THE EFFECTS OF CALCULATOR USE ON MATHEMATICS IN SCHOOLS AND IN THE CERTIFICATE EXAMINATIONS: FINAL REPORT ON PHASE I

THE EFFECTS OF CALCULATOR USE ON MATHEMATICS IN SCHOOLS AND IN THE CERTIFICATE EXAMINATIONS: FINAL REPORT ON PHASE I

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Published by:

St Patrick's College
Drumcondra
Dublin 9
Ireland

Electronic version available at: http://www.erc.ie

Cataloguing-in-Publication Data

Close, Seán
The effects of calculator use on mathematics in schools and in the certificate examinations: Final report on Phase I / Seán Close. . . [et al.].
xx, 126, 30 cm
ISBN 1-872327-49-4

1. Mathematics – Study and teaching (Secondary) – Ireland
2. Pocket calculators

I. Close, Seán. II Title
2004
510.712-dc22

Cover Design
e-print limited, Dublin

Printed in the Republic of Ireland by e-print limited, Dublin

Contents

Contents (continued)

List of Tables and Figures

List of Tables and Figures (continued)

List of Tables and Figures (continued)

List of Tables and Figures (continued)

List of Tables and Figures (continued)

Preface

In 1999, the Department of Education and Science awarded a contract for conducting a study on 'The Effects of Calculator Use on Mathematics in Schools and in the Certificate Examinations' to a consortium consisting of the Education Department, St Patrick's College, Dublin; the School of Education, Trinity College, Dublin; and the Educational Research Centre, St Patrick's College, Dublin. The study arose in the context of the introduction of calculators in the revised Junior Certificate mathematics syllabus (introduced in September 2000), and a decision to allow the use of calculators in the Junior Certificate mathematics examination from June 2003 onwards.

It was recognised at the outset that the effects of calculator usage on mathematics achievement would need to be studied over a number of years (i.e., before and after the formal introduction of calculators into the Junior Cycle mathematics syllabus and Junior Certificate mathematics examination). Phase I, which the current report describes, involved administering mathematics tests to a nationally-representative sample of Third-year students who had studied the pre-2000 Junior Certificate mathematics syllabus, and who would not expect to have access to a calculator when attempting the Junior Certificate mathematics examination. Phase II will involve a similar sample of students taking the same tests. However, these students will have studied the revised Junior Certificate mathematics syllabus, and will expect to have access to a calculator when sitting the Junior Certificate mathematics examination. It is anticipated that data gathering associated with Phase II will be carried out towards the end of 2004.

Objectives of the Study

The following objectives for Phase I of the study (1999-2002) were agreed with the Department of Education and Science:

- To summarise international research on the effects of calculator usage and the availability of calculators during testing on students' performance in mathematics;
- To examine the extent of calculator usage by teachers and their students in Third-year mathematics classes, and the attitudes of both teachers and students towards calculator usage;
- To develop tests of mathematical achievement (the 'Calculator Study' tests) that would examine the effects of access to a calculator during testing on student performance in such areas as mental and written arithmetic skills (including estimation), conceptual understanding of number, and data analysis;
- To examine the effects of calculator availability during testing on performance on items deemed to be calculator inappropriate, calculator optional, and calculator appropriate;
- To examine variables that may be related to student performance with or without access to a calculator including student ability, students' access to calculators at home and at school, and the extent of students' use of calculators at home and at school;

- To relate students' performance on the tests to their performance on the Junior Certificate mathematics examination (where use of a calculator was not permitted).

In Phase II of the study (2004-05), when students will have had experience in using calculators in their mathematics programmes, in line with the revised Junior Cycle mathematics syllabus, and would expect to have access to a calculator in the Junior Certificate mathematics examination, it is intended to address the following objectives:

- To examine the extent of calculator usage in mathematics lessons, and the ways in which calculators are used during such lessons;
- To explore links between the extent of calculator usage in mathematics lessons, and performance on the three tests of mathematical achievement developed in conjunction with the current study;
- To establish links between the performance of students on the tests and their performance on the Junior Certificate mathematics examination, and to relate this performance to the availability and use of calculators in Junior Cycle mathematics classes, and in the Junior Certificate mathematics examination;
- To compare performance of Third-year cohorts across the two phases of the study on the tests of mathematical achievement, and to examine any differences that emerge in terms of changes in calculator usage levels in mathematics classes and at home.

Implementation of the Study

Phase I of the study was implemented at a time during which teachers in some schools were in dispute with the Department of Education and Science. School closures and other difficulties meant that it was not possible to implement the study in accordance with the schedule that had originally been planned. The sample for the main study consisted of students in the last cohort to study Junior Cycle mathematics under the pre-2000 syllabus.

The project team, consisting of the six authors of this report, met on 23 occasions during the study, to address such matters as item development, the scaling of the test, the interpretation of the data, and the preparation of the report. Subgroups met on several other occasions to address specific tasks.

