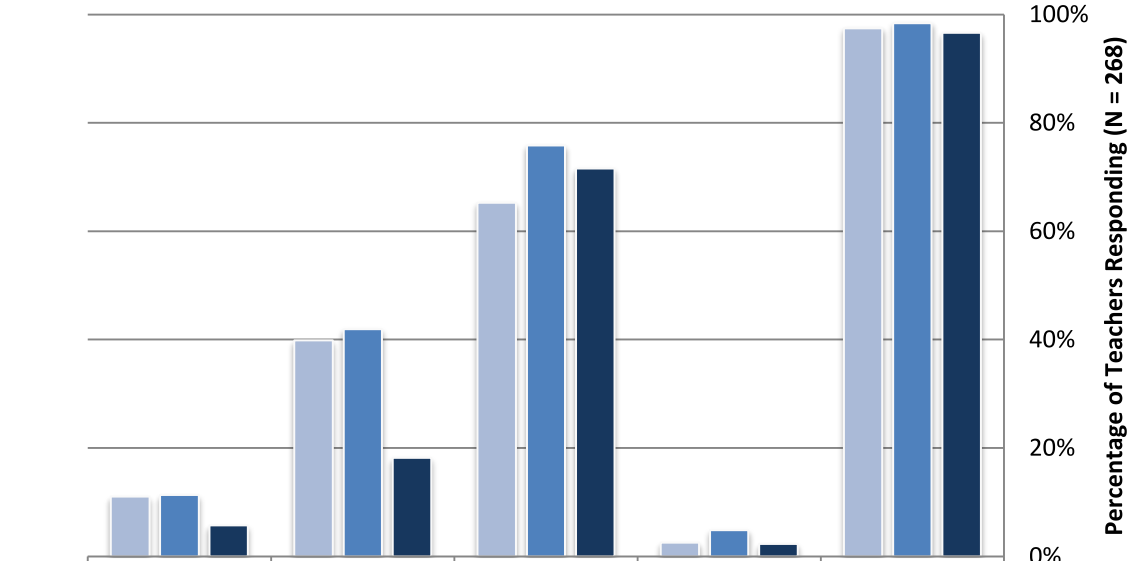


	Maths 2AB	Maths 2CD	Maths 3AB	Maths 3CD	Maths Spec 3AB	Maths Spec 3CD
CAS Calculator	100%	100%	99%	100%	100%	93%
Graphics Calculator	0%	2%	1%	3%	0%	10%
Scientific Calculator	92%	72%	71%	72%	54%	60%
Notebook/Laptop	54%	32%	26%	39%	31%	33%
Tablet	8%	11%	10%	11%	8%	5%

Figure 8b. Types of technology to which students have "routine personal access" in class, as reported by teachers who also identified their school sector (N = 265).

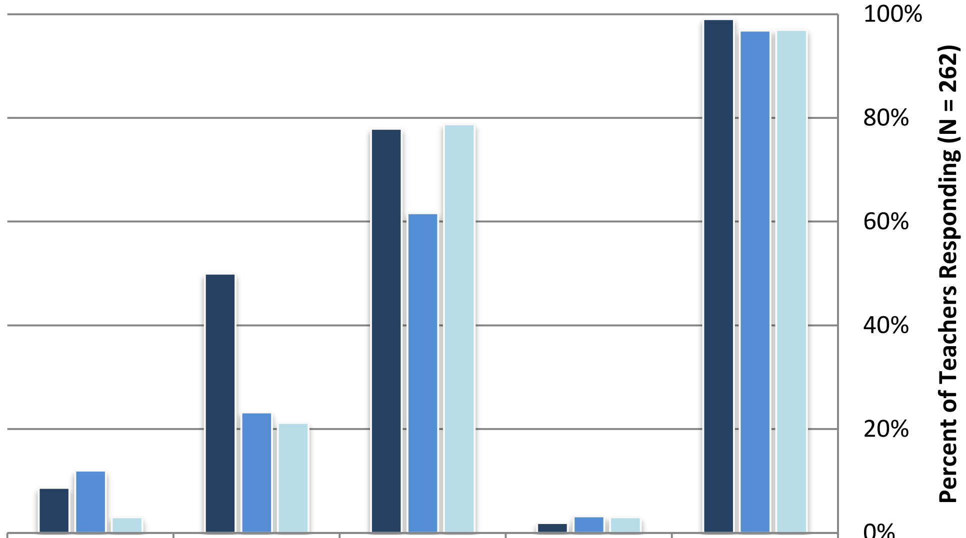
To follow up on these differences, Figure 10 examines differences in teacher-reported routine student access to technology among schools of different SES. As depicted in Figure 10, students' routine access to CAS calculators does not appear to differ meaningfully by school SES. The two types of technology for which there are notable differences in routine access across three (teacher-estimated) levels of school SES are notebooks/laptops and tablets. For notebooks/laptops, more than twice as many high SES school teachers report routine student access as compared to students in average and low SES schools. Similarly, although few teachers overall report routine access to tablets for their students, more than twice as many in average and high SES schools report routine access as compared to Mathematics students in low SES schools.

In addition to their students' routine access to various technologies in school, teachers were also asked about their expectations regarding students' regular use of technology at home: *Which technologies, if any, do you expect students in this course to use regularly at home?* As shown in Figures 11a and 11b, teachers' expectations for their students' technology use at home mirrored their experiences of access at school. In the main, teachers' expectations for students' regular use centred on CAS and scientific calculator capabilities. As shown in Figure 11a, more than 80% of teachers reporting on Maths 2AB or 2CD expected regular use at home of a scientific calculator, and similar proportions reporting on Maths 3AB, 3CD and Specialist 3AB expected regular use of CAS at home. Much smaller proportions of teachers expected regular, at home use of spreadsheets, apps, or free or commercial software.



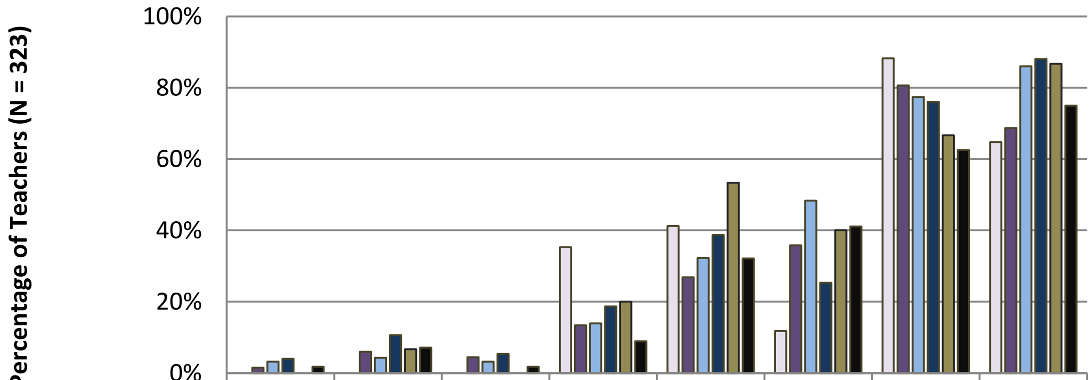
	Tablet	Notebook/ Laptop	Scientific Calculator	Graphics Calculator	CAS Calculator
DOE	5.7%	18.2%	71.6%	2.3%	96.6%
CEO	11.3%	41.9%	75.8%	4.8%	98.4%
IND	11.0%	39.8%	65.3%	2.5%	97.5%

Figure 9. Types of technology to which students have "routine personal access" in class, by school sector, as reported by teachers (N = 268).



	Tablet	Notebook/ Laptop	Scientific Calculator	Graphics Calculator	CAS Calculator
Low SES	3.0%	21.2%	78.8%	3.0%	97.0%
Average SES	12.0%	23.2%	61.6%	3.2%	96.8%
High SES	8.7%	50.0%	77.9%	1.9%	99.0%

Figure 10. Types of technology to which students have "routine personal access" in school, by school SES, as reported by teachers (N = 262).



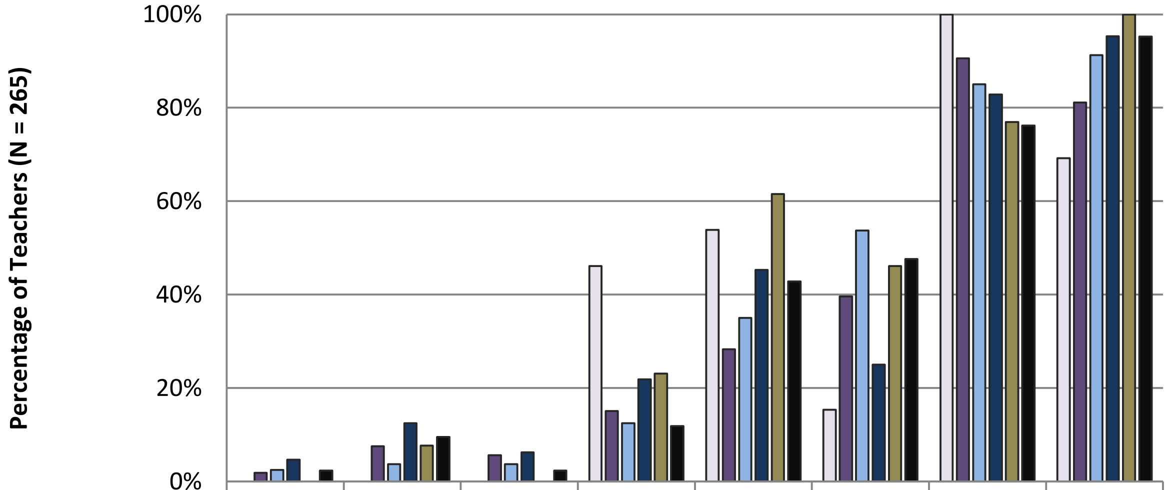
	Soft-ware-com'l	Soft-ware-free	Apps on tablets	Spread-sheets	Web-sites	Graphics Calc capab-ilities	Scientific Calc	CAS Calc capab-ilities
Maths 2AB	0%	0%	0%	35%	41%	12%	88%	65%
Maths 2CD	1%	6%	4%	13%	27%	36%	81%	69%
Maths 3AB	3%	4%	3%	14%	32%	48%	77%	86%
Maths 3CD	4%	11%	5%	19%	39%	25%	76%	88%
Maths Spec 3AB	0%	7%	0%	20%	53%	40%	67%	87%
Maths Spec 3CD	2%	7%	2%	9%	32%	41%	63%	75%

Figure 11a. Types of technology that students are expected to use at home, by Mathematics course (N = 323).

As for the previous case of students' routine in-class access to technology, Figure 11b also depicts the types of technology teachers expect their students to use at home, but these results consider only those 265 teachers who identified their school sector Considering only this more restricted sample of teacher respondents who participated fully in the survey, more than 80% of teachers expect students' use of CAS calculator capabilities at home. The only exception to this was for teachers of Maths 2AB, 69% of whom expected students to make use of CAS capabilities at home. Teachers' expectations around students' use of scientific calculators was also consistently strong, ranging between 100% of teachers in Maths 2AB, and steadily decreasing to three-quarters of teachers in Maths Specialist 3AB and 3CD.

10.2.4 How frequently do students use various types of technology at school?

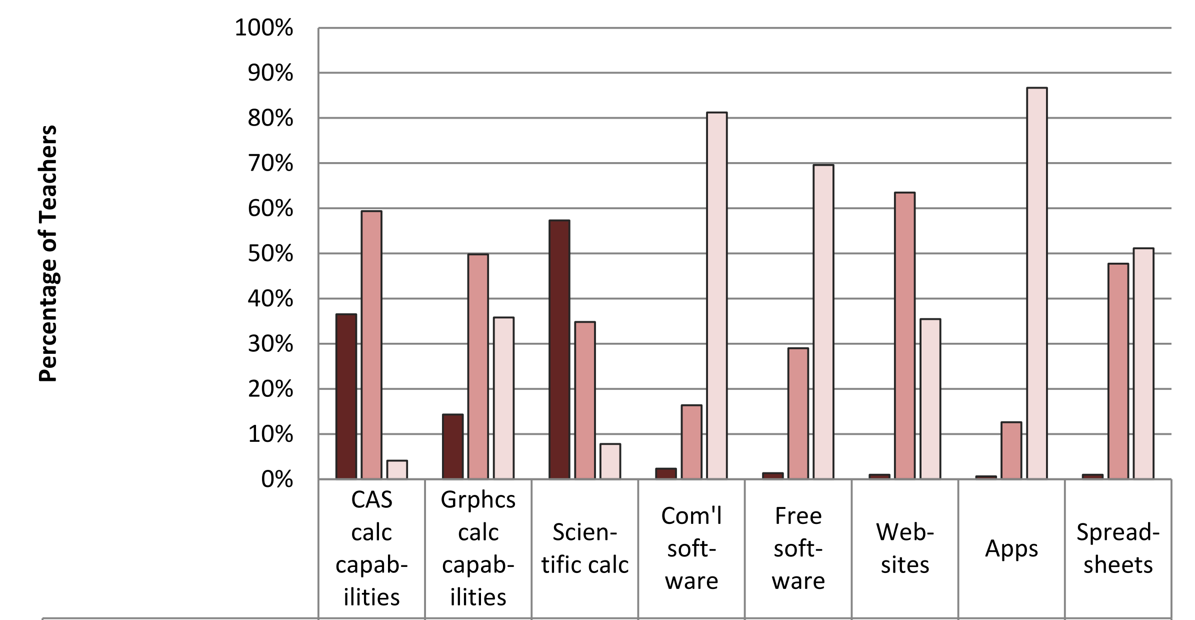
Teachers were also asked how frequently students use technology in learning mathematics in their classes. As shown in Figure 12, and consistent with teachers' expectations about access and use, the types of technology that dominate in terms of *frequency* of use are scientific and CAS calculators. For these two types of technology, about three-quarters of the 293 teachers who answered this question indicated that they were used in some, a few, or most lessons. Additionally, 5 out of 10 teachers responding indicated that graphics calculators are used in some, a few or most lessons, and 5 out of 10 teachers reported similarly for "websites".



	Soft-ware-com'l	Soft-ware-free	Apps on tablets	Spread-sheets	Web-sites	Graphics Calc capab-ilities	Scientific Calcul-ator	CAS Calc capab-ilities
Maths 2AB	0%	0%	0%	46%	54%	15%	100%	69%
Maths 2CD	2%	8%	6%	15%	28%	40%	91%	81%
Maths 3AB	3%	4%	4%	13%	35%	54%	85%	91%
Maths 3CD	5%	13%	6%	22%	45%	25%	83%	95%
Maths Spec 3AB	0%	8%	0%	23%	62%	46%	77%	100%
Maths Spec 3CD	2%	10%	2%	12%	43%	48%	76%	95%

Figure 11b. Types of technology that students are expected to use at home, as reported by teachers who also identified their school sector (N = 265).

Table 2 presents the percentages of teachers, by Maths course indicated for the survey, who responded that various types of technology are used frequently (i.e., *in all or most lessons*). Consistent with the approach explained above, the percentages in Table 2 are restricted to the 265 teachers who identified their school sector. As shown in Table 2, the course in which CAS is reportedly most frequently used is Maths 3CD, for which 53% of teachers indicated use *in most or all lessons*. CAS calculators are also frequently used by about 4 in 10 teachers for Maths 3AB, Maths Specialist 3AB and Specialist 3CD. By comparison, scientific calculators are used frequently by more teachers. Specifically, scientific calculators are frequently used by 8 out of 10 teachers in Maths 2AB and 6 out of 10 teachers in Maths 2CD, 3AB, and 3CD; and by 3 or 4 of 10 teachers in Specialist 3AB and Specialist 3CD. Other types of Maths-supportive technology, including graphics calculators, free and commercial software, apps on tablets, websites and spreadsheets were not used frequently in class by this group of teachers.



	CAS calc capab-ilities	Grphcs calc capab-ilities	Scien-tific calc	Com'l soft-ware	Free soft-ware	Web-sites	Apps	Spread-sheets
all or most lessons	37%	14%	57%	2%	1%	1%	1%	1%
some or a few lessons	59%	50%	35%	16%	29%	63%	13%	48%
never or hardly ever	4%	36%	8%	81%	70%	35%	87%	51%

Figure 12. Teacher-reported frequencies of classroom use for various types of technology in Maths (N = 323).

Table 2: Percentages of teachers reporting frequent use (*in most* or *all lessons*) of various technologies, according to Maths course (N = 265).

Technology type	Maths 2AB	Maths 2CD	Maths 3AB	Maths 3CD	Maths Spec 3AB	Maths Spec 3CD
CAS Calculator capabilities	23%	21%	36%	53%	38%	36%
Graphics Calculator capabilities	8%	11%	18%	9%	15%	14%
Scientific Calculator	77%	64%	61%	56%	31%	40%
Commercial Software	0%	0%	1%	5%	0%	0%
Free Software	0%	0%	1%	3%	0%	0%
Websites	0%	0%	3%	0%	0%	0%
Apps on tablets	0%	0%	1%	0%	0%	0%
Spreadsheets	0%	2%	1%	0%	0%	0%

10.2.5 How confident are teachers in using technology and in supporting students using technology at school?

We know empirically and conceptually that confidence can play an important role in teachers' effective use of instructional technology. Teachers were therefore asked to indicate their levels of confidence in using, and supporting students' use of technology. As portrayed in Figure 13, 40% of the 279 teachers who responded to this survey item indicated that they are "very confident" in using and supporting students' use of technology. A further 50% indicated that they are "mostly confident" in their own use and in supporting students' technology use. These levels of confidence seem to suggest relatively positive self-assessed abilities for teachers' using and supporting students' use of technology across upper secondary Mathematics courses. To further investigate teachers' confidence with technology, Figure 14 unpacks confidence according to length of experience teaching in WA.

As shown in Figure 14, years of experience seem to play a role in teachers' confidence in supporting students' technology use within the first 5 years of teaching, and this is particularly apparent for first year teachers. Four out of 10 first-year teachers express "limited" confidence in supporting students' use of technology in Maths; this falls to about 3 out of 10 teachers with 1 to 5 years' experience, and to much less than 1 of 10 teachers with 6 to 10 years' experience. Such shifts in teachers' confidence according to their experience teaching in the schools would be entirely expected.

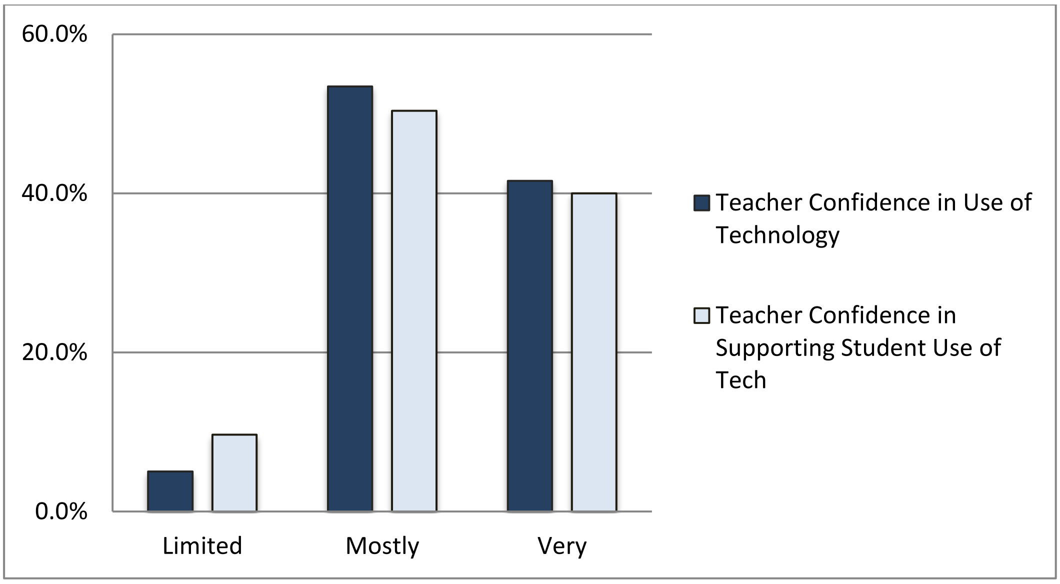


Figure 13. Teachers' self-reported confidence in using and supporting students' use of technology in Mathematics.

10.2.6 Where do teachers seek advice in using technology in Mathematics?

In being helpful to teachers in their use of technology in Maths, it was also important to understand what sources of advice or help teachers currently draw on. As shown in Table 3, teachers responding to this survey access a variety of sources for advice regarding technology for teaching/learning Maths. Across the senior secondary Maths courses canvassed for this survey, colleagues at school are the most commonly tapped source of advice for this group of teachers; on average three-quarters of respondents seek advice from their in-school colleagues on the use of technology in Maths. Additionally, textbook examples or suggestions, online resources, and professional development events or conferences also provide noteworthy sources of advice. Students also constitute an important source of advice for teachers, particularly in the more advanced courses like Maths Specialist 3AB and 3CD. On the other hand, for these teachers, SCSA's online support does not currently constitute a widely accessed source of advice on technology in Maths.

10.2.7 What obstacles do teachers perceive to their use of technology in senior secondary Maths?

In addition to the sources of advice typically accessed by teachers, respondents were also asked about perceived obstacles to their use of technology in teaching Mathematics. Specifically, teacher respondents were asked to rate a series of possible obstacles to their effective use of technology, as shown in Figure 15. None of the potential obstacles listed stood out as a particularly significant issue for these teachers. A lack of preparation time, the necessity of teaching some topics twice (with technology and without), and a lack of classroom time for using technology were the issues most commonly noted as frequent (often or always) obstacles. Of the 282 teachers who responded to this set of items, between 26% and 29% indicated each of these three time-associated issues as frequent obstacles. Often cited issues like "expense of technology" and "limited school resources" were rated as frequent obstacles by only 1 of 10 teachers responding.

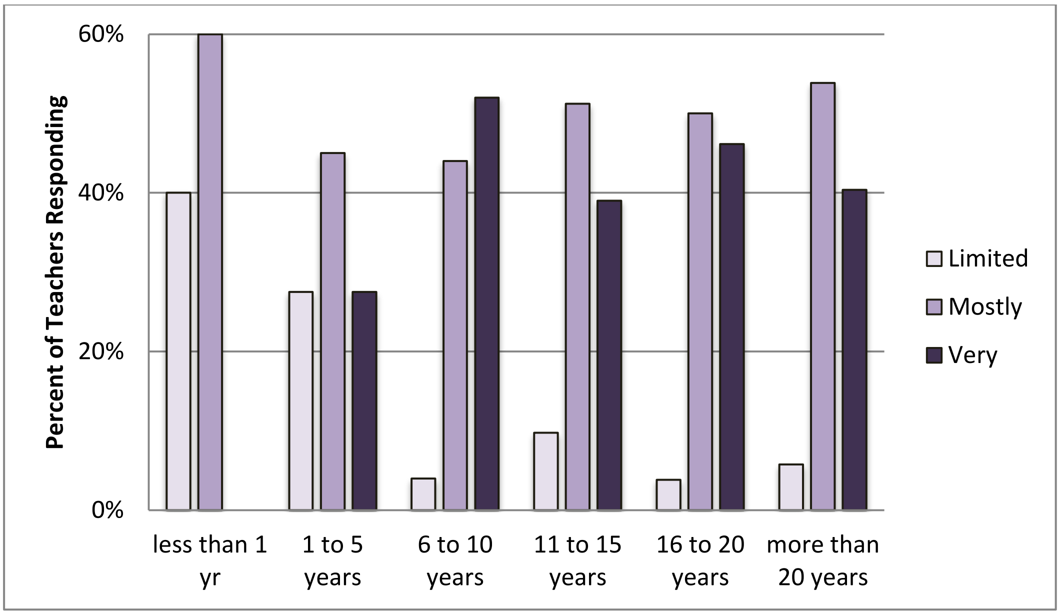


Figure 14. Teachers' confidence in supporting students' use of technology in Maths, by length of teachers' experience.

Table 3. Sources of advice on technology in Mathematics drawn on by teachers (N = 323).

Source of advice	Maths 2AB	Maths 2CD	Maths 3AB	Maths 3CD	Maths Spec 3AB	Maths Spec 3CD
Colleagues at school	76%	78%	77%	75%	87%	63%
Other colleagues	24%	25%	23%	40%	20%	25%
Students in class	29%	27%	29%	36%	47%	50%
Textbook suggestions/ examples	71%	57%	45%	57%	47%	45%
Online sources	65%	61%	73%	65%	73%	54%
SCSA online support materials	12%	9%	9%	15%	13%	11%
PD events/ conferences	53%	51%	61%	65%	67%	57%
Other	0%	4%	3%	5%	0%	4%

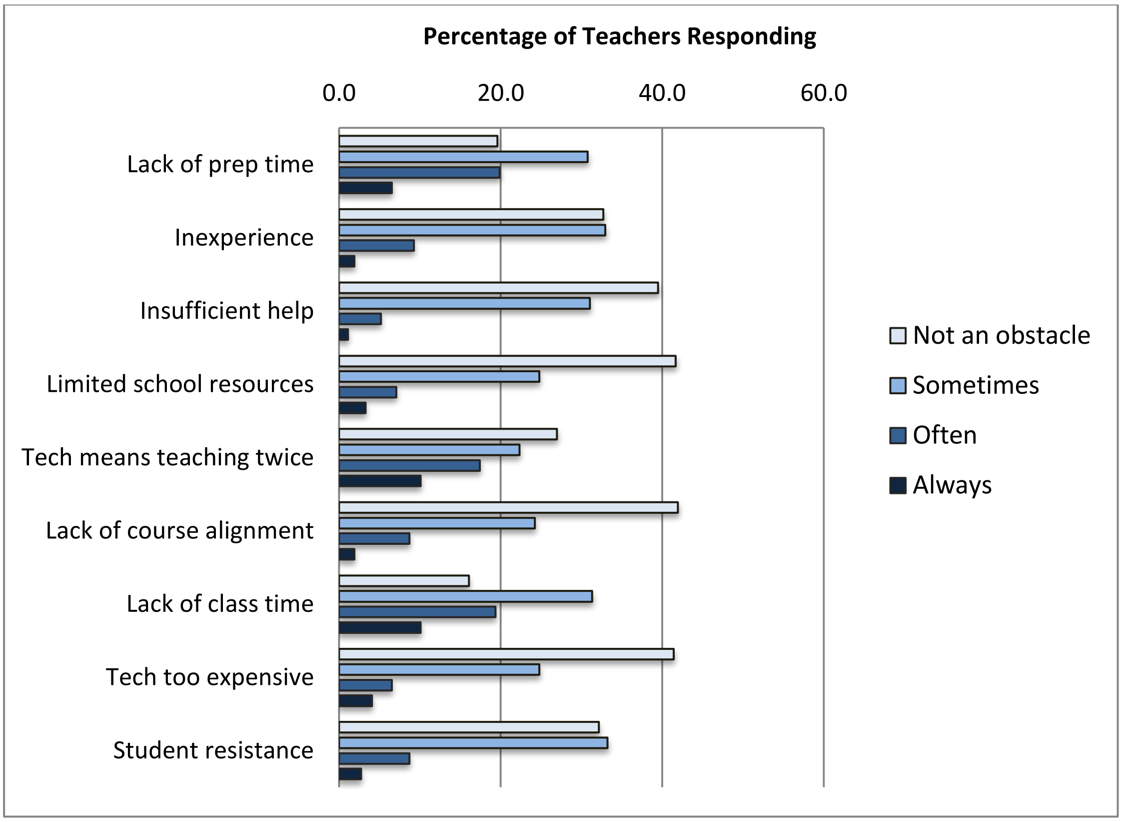


Figure 15. Teachers' ratings of potential obstacles to their use of technology in teaching Mathematics (N = 282).

To further unpack responses about potential obstacles, we also examined teachers' ratings according to school sector, as shown in Figure 16. Figure 16 presents the percentages of teachers, in each school sector, who rated various issues as *always* or *often* (i.e., frequent) obstacles to their use of technology in Mathematics. Sectoral differences were evident for several potential obstacles. For example, about twice the fraction of Government school teachers saw the expense of technology as a common obstacle, compared to their Catholic and Independent school counterparts; similar differences are evident between Government and Independent school teachers for limited school resources and insufficient help, with even larger differences evident between Government and Catholic school teachers for these potential obstacles. Further, noticeably more Government school teachers (about 4 out of 10) rated preparation and class time as frequent obstacles as compared to their Catholic and Independent school peers (about 3 out of 10). Interestingly, substantially more Independent school teachers (20%) saw student resistance to technology as a frequent obstacle, compared to Catholic (6%) and Government school teachers (13%), although these percentages are all rather modest.

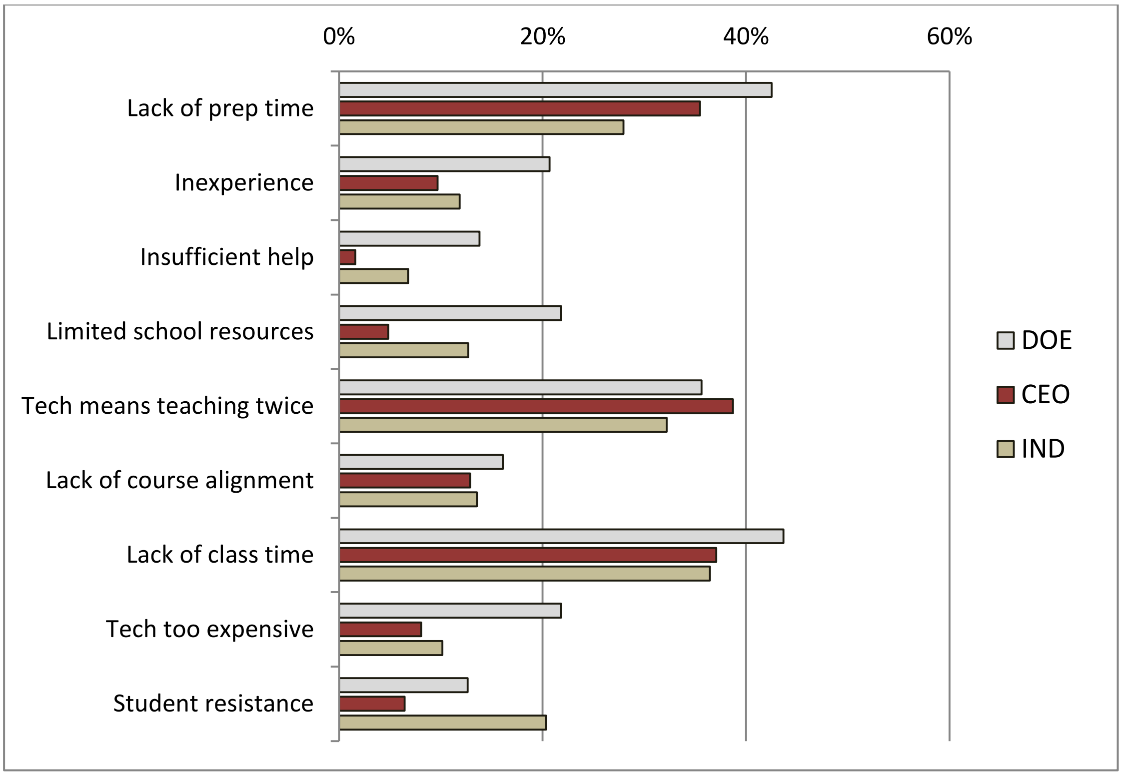


Figure 16. Percentage of teachers, by school sector, who rate various issues as *always* or *often* obstacles to their use of technology in teaching Mathematics (N = 267).

10.2.8 How do teachers perceive relationships between various types of technology and learning and teaching in their chosen Maths courses?

To better understand perceptions about the relationship of technology to learning Mathematics in their chosen courses we also asked teachers' to respond to several Likert-scale items, about the integration and sufficiency of various types of calculator in their courses. Specifically, we canvassed opinions on the relationship of Computer Algebra Systems (CAS) and other technologies to the Maths courses teachers about which teachers chose to report. When considering CAS, teachers were asked to focus on symbolic aspects of these calculators (such as algebraic manipulation, symbolic differentiation and integration, exact solutions to equations, etc.) rather than numerical features (such as graphing, tables, statistical analysis and numerical equation solution). Summaries of the 271 teacher responses to this series of Likert items are given by Table 4 and Figure 17.

As shown in Table 4, the percentage of teachers who agreed or strongly agreed that to learn the Mathematics in their course, it is important for students to have access to CAS, varied between 40% (Maths 2AB) and 60% (Maths 2CD). Generally, about 5 in 10 teachers agreed that student access to CAS is important for learning the Mathematics in the course. There was also variation in teachers' views about the degree of integration of CAS into their chosen course. For example, while seven out of 10 teachers in Maths 2CD and Maths 3CD agreed that CAS is well-integrated into their courses, a more modest 5 out of 10 teachers shared this view in Maths 2AB and Maths Specialist 3AB.

Further with regard to teachers' views about the need for CAS, about 6 in 10 teachers perceive that a graphics calculator is sufficient for learning the Mathematics in Maths 2CD, 3AB, 3CD and Specialist 3AB. Similar proportions agreed that graphics calculators are well-integrated into their courses, except for Maths 2AB in which only 3 in 10 teachers perceived graphics calculators to be well integrated. Smaller proportions of teachers (2 out of 10 in Maths Specialist 3AB and 3CD; between 3 and 4 out of 10 teachers in Maths 2CD, 3AB and 3CD) agreed that a scientific calculator is sufficient for learning the Mathematics in their courses, except for most teachers in Maths 2AB (87% agreed or strongly agreed that a scientific calculator is sufficient).

Additionally, across the suite of secondary Maths courses, consistently high percentages of teachers (73% to 85%) agreed or strongly agreed that the use of calculators in their classrooms is focused on meeting needs associated with Australian Tertiary Admissions Rank (ATAR) examinations. Somewhat more modest percentages of teachers—typically 5 or 6 teachers out of 10—agreed that their concerns about the over-use of technology in their Maths course were offset by non-calculator components of ATAR examinations.

In summary, there is a consistent and moderately strong view that graphics calculators are sufficient for learning Maths across the courses. In contrast, a slightly weaker, less consistent view indicates that CAS is important for students learning Maths; this second view varies according to course. There is also a strong and consistent view on the part of teachers that calculator use in Maths is driven by the requirements of ATAR exams; this concern is only partly mitigated by the non-calculator components of the examinations.

Two hundred and seventy-one responding Maths teachers also provided their views regarding three statements about possible relationships between technology and learning Mathematics in their chosen courses. The percentages of teachers, by Maths course, who agreed or strongly agreed with these three statements are shown in Figure 17.

For each of the six Maths courses canvassed, a strong majority of teachers agreed or strongly agreed that using technology makes Mathematics more enjoyable for students; this is especially the case for teachers on Maths Specialist 3AB and Maths 2AB. For each course, a majority of teachers also agree that using technology helps students gain a deeper understanding of Mathematics than would be possible by hand, but this result also varied. Specifically, while a bare majority of teachers in Maths 2CD (53%) agree that technology helps students gain a deeper understanding, fully 87% of teachers in Maths 2AB and 79% in Maths Specialist Specialist 3CD agree or strongly agree to the proposition. In other words, across all 6 courses, a majority of teachers agree that there is both cognitive and affective value in the use of technology in learning Mathematics. Despite this strong recognition of value regarding the potential role of technology in learning Mathematics, majorities of teachers (57% to 77%) also agreed that *students do not understand Mathematics unless they first do it by hand*; the exception to this was teachers of Maths 2AB, in which just 4 in 10 teachers agreed that to learn Mathematics students need to first do it by hand.

Table 4. Percentages of teachers who *agree* or *strongly agree* with statements about the relationships of various technologies to learning and teaching their chosen Mathematics courses (N = 271).

Statement	Maths 2AB	Maths 2CD	Maths 3AB	Maths 3CD	Maths Spec 3AB	Maths Spec 3CD
For learning the mathematics in this course, it is important for students to have access to CAS	40%	60%	53%	52%	46%	57%
CAS is well integrated into this course	47%	73%	62%	69%	54%	62%
For learning the mathematics in this course, a graphics calculator is sufficient	53%	58%	63%	57%	62%	52%
Graphics calculators are well integrated into this course	33%	53%	60%	58%	54%	43%
For learning the mathematics in this course, a scientific calculator is sufficient	87%	35%	40%	34%	23%	24%
The use of calculators in my classroom is focused on ATAR examination needs	73%	85%	80%	78%	85%	81%
The non-calculator examination components of this course address my concerns about over-use of technology	67%	56%	46%	62%	46%	48%

10.2.9 Do teachers want change in the use of technology in secondary Mathematics exams?

To gauge teachers' views on the desirability of change in the use of technology in Mathematics exams, teachers were asked whether the use of technology should be increased (with certain conditions), or decreased. Teachers' responses are portrayed in Figures 18 through 21.

Two hundred and sixty-five teachers answered this series of questions. First, responding teachers were asked *should the use of technologies in mathematics exams for your chosen course be increased?* As shown in Figure 18, between 60% and 80% of teachers responded *No* to this question. This view that the use of technologies in exams should not be increased was especially strong for teachers of Maths 2CD and 3CD. Smaller proportions of teachers (between 2 and 3 teachers out of 10) responded that technologies should be increased by allowing tablets and computers, but with restricted access to software and no access to the internet.

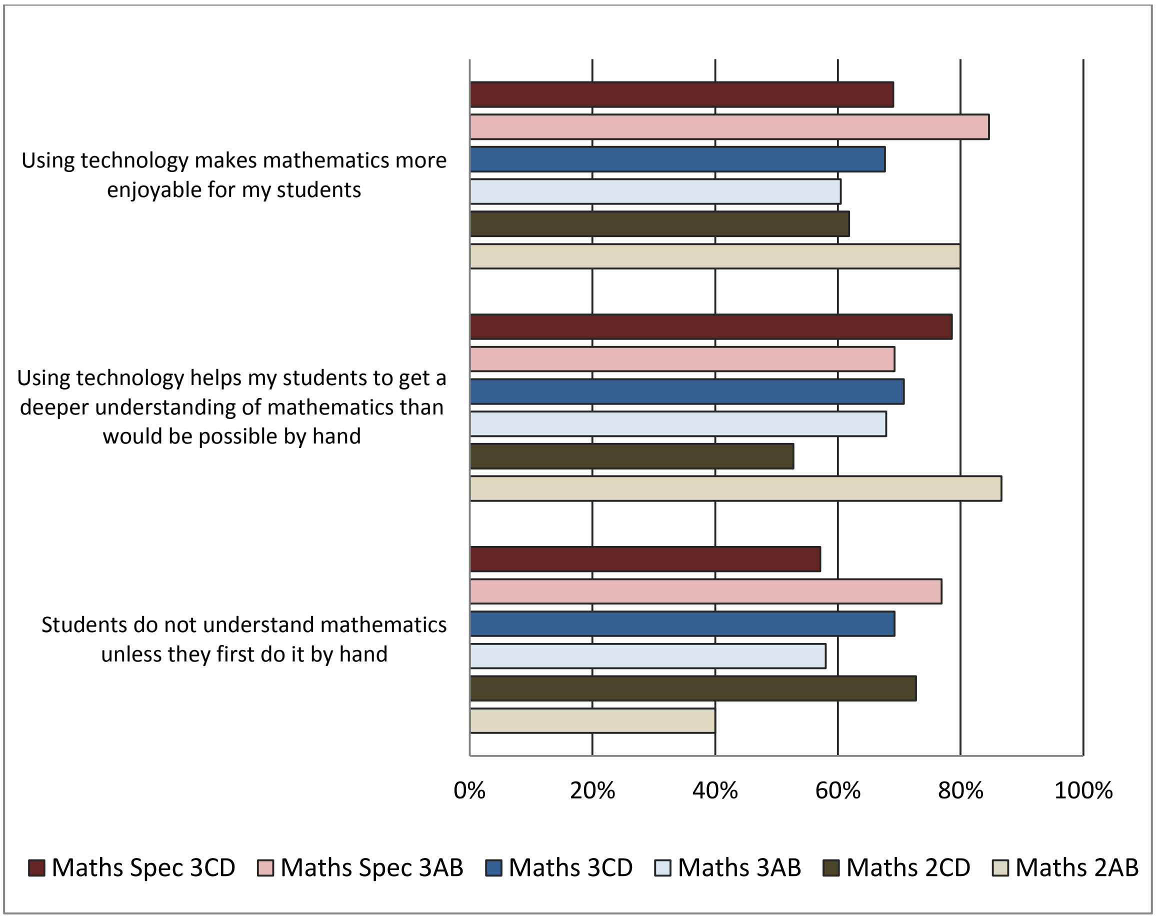


Figure 17. Percentages of teachers who *agree* or *strongly agree* with statements about relationships between technology and learning in their chosen Mathematics courses (N = 271).

Figure 19 provides teachers' views, organised by school sector, about increasing technology in exams. As Figure 19 shows, teachers' views on this issue are consistent across school sectors. Seventy-five percent of Government school teachers, 81% of Catholic school teachers and 73% of Independent school teachers believe that technology use in exams should not increase.

Teachers were similarly asked *should the use of technologies in mathematics exams for your chosen course be decreased?* As shown in Figure 20, between 40% and 60% of teachers also responded *No* to this question, depending on the course. On the other hand, except for teachers of Maths Specialist 3CD, a consistent 30% of responding teachers thought that technology in Maths exams should be decreased by allowing scientific calculators only, and smaller percentages (1 to 2 teachers out of 10) thought that technology in exams could be decreased by allowing graphics calculators but not CAS.

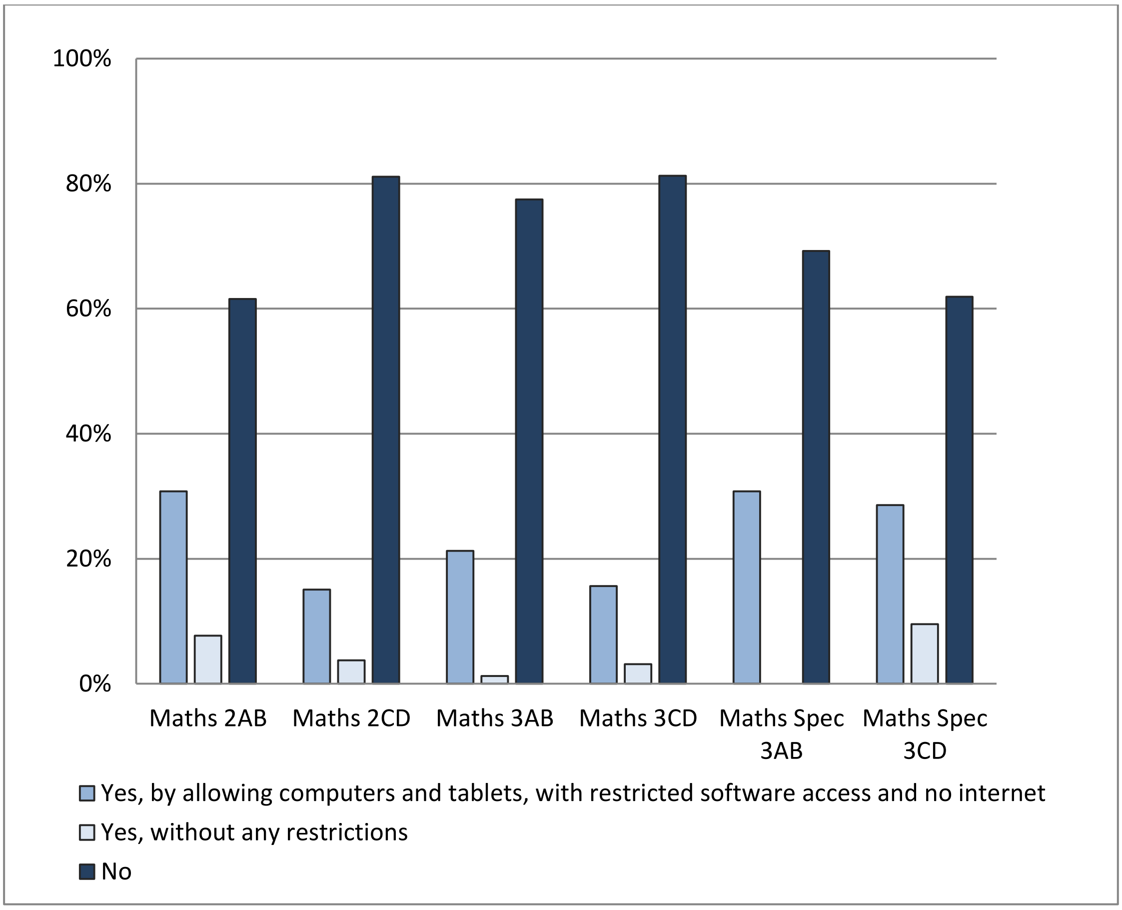


Figure 18. Teachers' views of whether technology should be increased in exams in their chosen Mathematics courses.