Organisation of this Report

This report includes an introduction and eight chapters. The introduction sets the context of the study. Chapter 1 consists of a review of the international literature on calculators in mathematics, including the effects of access to a calculator during assessments of mathematics. Chapters 2 and 3 deal with preparation for and implementation of the main study. In Chapter 2, the frameworks for the calculator test and for the questionnaires are outlined, while in Chapter 3, the sampling of schools and students is discussed, and procedures used to scale and analyse the data are outlined. Chapter 4 provides an overview of performance of students on the calculator tests. It focuses both on the overall performance of students on the tests, and on their performance on relevant subsets of items. In Chapter 5, relationships between student-level variables and student performance on the tests are examined. Chapter 6 relates performance on the Calculator tests to performance on the Junior Certificate mathematics examination. Chapter 7 looks at relationships between teacher-level variables and student performance. Chapter 8, the final chapter, presents some conclusions arising from the study and looks ahead to Phase II.

Acknowledgements

The research team wishes to acknowledge its thanks to the many teachers and students who participated in the different elements of the study to date, including those who participated in the pre-pilot study in March 2000, in the pilot study in October 2000, and in the main study in November 2001. Without their co-operation and participation, it would not have been possible to conduct Phase I of the study.

Thanks are due to Thomas Kellaghan, Director of the Educational Research Centre, who supported the study from the outset and reviewed a draft of this report, to Hugh McManus (Department of Education and Science), who liaised between the research team and the Department, to Doreen McMorris (Department of Education and Science) who provided feedback on earlier drafts of this report, to Joe English (Co-ordinator of the Junior Certificate Mathematics Support Service) for providing calculators, and to the School of Education, Trinity College and the Department of Education, St Patrick's College for their encouragement.

Thanks are also due to staff members at the Educational Research Centre who supported the study in various ways: to David Millar, who provided advice on sampling and on the construction of sampling weights; to John Coyle, who provided data management support; to Mary Rohan, who provided administrative support; and to Hilary Walshe, who typeset the test booklets and questionnaires. Thanks are due to Catherine Hombo (Educational Testing Service) and Neal Kingston (Measure Progress, New Hampshire, U.S.A.) for advice on scaling, to Edel Connolly (Trinity College) for her analysis of students' written work, and to the Third-year mathematics students from St Patrick's College who corrected the tests.

Summary

This report documents the outcomes of Phase I of a study on 'The Effects of Calculator Use on Mathematics in Schools and in the Certificate Examinations', which was conducted by a consortium consisting of the Education Department, St Patrick's College, Dublin, the School of Education, Trinity College, Dublin, and the Educational Research Centre, St Patrick's College, Dublin. The study arose in the context of the introduction of calculators in the revised Junior Cycle mathematics syllabus that was introduced in 2000 for first examination in 2003. The study was supported by the Department of Education and Science.

The objectives of Phase I, which were agreed with the Department at the beginning of the study, included the following: to summarise international research on the effects of calculator usage and the availability of calculators during testing; to examine the extent of calculator usage by teachers and their students in Third-year mathematics classes; to examine the attitudes of both teachers and students towards calculator usage; to examine the effects of calculator availability during testing on student performance; and to examine variables that may be related to student performance on tests, where students may or may not have access to a calculator.

A review of the international research on the effects of calculator usage on students' mathematical achievement indicated that students' basic skills were not adversely affected by calculator usage during mathematics lessons, and that, in some cases, instruction in effective calculator usage resulted in gains in achievement in such areas as computation and problem solving. The literature suggests that instruction in mental arithmetic and estimation takes on added importance in classes where calculators are routinely available during instruction.

In preparation for implementing Phase I of the Calculators in Mathematics study, three tests were developed:

- A *Calculator Inappropriate* test consisting of items that could (and should) be answered without use of a calculator – the test would be taken by all students, without access to a calculator;
- *A Calculator Optional* test, consisting of items that could be answered with or without a calculator – the test would be taken by all students, but only some would have access to a calculator;
- A *Calculator Appropriate* test, consisting of items for which access to a calculator was deemed necessary – all students taking the test would have access to a calculator.

The content of the tests covered aspects of the Junior Cycle mathematics syllabus that were deemed to be calculator sensitive and common to all three syllabus levels, including Number Systems, Applied Arithmetic and Measure, and Statistics. In addition, some Algebra items were included. While some items were context-free, others were set in 'realistic' contexts, mirroring the approach taken in the recent OECD Programme for International Student Assessment.

In addition to the cognitive tests, Teacher and Student questionnaires were developed to generate contextual information that could be used to interpret the performance of students on the tests.