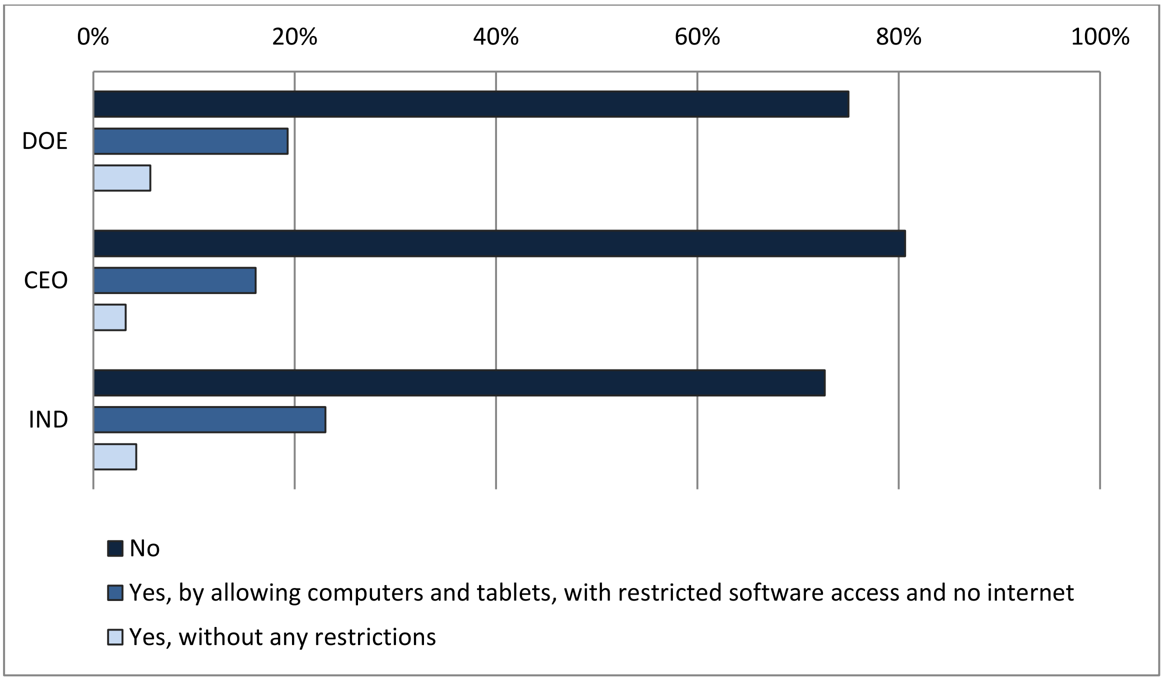


Figure 19. Teachers' views about whether technology should be increased in exams, by school sector (N = 267).

Figure 21 presents teachers' views on this question by school sector. As shown, strong pluralities of teachers in each sector also responded *No* to this question, ranging from 42% of Catholic school teachers to 59% of Government school teachers. About 20% of Catholic and Independent school teachers indicated their support of allowing graphics calculators in preference to CAS, but only 13% of Government school teachers shared this view. There was very little support for the notion of removing technology from exams completely.

Teachers expectations about how their teaching might be affected if current requirements associated with CAS were to change was further interrogated by the survey item: *How would your own teaching in this course be affected if CAS calculators were not permitted in maths exams?* Using a Likert scale ranging from *strongly agree* to *strongly disagree*, teachers rated several specific ways in which their teaching practice might change. The number of teachers that responded to this question ranged between 261 and 266.

Table 5 provides the percentages of teachers, by secondary school Maths course chosen, who agreed or strongly agreed with the propositions suggested about possible ways in which their own practices might change. As suggested by the percentages in Table 5, between 4 and 6 teachers out of 10 agreed or strongly agreed with the proposition that "there would be no significant change to my teaching" if CAS calculators were not allowed in Maths exams. Notwithstanding this, notably smaller proportions of responding teachers (between 24% in Maths 2CD and 46% in Maths 2AB) agreed that they would continue to use CAS calculators regardless of whether they were allowed in exams or not.

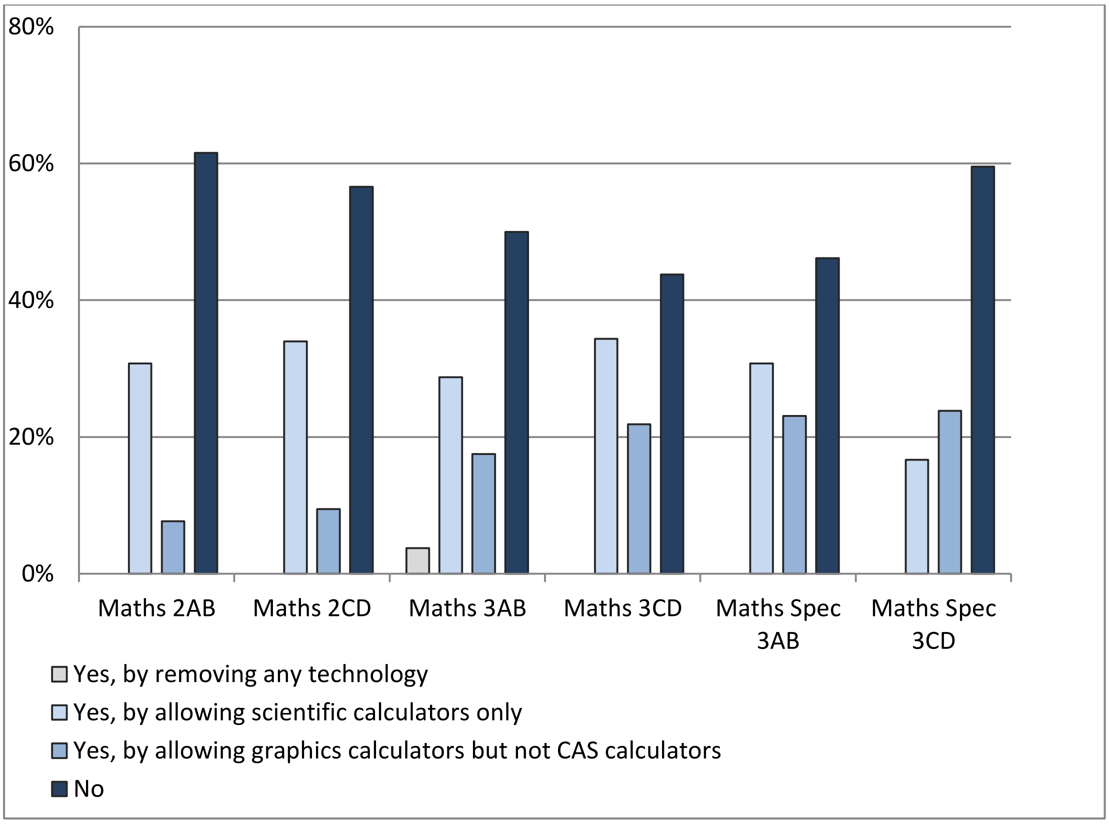


Figure 20. Teachers' views of whether technology should be decreased in exams in their chosen Mathematics courses. (N = 267)

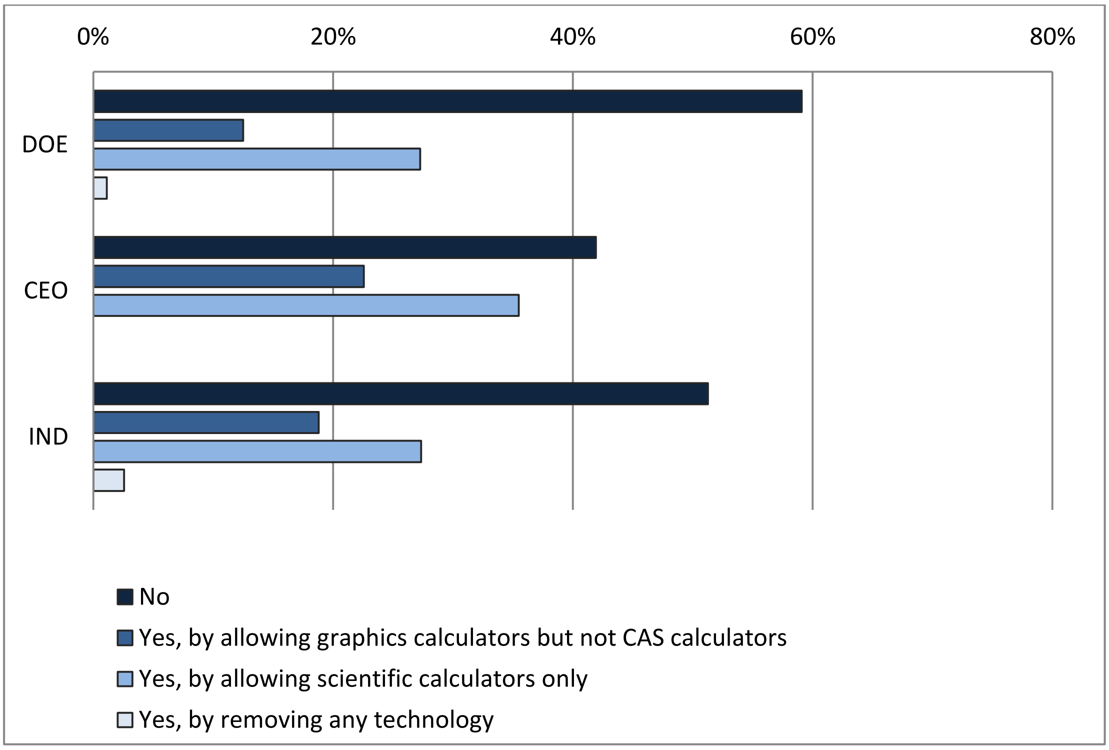


Figure 21. Teachers' views about whether technology should be decreased in exams, by school sector (N = 267).

At the same time, quite varying percentages of teachers—between 4 and 8 out of every 10 teachers—agreed that if CAS were disallowed, they would increase their use of scientific or graphics calculators, or their use of computers, tablets and the internet. There was, however, no particularly discernible pattern of responses, according to Maths course, regarding teachers' views of what technologies they might increase if CAS were no longer required in exams. The strongest level of agreement among teachers, and hence the strongest pattern across courses was that whatever technology is allowed in Maths examinations becomes the focus of teaching and learning; between 76% and 92% of responding teachers agreed or strongly agreed with this proposition.

To gauge teachers' overall views about the use of technology in secondary school Maths courses, as distinct from their views about technology in exams, respondents were also asked about what they would generally prefer in terms of potential change. Two hundred and sixty-six teachers answered this survey item, and their responses are summarised in Figure 22. Consistent with the plurality of teachers who had indicated their preference for no change with regard to the allowed use of technology in examinations, a plurality of teachers (47%) responded that the use of technology generally should *stay about the same*. Another 40% of respondents indicated that their overall view is that technology in secondary school Maths should be *reduced in importance*; only 1 in 10 teacher respondents suggested that technology in Maths should be *increased and extended*.

Table 5. Percentages of teachers who *agree* or *strongly agree* with statements about how their teaching might change if CAS calculators were not a feature of examination.

Potential change in teaching	Maths 2AB	Maths 2CD	Maths 3AB	Maths 3CD	Maths Spec 3AB	Maths Spec 3CD
There would be no significant change to my teaching	38%	57%	44%	53%	38%	62%
CAS calculators would continue to be used regardless	46%	24%	30%	30%	31%	37%
Computers, tablets and the internet would be used more than at present	77%	39%	49%	45%	42%	60%
Graphics calculators would be used more than at present	46%	38%	47%	50%	69%	60%
Scientific calculators would be used more than at present	69%	60%	64%	80%	77%	60%
Whatever technology was permitted in examinations would be the focus	83%	90%	84%	88%	92%	76%

Figures 23 and 24 further investigate whether these overall views differed by Maths course or by school SES. As shown in Figure 23, in all secondary Maths courses, a strong majority of teachers prefer that the importance of technology should stay the same or be reduced. Specifically, for example, 5 out every 10 teachers in Maths 3AB, 3CD and Maths Specialist 3AB indicated their preference that the importance of technology in these courses be reduced. The only course for which more than 2 in 10 teachers preferred that the role of technology be increased and extended is Maths 2AB in which 33% held this view.

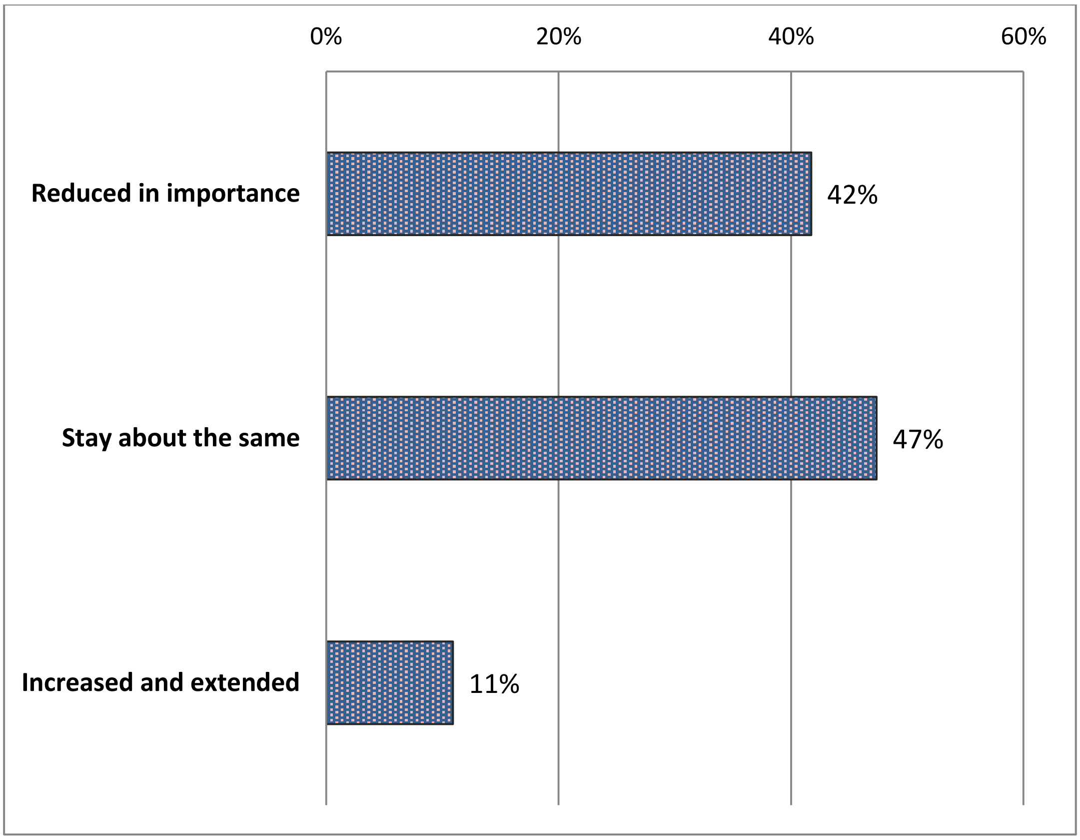


Figure 22. Teachers' overall views about the use of technology in secondary school Mathematics.

Teachers' overall views about the potential direction of change in the role of technology were less consistent across schools grouped by SES. As shown in Figure 24, teachers in high SES schools most commonly expressed the view that the role of technology should be reduced in importance (50% of teachers). In contrast, teachers in low SES schools most strongly expressed the view that technology should be increased or extended, although this constituted only 2 teachers out of 10. Thus, while strong majorities of teachers across the three SES school groupings are of the view that the importance of technology should stay about the same, or be reduced, the plural view in both low and average SES schools was that it stay the same, while in high SES schools, the preference was for a reduction.

Similarly, teachers' views about potential directions for change in the role of technology were examined across schools grouped by sector, as shown in Figure 25. Again, across each of the three school sectors, about 4 in 10 teachers held the view that the role of technology in Maths should be reduced in importance. This view was most common among teachers in Catholic schools (49%). Teachers in Government schools most commonly expressed the view that the role of technology in Mathematics should stay about the same (49%). A distinct minority of teachers, most frequently in Independent schools, held the view that the role of technology could be increased and extended, but this constituted only 1 out of 10 (or fewer) teachers responding to the survey. In sum, very strong majorities of senior secondary Mathematics teachers (between 8 and 9 out of every 10 teachers) across the three school sectors are of the view that the importance of technology should stay about the same or be reduced.

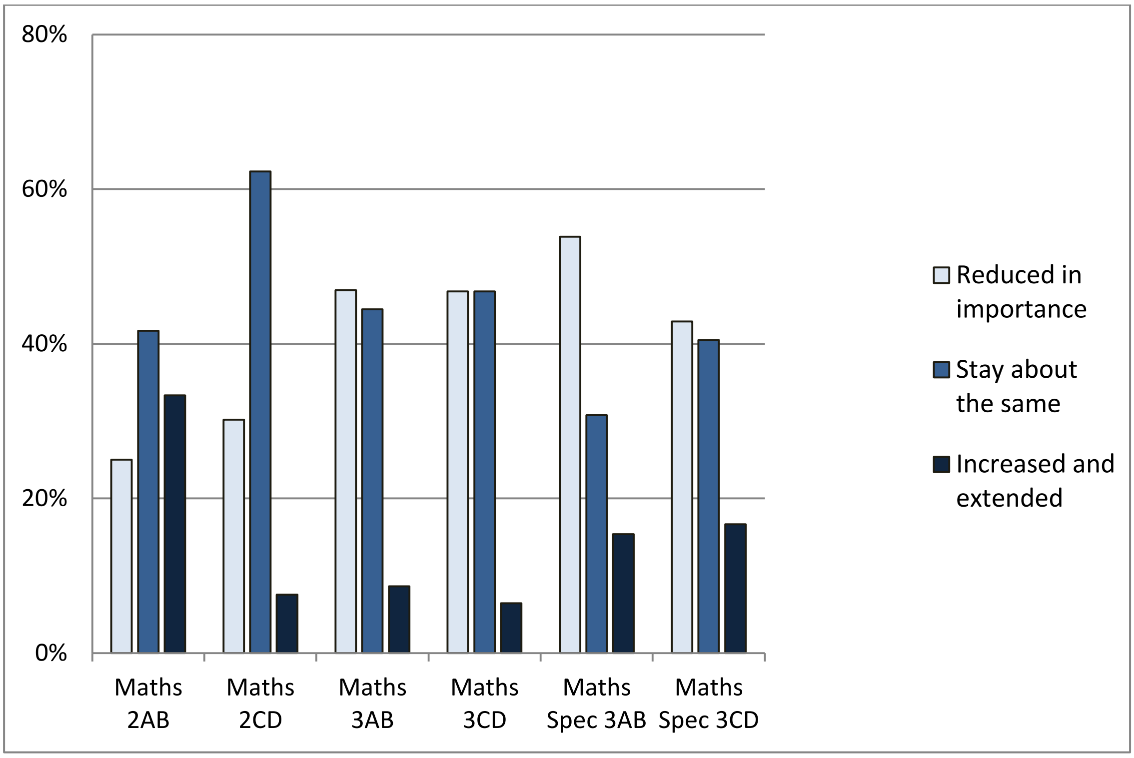
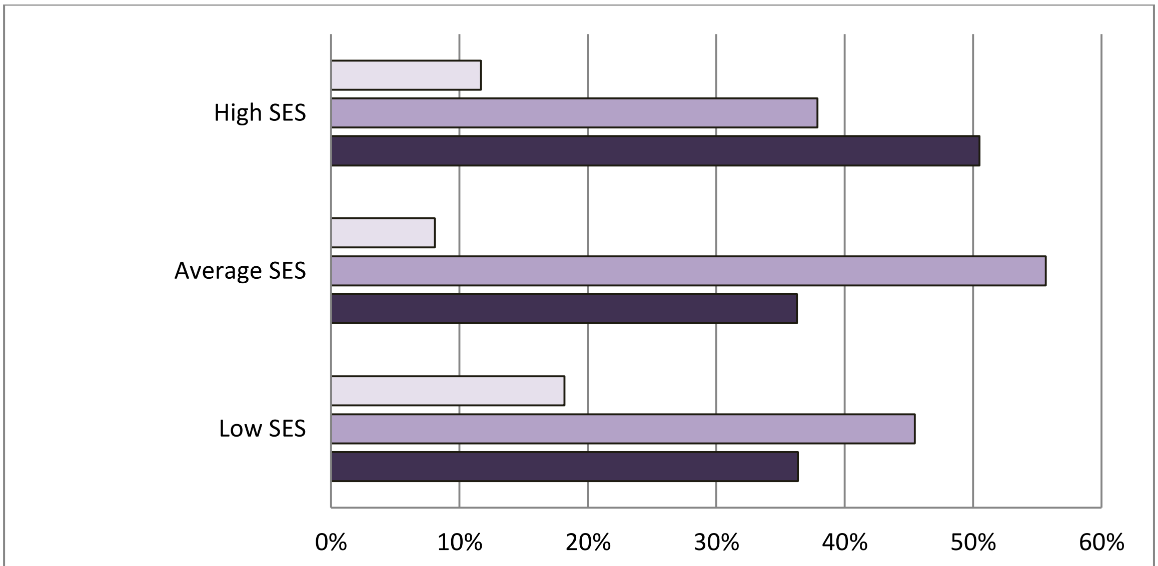
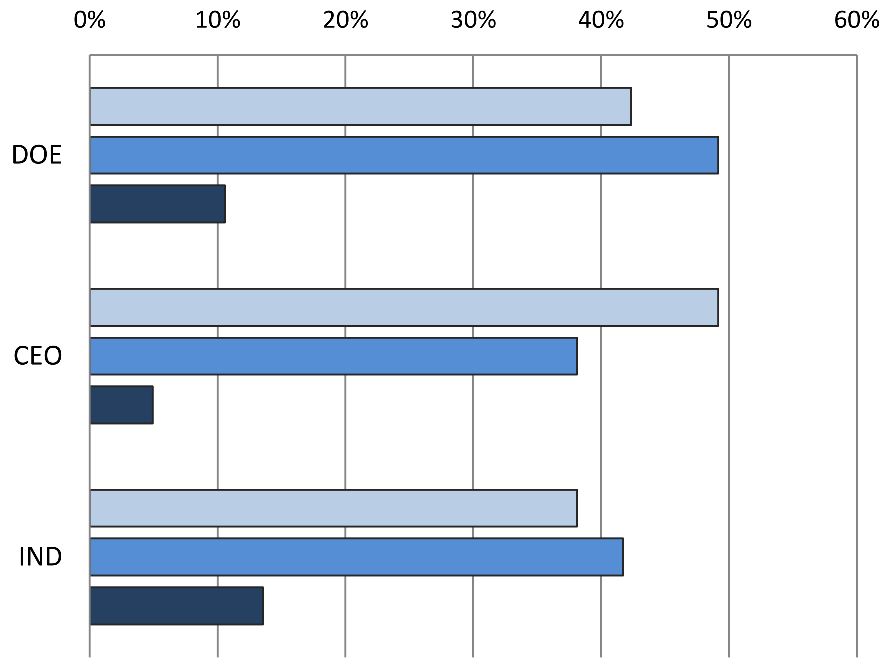


Figure 23. Teachers' overall views about potential change to the use of technology in secondary school Mathematics, by course (N = 263).



	Low SES	Average SES	High SES
Increased and extended	18%	8%	12%
Stay about the same	45%	56%	38%
Reduced in importance	36%	36%	50%

Figure 24. Teachers' overall views about potential change to the use of technology in secondary school Mathematics, by school SES (N = 266).



	IND	CEO	DOE
Reduced in importance	38%	49%	42%
Stay about the same	42%	38%	49%
Increased and extended	14%	5%	11%

Figure 25. Teachers' overall views about potential change to the use of technology in secondary school Mathematics, by school sector (N = 264).