The tests and the Student questionnaire were administered to 1469 Third-year students in 66 second-level schools in November, 2001, while the Teacher

questionnaire was administered to the students' mathematics teachers. The students were drawn from secondary, community/comprehensive and vocational schools. They represented the last cohort of Junior Cycle students to study the pre-2000 Junior Certificate mathematics syllabus, which did not refer the use of a calculator in mathematics lessons. Moreover, these students were not allowed to use a calculator in the Junior Certificate mathematics examination. The three tests completed by the students were scaled using Item Response Theory methodology. The mean and standard deviation of each test were set at 250 and 50 respectively. In the course of analysing the data, test scores and questionnaire responses were weighted to take into account the unequal distributions of students from different school-types in the sample.

The study generated important baseline data against which the performance of students in a different representative sample of schools can be compared once implementation of the revised Junior Cycle has been consolidated. In addition, the performance of students at the 10th, 25th, 50th, 75th and 90th percentiles on each test can be compared. Examples of items at different levels of difficulty on the tests were provided.

Students with access to a calculator achieved a statistically significantly higher mean score on the Calculator Optional test in comparison with their counterparts who did not have access to calculator (the difference was in the order of a third of a standard deviation). However, the difference in the scores of high-ability students (those achieving at the 90th percentile) with and without access to a calculator was not statistically significant, indicating that calculator availability may be less important for these students.

When performance on the Calculator Optional test was analysed by mathematical content area, the greatest difference in performance between those with and without access to a calculator was observed in the area of Number Systems (including items involving square roots and/or long division), with smaller differences on items in Applied Arithmetic and Measure, and Statistics.

The Calculator Appropriate test (32.5% correct) was more difficult for students than either the Calculator Optional (53.3%) or Calculator Inappropriate (60.0%) tests, perhaps reflecting students' lack of familiarity with calculators when solving 'real-life' mathematical problems. Related to this is a finding, arising from a qualitative analysis of students' written responses to the Calculator Appropriate items, that many students did not record intermediate steps in their work, even when it might have been advantageous to do so.

While male students outperformed female students on two of the three tests (Calculator Inappropriate, Calculator Optional), and female students outperformed male students on the third (Calculator Appropriate), differences between mean scores were not statistically significant. Students who sat the Junior Certificate mathematics examination at Higher level in 2002 achieved significantly higher mean scores on the three tests than students who sat the examination at Ordinary or Foundation levels. On the Calculator Optional test, the mean score of Ordinary level students with access to calculators approached the mean score of Higher-level students who did not have access, though the difference between their respective mean scores was statistically significant. Correlations between performance on the Junior Certificate mathematics examination and on the Calculator tests were moderately strong ranging from .59 (Calculator Optional Test with no calculator) to .69 (Calculator Inappropriate test).

The current study suggests that students who worked with a calculator at school (regardless of subject area) enjoyed an advantage on the Calculator

Appropriate test over those who did not. This suggests that, as students become more familiar with the use of calculators in mathematics, their performance on tests such as the Calculator Appropriate test may also improve.

Students were generally positively disposed towards calculators. While 70.6% ‘agreed’ or ‘strongly agreed’ with the view that calculators could help them to achieve better marks in school mathematics, just 46.7% showed similar levels of agreement with the view that calculators could help them to get better at mathematics. A minority of students (18.9%) ‘disagreed’ or ‘strongly disagreed’ with the view that they should be allowed use calculators in the Junior Certificate mathematics examination.

Two-thirds of students in Phase I of the study were taught by teachers who did not approve of calculator usage in Third-year mathematics classes at the time of the study (i.e., under the pre-2000 mathematics syllabus), while 14% were taught by teachers who approved of the use of calculators in mathematics classes. On the other hand, over 70% of pupils were taught by teachers who believed that Junior Cycle students should be allowed to use calculators in class, while 73% were taught by teachers who believed that calculators should be used in the Junior Certificate mathematics examination. A discrepancy between teachers’ low approval of calculator usage at school by their current Third-year students, and their endorsement of calculator usage in Junior Cycle mathematics classes and in the Junior Certificate mathematics examination, was probably influenced by their efforts to prepare students in the current study to attempt the Junior Certificate mathematics examination in 2002 without access to calculators. However, about 15% of students are taught by teachers who are negatively disposed towards calculator usage during mathematics classes or in the Junior Certificate examination. According to teachers, the areas of mathematics in which it is most likely that a calculator would be used as a tool for teaching and learning mathematics are Trigonometry, Applied Arithmetic and Measure, and Statistics, Functions and Graphs.

In Phase II of the study (2004-05), when all Junior Cycle students should have had some experience in using calculators in their mathematics programmes and will be preparing to use them in the Junior Certificate exam, it is planned to examine in greater depth the extent of calculator usage in mathematics lessons, and ways in which calculators are used during lessons, and to explore links between the extent of calculator usage in mathematics lessons, and performance on the three Calculator Study tests.