10.2.10 Do teachers perceive equity issues associated with the use of CAS technologies in their Mathematics courses?

Ongoing and important discourses, in WA and across the nation, about resource and funding disparities by school sector or by SES grouping, made it important to inquire of teachers regarding perceived equity issues related to the use of CAS and other technologies. Teachers' responses, according to school sector and school SES are provided in Figures 26 and 27. As shown in these two figures, between 7 and 8 out of 10 teachers in Catholic and Independent schools believe that there is no equity issue with regard to the use of CAS technologies in secondary Mathematics. In contrast, only one-half of Government school teachers hold the same view. This difference in view about whether equity poses an issue for CAS in Maths is perhaps not surprising given that low SES schools are disproportionately represented by Government school teachers in this sample.

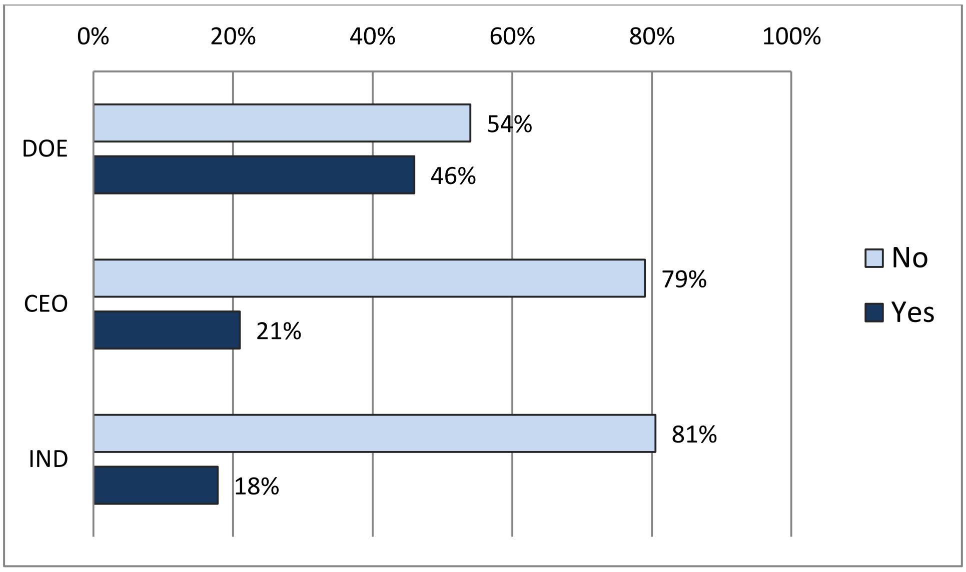


Figure 26. Teachers' views on whether there are equity issues associated with the use of CAS technologies in Mathematics, by school sector (N = 265).

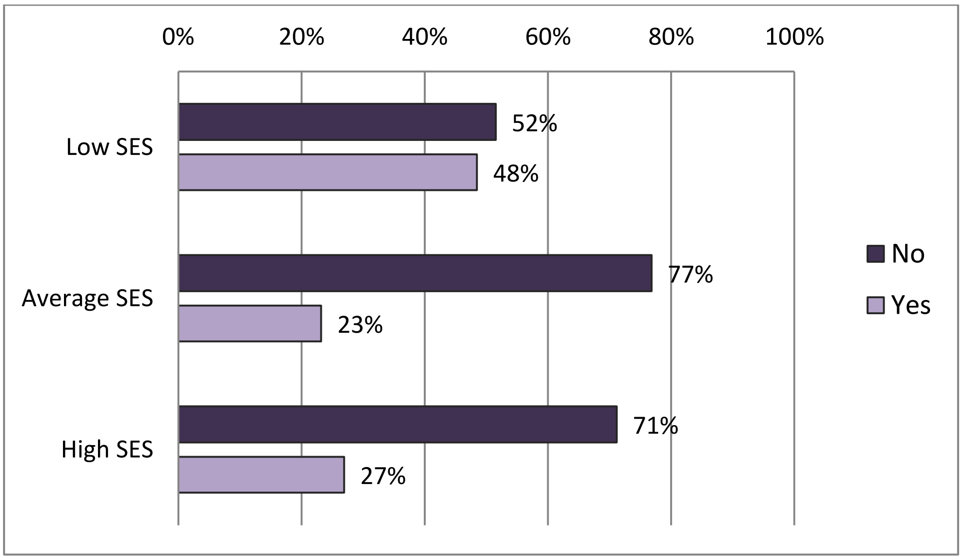


Figure 27. Teachers' views on whether there are equity issues associated with the use of CAS technologies in Mathematics, by school sector (N = 260).

10.3 Survey findings for students

10.3.1 How many Year 12 Mathematics students responded to this survey?

Six-hundred and thirteen (613) students accessed and began the online survey. Of these, 522 students answered enough questions to be reasonably considered to have "finished" the survey. Of these, 298 students are female, 215 are male and 9 did not report their gender.

As shown in Figure 28, among student respondents, the most common course being studied in 2015 is Maths 3AB (215 students) followed by Maths 3CD with 176 students. Only 5 student respondents are studying Maths Specialist 3AB. It was also the case that many students (99) are studying 2 courses contemporaneously; these students comprise 19% of the student sample, or 1 in 5, responding to this survey.

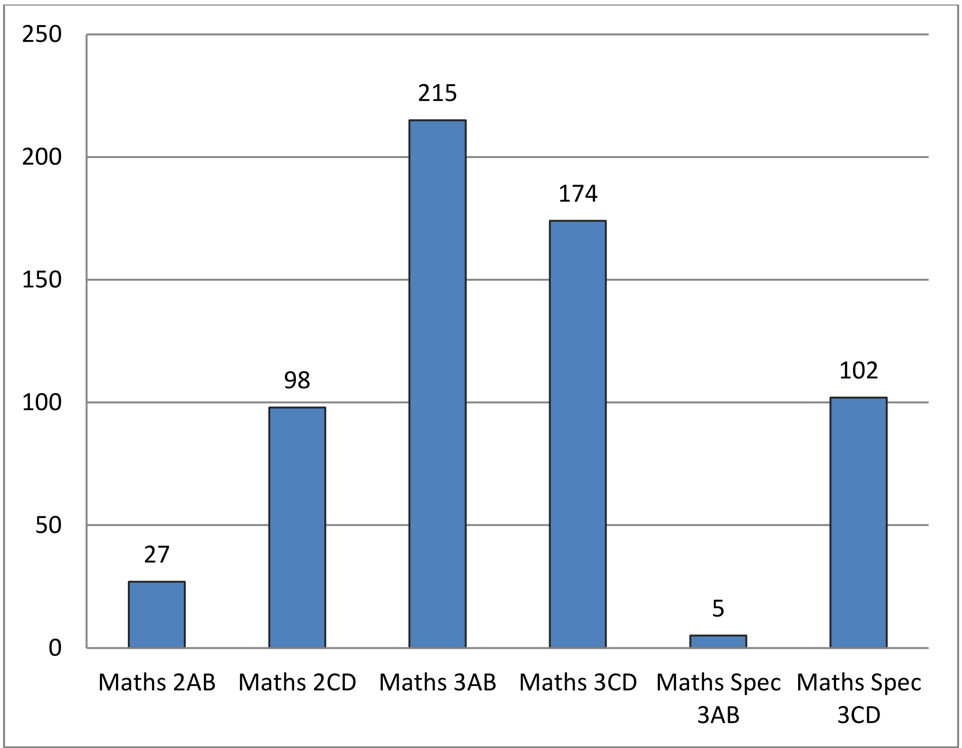
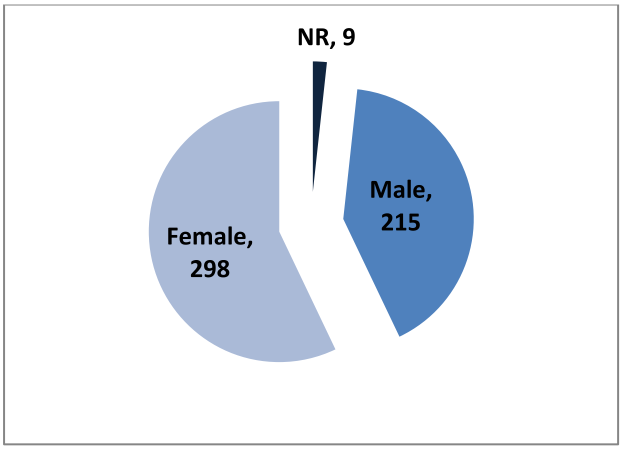


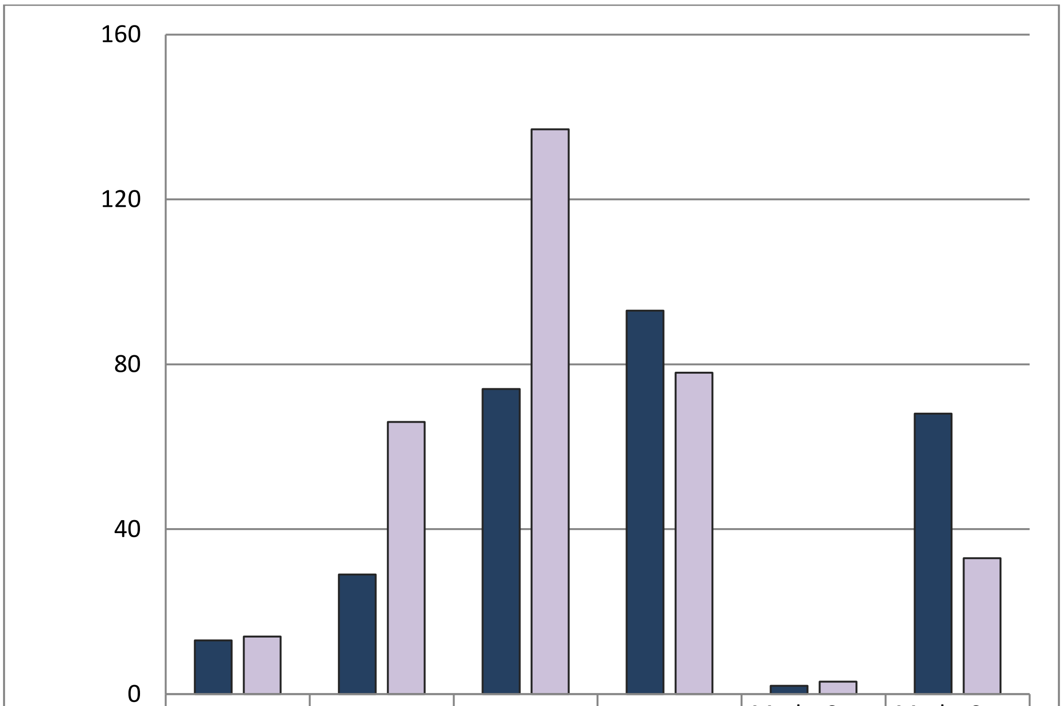
Figure 28. Numbers of students responding, by Maths course studied in 2015.

Figures 29 and 30 provide summaries of student respondents by Maths course studied in 2015, and by gender. As shown in Figure 30, among this sample of secondary Maths students, Maths 2CD and Maths 3AB are represented by twice as many females as males. Conversely, Maths Specialist 3CD is represented by twice as many male students as compared to females.



Note. NR = not reported.

Figure 29. Student respondents by gender (N = 522).



	Maths 2AB	Maths 2CD	Maths 3AB	Maths 3CD	Maths Spec 3AB	Maths Spec 3CD
Male	13	29	74	93	2	68
Female	14	66	137	78	3	33

Figure 30. Numbers of student respondents by Mathematics course and gender.

10.3.2 To what technologies do Year 12 Mathematics students have routine access?

Students were asked to indicate, for various technologies, those to which they have routine access in their Mathematics classes. Table 6 summarises students' responses. As shown, more than 9 in 10 students reported routine access in class to a CAS calculator, for Maths 2CD, 3AB, 3CD and Specialist 3CD. Unsurprisingly, only 1 in 3 students reported routine access to CAS for Maths 2AB; it was somewhat unexpected that only 6 of 10 students in Maths Specialist 3AB reported routine access to CAS, but it is likely that this is more reflective of the very small number of students in the survey who are studying this course (5 students).

Scientific calculators are the second most prevalent technology for which students report routine access across the six Maths courses studied. Scientific calculators were reported by students as most routinely accessed in class for Maths 3CD and Specialist 3CD (9 out of every 10 students). Other technologies to which students report in-class access are notebooks/laptops and generally, "the internet". Between 4 in 10 and 6 in 10 students report routine, in-class access to these technologies, except for students studying Maths 2AB (2 in 10 report routine access to these technologies and to "computers").

Table 6. Percentages of students who report routine, in-class access to various technologies, by Maths course studied in 2015 (N = 522).

Technology	Maths 2AB	Maths 2CD	Maths 3AB	Maths 3CD	Maths Spec 3AB	Maths Spec 3CD
CAS calculator	33%	95%	94%	97%	60%	95%
Graphics calculator	11%	6%	15%	7%	40%	5%
Scientific calculator	78%	72%	80%	89%	80%	93%
Notebook or laptop	19%	31%	45%	43%	40%	43%
Tablet	0%	19%	11%	16%	0%	19%
Computer	22%	18%	14%	16%	0%	18%
Internet	19%	45%	52%	60%	40%	59%

Students were also asked to indicate, for various technologies, those to which they have routine access *at home*. Table 7 summarises students' responses regarding routine access to technology at home.

Table 7. Percentages of students who report routine, at-home access to various technologies, by Maths course studied in 2015 (N = 522).

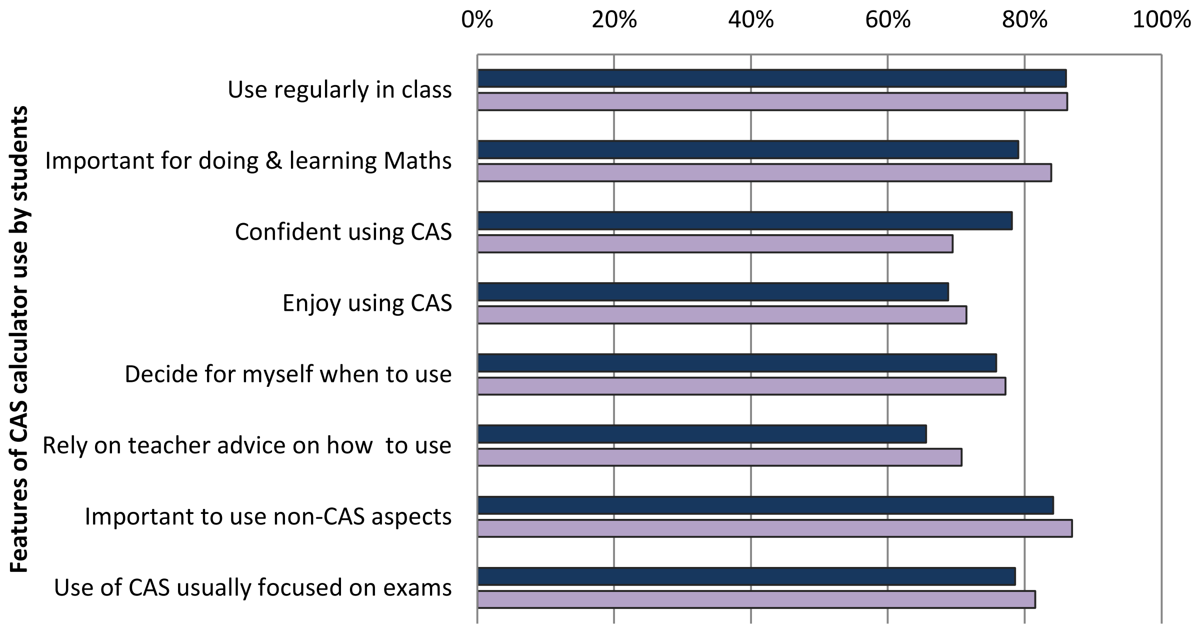
Technology	Maths 2AB	Maths 2CD	Maths 3AB	Maths 3CD	Maths Spec 3AB	Maths Spec 3CD
CAS calculator	41%	92%	90%	98%	60%	95%
Graphics calculator	15%	7%	16%	11%	40%	10%
Scientific calculator	74%	67%	84%	91%	100%	92%
Notebook or laptop	52%	58%	69%	67%	80%	64%
Tablet	44%	42%	40%	40%	60%	43%
Computer	74%	53%	62%	66%	100%	72%
Internet	81%	74%	83%	89%	100%	88%

As shown, more than 9 in 10 students reported routine access to a CAS calculator at home, for Maths 2CD, 3AB, 3CD and Specialist 3CD. This is consistent with what students reported for in-class access. Very modest rates of routine student access to graphics calculators at home were also consistent with those reported for access in class.

For other types of technology, however, students reported routine access at-home at considerably greater rates than for access in Maths class. For example, between 74% (Maths 2CD) and 100% (Maths Specialist 3AB) of students reported routine access to the Internet at home, as compared to between 19% and 60% in class. For the Internet, this perhaps is not very surprising; however, similar large differences were also evident for access to computers and tablets, greatly favouring routine access at-home over access in class.

10.3.3 How do Year 12 Mathematics students use CAS calculators?

To better understand the actual use of CAS calculators in Maths classes, students were also asked about various specific aspects of CAS use at school. Students were presented with a series of Likert-type statements about their use of CAS calculators in class, and asked to indicate their levels of agreement with each statement using a 4-point scale ranging from *strongly disagree (1)* to *strongly agree (4)*. The percentages of students' who agreed or strongly agreed with this series of items are shown in Figure 31, according to student gender.



	Use of CAS usually focused on exams	Important to use non-CAS aspects	Rely on teacher advice on how to use	Decide for myself when to use	Enjoy using CAS	Confident using CAS	Important for doing & learning Maths	Use regularly in class
Males	79%	84%	66%	76%	69%	78%	79%	86%
Females	82%	87%	71%	77%	71%	69%	84%	86%

Figure 31. Student agreement with various aspects of CAS calculator use in Maths classes (N = 513).

As displayed in Figure 31, percentages of male and female students who agree or strongly agree are quite similar across this set of items about CAS calculator use in class. For example 86% of both male and female students report regular in-class use of CAS calculators, about three-quarters of boys and girls agree that they choose when to use their CAS calculator, and 8 in 10 boys and girls agree that the use of CAS is typically focused on use in examinations. There were, however, a couple of points of difference in CAS use between males and females. Notably more boys (78%) than girls (69%) agreed that they are confident in using their CAS calculator; on the other hand, somewhat more girls (84%) than boys (79%) agreed that the CAS calculator is important for doing and learning Maths, and by a similar margin, more girls than boys agreed that they sought advice from their teachers in how to use their CAS calculator.

To further understand the purposes associated with the in-class use of CAS calculators, students were asked: *What is the purpose of your most frequent use of the CAS aspect of your calculator?* Figures 32 and 33 provide summaries of students' responses to this item, by Maths course and by gender, respectively.

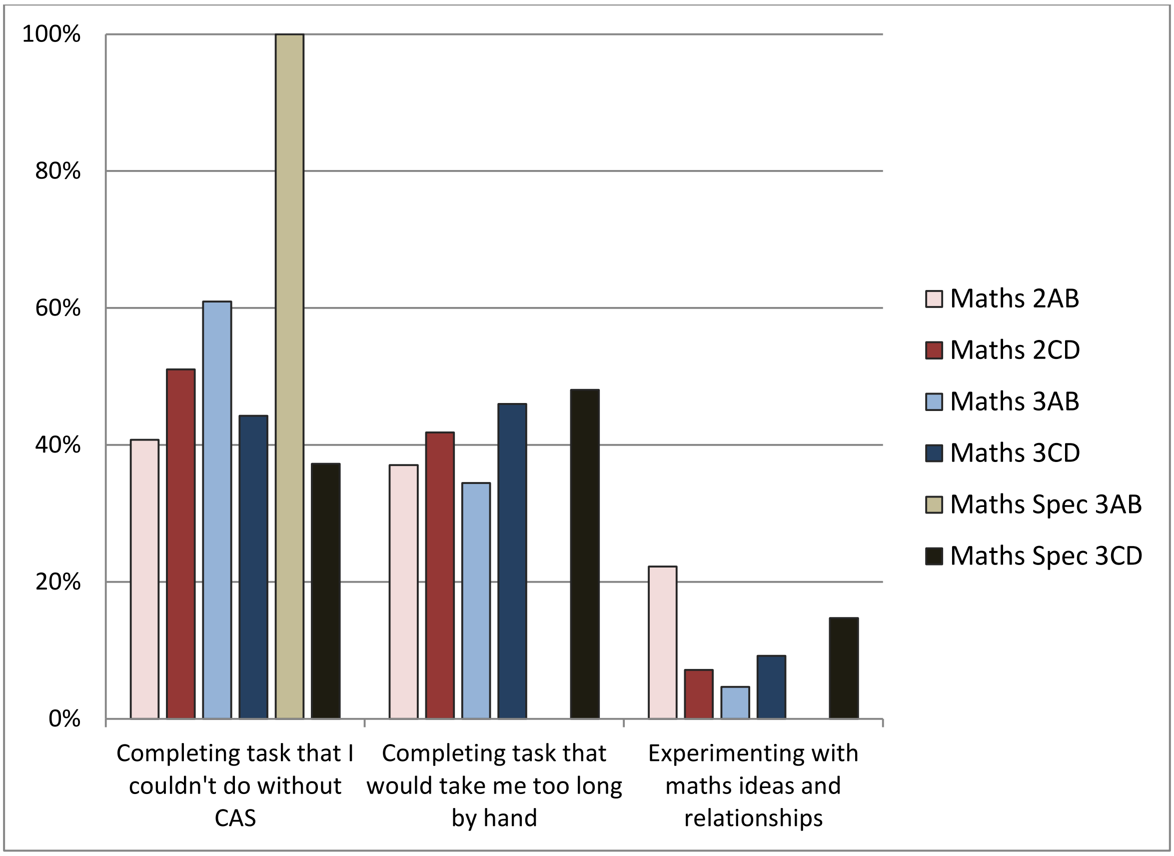


Figure 32. Percentages of students reporting various purposes of CAS calculator use, by Maths course.

As shown in Figure 32, across the secondary Maths courses being studied, students' most frequent use of CAS is for completing tasks that cannot be done without using the technology. Between 4 and 6 students out of 10 reported this as their most frequent use of CAS. (The exception here is students in Maths Specialist 3AB, 100% of whom report this as their most frequent use; it should be noted that only 5 students in this sample reported studying Maths Specialist 3AB.)

Closely behind using CAS to complete tasks that couldn't be done without the technology, about 4 in every 10 students reported that they most frequently used CAS to complete tasks that would otherwise take too long. Few students (between 1 and 2 in every 10) indicated that their most frequent use was related to experimenting with Maths ideas and relationships.

As depicted in Figure 33, when examined by student gender, some noteworthy patterns of CAS use are evident. Four in 10 boys but nearly 6 in 10 girls report that their most frequent use of CAS is for completing tasks that could not be done without the technology. Further, another 45% of males but only 36% of females reported that their most frequent use is for doing tasks that would take too long by hand. Few (1 in 10 or fewer) girls or boys report that their most frequent purpose for CAS use is experimenting with Maths ideas or relationships. These gender differences may reflect slightly more rule-bound or cautious CAS use on the part of female students, consistent with somewhat more confident and exploratory CAS use on the part of male students, as shown in Figure 31.

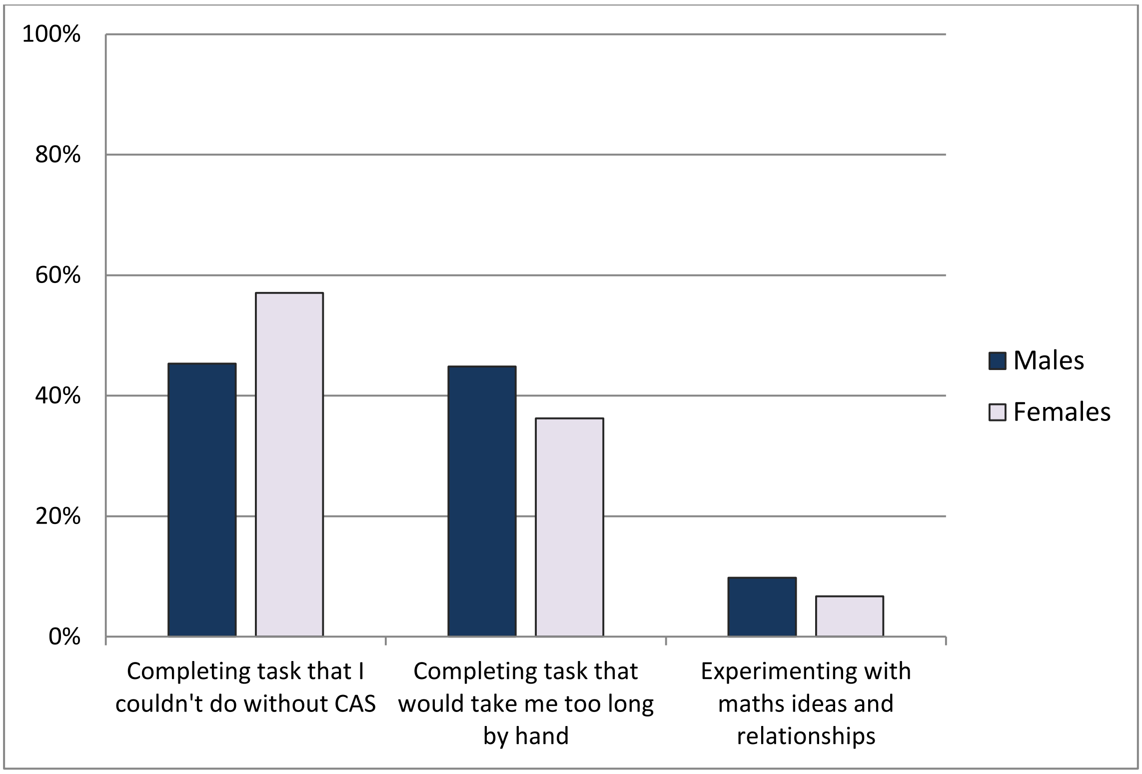


Figure 33. Percentages of students reporting various purposes of CAS calculator use, by gender.

10.4 Survey elaborations

As part of the survey process, all teacher respondents were invited to elaborate their perspectives. The 68 teachers who agreed to do so provided contact details for this purpose, and so they form the database for this section of the report. The intention was to capture something of the flavour of local classrooms and a range of key perspectives held by teachers, in order to understand better the constrained survey responses on various issues. In the circumstances, with only some respondents agreeing to provide further information, and only some of those responding to specific requests, it would not be defensible to claim that the responses were a random or representative sample of teachers. Nonetheless, it is hoped that they capture some of the diverse range of opinions reflected in the wider survey and the mathematics teaching community at large.

10.4.1 Scientific calculators

On the question of the place of scientific calculators, 53 of the group of 68 respondents indicated that their students routinely used scientific calculators in ‘all or most’ or ‘some’ lessons. These respondents were specifically invited via email to elaborate the place of scientific calculators in the teaching, learning and assessment programs involved, and 19 chose to do so. (Many of the respondents had previously provided some detail on their students’ use of technology, including scientific calculators.) Details of the email request are appended to this report.

Unlike the case of CAS calculators, where schools are quite specific in strongly suggesting or even requiring a particular model, it seems that students typically used a scientific calculator that had been used by them since the beginning of secondary school. In many cases, this original calculator purchase was as a result of a school booklist, but most respondents were generally unconcerned about the details, and did not recommend particular scientific calculators for ATAR courses. A typical response was:

> *Any scientific calculator is fine as long as it has trig functions and does rule of order.*

Some schools did offer specific advice, however, such as:

> *Our students are asked to purchase the Sharp EL531XHBWH. There are no specific features that made us choose that one. It has trig functions and performs the basic calculation we, and the science department wanted. We particularly wanted to get away from using calculators on iPads or other internet-connected devices for security issues on our tests. The greater number that have the same calculator makes it easier on the teacher as finding a specific function is then standardized across the class. Students who have differing calculators take up excess time with questions of process that could be better used in teaching and learning.*

No respondents specifically referred to Advanced Scientific calculators, in the sense that this term was used earlier in this report. However, one respondent noted a preference for more than a standard scientific calculator:

> *[W]e decided to go with a powerful scientific calculator that we put on the booklist in the Junior School. We find that most students keep the same scientific calculator throughout their schooling and rarely lose it. The calculator we chose is the Casio fx-100 PLUS because it has vectors, complex numbers and statistical capabilities as well as all the normal functions. We also have the emulator for teachers' computers.*

Overwhelmingly, respondents reported that the scientific calculators are used to obtain numerical answers to particular questions, rather than for learning activities. Typical responses were:

> *Generally just used for calculations.*
>
> *The calculators are used mainly for numerical or trig type calculations.*
>
> *Almost always purely for calculation.*
>
> *The role I see for scientific calculators is numerical, not learning. To me the scientific calculator replaces the SEA tables book.*

One respondent noted that some students use a scientific calculator as they have no choice:

> *Some [use scientific calculators] for everything as they don't have a Classpad. If they have a Classpad they tend to use it for all calculations.*

In the WACE examinations at present, students are permitted to use *both* scientific calculators and CAS calculators, and it seems from survey responses that most students have both kinds of calculators available to them. Unlike CAS calculators, scientific calculators handle relatively few operations and so it is generally the case that each operation is accessible via a labelled calculator key. A more sophisticated device unavoidably requires a less direct method to access calculation functions, usually through a menu structure of some kind, and thus is more complex.

Respondents were asked specifically to advise whether (and why) students prefer to use their scientific calculators than their CAS calculators or other technologies and for which purposes. Many responses draw attention to the familiarity of the scientific calculators and their (relative) ease of operation when only numerical calculation is involved.

> *It is the calculator they are the most familiar with. Our students do not get a CAS calculator until Year 11 as the school executive feel that it is a too large expense to ask of parents when students may get such limited use out of it. Until they know which course they will go in to in Senior School they just have the scientific calculator. As a result of this, by the time they are in Year 11/12 they are most familiar with the scientific calculator and tend to go to this first.*
>
> *Scientific calculators are familiar and predictable. All functions can be found easily and they have been using them for years. CAS calculators require much time to become familiar with their menus and to learn where to find things, especially if you can't remember the name of what you are searching for.*
>
> *90% of girls prefer the scientific calculator – the Classpad is heavy, counter-intuitive and only useful (in their minds) for specific activities. They do not experiment or test theories on it unless forced to.*
>
> *Faster (more responsive, particularly compared to Classpad 300 series); more familiar - less menu navigation to find symbols and functions; better display clarity; better battery life; smaller and more convenient; cheap. Most students always use a scientific calculator for general calculations. They find the CAS calculator too cumbersome to use for general calculations. The scientific calculator is much easier and quicker to use.*
>
> *My Mathematics: Specialist Year 11 always find their scientific preferable to the CAS except for drawing graphs. They are not going to use it to solve basic equations, factorise or solve trig except in the trickiest cases so for most of them it is preferable to use their scientific. They find the buttons easier to access without trawling through menus.*
>
> *The students who prefer to use their scientific calculators for number calculations rather than the CAS do so because they are familiar with the scientific calculator from lower school and find it easier to use without the stylus and moving through keyboards and screens. Students use the scientific calculator concurrently with the CAS.*

Some respondents noted a process of transitioning from the less to the more sophisticated device:

> *When they purchase a CAS in Year 10, they tend to prefer to use their scientific for calculations. I think they prefer the actual buttons, and there's no need to search the various keyboard menus for whatever function they may be looking for. I find that good teaching of the CAS helps students become more confident with it and help the transition to using CAS more often than the scientific.*
>
> *Until they get used to the Classpad, they tend to use the scientific a bit.*
>
> *Students who have not had previous exposure to Classpads prefer their scientific calculators purely because they don't know how to operate the CAS ones. Once taught to use Classpads effectively they generally see the enormous potential of them.*
>
> *Initially (Year 11) students tend to use the scientific calculator for most calculations, however as they become more confident in the use of the Classpad, I see less of the scientific calculator and more of the Classpad.*

Some respondents drew attention to differences at different levels of sophistication:

> *In general students do not bring their CAS to class because I do not use them much myself. (In year 10 or stage 2 Maths) and so they prefer their SC because: it is lighter, there is less anxiety about it being lost or stolen; it is quicker to turn on; it is quicker to get numerical answers; it is easier to understand how to use it. For my Specialist classes, the students do bring their CAS regularly because they frequently need it for the kinds of questions they are being asked, even in [a popular textbook].*
>
> *Some students use their scientific calculators when they have a choice since it is easier for them to use, as it requires less specific mathematics to operate. Of course this depends on which student group you are speaking about. Very able students are able to work with their CAS much more since they are more attuned to the Mathematics required (Specialist students).*
>
> *Stage 2 and 3AB students prefer their scientifics until they get to parts of the course that really benefit from the layout of the CAS, such as Stats and graphing, when they change over to the use of the CAS, and begin to prefer that calculator.*

One respondent drew attention to some of the advantages of a scientific calculator in a school in which technology resources of diverse kinds were available to students:

> *Scientific calculators turn on instantly (speed of use), do not require any particular syntax or different keyboards (simplicity of use) and can do a large percentage of the tasks for which the CAS is used. The Computer screens are bigger with mouse maneuverability and much bigger screen plus the ease with which investigative tasks can be performed. For example, using DESMOS to help understand graph transformations is far easier than trying to incorporate a CAS calculator. This goes for spreadsheets, geometry construction and many other tasks that a CAS can be used for but nowhere near as simply or clearly.*

Some respondents drew attention to issues associated with students being permitted to use scientific calculators (but not CAS calculators) in other subjects, notably the sciences:

> *With the decline of the CAS calculators in science subjects, we are conscious of providing a calculator and instruction on using it that helps in the physics course in particular. My year 11 teachers are instructed to show the kids how to use the various parts of the calculator which will assist them in physics (solving quadratics, solving systems of equations and other useful functions)*
>
> *The fact that the students have to use the scientific calculator in other subjects makes the Classpad seem only useful for a few problems in a Maths course and is not transferrable to other areas, which a powerful scientific would overcome.*

Finally, some general comments made by respondents regarding the use of scientific calculators are also noteworthy:

> *In my classes the purpose of a scientific calculator is generally to obtain an answer. On many occasions I will explain to them that the answer is not what is important to me. How they arrived at their answer has greater importance. Being able to verbalise (to their peers and myself) the method used and transferring this to their page in a "mathematical format" demonstrates their level of understanding.*
>
> *A scientific calculator is an essential part of a toolkit for a high school mathematics student. Once a CAS calculator has been introduced students may choose to use this for numerical calculations however many prefer to continue to use their scientific calculator.*
>
> *I think the introduction of natural display has brought along the use of scientific calculators leaps and bounds. No longer do weaker students struggle to add the right number of brackets and no long see mixed number fractions in a weird way that doesn't match what they see on their page.*

Together, these comments from survey respondents make clear that the scientific calculator has been an important and useful numerical tool in secondary school mathematics, with students typically using them from the early secondary years to support calculation, where required. Many teachers referred also to the importance of students undertaking calculations without the aid of calculators, both in the context of technology-free assessments and also in regular class work. The familiarity of the scientific calculators means that very few teachers reported using them for learning purposes, few used an emulator to support their teaching, and most assumed that their students would already have developed suitable calculator skills by the time they reached senior secondary school.

10.4.2 Computer software

In contrast to the situation with scientific calculators, most respondents to the survey reported that students used computer software for mathematics, whether commercial or free, ‘never or hardly ever’. Of 294 respondents to the survey, only seven reported that students used commercial software in ‘all or most’ lessons, while a further ten reported that this occurred in ‘some’ lessons. Accordingly, relatively few of the 68 respondents willing to provide further information indicated that the student use of computer software was an important and frequent activity. Furthermore, when contacted for advice, most of the 16 respondents who indicated that their students used commercial software in either ‘some’ or ‘a few’ lessons did not respond; noticeably, all but one of these 16 potential respondents was teaching in a non-government school. Details of the request are appended to this report.

It appears that computer software is mostly being used when schools have a program in which students have their own laptop computers with them, but no instance was reported of students being required to purchase commercial software specifically for mathematics on those computers. An exception to this is the spreadsheet, Microsoft *Excel*, which is often available as part of a suite of Microsoft software, frequently bundled with computer purchase or made available on a school network. Several teachers referred to the distinctive merits of using *Excel* in mathematics, especially for purposes such as budgeting and financial mathematics.

In a few instances, schools held a site license for particular mathematical software: one school referred to *Geometer’s Sketchpad* another to *Tinkerplots* and *Geometry Expressions*, and two schools referred to *Autograph*. One school referred to students using mathematical layout software (specifically *MathType* and *Efofex*), for which the school has a license, intended mostly for teachers but available also to students via a school server. Some schools referred to calculator emulators, although it was not clear whether these were for teacher or student use. It is problematic to draw strong conclusions from such limited data, but it seems safe to conclude that very few schools are making use of commercial mathematical software, even when students have a laptop computer at their disposal. It seems that a major use of the computers (for mathematics, at least) is to access the Internet and the school’s internal website, as well (possibly) as publisher materials associated with their textbooks (although these were also not mentioned by respondents).

Respondents indicated that the software was generally prohibited for use in formal assessments (such as tests and examinations) although might be used by students in some investigations. One of the respondents reported that the software was important for student projects, which are part of the International Baccalaureate course they were studying. In that case, the teacher used the software as well, to support student work:

> *Because I know I need to prepare students for their projects in year 12, I use Autograph and Excel in ways that make students participate, not just watch demonstrations so they build a bit of knowledge/confidence with the programs. I want them to see enough of the programs to see that they are a tool students know they can use even if they need to research or get guidance on how to do some things.*

Slightly more respondents referred to students using free mathematical software, although overall only four of 294 respondents reported this occurred in ‘all or most’ lessons, with a further eighteen respondents reporting that this occurred in 'some' lessons. (This group is not distinct from the previous group of respondents whose students use commercial software; in fact, most of those also reported that their students used free software as well, so it was generally unnecessary to contact them twice.) Of the 68 respondents agreeing to provide further detailed information, only 2 reported that their students used free software in all or most lessons and a further 8 indicated that their students used free software in some lessons. Again, it is noticeable that all but one of these ten respondents taught at a non-government school. Some respondents were contacted by telephone, with the details appended to this report.

Detailed advice on the free computer software used by students was not provided extensively, but it seems that *GeoGebra* is used in some schools and that students sometimes have free software on laptop computers (such as inbuilt graphing or numerical calculator programs). One teacher reported that he encouraged students to find suitable software for various topics that matched their particular laptop computer, rather than specifying the use of particular software, as a means to accommodating a range of models in the class.

It is difficult to interpret these limited data, suggesting that the use of computer software for mathematics is very limited at present. One interpretation is that most teachers are reluctant to make use of technologies other than calculators, as these are the only tools that students are permitted to use in examinations. Furthermore, even when the software is superior to that on calculators (such as for a spreadsheet or a graph on a large screen), students are still typically not permitted to use it in school assessments, which are designed to match external assessments. A corollary is that teachers want to focus their students' attention on use of the calculators, and spending time on other technologies will reduce the opportunities to do so.

10.4.3 Apps on tablets

As with the use of computers and computer software, most survey respondents reported that students used apps on tablets 'never or hardly ever'. Accordingly of the 68 respondents who agreed to provide further information, only six indicated that students used apps on tablets in 'some' lessons (five respondents) with only one respondent indicating this occurred in 'all or most lessons'; all 14 of the respondents who indicated use of tablets at least in a few lessons were invited to provide further detail, and six of them did so. The details of the request are appended to this report. All but two of the 14 respondents were in non-government schools. Clearly, this is not a large body of data to draw upon, but perhaps it is sufficient to identify some of the issues.

The main device referred to by respondents was an Apple *iPad*, although one school used a Toshiba *Ultrabook* in a 1-1 program. It was clear from respondents that the tablet was typically personal to the students (rather than being made available via a trolley, for example) and was usually in addition to other devices to which students had access, at least a CAS calculator and generally a laptop as well. So the tablets in use were not the students' main device for technology access in mathematics, which might account for the relatively rare use of them. The details of the circumstances of tablet use were generally not provided, although one respondent noted:

> *Students are obliged to purchase their own device – and the school specifies iPad (not 3G enabled) at an approximate cost of $500-$600. The school installs management software (Airwatch) to install required Apps and*

> *monitor appropriate use. Some commercial apps are provided to students under a school license (e.g. Pages, Numbers etc). Most other apps used in class are freely available.*

Respondents were asked which particular apps were used on the tablets most often by their students. The most common response was *GeoGebra*, the dynamic geometry package available for computers and recently transported to tablets on both iOS and Android platforms:

> *I ask the students to use Geogebra on a regular basis to help solidify understanding and for testing thoughts, conjectures and other unusual features. As an example we have just extended matrix transformations to 3D to investigate the determinant and effects. This is in 3 CD MAS. Also using Geogebra in years 10 and 11 in 10A and in Methods. Will also look to push it further down the age range. I accept it cannot be used in examination but the usefulness is in the concrete visualisation rather than helping in tests.*

> *For mathematics, GeoGebra is AMAZING!*

> *Geometry is much easier using GeoGebra (and other sites) than a CAS.*

Because tablets also allow Internet access, provided WiFi is available, some respondents also used it for other purposes such as *iBook* versions of textbooks, and applications related to the Internet, notably the commercial subscription package, *Mathletics*, used to provide targeted exercises and practice for students. One respondent also referred to *Khan Academy*, a popular web-based video series from the US that provides didactic and procedural advice for students:

> *Initially there were many apps put on the "booklist", as suggested by our Apple expert (employed part time by the school). For 2015 we have cut this down to Mathletics, GeoGebra and Khan Academy.*

One respondent indicated daily use of a range of apps and websites via the tablets:

> *Geogebra, Desmos (in Mathletics), all the interactives available in software packages like Mathletics, NelsonNet, plus Wolfram Alpha, Mathspace lite, instructional sites like Khan Academy, PatrickJustMaths.*

Another respondent referred to some use of apps by students for mathematics, but indicated that the *iPad* was important for other purposes than these:

> *iPads are used mostly for organizational purposes rather than actually education based apps – downloading and completing worksheets, submitting work, accessing notes. ... One of the greatest benefits of tablet devices is the ability for students to download, organize and submit work without having to manage piles of photocopied worksheets. Nevertheless, organization is still a challenge for many students.*

As noted by Kissane (2011) in reviewing iOS apps (most of which work on both *iPods* and *iPads*), tablets offer many different calculators in apps, although students generally use a hand-held calculator instead. Calculator apps are less often designed for educational purposes. However, one respondent referred to these:

> *Many students still have various calculator apps on their iPad, but we try to discourage the use of these, as the iPad cannot be used during assessments, hence we still want them to be familiar with the handheld scientific calculator. In particular, the MyScript calculator app is very popular with students (this is the one where they write the calculation with their finger, and the app converts it into mathematical symbols) ... this app tends to lack many of the handy features of a scientific calculator.*

One respondent observed that the development of apps is an emerging field:

> *For maths education there are some interesting apps coming available that take full advantage of the intuitive, interactive tablet platform. Such as MathSpace which allows students to handwrite equations, requires students to work through problems step by-step and provides hints and context appropriate lessons and examples to students. … It is true that tablets cannot replace CAS calculators right now, mainly because of the security issues involved with use of tablets in assessments. Current CAS calculators have some features that might not be currently available on tablets but this would be quickly resolved if tablets were widely adopted for assessments.*

Another respondent who used apps often was enthusiastic about their use:

> *[T]he apps are always much more user-friendly than the CAS. To learn even simple spreadsheets on a CAS requires a great deal of preparation even for those who are familiar with Excel. Geometry is much easier using GeoGebra (and other sites) than a CAS. Desmos is brilliant for showing transformations of graphs. Using CAS BECAUSE you can use it in assessments does not seem to be good pedagogical practice when there are much better ways to derive an answer. There are a number of great free statistics apps that could do what a CAS does. Oh, and if the students have access to a tablet they wouldn't have to pay over $200 for a CAS – a <$25 scientific calculator would do all the necessary calculations.*

A potential issue for tablet users with a range of apps is that, as for computer software or for calculators, each app is likely to operate differently and hence requires time for familiarity and smooth operation. This is the case for both teachers and students, as the same respondent observed:

> *In terms of the GeoGebra and Mathletics, I have used them on occasion for demonstration ... having said that, they are definitely usable by students ... though quite a bit of initial work would be required to get the students using GeoGebra effectively (and myself, I would probably need much more training to become an efficient user ... my skills on this app are pretty rudimentary). One of the issues comes down to class time (as it always has). As a classroom teacher, do I have enough time to invest in getting the students up to speed in using these apps ... this has to be balanced against keeping up with the program (and the other classes), and making*

> *allowances for all of the lost time due to the normal school interruptions (sporting events, photos, etc etc).*

None of the respondents allowed the tablets and the apps to be used during formal assessment. The likely reasons are captured in this response:

> *I look forward to the time when they can overcome the ability to communicate with one another (and the www) on the iPad, so that it can be used in assessments. Eg If they could develop a "jamming" device which blocked access to external networks, then students could potentially use everything on the device within a timed assessment.*

Another respondent was keen for these problems to be resolved:

> *Students generally do not use any of these apps for in-class assessments. I would like this to change, and have explored a number of possible strategies for completing in-class assessments, however security of the test questions remains an issue and reliability of devices and network is also an issue. Rare exceptions have been made for students who have been unable to hold a pen to use Notability to complete a test. ... Students have not been allowed to access the Internet, but in the specific circumstances this has been possible to ensure by direct supervision – not really manageable for a full class. There are still some concerns to ensure that the student does not pass on the electronic version of the assessment to other students, and again this was dealt with by directly asking the student to delete the document after submitting the test. I do think that integrity of tests could be ensured with specifically developed assessment apps.*

While promising, tablets may have some distance to go before they are integrated as effective educational tools, according to one of the respondents:

> *They look to have significant potential for good ... and for distraction. Unfortunately, escape from a not so exciting maths lesson is just a few finger swipes away. I like the fact that the iPad can significantly reduce the amount that a student has to carry (in terms of textbooks). ...*
>
> *We do need to understand that we are dealing with children, and the tablet is viewed by them as a really good toy, not an educational device. At my school, the students/families own the device, hence they have full control over what goes on that device, be it educational material, or frivolous games. Many hedge towards the latter (probably what I would have done when I was a kid, given the opportunity). ... My school has a long way to go before we are using these devices effectively. They were introduced as part of a 'jumping on the band wagon' thing, and currently, the political climate is resistant to 'evaluating' their effectiveness, and whether we need to look at doing things differently. E.g., Students lease the device from the school, school has control as to what goes on the device. These are interesting and fast moving times in education. I am still unsure whether the impact will be positive or negative.*

Partly in response to suggestions in general survey comments from a small number of teacher respondents, the research team also investigated briefly the possibility and consequences of students purchasing and using less expensive tablets than those described here. Given the observations of concern from many respondents that modern CAS calculators cost in excess of $200, attention was focused only on tablets that could be purchased for less than that amount.