Introduction

The 'Calculators in Mathematics' study is intended to monitor Junior Cycle students' numeracy and calculator skills over the period of transition to a revised Junior Certificate syllabus, introduced in Autumn 2000, for first examination in Summer 2003. The syllabus formally incorporates calculators into the Junior Certificate mathematics curriculum. This development needs to be set in context by a brief discussion of the policy and practice with regard to calculators in mathematics education in Ireland over the last 30 years.[1]

At the time of the introduction of the revised Junior Cycle mathematics syllabus (September 2000), *Curaclam na Bunscoile* (Primary School Curriculum, Department of Education, 1971) was operating in primary schools. Not surprisingly, *Curaclam na Bunscoile,* which pre-dates the widespread availability of calculators, makes no mention of them. However, in the revised *Primary School Mathematics Curriculum* (Department of Education and Science / National Council for Curriculum and Assessment, 1999a, 1999b), the calculator is introduced in Fourth class. In the revised curriculum, objectives dealing with computation specify that 'students should be able to perform the various operations/computations without and with a calculator' (DES / NCCA, 1999a, p. 88). Although implementation of the revised *Primary School Mathematics Curriculum* did not begin until Autumn 2002, the current Junior Cycle mathematics syllabus was designed to take into account the impending changes.

While the 1971 Primary School Curriculum was in use for some thirty years, mathematics syllabi at the second level were revised a number of times in that period. Updates were made to what was then the Intermediate Certificate syllabus[2] in 1973 (for first examination in 1976), and the Leaving Certificate syllabus in 1976 (for first examination in 1978). In neither case was calculator use a matter of major discussion, and calculators were not mentioned in the syllabi. In the ensuing years, the issue came to the forefront. Arguments in favour of calculators typically emphasised their usefulness in obviating tedious computation when this was not the main focus of attention (for example, when dealing with percentage, area or volume) or in preparation for life in the world beyond school. Arguments against their use tended to focus on financial, social or practical issues: for example, whether or not the Department of Education would provide the calculators; whether students from poorer families would suffer if they were expected to buy their own machines; and what would happen if a calculator malfunctioned in an examination. These issues tended to overshadow educational matters such as the potential value of the calculator as a learning tool as well as a computational device. One educational argument against the use of calculators specifically in the Intermediate (and, later, the Junior) Certificate mathematics examination was that the examination should test basic numeracy skills. According to this argument, calculator use in examinations for other subjects at Junior Certificate level, and in Leaving Certificate examinations, was acceptable because basic numeracy was not an assessment objective in such cases.

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[1] Information in this section is collated from editions of *Rules and Programme for Secondary Schools* from the 1970s and 1980s (DES, published annually), *Mathematics – Junior Certificate: Guidelines for teachers* (DES / NCCA, 2002), and accounts documented at the time (Oldham, 1992).

[2] The Intermediate Certificate, and also the Group Certificate, were replaced by the Junior Certificate in 1989 (with the first Junior Certificate examinations being held in 1992).

The Intermediate Certificate mathematics syllabus was revised again during the 1980s – the revised version being introduced in 1987 for examination in 1990 – but no mention was made of calculators, and the ban on their use in the corresponding examination remained in force. Their use in class or indeed in school examinations was not officially prohibited; like other educational aids, such as textbooks, concrete materials and computers, they could be used at the discretion of the teacher. However, the fact that they were not allowed in state mathematics examinations at this level appears to have acted as a disincentive to their utilisation.

At Leaving Certificate level, non-programmable calculators were permitted in the examinations from 1986. The transition took place without any change in the syllabus content, and without alteration in the style of examination questions. Questions were formulated in such a way that the calculator was unlikely to confer much advantage; for example, in questions on the area enclosed by a circle, candidates typically were told to take π to equal $^{22}/_{7}$ and the radius of a circle would typically be a multiple of 7 to allow easy cancellation. In practice, however, use of a scientific calculator appears to have become the norm.

The explicit introduction of the calculator into the Leaving Certificate mathematics syllabus came in 1990 with the inception of the Ordinary Alternative course.[3] Parts of this course were built around calculator use; moreover, in the examination, there was a question specifically designed to test computational skills with a calculator – though this question could be avoided and a more traditional one answered instead. When revised Higher and Ordinary Leaving Certificate syllabi were introduced in 1992 (for first examination in 1994), a slightly more conservative approach was taken. Calculator use was mentioned but was not specified as an assessment objective, and examination questions continued to be designed to facilitate candidates who had not brought a calculator to the examination. By the time that the Ordinary Alternative syllabus was re-designated (with only minor changes) as a Foundation level syllabus in 1995 (for first examination in 1997), it had become clear that the 'calculator option' question was much more popular than the traditional option, and the latter was dropped. Thus, finally, a calculator was effectively required – in the same way that pen or pencil, ruler and geometrical instruments were 'required' rather than just permitted – for a state examination in mathematics.