It was not possible to purchase an iOS tablet for less than $200, but it is possible to purchase small Android tablets for such a sum. Indeed, one tablet was available (at a store sale) for $49.

Tablets of these kinds can successfully operate *GeoGebra*, the most popular app referred to by the respondents above, albeit in a smaller screen than an Apple *iPad*, but are not able to operate some other apps, such as that for the *TI-nSpire*, which requires the larger iOS to operate. Similarly, other apps referred to by mathematics teachers, such as *Desmos* or *Wolfram Alpha*, also operate on the inexpensive Android platform.

The less expensive devices have not been developed with school use in mind, and evidence on their physical robustness or experience with the one-year warranties for defective products is not available. When asked regarding battery life and battery replacement for the devices, retailers seemed unaware of the mechanisms and generally suggested that it would be better to replace the device than to try to replace the battery, which requires finding another firm that specialises in battery replacements. Battery life was thought to be around two years, possibly three, under normal use patterns, but definitive answers were not easily available.

It is not clear whether it is possible for tablet screens to be projected for class use and discussion, and retailers seem generally unaware of such practices, as the tablets are intended for individual and personal use, not educational use. While it may be possible, it seems that it is likely to be possible only for teachers with particular IT skills.

For these reasons, it seems as if inexpensive tablets may have a place in some classrooms, but unlikely that they would be satisfactory as the only devices students had for technology use in mathematics education. Rather, they may in time become useful supplements to other technologies used in the classroom, if the practical issues can be resolved and advice more easily obtainable for teachers who are not IT-enthusiasts.

10.5 General survey comments

As part of the survey process, teacher respondents were invited to add additional detailed information at various points, which serve to provide more complexity and depth to the survey responses summarised in the data analysis section of this report. In addition to these comments within the survey, all 68 teachers agreeing to provide further information were offered an individual opportunity to do so, via email and, in some cases, telephone conversations, and those who did not respond to the invitation were given a further opportunity to do so after a period of time. Details of the email request are appended to this report.

Many aspects of the comments received in these ways are already evident in the further detailed information reported in the previous section, but some particular issues and themes emerged more generally, without prompting, and are worthy of additional attention. Some of these are reflected in this section, which is intended to highlight some of the diversity of opinion amongst the mathematics teaching community. As might be expected, teacher attitudes and opinions on many aspects of the use of technology differ; the quantitative data provide the best mechanism for understanding the broad perspectives of those who responded whereas the purpose of these comments is to highlight some of the rationales for particular viewpoints and responses.

Each of the 68 teachers who volunteered to provide further information related to the survey issues, was contacted and invited to elaborate their views, with some of them contacted several times. Overall, 51 of the 68 respondents took the opportunity to elaborate on their survey response in at least one way. The remaining 17 had been contacted by email at least twice and it seems reasonable to assume that they did not feel that their survey responses required further elaboration.

10.5.1 Teaching with CAS technology

Although many of the comments (such as those in relation to the use of scientific calculators, reported earlier) focused on calculators as computational devices, some teachers offered advice regarding the use of CAS calculators for teaching and learning purposes. Comments of these kinds are included below, in order to highlight the range of issues canvassed.

> *Classpads greatly facilitate learning! Some students are more effective at maintaining notes across years of learning with these than they are using paper or other methods as they are small and portable and allow notes, formulas and learning to be stored. It motivates many students to tackle concepts they find difficult and provides visual learning opportunities. Why would we get rid of these? We live in a technological age and students need to learn to drive their technological devices.*

> *Let's use the technology to learn and understand but examine the thinking and understanding.*

> *Allows concepts to be picked up quicker - for example the instant feedback from the "verify" function of Classpad gives students confidence without needing constant teacher support. Provides "visual" feedback of what they are learning.*

> *I teach in a private school so the parents can afford to purchase the technology listed on the booklist. I use a Casio CAS calculator at this school and the clarity of the screen makes it a good learning tool. If an emulator was allowed to be used on a tablet then that could be used instead of the CAS calculator.*

> *Teaching tool not assessment tool like now.*

> *Technology opportunities are vast and provide great opportunities for students to explore investigate and ultimately understand.*

> *Technology especially CAS calculator is good in helping students to understand and expand their mathematics knowledge. It is helpful for learning mathematics.*

Technology can help students get a broader understanding of mathematics, not deeper. Tedious, routine work can be done quickly, so students can cover more topics.

I often use the TI CAS and navigator to introduce new concepts, especially in the new Methods course. For example, teaching domain and range, a TI CAS document allows students to drag a point on a function, and see the domain and range being plotted on the relevant axes "live" as the move the point on the function.

The ability to look at the applications of the mathematics they are learning is more possible with the use of CAS. Prior to CAS the focus was on boring skills and there was too much... "Why are we learning this?", "where will I ever use this?" negativity whereas with the use of technology they get to the opportunity to see some of the applications and higher order thinking that was NOT possible prior to CAS.

I have taught all levels of maths with the CAS (and all calculators over the years) and they are powerful for the most able, difficult for the average student and impossible for the least able student.

Surprisingly, relatively few comments from teachers referred particularly to the symbolic aspects of CAS calculators that distinguished them from graphics calculators, in particular the symbolic capabilities related to algebra, calculus, exact solution of equations, general results, indefinite integrals, and so on. Two (opposing) comments related to this aspect are included below:

CAS used well can enable students to easily make connections between different parts of mathematics that would otherwise be more difficult; for example seeing the connection between symbolic notation, graphical approaches and tables in algebra is facilitated through the click of a few buttons.

I see no point when students are learning basic algebra skills to use the CAS calculator to highlight and solve equations, factorise, expand, simplify etc. Far too many students have the Trig formulae in e-activities where they put in values and have no idea how to manipulate, rearrange or substitute values into the rules.

Not all teachers regard CAS calculators as a positive teaching and learning tool. Comments from teachers indicated various kinds of concerns, of which the following are examples:

Having assessments which include CAS calculators are the biggest barrier to teaching and learning. They change the way we have to teach the material and the way in which student "learn". It is not a support technology. CAS calculators have become a "learn this particular device or fail your exam". Nothing to do with mathematical understanding or thinking.

Often the use of CAS technology only helps more able students. If they are more able they are able to use the technology to their advantage whereas *less able students are stumped by the technology as well as the maths content.*

As all students have access to a computer or 1-1 device, a $230 CAS or graphics calculator is antiquated technology. Students can use the technology available on their computer to generate data, explore graphs, collate information, model problems etc the calculator is an extra cost for no real benefit. All 21st century mathematics teachers integrate technology into their classroom practice. With the curriculum designed to focus on the use of an expensive and limited graphics calculator, we are limiting students' exposure to technology.

I do not feel that the use of technology is a barrier to teaching mathematics. In principle, I would welcome the continued use of CAS technology as well as computer based programs and graphing applications AS A TEACHING TOOL. Where it becomes problematic is the requirement to then assess students on their use of this technology.

CAS and Graphics calculators often become another thing to learn for the students, so effectively increase the content in the course. Some students see it as a cure for their lack of knowledge and expect to be able to do maths if they have the CAS calculator. It often interferes in the learning as we are expecting students to learn pen and paper methods, and calculator methods at the same time, rather than using the calculator as a tool after the learning has been properly established.

Students end up stressing out about using the calculator rather than the learning experience.

Students can write programs which can instantly solve a mathematics problem. This is good for that student ... however not so good for the next 1000 who copy the program and use it without understanding. Technology should be there to assist in the understanding of the concepts, not the reverse (someone who only uses a program written by others is unlikely to learn the concepts effectively).

The calculator makes it QUICKER once concepts are understood. But to understand the maths, the students need to work through it without a calculator. Some students just learn the calculator rules and tricks - for example e-activities on the Classpad and simply put in values and have no understanding whatsoever.

It is a crutch for the weaker students to get through without a genuine understanding, it is a stumbling block for the stronger to genuinely understand as they tend to say "oh but my calc can do that" without gaining full understanding.

Graphing and statistics on the calculator - useful and enhance learning. E-activities on Classpad detract from learning. Solving equations, algebra and calculus on the Classpad do not enhance learning but they make working a problem quicker.

Some student comments also referred to issues related to learning with CAS calculators, both positive and negative, such as the following:

> *It's an extremely useful device that I believe furthers the potential and the learning of all the fellow students in my mathematics class.*

> *The CAS calculator is an effective tool used by students to develop and further enhance their mathematics abilities. The CAS aids with long hand questions and allows students to then adventure more into new concepts without the restraints of working by hand. the new version also makes it easy to use and navigate.*

> *They are time consuming and it has nothing to do with mathematical ability to plug numbers into a calculator that will give you all the answers, and is hard to understand as well.*

> *I find using CAS calculators for problems in our curriculum doesn't teach us much. It seems like sometimes things we are taught on the calculator requires no thinking, just pressing 5 buttons and getting the required result.*

> *It is useful in experimenting with ideas and relationships however it is important that students are able to do the mathematics by hand and with the CAS calculator.*

> *Is it really necessary? It takes away from the actual understanding of the concepts and replaces it with wrote [sic] learning how to solve certain types of problems on your calculator.*

10.5.2 The influence of university practices

Many of the comments from teachers and also some from students make it clear that they are aware of the general reluctance of mathematics teachers in local universities to use CAS calculators (and before them, graphics calculators) either for teaching purposes or in examinations. For a number of teachers, this is proposed as a sufficient argument for a change to examination requirements in schools, to match those in the universities, mindful that stronger students in particular are likely to study mathematics in some form in university.

Typical teacher comments of this kind follows:

> *A problem with CAS or graphics calculators is that are only used in education. No engineer or scientist would ever use a Classpad. But they do use spreadsheets.so these should get greater attention in the courses. That is, real spreadsheets on PC or tablet, not limited Classpad versions. And, for advanced courses, exposure to Matlab or other software that is used in industry would be more relevant*

> *The Classpad is a throw away item once students have left high school.*

> *Most have used a scientific calculator all their school life, and know they must use a scientific calculator in tertiary studies, so are reluctant to invest time and money in a CAS.*

> *All students doing Methods and specialist are planning on going to university and if they decide to study mathematics at Uni and they are not allowed access to CAS or class pads in exams then they should not have access in school as it is setting them up for failure.*
>
> *One of my concerns about the use of the technology of CAS calculators is that they cost a lot of money for use in two or maybe 3 years. Then the kids go to uni and they are not generally allowed to use the calculators.*
>
> *I would happily remove the CAS calculator from the booklist for my school- they are expensive and are not part of the technology used in courses beyond WACE so why continue with it? For a similar price tablets can be bought at thus access to a vast range of resources could be had.*
>
> *Universities only allow scientific calculators. We use CAS calculators and then they are taken away at uni.*
>
> *For year 12 students who will continue with mathematical studies in University, we should be looking at what is permitted by the Unit Coordinators and should follow their lead.*
>
> *Students don't want to purchase ClassPads for one year and then not use it again if they are not going to university.*
>
> *Students will not be using classpads once they leave school and therefore is irrelevant for their life.*
>
> *If industry would not use CAS and universities do not endorse CAS, then I think there are valid questions why CAS should be used in schools. I think that the justification is dependent on the expectations of course, and the usual destination of students doing the course.*

Some students were also clearly aware of differences between school and university practices regarding technology, as reflected in the following comment:

> *It is annoying to learn to almost rely on the capabilities of the CAS calculators and then get to uni, and throw it all out the window and go back to learning it by hand. / School should prepare you for life, and I think by using something we will never use again, we are not being prepared for the outside world, and certainly not for uni.*

10.5.3 Equity concerns

Teachers were invited in the survey to comment on equity concerns, and the extent of these concerns was described earlier in Figures 26 and 27. Other feedback referred to equity issues as well. The most common equity concern related to the cost of the CAS calculator technology and its affordability to some families. Typical responses of this kind are the following:

> *They cost a lot and put some families off attempting ATAR maths.*

> *We don't require the students to have the CAS calculator until Yr 11 (due to the cost), thus they have less experience in using the technology*
>
> *Some students do not have a CAS calculator and their parents will not buy one for them.*
>
> *In previous schools most students could not afford CAS and school only had limited funds to buy copies for some students to use. One class hired them, two others had no access to CAS. How is that equitable?*
>
> *Many students purchasing 2nd hand CAS calculators with broken buttons blurred screens and outdated software*
>
> *While new CAS are >$200, second hand ones can be bought for less than $50. Any student that has claimed financial hardship has recanted after I spoke to parents.*
>
> *Some parents will understandably not spend on CAS now that they are required by the school to spend on 1:1 laptop technology.*
>
> *Students who can't afford CAS calculators only practice on school ones and are less capable of using them than if they were their own.*
>
> *Of course the cost argument is a bit spurious, some people spend as much on sports shoes that might only last 6 months.*
>
> *They all have phones, and they are smaller than their calculators. They would rather use a simple calculator on their phone than bring their calculator. My difficulty is that they have to use the calculator regularly to be confident users.*

The teachers most likely to experience equity concerns at first hand, hardly surprisingly, are probably those in low SES schools. Some teachers from these schools observed that alternatives to CAS calculators were unlikely to be available, which is probably different for the case of students in other schools. Although of course there are variations, schools that are classified as low SES serve mainly families with more limited resources than those with high SES, and are thus likely to have less home resources and, in some cases, less resources at school. Comments such as the following reflect this situation:

> *In low socio economic schools the fact the calculator is needed for the exam is a major motivator in students purchasing the product. Without a CAS calculator students would not have access to technology which helps gain deeper understanding of many concepts and allows us to use real life messy data in our questions and student learning activities.*
>
> *Without CAS calculators we would have almost no access to appropriate technology.*
>
> *Use of CAS technology has improved equity, with our students accessing technology only previously available on computers that our low socio economic school did not have for Maths students to access.*

Students proficient with use of e-activities and all functions of calculator have advantage over others. Our students have the funds to purchase 2 calculators, attend Charlie Watson seminars and have private tutoring on the use of the calculators. This gives them an enormous advantage over lower socio economic students who do not have access to the same resources.

Not at my school, we draw from fairly wealthy suburbs. But colleagues have reported difficulties with the expense of CAS calculators for many of their students. These students sometimes borrow calculators for assessments, but this prevents them from having a mastery of the device through regular classroom practice.

The CAS are too expensive. The companies seem reluctant to lower prices and I am unsure if a state contract would help. However, if we get rid of them in the exams, most classrooms will see little technology and I see this as a step backwards, as the CAS can lead to discussions that are rich in analysis, particularly in statistics and applications.

Some schools do not provide equipment eg no emulator or overhead projectors - cannot afford them. Some students do not want to buy them; their priorities are elsewhere.

I am sure we would all love to believe that every teacher in the state would use technology to enhance their students learning and expose them to new ideas no matter what the WACE exam format was….but if CAS calculators were not a compulsory part of the exam, how many students would honestly never be exposed to these things? Not every school has one-to-one computer access, not every teacher feels comfortable teaching with technology – but making the calculators a required piece of equipment equalises the technology playing field and means every student has a powerful mathematical device available to them.

Another aspect of equity is access to a suitable mathematics teacher, and some comments alluded to the inequity associated with a student's access to teachers:

As a marker it is obvious which students have had access to CAS technology and a teacher who has shown them how to use it in exam conditions.

Some teachers know more tricks

Different teacher capacity to encourage students to use them to their full potential.

Students change schools and bring a different device. The teachers are experienced with the Casio, but not this new device. Hence this student is disadvantaged (unless they purchase a new CAS).

If the teacher is able to use the technology well then their students are at an advantage.

Some student comments also drew attention to equity issues, especially those related to cost:

> *Please make the calculators cheaper, there are some of us not able to access extravagant funds with which to purchase said, expensive calculator.*
>
> *They are expensive.*
>
> *I don't have one - they are a waste of money...*
>
> *I think it's a waste of time and money to focus the non specialist courses on using these calculators, as we will often not have access to these 'in the real world'*

10.5.4 Supporting students and teachers

Both teachers and students commented on issues related to getting help with calculator use, and, obliquely, to the lack of explicit advice regarding its use in teaching, learning and assessment. Although the survey results suggest that teachers are mostly quite confident with the technology, of course that is not the case for all teachers (or all students). The comments below provide some perspective on this matter.

> *Teachers have been left alone a bit to work out how much to use the calculator. Anxiety about your students being disadvantaged in WACE if they do not use calculator enough. Some questions seem (not in 2AB) to be contrived for technology use. More time needs to be given and guidelines about when it is essential to use calc and when not. Not covered in syllabii. / Most teachers work together to muddle through and help one another.*
>
> *Teacher understanding of how the technology could be used to enhance lessons is diverse.*
>
> *The CAS calculator does little to make learning maths an even playing field. New and recent syllabi have not given sufficient time for the calculator to be taught thoroughly. Many teachers do not know a great deal about the calculator and others are quite expert. Some teachers spend a great deal of time teaching time saving and mark gaining techniques to students with or without understanding whilst others stress understanding of concepts and use the calculator only to support understanding and/or enabling students to complete problems with more realistic computations or graphs. It is difficult to know exactly where and to what degree the calculator should be used and syllabi do not specify this. Not saying that all maths teachers are equal in other ways either, but this is a problem.*
>
> *Teachers who have access to PD can show their students tips and hints but not all teachers have access.*
>
> *Lack of PD is an issue. Charlie Watson provides excellent 3 hour PDs in Perth for Classpad but as a teacher in a country school, I can't justify the cost of travel to Perth and of relief cover for only 3 hrs. Management need a course to be more substantial.*

> *We will need more or better access to materials that complements teaching mathematics using technology.*
>
> *I do feel that there is a lot of support material available and I always feel that my students have the resources and the material available to become confident, capable users of graphics calculators.*
>
> *Students are not willing to 'work it out' for themselves, expecting me to teach them everything about the calculators. This is a drain on class time and is a ridiculous expectation.*
>
> *I realise I should be doing professional development but with two primary aged children and being a single parent it makes it harder to organise I know updating my skills helps my students so I do ask my colleagues for help and will look for some PD on how to incorporate computers into a maths classroom. I feel under pressure to get through course content and find my lack of efficiency with computers takes up too much of my program time so also revert back to chalk 'n talk. When computers don't do what is expected I do not know how to fix the problem I get flustered and off track.*

Students also commented on the need for support to use their CAS calculators:

> *Not enough education on how and when to use them.*
>
> *I find that there is not enough information and teaching about using the CAS calculator, I find there are always easier ways I could have done things if I had known how to use it better.*
>
> *I do not know how to properly use them as I have not regularly used the Classpad and after a brief run down of the functions on the Classpad, it was assumed that we could use them competently. There was not much practices at all in class on the Classpads and I dislike using them as I don't really know how to.*
>
> *We never learnt how to use the ClassPad prior to year eleven, yet they just assumed that we knew all the basics. Which we didn't. I still have no idea tbh* [to be honest].
>
> *Many people in my class struggle to use the CAS because they have not been taught how to use it properly. I enjoy using my CAS because I have taught myself how to use it, and because it makes doing complex equations much easier and makes studying the relationships between functions easier.*
>
> *I would like my teacher to teach me more on how to use the CAS calculator.*
>
> *I have no idea how to use it very well for Finance especially, we have whole questions in the math test that's calc assumed and done limited of that in class of the kind of question - and it's pretty hard to teach yourself unless someone teaches you.*

10.5.5 Examination issues

Many teacher comments referred to aspects of the external examinations, clearly regarded as of considerable importance. Some comments seem to reflect the lack of detailed and explicit official guidance regarding the use of CAS in exams. The following comments indicate some of the key issues raised.