By this time, the position at Junior Certificate level had become anomalous. Reviews of Junior Certificate mathematics in the early 1990s by the National Council for Curriculum and Assessment (NCCA) Mathematics Course Committee had identified the absence of calculators from the syllabus and examinations as one of the chief negative aspects. Arguments against calculator use on grounds of cost or social inequity were less powerful than previously because of the falling price of machines. The availability of reasonably-priced scientific calculators, in particular, obviated the need for very time-consuming (and arguably outdated) use of four-figure tables in dealing with trigonometry. Technical problems with calculators in the examinations in which they were permitted did not appear to be an issue. In fact, more problems could be envisaged in trying to prevent illicit access – for instance to a miniature calculator on a watch – than in facilitating intended access. Moreover, it was becoming clear that calculators would be included in the revised *Primary School Mathematics Curriculum*. The body of research broadly in favour of calculator use was well

[3] The Ordinary Alternative syllabus was introduced as an interim measure to follow on from the Intermediate Certificate Syllabus C (later Foundation level Junior Certificate) until a Foundation level was introduced to the Leaving Certificate.

established. Thus, when permission was granted for a limited revision of the Junior Certificate mathematics courses, in order to address major problems and consider any mismatch with the then forthcoming Primary curriculum, calculators were introduced 'for appropriate use', and their use was included in the assessment objectives. Also, as in the revised *Primary School Mathematics Curriculum*, increased emphasis was given to estimation in the syllabus, and it was intended that this too should be assessed. Benefits with regard to examinations include the fact that questions could now include more realistic data and – a minor but not insignificant point – a more accurate value of π could be specified.

It should be noted that some consideration was given to the idea of having one calculator-free paper in the examination, in order to test mental and written numeracy. However, the difficulty of monitoring students in the usual examination settings would make such a policy hard to implement, as indicated above. Of course, this position might need to be revisited in the future, if there is evidence of a decline in mental and written numeracy skills.

Finally, it should be noted that the types of calculators sanctioned for use in the examinations are four-function and scientific (non-programmable) machines. The price of graphics calculators in Ireland is still sufficiently high to rule out their 'required' use. However, as was the case for less powerful machines in the 1980s and 1990s, there is no embargo on their use as teaching and learning tools. In fact, the possibility of such use is flagged in the Teacher and Student questionnaires used in the current study.

1 Calculators in Mathematics – A Review of the Literature

The main focus of this chapter is on relationships between calculator usage and student achievement in mathematics. In considering the effects of calculator usage on mathematical achievement, reference is made to both short-term and long-term intervention studies. Relevant information from recent international studies is considered. Some research on the attitudes of students and teachers to calculator usage is also described. In the final section, consideration is given to issues surrounding the use of calculators in assessment.

CALCULATOR TYPES AND FEATURES

The first electronic calculator, the *Anita*, was developed and manufactured in the United Kingdom in 1961. The machine weighed 33 pounds and, although large in size, was regarded as a major breakthrough in calculating devices as it was silent and relatively fast-operating. In the late 1960s, the EL-8, a 'small' portable calculator with four function calculating power, an 8 numeric tube for display, and rechargeable batteries was marketed in Japan. It weighed 1.7 pounds and was priced in advertisements in the United States at $345. Five years later, the pocket calculator was widely used by students as some simple four-function calculators were available for as little as US$20 (Ball & Flamm, 1996). Much research on the effects of calculator usage in classrooms took place in the late 1970s and early 1980s, but the swift arrival of the microcomputer reduced interest in the simple hand-held calculator to a great extent. In recent years, there has been an increase in the sophistication, functionality and compactness of portable calculating devices and there are now several types of calculator (Ruthven, 1996; DES/NCCA, 2001):

- The *arithmetic calculator* provides basic facilities for everyday calculations and features the four basic operations, although some models also provide square root and percentage operations.
- The *scientific calculator* provides a wider range of operating facilities, including basic mathematical functions and their inverses, and standard statistical aggregations.
- The *graphics calculator* features a more extensive range of mathematical and statistical operations than the scientific calculator and allows the graphing of numeric data and symbolic expressions.
- The *symbolic calculator* provides operations to restructure, differentiate and integrate symbolic expressions.
- Both *palmtop* and *laptop* computers represent a convergence between the calculator and microcomputer and combine all the facilities of the symbolic calculator with standard application software such as word processor, database and spreadsheet. Of the software that is available for computers, the *computer algebra system* extends calculator functionality and provides additional features for dealing with algebra and differential and integral calculus.

Use of the arithmetic or four function calculator is permitted at primary level in many countries. At second level, the scientific calculator is well established but, increasingly, the graphics calculator is gaining a foothold. In Ireland, the revised *Primary*

School Mathematics Curriculum provides for the use of calculators in mathematics from Fourth to Sixth classes (DES/NCCA, 1999a, b). The scientific calculator has been permitted in examinations at Leaving Certificate level for nearly twenty years. Since 2003, its use has been permitted in the Junior Certificate mathematics examination and in other Junior Certificate examinations in which it was not already in use.

CALCULATOR AVAILABILITY AND USAGE

Given the affordability of the simple hand-held calculator, it is hardly surprising that it became a device that was easily available in the workplace and at home. Research studies into the mathematical needs of various types of employment were cited in *Mathematics Counts* (DES, 1982), a seminal volume that has had pervasive influence on mathematics education; it was reported that there was popular acceptance of calculators in the workplace. In 1987, nearly 75% of 15 year olds and over 50% of eleven year olds in England reported personal ownership of a calculator (Foxman et al., 1991). However, much controversy surrounded the introduction of the calculator in the classroom in England. It was felt by some teachers, parents and students that calculator usage would cause a diminution of mathematics skills. These fears prevailed almost twenty years after the debut of the calculator into society. In 1991, a study by the Assessment of Performance Unit in Britain found that nearly 30% of 11 year olds considered that the use of calculators was harmful because 'they stop you using your brain' or 'prevent you from learning all sorts of sums' (Foxman et al., 1991). The extent of the gap between acceptance of the calculator in society and its acceptance in the classroom varies among countries. Internationally, there is a reluctance to incorporate the device on a frequent basis in primary schools (Mullis et al., 1997). In Ireland, the National Assessment of Mathematics Achievement involving pupils in Fourth class in 1999 indicated that fewer than 5% of pupils were in classes in which calculators were available during mathematics lessons and that just 1% of pupils used calculators more frequently than once or twice a month (Shiel & Kelly, 2001). Furthermore, calculators tended to be used more by lower-achieving than by higher-achieving students.

In considering the frequency of calculator usage in Irish second-level schools, pertinent information is available in international surveys such as the Second International Assessment of Educational Progress (IAEP II), and the Third International Mathematics and Science Study (TIMSS). In the Irish national report on the 1991 IAEP II study, it was reported that the use of electronic calculators for mathematics was less common in Ireland than in most participating countries, with just over 25% of Irish 13 year old students reporting usage of a calculator in mathematics classes (Martin et al., 1992). Data from TIMSS suggest that personal ownership of calculators among Grade 8 (Second-year) students is over 90% in most of the participating countries except Iran and Thailand (Beaton et al., 1996). However, there are substantial differences in reported usage of calculators between countries. Much of this may be due to policy on the availability of the calculator in assessments. For example, 97% of Grade 8 (Second year) students in Ireland reported having a calculator at home, yet 68% were in classes whose teachers reported that their students 'hardly ever or never' used a calculator in mathematics classes. Similar to the findings of IAEP II, just 24% students were taught by teachers who reported calculator usage in class at least once a week. This contrasts sharply with countries like Australia, Canada, England, Iceland, the Netherlands and Singapore where at least 80% of students were in mathematics classes whose teachers reported usage of calculators 'almost every day' (Beaton et al., 1996).

In the TIMSS Repeat Study in 1999, in which Ireland did not participate, an 'emphasis on calculator use' scale was developed, based on responses of students in Grade 8 and their teachers about the frequency use of calculators in mathematics classes. Considerable variation in usage was observed across countries. In the Netherlands, Singapore and Australia, between 84 percent and 95 percent of students were classified as 'high' calculator users, while several high-performing countries on the test, including Korea and Japan, had over 70% of their students classified as 'low' users (Mullis et al., 2000). The TIMSS Repeat report also notes a decline between 1995 and 1999 in the proportions of students in several countries reporting that they 'almost always' used calculators in mathematics classes. In England, for example, 16% fewer students reported using calculators 'always almost' in mathematics classes in 1999 than in 1995. On the other hand, the Netherlands saw an increase of 13% in the proportion of students 'almost always' using calculators.

CALCULATORS AND ACHIEVEMENT

As the calculator gains acceptance in both primary and second-level schools in Ireland, what will its effects be on mathematical achievement? American and European research on the use of the arithmetic calculator was conducted mainly in the 1980s and early 1990s, predominantly in primary schools. As was mentioned earlier, interest then turned towards the microcomputer but, more recently, the effects of graphics calculator usage at second-level has received some attention. A discussion paper published in 1997 by the Schools Curriculum and Assessment Authority in Britain gives a comprehensive overview of research into the impact of calculator usage on mathematical achievement (SCAA, 1997).

Short-Term Studies

Early research into its effects of the calculator boded well for its introduction. In a summary of research into the effects of calculator usage in pre-college education in the US, the mean score of the calculator group was the same as or higher than the mean score of the non-calculator group in 90 out of 95 studies (Suydam, 1982). However, in reporting on these studies, no distinction was made between groups that were permitted to use a calculator in the post-test and those that were not.