> *If the CAS are not in the exam no technology will be used in the classroom.*

> *A lot of technology use is driven by the WACE exams. I have concerns that there is a lot of pressure on teachers to be able to show students exactly what they need to do by hand and what they can do on their CAS (but this is difficult to know). / / I am concerned that some students have an advantage in the WACE exam purely because their teacher was able to show them good CAS tips/tricks and develop programs that do the work for them. The other concern is that then to counteract this, examiners are required to come up with obscure and complex questions to force students to not just use a CAS program.*

> *Calculator sections of assessments tend to become a case of the "trained monkey" getting sufficient marks to not feel the need to understand mathematics at a deeper level.*

> *The removal of CAS calculators in exams would, in my opinion, re-emphasise the teaching of by-hand skills to the detriment of mathematical understanding. The new courses (well the syllabus outcomes at least) already place a greater emphasis on paper and pen techniques than the previous suite of courses. I do not believe sufficient consideration of technology capability was taken into account when writing the courses (although this was challenging given the differences between the states with permitted technology).*

> *The whole world is moving forward with technology use, don't let mathematics live up to its misplaced reputation as being an out-dated subject! Students can do more amazing maths with the technology than ever before, exams should be allowing them to showcase what they CAN do with technology, not what they are restricted to without it. / It is the exams that need to change (and teachers will change if the exams do), not the courses.*

> *A scientific calculator is sufficient for examination purposes, they are quite powerful these days. This would allow examiners to focus on the course fundamentals accessible to all students and not design obscure questions that can only be answered by students who have downloaded the correct e-activities. Removing the CAS calculator would give teachers the freedom to explore more interactive technology and remove the unnecessary cost of an awkward device for parents.*

> *I would like computers wholly in the exam but don't think we are ready yet, so instead use iPads and computers in class and scientific calculators for exams*

> *I would like to see examinations only have one section, where a graphics calculator is permitted*
>
> *Exams will determine the technology used*
>
> *There are quick methods of performing calculations using CAS that take away meaningful understanding of the mathematics involved. What becomes the focus is the quick way to get the answer with less understanding of the mathematics in the process because the focus is being able to perform well in the WACE examination. I strongly recommend that we do not allow CAS in WACE examinations in the future.*
>
> *Get rid of the CAS from Exams. Let's come up with solutions to assessing some areas of courses that require more than a scientific calculator. Use the Classpad or laptop or GeoGebra or iPad or whatever the teacher chooses to use in class to learn.*

A number of teachers referred to the dilemma faced by examiners in getting a suitable balance between expectations of questions in exams, referred to earlier by examiners themselves. Once again, a lack of official guidance on this point seems clear from some responses. The following are some indicative comments:

> *Well over 95% of questions presented in WACE examinations over the past four years did not require the use of CAS. A scientific calculator could have been used to satisfactorily answer these questions. Designing questions that can only be solved using CAS is a waste of time and resources and far from good pedagogy.*
>
> *I would prefer to see CAS calculators made "mandatory" - questions in exams that really require the CAS calc's to encourage ALL students to get them, knowing they won't be able to answer all questions without them*
>
> *The questions in the calculator question that do require use of a CAS Calculator over a Graphics Calculator are often obscure uses that only very experienced teachers may know about (or bother teaching)*
>
> *The use of CAS calculators should promote more high-order questions in the examination which focusses on problem solving rather than demonstrating routine skills; yet the examination questions are very similar in nature in both sections*
>
> *Having attended some SCSA examiners' briefings, I was disappointed to hear one examiner say that they had written questions to justify the use of CAS calculators. We are teaching the skills, processes and understandings of Mathematics. Why are we examining students' facility with technology?*
>
> *I would love to have two thirds non calculator and one third calculator or something along those lines.*
>
> *If we did not do exams, the CAS would be wonderful. It just seems that some of the questions are written to justify the use of the calculator and are unnecessarily complex.*

> *One of the arguments I have heard against using CAS calculators is that not enough questions in the WACE exams require their use. If this is the case, I would argue that the exams need to be changed to reflect the curriculum – which states students should be able to use technology. Students not knowing or not being taught how to use the technology appropriately is not an excuse to leave it out of an exam (would we remove algebra from an exam just because students find it difficult or teachers don't want to teach it?).*

A number of teachers made comments about the use of *eActivities* for the CASIO *Classpad*, which are essentially pre-programmed steps to handle particular mathematical tasks efficiently. Most were concerned about the use of technology in this way, which they regarded as inappropriate, especially for weaker students. Some teachers saw advantages in the use of *eActivities* however. These comments indicate both viewpoints:

> *I find the calculators a fantastic devise to assist in concept learning. The graphing mode, geometry, stats and eActivities in particular, provide rapid results and information to problems you set without the tedious calculations which distract students from the concept you are trying to develop.*

> *One memory that stuck with me from the start of teaching, then 3AB was showing the girls the sine rule, I was telling them that if you want to find the angle my suggestion was to write it as SinA/a = Sin B/b instead of the a/SinA etc their answer was - why bother, there is an e-activity for that! They came undone in the exam when we threw them a cosine rule question using algebra and the exact value of cos(x). It was the worst question on the paper.*

> *In my experience, the eActivities are themselves important for students learning. They still have to think about a problem, extract the necessary data to include into an appropriate eActivity (after selecting the appropriate eActivity), and then interpret the result. All that the eActivity automates is remembering a formula (which would be provided on the formula sheet anyway)*

> *The use of eActivities worries me. I see teachers providing students with a bank of eActivity folders and formulae and telling them that is all they need. Too often students will seek help on a question and their concern is what numbers to put into the e activity formula. When you ask them about the maths in the question, they have no idea what you are talking about. So they are not being developed mathematically as the understanding of the concept will tell them what numbers they need to substitute. A consequence is their inability to present a step by step solution to questions.*

Unsurprisingly, student comments also referred to the use of the CAS calculators in examinations. The following comments illustrate some of the perspectives offered:

> *All courses should NOT have a calculator, we spend so much time trying to work out how to use them just to pass a test or exam*

The CAS calculator is difficult to use and wastes a lot of time in tests and exams.

For exams, those who know EVERYTHING about how to use CAS calculators are extremely advantaged compared to students who only know the basics or are slow at functioning the CAS / -making careless errors on the calculator, eg. pushing wrong buttons, under pressure due to limited time in exams isn't reflective of the student's capability in mathematics

Never seem to really need them in exams - questions where they'd be useful always come up in CAS free parts of test.

The CAS calculator is effective in exam situations, so things can be done quicker and easier, for the purpose of relieving some time pressure.

Amazing, if you take the CAS out. Children will weep

I use my calculator for all questions, for peace of mind that even simple answers are correct so that the remainder of the question can not be wrong. The calculator allows me to quickly and effectively gain answers and with repetitive use and practise, time on questions can be greatly minimised.

Please banish calculator free paper.

10.5.6 Alternative technologies

Although relatively few teacher respondents indicated that their students made regular use of technologies other than calculators, and relatively few respondents provided detailed feedback on these, a number of general comments indicated some frustration that a wider range of technologies is not being encouraged. The extent of use of alternative technologies is of course affected by the existing examination constraints, and perhaps also by the limited references to the use of technology in courses generally. Frustration about the use of other technologies seemed to be evident especially in schools that were relatively well-resourced, so that students might have had ready access to alternatives. The following comments are indicative of these sentiments:

Perhaps we should be asking parents to purchase cheap tablets and an emulator rather than an expensive calculator, enabling teachers to take advantage of the myriad of resources available through the Internet and free software.

Our Year 11 students all have devices so they can use Desmos (either the app or the website) in the classroom and it is very easy to use. I also use it as a demonstration tool.

All students have a laptop in class. In some way we are confined to using the Graphics Calculator and its software in class for our senior courses because its use is mandated for the examination. For students to become proficient and quick in its use under examination conditions, we are obliged to use it as our primary source of technology. If this was removed from examinations, technology would not be removed from the classroom as *some of my contemporaries have suggested, rather we would be freed up to explore the myriad of other technology links and options available online.*

Most of the time, it takes longer to type it in the calculator than to solve it mentally or by hand. I am fairly well skilled in the use of the calculators, but I seldom use it other than for some graphs and statistics. I have actually been using Desmos and GeoGebra more, as well as Excel (which I have always liked to use). The size of the screen is just so limiting compared to a computer.

Computers and mathematical software (free and licenced) offer a far more sophisticated approach to solving problems, not to mention a greater variety from which teachers can choose. For example, use of MS Excel is far more student-friendly to teach and learn about finance topics than using the spreadsheet application on a CAS calculator.

I feel that the CAS element has been downplayed in the teaching of mathematics by some in that there is an abundance of software that can run on a computer. So those against the CAS calculator advocate that a computer can be used for the demonstration of what can be done on a CAS. So perhaps if we are NOT going to permit CAS in examinations, then are we going to permit the use of computer software to answer questions requiring the technology?

I do not feel that the use of CAS calculators improves the level of understanding of the students, for example when teaching transformations of functions I prefer to use software such as Desmos. In my experience 2CD and often 3AB level students do not find the Classpad easy to use and therefore avoid using it and are as a result disadvantaged in assessments.

11. Discussion and implications

This study has drawn on a number of complementary resources in order to investigate the place of technology in senior secondary school mathematics in WA, and particularly the use of CAS calculators in both teaching and learning and in assessment. These sources include: research literature on the effects of using technology for teaching and learning mathematics; related professional literature regarding technology for mathematics; policies and practices elsewhere regarding the use of technology for school mathematics; analysis of previous and existing WA Mathematics courses with respect to technology; analysis of available technologies relevant to school mathematics; survey responses of local mathematics teachers and some Year 12 students regarding existing practices and opinions with respect to the place of technology in senior school Mathematics courses.

The nature of the resources tapped suggests that caution is required to interpret the resulting data, and to recognise some inherent limitations in this mixed methods study of a range of complex issues, especially as the scope of the study has required relatively light treatments. Thus, for example, examination of curriculum practices elsewhere in Australia has been limited in scope, international comparisons have been limited to available resources, examination practices have been limited to members of examining panels volunteering to participate, university practices have been limited to discussions with key personnel. With respect to the survey data obtained, despite the best efforts of all concerned, the attained sample of survey respondents is modest and therefore limited, as teachers in Independent and Catholic schools appear to be over-represented and teachers in Government schools under-represented. In addition, it is not clear that schools from all levels of SES have been represented equivalently, with less than expected responses from teachers in low SES schools. Furthermore, comments from teachers and students have been volunteered; although the study provided various mechanisms for further comments to be provided, only some teachers opted to use these, and caution is advised regarding interpreting these as a representative sample of opinions of WA senior secondary mathematics teachers.

Limitations of these kinds are inevitable in a study of this kind and scope, however, and readers should be mindful of avoiding undue inferences or generalisations from these data. We are nevertheless of the view that the mixed method approach utilised for the research does provide a highly useful portrait of the current state of use of calculators and other technologies in senior school Mathematics in WA, if the portrait provided is carefully considered.. In this section, the various data sources are brought to bear on some key issues in the study and the report’s findings summarised.

11.1 Technology in school mathematics

Empirical research summaries have consistently suggested that the use of graphics calculators and CAS calculators by secondary school teachers and students can result in improvements in conceptual understanding in mathematics, although the improvements are typically modest and depend on the extent to which teachers and students make effective classroom use of them. Definitive large-scale studies on the effectiveness of sound use of CAS in secondary schools are not yet available.

Currently, there is neither a national nor an international consensus on which technologies are most appropriate for use in senior secondary schools, although it is clear in recent years that technology is regarded as an increasingly important part of the school learning environment for mathematics. CAS technology, including CAS calculator technology, is used elsewhere in Australia and in a number of overseas countries to enhance school mathematics curriculum and instruction. Developments to make use of computers as alternatives to calculators also make use of significant computer algebra software.

If in fact technology was intended to be used mostly for numerical computation purposes in local courses, a scientific calculator might well be regarded as sufficient; however, teachers clearly regard a scientific calculator as insufficient for learning in most courses, especially as the lack of a graphics (and tabulation) capability, and thus limited support for work in statistics, would be a significant loss for learning purposes. In many locations, a graphics calculator is regarded as the minimum necessary tool for senior secondary mathematics.

When technology is used mostly for numerical computational purposes, some teachers report that students prefer a scientific calculator as it is already familiar to them, most commands are written on the keyboard (and so don't require the use of menus), it is less complicated and may even be faster to get a straightforward numerical answer. If students don't use their CAS calculators much, they are unlikely to get better at using them efficiently.

11.2 The use of CAS calculators

In practice, CAS calculators have often been used to replace traditional computational procedures more than they have been used to enhance students' conceptual understanding. Consistently, research has demonstrated that students do not suffer a decline in by-hand mathematical skills as a result of using technologies of these kinds. Research and careful analysis have highlighted some of the challenges of effective use of CAS in particular, requiring careful consideration of the nature of algebra and calculus especially in both CAS and non-CAS environments, and developing suitable expertise by both students and teachers to integrate the tools appropriately.

Research evidence on CAS sufficiently robust to offer clear direction is sparse. Moreover, it is clear that there are divided opinions about it both nationally and internationally, amongst teachers, mathematics educators and researchers. The ways in which CAS is actually used in the classroom by teachers and students seem likely to be of key importance to the results obtained, not just the technology itself.

Many teachers' comments, especially those favouring a reduction in the use of technology, give the impression that they regard the main purpose of technology to be *computational*. The use of sophisticated technologies like CAS calculators and graphics calculators as *learning* tools for students seems to be a less prominent interpretation. Indeed, it is not clear from teacher comments that the use of computer algebra capabilities in particular has been regarded as an important feature of CAS calculators in WA. Further, it is not clear that survey respondents consistently distinguished computer algebra from other graphics calculator capabilities in their responses to some survey questions. In this respect, some explicit advice about the rationale and intents of allowing CAS calculators would be helpful additions to syllabus materials.

The use of calculators as devices to support the learning of mathematics seems to be uncommon at the tertiary level, where calculators are generally regarded only as devices to get a numerical answer and are rarely used for teaching and learning purposes by staff or students. It seems that early tertiary teaching is still dominated by the formal lecture and that personal use of technology by students for *learning* is rarely used or actively encouraged. Where personal technology use is permitted in formal assessment, such as examinations, scientific calculators are used and more sophisticated calculators mostly prohibited, reflecting the perspective that calculators are intended only for computation. This perspective seems to have a substantial effect on schools' thinking on the matter, since CAS calculators (and graphics calculators) are thereby regarded by some teachers and students as devices that are not useful beyond school for either tertiary study or professional practices in quantitative fields.

11.3 Examination practices

The fact that students are permitted to use *both* a scientific calculator and a CAS calculator in Mathematics examinations may act as a disincentive for students to learn how to use their CAS calculator efficiently, especially if their teacher does not use it often for learning purposes, and they do not acquire it until Year 11 or 12. Many students studying Mathematics courses also study other subjects requiring some calculation (e.g., science subjects) but which permit the use of a scientific calculator only in examinations; thus students are obliged to have some expertise with both. Otherwise, it is hard to see why the Mathematics examination rules should permit multiple models. Almost no responses from teachers completing the survey have drawn attention to this issue at all, so that it is not apparently thought about. Clearer guidance on the rationale for the use of multiple calculators would be helpful to support teachers and students.

Examinations presently do not typically require many of the computer algebra (CAS) features to be used in order to answer questions. Examiners are reluctant to expect high-end use of the CAS calculators so that it is comparatively rare that a CAS calculator is necessary or would be an efficient means to answer questions. Examiners are typically walking a tightrope between anticipating high-end use of calculators (which will be problematic for students who have not developed adequate expertise, possibly because of teacher limitations) and very limited use of calculators (which reinforces an impression among some that they are not really useful). Overall, examiners are not arguing strongly for a change, but seem to be the meat in the sandwich.

Ideally, perhaps, the calculator-assumed examinations could be designed so that students would be significantly disadvantaged by trying to use their calculator for almost *all* examination questions and similarly would be unable to do *some* questions in the time available in examinations without the calculator – so that discretionary use of technology was designed into the examination process. It seems hard to argue that this is the case at present, especially as there seems to be no official position publicised on this matter. It is not clear whether it is a conscious criterion of examiners or reviewers, but it would seem advisable for some clarification to be provided, perhaps through the mechanism of developing and promulgating a suitable policy.

The use of pre-built or pre-programmed activities (such as *eActivities* in CASIO *ClassPads*) seems problematic, although some students and teachers regard this as a good way to make sure that the calculator can be used for efficient computation under exam conditions (of limited time). Essentially, these emphasise the computational aspect of the calculators. While some regard these as pedagogically appropriate, especially if developed by students themselves, or if they are discussed in class, others are concerned that such uses of technology can be quite procedural and mechanical, and reflect limited understanding; and some even regard these as unavailable to some students (because they don't attend out of school coaching courses), although in fact they are in the public domain.

11.4 The role of the teacher

Research has clearly indicated the pivotal role of teachers in the integration of technology into the school Mathematics curriculum. While teachers need support to develop the necessary technological and pedagogical content knowledge that is uniquely associated with the effective use of technology, adequate support has not been provided sufficiently, so that unrealistic expectations have been made of teachers.

While experienced teachers were generally both confident with personal use of technology and with supporting their students to use technology, this was less evident for less experienced teachers. Some comments from teachers indicated that access to support to use technology for teaching was not evenly distributed, and did not meet their needs, while some students expressed frustration that their teachers were not able to help them well enough to make sound use of technology. Further, some of the expressed obstacles to teachers' use of technology in Mathematics courses might be alleviated by the provision of better syllabus advice, such as addressing the intended balance between student work with and without technology (to minimise impressions that material needed to be taught twice) and offering targetted pedagogical advice regarding appropriate use of technology to reduce preparation time. More generally, it would seem likely that support for teachers would be improved (through pre-service education, professional development and commercial textbook preparation) if the syllabus materials were to clarify technology expectations more extensively.

While it is harder to justify the use of CAS calculators (at least the CAS parts) in less sophisticated courses than in more sophisticated courses, an advantage of using the same technology in all of the most mathematical senior courses is that teachers need to learn only one device and that students' requirements would not be changed by changing courses. By their nature, CAS calculators tend to include mathematical capabilities – software – relevant to the entire suite of courses. While these are not educational arguments, they are practical arguments at the school level. Some students in lower level courses (or even in Years 9 or 10) will have a device beyond their immediate needs, but it may be more problematic for teachers and schools to have a range of devices for courses at different levels. In WA, teachers typically teach a range of courses at a range of levels, rather than teaching only a single course.

11.5 Equity issues

After adjusting for Consumer Price Index movements, the costs of calculator technologies for WA students have remained fairly stable over time. In equivalent dollar terms, the cost of scientific calculators on their introduction to schools in the late 1970s, the cost of graphics calculators on their introduction to schools in the 1990s and the present cost of CAS calculators are about the same. In effect, similar financial outlay by students has provided substantial increases in mathematical and educational functionality over the past forty years.

Both examiners and (some) students suggest that students have differential access to help from their teachers to use their CAS calculators appropriately or well; examiner reports regularly refer to this issue, and a number of students do also. It seems clear that there are inequities regarding access by students to comparable teacher expertise in that sense; maybe such inequities are unavoidable about a range of aspects of education, however.

Teachers in well-resourced schools are more likely to have alternatives to CAS calculators and thus some feel constrained by being required to use the calculators to support student achievement in examinations. Overall, however, very few respondents seem keen on *increasing* the technology expectations of the mathematics courses. Nonetheless, it is important to encourage teachers to make good use of whatever technology is available in their school context and that seems in their professional judgement to be valuable for teaching and learning mathematics.

Remarkably little advice was offered by survey respondents about the use of computer software or apps for tablets that are specifically mathematical. While the commercial spreadsheet software Microsoft *Excel* and the free software *GeoGebra* were both mentioned by teachers, very few teachers indicated that these or other examples of computer software for mathematics education were frequently used in class teaching. This may be a symptom of a wider generalisation: that the technology used in school will be generally restricted to the technology allowed in examinations, especially as the examinations are widely regarded as self-evidently valid measures of important achievement. If that is the case, it seems important to recall that, for many students—especially those in less privileged circumstances—the technology that they are permitted to use in the exams will be the ceiling for their technology access. If it were reduced significantly (to a scientific calculator, for example), this would mean that many students did not encounter anything more powerful than that in the classroom for learning purposes.

11.6 Communication of syllabus intent

The intended roles of CAS calculators are currently not clear in the WA syllabus documents, including expectations for learning and teaching and assessment, although all of the documents make explicit reference to general aims for student use of technology for mathematics. The documents do not offer adequate pedagogical advice and do not provide clear statements of intended roles of CAS calculators in either school-based or external assessments. It is not clear how school-based assessment can expect to provide insight on the extent to which students have achieved a specified aim regarding the choice and use of technology, if there is no specific reference at all to technology in the framework.

In particular, it is not clear that the WA syllabi emphasise the roles that technology might play in learning; currently they have a more computational focus. Can the *pedagogical* uses of technology be better emphasised somehow in syllabus documents? It is not clear that a novice teacher would see from the published course materials how a calculator might be used to help learning, and learning uses tend to not be evident in published textual materials. Other state curricula (e.g., SA and QLD) seem to be much more explicit about the place of technology in general and the calculator in particular for learning mathematics, so that mechanisms for clarification might be sought by examining those or similar documents.

Schools seem to mimic the external examination structure in their own examinations and it is not clear that they are encouraged to make greater use of technology in general, or CAS calculators in particular, in school-based assessments (such as extended investigation assignments) than is typical in the (unavoidably more constrained) examinations. These practices may reinforce an impression that the calculators are mostly intended for computation. Again, clarification of syllabus intentions, as well as Grade Descriptions, may help to alleviate any misunderstandings.

11.7 Ways forward

As many senior secondary teachers in WA schools teach at more than one level and in separate courses, changing the technology expectations so as to have different expectations for different courses might be problematic, because it would increase demands on teachers to be comfortable with a wider range of technologies than at present. If it were regarded as unproblematic, however, perhaps after suitable opinions were canvassed from teachers, consideration might be given to restricting CAS calculator use to only those students studying both Mathematics Specialist and Mathematics Methods, as these courses seem most likely to benefit from the sophisticated use of computer algebra. Such a restriction would require attention to advice for the Mathematics Methods course and its assessment, since there are students studying that course who do not study Mathematics Specialist. Students in Mathematics Methods and Mathematics Applications might be advised that judicious use of a graphics calculator is necessary for classroom learning, and competent use is expected in examinations and, while CAS calculators might continue to be permitted for examination use, the CAS features will neither be required nor necessary for successful examination completion.

If it is too problematic for teachers to be expected to develop expertise with a range of sophisticated calculators in common use, the status quo in WA regarding the use of CAS calculators in all ATAR Mathematics courses might be maintained, but teachers, examiners and others need to be clearly advised that the computer algebra aspects will not required or important in some particular examinations, via mechanisms suggested earlier for clarifying the syllabus intentions.

For consistency of learning, teaching and assessment, the minimum technology expected for teaching and learning mathematics should also be used by students in examinations. While there is not a strong case at present, nor significant teacher support, for extending the technology expectations for Mathematics beyond CAS calculators to computers or tablets, this question should be revisited in three to five years, because of rapidly changing technological and societal circumstances. Accordingly, teachers with adequate resources in their schools should continue to be encouraged to make use of them in the school programs, in part to continue improving local understanding of suitable use of technology in mathematics courses.

Clearly, there will be a continuing need to review the use of technology in Mathematics education and the related use of CAS calculators in teaching, learning and assessment. This project has highlighted several pertinent areas that warrant attention and review, something which SCSA together with schools, universities and other institutions concerned with teacher education and development are well-placed to address.

12. References

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Appendices

Appendix 1: Teacher Survey

About You

1. Please indicate your gender: Male Female

2. What type of university degree(s) do you hold? (click all that apply)

   a. Undergraduate degree with major in mathematics, science or engineering
   b. Undergraduate degree in Education
   c. Other undergraduate degree
   d. Post graduate diploma (e.g., Dip Ed)
   e. Post graduate degree (e.g., MEd, MSc, MA, PhD)
   f. Other (please specify ______________________________________)

3. How long have you taught senior high school Mathematics in WA schools?

less than 1 year	1 – 5 years	6 – 10 years	11 – 15 years	16 - 20 years	More than 20 years

4. How do you classify your current teaching position?
   a. regular full-time teacher
   b. regular part-time teacher
   c. long-term relief teacher (i.e., your assignment requires that you fill the role of a regular teacher on a long-term basis, but you are still considered a relief teacher)
   d. short-term relief teacher

5. Please indicate the *level of schooling* that you are qualified to teach in WA.

Early childhood Primary Secondary Other (specify: __________________)

6. Please list the Learning Area(s) that you are qualified to teach in WA (e.g., Mathematics, Science, English)

7. Please indicate ATAR Mathematics courses you have taught in 2014 or 2015 (click all that apply)

   - Mathematics 2AB
   - Mathematics 2CD
   - Mathematics 3AB
   - Mathematics 3CD
   - Mathematics Specialist 3AB
   - Mathematics Specialist 3CD
   - Mathematics Specialist (new from 2015)
   - Mathematics Methods (new from 2015)
   - Mathematics Applications (new from 2015)

About Your School

8. Please indicate the school sector where you currently teach:

Government (public) | Catholic | Independent

9. Please indicate the school's geographical setting where you currently teach:

Metro | Regional | Rural | Remote

10. Please estimate your school's overall socio-economic status*:

Low | Average | High

*****Most schools will have an ICSEA (*Index of Socio-educational Advantage*), an aggregate measure of SES developed by ACARA. The middle of the ICSEA scale is 1000, and the scale has a standard deviation of 100. Therefore it seems reasonable to suggest that schools with ICSEAs less than 900 might be considered to have a low SES. Schools with ICSEAs greater than 1100 might be considered to have a high SES. A school's ICSEA information is available on the *MySchool* website at http://www.myschool.edu.au

Student Use of Technology

We would like to get a sense of the learning environment for students in your classes for one of the mathematics courses below. For this purpose, throughout this survey, please choose ONE of the following maths courses that you have been teaching recently. We would prefer you to choose the course with which you are most experienced.

11. Please indicate your choice of these maths courses:
    - O Mathematics 2AB
    - O Mathematics 2CD
    - O Mathematics 3AB
    - O Mathematics 3CD
    - O Specialist Mathematics 3AB
    - O Specialist Mathematics 3CD

12. To which of the following technologies do your students in the chosen course have routine personal access in your mathematics class? (Mark all that apply.)
    - O CAS calculator (such as ClassPad, TInspire or Hewlett-Packard HP-50
    - O Graphics calculator (such as TI-84, Casio fx-9860, Hewlett-Packard HP-40)
    - O Scientific calculator (such as CASIO fx-82, TI-30, Sharp EL-531, HP-35)
    - O Notebook or laptop (such as MacBook, ChromeBook)
    - O Tablet (such as iPad or Samsung)

13. In your chosen maths course, how frequently do students use technology in learning mathematics?

Technology	Never or hardly ever	A few lessons	Some lessons	All or most lessons
CAS calculator capabilities (such as algebra, exact equation solution, calculus)				
Graphics calculator capabilities (such as graphing, tabulating, statistics)				
Scientific calculators				
Commercial software (such as *Tinkerplots*, *Mathematica*, *Geometer's Sketchpad*)				
Free software (such as *GeoGebra*, *Graphmatica*, *Peanuts*)				
Websites for maths (on computers or tablets)				
Apps on tablets				
Spreadsheets on computers or tablets				

14. If necessary, please describe briefly any other technologies that students use regularly in your classes for this course:

15. Which technologies, if any, do you *expect* students in your chosen maths course to use regularly at home? (Mark as many as apply)

O CAS calculator capabilities (such as algebra, exact equation solution, calculus)
O Graphics calculator capabilities (such as graphing, tabulating, statistics)
O Scientific calculators
O Commercial software (such as *Tinkerplots*, *Mathematica*, *Geometer's Sketchpad*)
O Free software (such as *GeoGebra*, *Graphmatica*, *Peanuts*)
O Websites for maths (on computers or tablets)
O Apps on tablets
O Spreadsheets on computers or tablets

Support for Sound Use of Technology

We would like to know how your work with technologies in your chosen course is supported.

16. How confident are you with your own use of technology for your chosen course?

Not confident Limited confidence Mostly confident Very confident

17. How confident are you to support student use of technology?

Not confident Limited confidence Mostly confident Very confident

18. Which of the following sources of advice on technology for mathematics in your chosen course do you draw upon? (Mark as many as apply)
    - O Colleagues at your school
    - O Students in your class
    - O Other colleagues
    - O Textbook suggestions and examples
    - O Online sources, such as calculator company websites
    - O SCSA online teacher support materials
    - O PD events and conferences
    - O Other (please describe briefly)________________________

19. Please rate each of the following obstacles to your effective use of technology in the chosen maths course:

	Not an obstacle	Sometimes	Often	Always
Lack of personal preparation time				
Inexperience with the technology				
Insufficient help				
Limited school resources				
Using technology means I need to teach many things twice, with and without the technology				
Lack of course alignment with technology.				
Lack of classroom time				
The technology is too expensive for my students to afford				
Student resistance to using the technology				

20. If you would like to comment further about barriers to technology use in teaching maths, please use this space:

Relationship of Technology to the Chosen Course

We would like your opinions on the relationship of Computer Algebra Systems (CAS) and other technologies to your chosen maths courses, including examinations in those courses.

For this purpose, when considering CAS, please focus on the *symbolic* aspects of CAS calculators and computer software (such as algebraic manipulation, symbolic differentiation and integration, exact solutions to equations, etc.) rather than the *numerical* features of graphics calculators (such as graphing, tables, statistical analysis and numerical equation solution).

21. Please rate each of the following statements with your chosen maths course in mind.
    [SD = Strongly disagree D = Disagree A = Agree SA = Strongly agree]

	SD	D	A	SA
For ***learning*** the mathematics in this course, it is important for students to have access to CAS				
CAS is well integrated into this course.				
For ***learning*** the mathematics in this course, a graphics calculator is sufficient.				
Graphics calculators are well integrated into this course.				
For ***learning*** the mathematics in this course, a scientific calculator is sufficient.				
The use of calculators in my classroom is focused on ATAR examination needs.				
The non-calculator examination components of this course address my concerns about over-use of technology.				

22. Please rate each of the following general statements about teaching mathematics with technology:

	SD	D	A	SA
Students don't understand mathematics unless they first do it by hand.				
Using technology helps my students to get a deeper understanding of mathematics than would be possible by hand.				
Using technology makes mathematics more enjoyable for my students.				

23. If you would like to comment further about technology use in teaching mathematics, please use this space:

Technological Change Processes

Technologies continue to change. We would like to know your views on some alternative possibilities for the future use of technologies in your chosen mathematics course and their examination.

We realise these questions are hypothetical, and that some decisions about technology are beyond your personal control, but seek your professional opinion on preferred and likely scenarios.

24. Assuming logistics of security can be resolved, should the use of technologies in mathematics exams for your chosen course be increased?
    - O No
    - O Yes, by allowing computers and tablets, with restricted software access and no Internet
    - O Yes, without any restrictions

25. Should the use of technologies in mathematics exams for your chosen course be decreased?
    - O No
    - O Yes, by allowing graphics calculators, but not CAS calculators
    - O Yes, by allowing scientific calculators only
    - O Yes, by removing any technology access

26. Please rate each of the following statements regarding how your own teaching in your chosen course would likely be affected if CAS calculators were not permitted in maths exams:

	SD	D	A	SA
There would be no significant change to my teaching.				
CAS calculators would continue to be used regardless				
Computers, tablets and the Internet would be used more than at present				
Graphics calculators would be used more than at present				
Scientific calculators would be used more than at present				
Whatever technology was permitted in examinations would be the focus				

27. If you would like to comment further about possible changes in technology for teaching and learning mathematics in your chosen maths course, please use this space:

Overall View and Interview

28. In general terms, would you prefer the use of technologies in your chosen mathematics course to be:

    O Reduced in importance
    O Stay about the same
    O Increased and extended

29. Have there been equity issues associated with the use of CAS technologies in your chosen mathematics course?
    O No
    O Yes

    If Yes, please elaborate briefly: ______________________________

30. Would you be willing to be elaborate on your views, if requested, via an interview, an email or a telephone conversation?
    O Yes (Please complete the details below)
    O No

Name: ____

School:____

Email:____

Telephone:____

Appendix 2: Year 12 Student Survey

About You

1. Please indicate your gender: Male Female

2. Please indicate the Mathematics courses you are studying in 2015.

- Mathematics 2AB
- Mathematics 2CD
- Mathematics 3AB
- Mathematics 3CD
- Mathematics Specialist 3AB
- Mathematics Specialist 3CD
- Mathematics Specialist (new from 2015)
- Mathematics Methods (new from 2015)
- Mathematics Applications (new from 2015)

Your Use of Technology for Maths

3. **Which of the following technologies do you have routine personal access to in your mathematics class? (Mark all that apply.)**

O CAS calculator (such as ClassPad, TI-nspire or HP?
O Graphics calculator (such as TI-84, Casio fx-9860, Hewlett-Packard HP 40)
O Scientific calculator (such as CASIO fx-82, TI-30, Sharp EL-531, HP-35)
O Notebook or laptop (such as MacBook, ChromeBook)
O Tablet (such as iPad or Samsung)
O The Internet

4. **Which of the following technologies do you have routine personal access to at home? (Mark all that apply.)**

O CAS calculator (such as ClassPad, TI-nspire or HP?
O Graphics calculator (such as TI-84, Casio fx-9860, Hewlett-Packard HP 40)
O Scientific calculator (such as CASIO fx-82, TI-30, Sharp EL-531, HP-35)
O Notebook or laptop (such as MacBook, ChromeBook)
O Tablet (such as Apple iPad or Samsung Galaxy)
O Computer
O Internet

5. Please tell us about your own use of a CAS calculator:

[SD = Strongly disagree D = Disagree A = Agree SA = Strongly agree]

	SD	D	A	SA
I use a CAS calculator regularly in my mathematics class?				
It is important to use a CAS calculator for doing and learning mathematics				
I am confident when I use my CAS calculator				
I enjoy using a CAS calculator in my mathematics class				
I decide for myself when to use my CAS calculator				

I rely on my teacher for advice on how to use CAS effectively
In this course, it is important to use non-CAS aspects of my calculator
(such as graphing, statistics, equations and numerical computation)
My use of a CAS calculator is usually focused on its role in examinations

What is the purpose of is your most frequent use of the CAS aspect of you calculator? [That is, the algebra, exact arithmetic and symbolic calculus capabilities of the calculator]
O Completing a task that I could not do without using the CAS
O Completing a task that would take me too long by hand
O Experimenting with mathematical ideas and relationships

Any other comments about CAS calculators in your course?________________________

Thanks for your assistance

Appendix 3: University staff interviews

The following prompts were used in informal face-to-face discussions with senior Mathematics staff at universities. Following discussions, a detailed written report was compiled, and an editorial process undertaken until it was agreed upon by the university staff as an accurate reflection of typical practice regarding student and staff use of technologies for teaching, learning and assessing mathematics at the university, especially at the first year level. In most cases, key staff were confident to describe a range of units in a first year program; in some cases, other people were contacted as well.

Focus of interview: The use of CAS calculators and other technologies at university

University:
Person:
Unit(s):

1. What technologies (e.g., calculators, software, if any) are students allowed or expected to use in classes for the unit(s)?

Why are these technologies preferred?

How are students supported to use these technologies?

2. What technologies (e.g., calculators, software, if any) are students permitted or expected to use in assessments (assignments, exams)?

Why is this?

3. Are decisions on technology in assessments (e.g. exam use) made by the individual coordinator of the unit or are they Departmental decisions?

4. Do coordinators personally

	Own?	Use?
CAS calculator?		
Graphics calculator?		
Scientific calculator?		

5. Is the use of technology important for this unit?

6. Have students commented on the role of technology in the unit?

Have recent school leavers reacted adversely (if prohibited from using their CAS calculators in much of their university work in mathematics)?

Appendix 4: Examining panel interviews

The following template was used as a series of prompts for telephone conversations with recent members of WACE Mathematics Examining Panels who had voluntarily accepted a request from SCSA to participate in the project. Phone calls typically lasted around 45 minutes, after a mutually preferred time was selected. Following the discussion, a detailed written report was prepared and an editorial process was undertaken via email and phone to ensure that the Examining Panel Member was confident that it reflected their opinions and experience faithfully. Interviewees were advised that the report might be quoted verbatim, and were reassured that this would be done anonymously.

Unit(s):
Role(s): Chief Examiner / Panel member
Name:
Institution:

Experience on WACE Examining Panels

Experience with CAS calculators in your own mathematics teaching?

What is your view of the place of technology in this mathematics subject?

To what extent is CAS in particular (i.e. symbolic algebra and calculus, not just graphs, tables, numerical solutions and data analysis) important for this subject?

Are there particular difficulties associated with setting and marking exam questions

(a) in the calculator-assumed section

(b) in the calculator-free section

(c) regarding student personal 2 x A4 notes

What impressions are reported by markers regarding the nature and extent of student use of calculators

Do you see any risks/benefits associated with a change of policy on use of calculators in exams?

What is your personal preference for technology use in this course:

Reduced in importance
Stay about the same
Increased and extended (e.g. computer use?)

Any other comments?

Appendix 5: General survey follow-up

Each of the 68 respondents who agreed to provide further information was sent a personal email as below and invited to elaborate any of the issues of concern regarding the use of technology in the senior secondary mathematics courses. In some cases, respondents needed further advice to clarify what was being requested of them (generally as they had forgotten what they had responded or because they felt the request was too vague), and they were provided with a reminder of the key aspects of the original survey.

Dear (name)

Thank you for responding to the recent SCSA survey on technology use in senior school mathematics and the related use of CAS calculators in external examinations.

Thank you also for offering to elaborate some of your views around these topics. We appreciate that a survey can sometimes be a limited medium for identifying and exploring key issues.

So, we would be grateful if you would be kind enough to reply to this email to help us to better understand the key issues involved from the perspectives of your own practice, experience or school setting. Please do not feel obliged to provide extensive and detailed feedback; we would be pleased to have a brief statement from you on matters that you regard as important for this work that you feel have not been adequately captured in your responses to the survey. It would help us if you would make it clear which particular courses you are referring to, if your comments are not of a general nature.

Your comments will be kept confidential, consistent with the information provided earlier to you regarding the project. However, we would like to reserve the option of reproducing some of your comments in our final report, to help readers appreciate a range of viewpoints on the issues involved. We would do this anonymously without your individual details being accessible outside the project team. Please advise us in your email if you are not prepared for us to do this.

Thanks very much for your help.

Respondents who had not replied to the follow-up request were later sent a reminder email, early in August, as shown below, alerting them to the main survey elements and inviting an elaboration if they chose:

Dear (name)

You may recall our earlier request, via the email below, to provide us with further advice regarding the use of technology for senior school mathematics. We recognised that surveys can be a bit limiting and wanted to give you the opportunity of advising us of your views about using technology in mathematics courses, and in particular the use of CAS calculators.

At present, we don’t seem to have had a response to our email. That may be, of course, that you did not feel that there were any particular matters you wanted to draw to our attention; should that be the case, please don’t feel under any obligation to respond.

Your lack of response might have been because you were unable to do so prior to our original suggested date of late in June, however. We now have a little more time and would still be able to accept your response by the end of August, if you had perspectives you wanted us to know about.

In your original responses, you told us about what your students do in your chosen course (name), about the amount of support you had and needed to use technology in the course, about the extent to which CAS and other calculators (graphics calculators, scientific calculators) were needed for the course, your general views on the place of technology for learning maths, whether or not we should change the use of technologies in the future (e.g., more, less, the same), how your teaching would change (if at all) if CAS calculators were not permitted in exams, whether you think the use of technologies for maths should change (more, the same, less) and whether there had been equity issues in relation to CAS calculators in your school.

That’s a lot of material, of course, but we thought that you might have views about some of these things that you felt hadn’t been captured by the survey and wanted to make sure we were aware of. Or that there might be other key issues that we had somehow missed, trying to keep the survey manageably short.

There wasn’t something in particular that we wanted you to elaborate on; rather we are trying to make sure that we understand the experience and opinions of mathematics teachers like yourself, so wanted to make sure that you had a chance to inform us about the things that matter regarding technology use in senior school maths.

Thanks again if you can provide us with further advice, but again please don’t feel obliged to do so if there is nothing in particular that you felt you wanted to bring to our notice.

Appendix 6: Scientific calculator follow-up

The email below was sent personally to all survey respondents who had volunteered to contribute further advice and who indicated that their students used scientific calculators in all or most lessons. If no response was received, a follow-up request was repeated after some weeks. In some cases, follow-up emails or phone calls were made to clarify responses.

Dear (name)

Thank you for responding to the recent SCSA survey on technology use in senior school mathematics and the related use of CAS calculators in external examinations. Thank you also for offering to elaborate some of your views around these topics. We appreciate that a survey can sometimes be a limited medium for identifying and exploring key issues.

You indicated in your response to the survey that your students use **scientific calculators** for learning mathematics in all or most lessons. To help us to understand better the role of this particular technology, we would be grateful if you would be kind enough to elaborate on this a little for us. In particular, we would like to know:

1.Whether students have a particular scientific calculator (e.g. they have been asked to purchase one with particular features for their course, or tend to have an assortment of calculators retained from their previous years of study)

2.For what kinds of purposes they use their scientific calculators (e.g. are they used for learning activities or mostly for getting numerical answers?). A brief description of a typical learning activity would help us here, if possible.

3. Whether (and why) students prefer to use their scientific calculators than their CAS calculators or other technologies for some (which?) purposes

4. About how often (if at all) you use a scientific calculator for teaching purposes (e.g., with a special activity or with an emulator) or help students to use their scientific calculators appropriately

5. Whether the students are expected/encouraged/permitted to use their scientific calculators for assessment purposes (such as assignments, tests and exams) as well as learning purposes

6. Any other perspectives you have on the use of scientific calculators that will help us to understand their importance in your students' learning of mathematics

It would help us if you would make it clear which particular courses you are referring to, if your comments are not of a general nature.

While you are welcome to elaborate with a separate document, please do not feel obliged to provide an extensive response if a sentence or two is sufficient to capture the essence of how your students use their scientific calculators. We would be happy to receive a reply to this email with your comments embedded, if you felt a separate email response was unnecessary.

Your comments will be kept confidential, consistent with the information provided earlier to you regarding the project. However, we would like to reserve the option of reproducing some of your comments in our final report, to help readers appreciate a range of viewpoints on the issues involved. We would do this anonymously without your individual details being accessible outside the project team. Please advise us in your email if you are *not* prepared for us to do this.

Thanks very much for your help.

Appendix 7: Commercial software follow-up

The tailored email below was sent personally to the survey respondents who had volunteered to contribute further advice and who indicated that their students used commercial software in ‘all or most’ or ‘some’ lessons. (Most of these respondents also indicated that their students used free software).

Dear (name)

Thank you for responding to the recent SCSA survey on technology use in senior school mathematics and the related use of CAS calculators in external examinations. Thank you also for offering to elaborate some of your views around these topics. We appreciate that a survey can sometimes be a limited medium for identifying and exploring key issues.

You indicated in your response to the survey that your students use **commercial software** for learning mathematics in (*all or most/some/a few*) lessons. To understand better the role of this particular technology, we would be grateful if you would be kind enough to elaborate on this a little for us. In particular, to understand the role of commercial software, we would like to know:

1. What devices the students generally use the software on (e.g. personal laptops, computer lab, tablet, home use only)
2. The names of the commercial software programs that are used most often by your students
3. How the software is made available to students (e.g. a school site license, students are recommended to purchase, book listed, etc.)
4. About how often the software is used (such as daily, weekly, monthly)
5. Whether the students are expected/encouraged/permitted to use the software for assessment purposes (such as for assignment, tests or exams) as well as learning purposes
6. Whether the software is used by the teacher as well as by the student (for class demonstration, software instruction, etc,)?
7. Any other perspectives you have on the use of commercial software that will help us to understand its importance in your students’ learning of mathematics

It would help us if you would make it clear which particular courses you are referring to, if your comments are not of a general nature.

While you are welcome to elaborate with a separate document, please do not feel obliged to provide an extensive response if a sentence or two may be sufficient to capture the essence of how your students use the commercial software concerned. We would be happy to receive a reply to this email with your comments embedded, if you felt a separate email response was unnecessary.

Your comments will be kept confidential, consistent with the information provided earlier to you regarding the project. However, we would like to reserve the option of reproducing some of your comments in our final report, to help readers appreciate a range of viewpoints on the issues involved. We would do this anonymously without your individual details being accessible outside the project team. Please advise us in your email if you are *not* prepared for us to do this.

Thanks very much for your help.

Appendix 8: Free software follow-up

Only ten of the survey respondents who had volunteered to contribute further advice indicated that their students used free software in 'all or most' or in 'some' lessons. In most cases, respondents had previously provided follow-up information that sufficiently clarified their use of free software, but others were contacted and telephone conversations were conducted, prompted by the points below. In those cases, a suitable summary was constructed and checked by the respondent as an accurate record.

(Telephone interviews)

Thank you for responding to the recent SCSA survey on technology use in senior school mathematics and the related use of CAS calculators in external examinations. Thank you also for offering to elaborate some of your views around these topics. We appreciate that a survey can sometimes be a limited medium for identifying and exploring key issues.

You indicated in your response to the survey that your students use free software for learning mathematics in (all or most/some) lessons. To understand better the role of this particular technology, we would be grateful if you would be kind enough to elaborate on this a little for us. In particular, to understand the role of commercial software, we would like to know:

1. What devices the students generally use the free software on (e.g. personal laptops, computer lab, tablet, home use only)

2. The names of the free software programs that are used most often by your students

3. How the software is made available to students (e.g. school network, students are recommended to download)

4. About how often the software is used (such as daily, weekly, monthly)

5. Whether the students are expected/encouraged/permitted to use the software for assessment purposes (such as for assignment, tests or exams) as well as learning purposes

6. Whether the software is used by the teacher as well as by the student (for class demonstration, software instruction, etc)?

7. Any other perspectives you have on the use of free software that will help us to understand its importance in your students' learning of mathematics

It would help us if you would make it clear which particular courses you are referring to, if your comments are not of a general nature.

Can I write some notes to return to you to check, please? We would like to reserve the option of making reference to discussions like this in our report, but would of course make sure that that was done anonymously. That's why it's important that you are comfortable that it reflects your position suitably.

Appendix 9: Follow-up apps on tablets

Survey respondents who had volunteered to contribute further advice and who indicated that their students used apps on tablets in ‘all or most’ or in ‘some’ lessons were sent an email request as shown below. (In most cases, respondents had previously provided follow-up information that sufficiently clarified their use of these.)

Dear (name)

Thank you for responding to the recent SCSA survey on technology use in senior school mathematics and the related use of CAS calculators in external examinations. Thank you also for offering to elaborate some of your views around these topics. We appreciate that a survey can sometimes be a limited medium for identifying and exploring key issues.

You indicated in your response to the survey that your students use **apps on tablets** for learning mathematics in some or most lessons. To understand better the role of this particular technology, we would be grateful if you would be kind enough to elaborate on this a little for us. In particular, we would like to know:

1. What kind of tablet your students are using (e.g., Android, Apple iOS, other)
2. Which particular apps are used most often by your students
3. About how often they are used (such as daily, weekly, monthly)
4. Whether the students are expected/encouraged/permitted to use the apps for assessment purposes (such as assignments, tests and exams) as well as learning purposes
5. Any other perspectives you have on the use of apps on tablets that will help us to understand their importance in your students’ learning of mathematics

It would help us if you would make it clear which particular courses you are referring to, if your comments are not of a general nature.

While you are welcome to elaborate with a separate document, please do not feel obliged to provide an extensive response if a sentence or two may be sufficient to capture the essence of how your students use apps on tablets. We would be happy to receive a reply to this email with your comments embedded, if you felt a separate email response was unnecessary.

Your comments will be kept confidential, consistent with the information provided earlier to you regarding the project. However, we would like to reserve the option of reproducing some of your comments in our final report, to help readers appreciate a range of viewpoints on the issues involved. We would do this anonymously without your individual details being accessible outside the project team. Please advise us in your email if you are *not* prepared for us to do this.

Thanks very much for your help.

Please cite this document as:

Kissane, B., McConney, A., & Ho, K.F. (2015, December). *Review of the use of technology in Mathematics education and the related use of CAS calculators in external examinations and in post school tertiary education settings*. Perth, WA: School Curriculum and Standards Authority.

ISBN 978 0 7307 2843 6

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