In order to draw firmer conclusions on the effects of calculators on attitude towards and achievement in mathematics, Hembree and Dessart (1986) conducted a meta-analysis of calculator research reports. The studies were concerned with students in mainstream mathematics programmes in Grades K-12 in the US. In each of 79 studies that met the criteria for inclusion in the analysis, one group had access to a calculator during a treatment period and the other group covered similar material without access. In sixty-six studies, the calculator was used by the students for computation, while in thirteen studies the calculator was used to help develop concepts or problem solving strategies. The length of treatment varied from one class period to a full school year. In analyzing test results, account was taken of calculator availability in the test situation so that the effect of calculator usage on paper-and-pencil skills could be determined. The results may be summarised as follows:

- In cases where skills acquisition was assessed without calculators, paper-and-pencil skills of low- and high-ability students who received training in calculator usage remained on par with those of the control group for computation and problem-solving. For students of average ability, however, paper-and-pencil skills improved significantly, except in Grade 4 where the calculator seemed to detract from these skills. Regarding the acquisition of concepts, there was a non-significant effect across all grades.

- In cases where skills acquisition was assessed with calculators, positive effects were found on tests of computation for low- and average-ability students, but not for high-ability students. On tests of problem-solving, positive effects were found for students of all ability levels, although the effects for low and high ability students were higher than those for average students.

Hembree and Dessart (1992) included nine additional studies in a later meta-analysis; the new data corroborated the findings of their 1986 study. Their work suggests that calculator usage does not lead to diminution of basic paper-and-pencil skills (except, perhaps, at Grade 4) and, in fact, enhances these skills for students of average ability. However, availability of the calculator during the testing process appears to be a crucial factor in producing better results.

If the calculator helps to produce better results, it is of interest to establish the ways in which it assists the solution process. In an attempt to answer this question, Szetela (1982) conducted a study to determine if students who use a calculator with story problems attempt more problems, choose the correct operation more frequently, and obtain more correct answers than students who do not have access to a calculator. The study involved two classes each in Grades 3, 5, 7 and 8. Following a pretest, students were randomly assigned to calculator and non-calculator groups. Students in Grade 8 participated in the study for a total of twelve weeks while activities for all other grades extended over a period of eight weeks. The calculator was used for checking computation, and as a tool in problem-solving. Two post-tests were administered. In the first, which consisted of items on computation and problem-solving, access to a calculator was not permitted. Results from this test showed that paper-and-pencil skills and problem-solving ability were similar for both groups, leading to the conclusion that these skills had not been impaired by calculator usage. In the second post-test, students from both groups were given twenty story problems to solve but students who had used the calculator in the treatment period had access to a calculator in this test. In Grades 3, 7 and 8, students from the calculator group performed significantly better than the non-calculator group on a measure of correct answers to problems. In Grade 7, students from the calculator group also performed significantly better than the non-calculator group on measures of the number of problems attempted and the number of problems where the correct operation was chosen. No other differences were statistically significant.

Szetela conducted a supplementary study at the same time as the main study. The purpose of this study was to compare the use of calculators with the use of paper and pen on a post-test of problem solving after all students had used the calculator during eight weeks of instruction. This study involved students in Grades 5, 6 and 7. For the first section of ten problems, half of the students used calculators and the other half used paper and pen; the groups reversed modes for the second half of the test. The calculator group performed significantly better than the non-calculator group on four out of eight comparisons on measures of correct answers. There was also a significant difference on a measure of correct operations for students with calculators in Grade 6. No other differences were statistically significant. Szetela (1982) concluded that the main advantage of the calculator was the avoidance of computational errors.

Long-Term Studies

In most of the American studies included in Hembree and Dessart's meta-analyses, calculator treatment was short-term (the median length was thirty days). Therefore, the outcomes cannot provide a basis for inferring how longer-term use of the calculator affects students' mathematical thinking and learning (SCAA, 1997). Most long-term studies have focused on the use of the pocket calculator at primary level. These include: ARK, a Swedish project that was carried between 1979 and 1982; the Calculator Aware Number Curriculum (CAN), which was implemented in England between 1986 and 1989; the Calculator as a Cognitive Tool (CTT), a follow-up study to the CAN project; and the Calculators in Primary Mathematics Project (CPM), an Australian study that was based on a similar approach to that used in CAN.

The *ARK* project was established by the Swedish National Board of Education in 1976 to analyse the consequences of using the pocket calculator. A longitudinal study involving eight Grade 4 classes began in 1979 and continued until these pupils reached the end of Grade 6. There were three control classes. For the purpose of this project, experimental texts dealing with mental arithmetic, estimation, algorithms, word-problems and project tasks were designed. These were to be used in combination with conventional teaching material (Hedrén, 1985). Very little time was given for practice with the calculator itself. Pupils in the control and calculator groups were tested at the beginning of Grade 4 and at the end of Grade 6. The test administered at the end of Grade 6 was also tried out on a representative sample of Swedish pupils in Grade 6. The latter was known as the 'NAB group' as the test taken by pupils in the group mainly involved non-algorithmic basic skills. The calculator group did not have access to a calculator during the test. There was no significant difference between the scores of the control group and those of the NAB group. Comparisons between the scores of the calculator and NAB groups showed the calculator group to be significantly better on 47 items and significantly worse on 9 items. The following were the general areas where the calculator group performed significantly better:

- quantitative understanding of number
- the number line
- word problem-solving
- choice of operation
- measurements and units
- interpretation of diagrams and tables
- approximation and estimation
- word problem-solving, using information in problems lacking one single answer.

Among the items on which the calculator group performed less well than the NAB group were two on algorithms and four on mental arithmetic. However, there were other items on algorithms and mental arithmetic on which the performance of the calculator group was significantly better than that of the NAB group.

The *CAN* project was part of the PRIME project, which was established to examine the effects of integrating new technology, especially calculators, into the number curriculum (Shuard, 1992). CAN commenced in September 1986 and initially involved twenty classes of 6-year-old children and their teachers. The schools spanned the range of social conditions found in England. Successive schools joined the project of their own choice. The teachers involved in the project were asked to allow the children to decide themselves whether or not to use a calculator and they were encouraged not to teach the paper-and-pencil methods for the four number operations. Although the evaluation of the project was qualitative in the main, a quantitative evaluation did take place using the 8+ LEA (Local Education Authority) mathematics test. The test was revised so that it would not give advantage to children who did or did not use calculators in their mathematics learning. It was administered to the CAN children in 1989, at which stage they had been part of the project for either one or two years. The performance of 116 CAN children was then compared with a randomly selected group of 116 children who did not have school access to a calculator. On 28 of 36 items, more project children than non-project children gave correct responses. Furthermore, on 20 items, a higher percentage of non-project children did not make any attempt to answer, suggesting a greater degree of confidence on the part of the project children. In the second year, project children had a higher success rate on 21 of the 36 items. Their results must be interpreted with caution, however, as the project schools had been carefully selected and the teachers therein received considerable external support. Among the observations that arose as part of the qualitative evaluation of the project were that children were working on topics normally considered too difficult for their age, that they had developed an interest in non-calculator methods of calculation, and that there was a growth in problem solving and investigative work.

The *Calculator as a Cognitive Tool (CCT)* research project looked at a cohort of primary children who commenced Year 1 at the start of the 1990/91 academic year and completed primary education at the end of 1995/96. Of the six schools involved, three had participated in the CAN project. Analysis of their Key Stage 1 results (based on national tests administered at age 7) found that the probability of high mathematical achievement was about four times greater in the post-CAN schools. However, the probability of low achievement was about three times greater in the same schools. The project children were likely to be at extremes of the achievement distribution. The authors of the SCAA document suggest that this finding might be due to the emphasis on investigative tasks that may have challenged the more able pupils but may have resulted in less systematic teacher intervention than may have been required by the pupils who were making poor progress. On Key Stage 2 mathematics tests (administered at age 11), no significant differences were found between the scores of the post-CAN and non-CAN schools, suggesting the participation in the project had neither advanced nor hindered the children's achievement in the long term; such findings suggest that factors other than tools used for computation impact on the learning of mathematics (SCAA, 1997).

The Calculators in Primary Mathematics Project (CPM) was an Australian project that commenced with Kindergarten and Grade 1 in 1990 and involved approximately 1000 children and eighty teachers in six schools in Melbourne (Groves & Stacey, 1998). The project followed the children through the schools' top Grade 4 in 1993. The approach followed was similar to CAN with a wide range of teacher support and development. Between 1991 to 1993, project children in Grades 3 and 4 were given a written test, a test of calculator use and two different interviews. Their performance was compared with that of a control group consisting of pupils who had attended the same schools but had not been part of the project. The interviews and written test did not give evidence of over-reliance on the calculator. The project children performed better on items involving negative numbers, place-value in large numbers and, in particular, decimal numbers. Furthermore, these children were more discerning in their choice of calculating device.

International Studies

The authors of the SCAA report lament the fact that there is no corresponding body of research at secondary level. However, data from international surveys give some indication of the levels of calculator usage in different countries, and associations between usage and the mathematics achievement of lower second-level students.

The results of the *IAEP II* survey showed that, in England, Scotland, France, Canada, Hungary and Taiwan, over two thirds of students in Grade 8 reported using a calculator in school. In each of the six countries, the average score of the group of students that used a calculator was found to be significantly higher than the score of the group that did not use a calculator, even though a calculator was not available during testing. In Ireland, however, where just over 25% of 13 year old students reported usage of a calculator in school, there was no difference between the average mathematics scores of those who did and did not use a calculator (Martin et al., 1992). As there are no data available on the ability levels of the Irish students who had access to a calculator, these results should be interpreted with caution.

The *TIMSS* study, which was conducted in 1995, provides information on calculator usage among students participating in the project. Table 1.1 summarises calculator usage in selected countries in Grade 8.

Table 1.1 Percentages of Grade 8 Students in Selected Countries Indicating Calculator Usage – Third International Mathematics and Science Study (1995)

Country	Never or hardly ever		Once or twice a month		Once or twice a week		Almost every day	
	Percent of Students	Mean Score	Percent of Students	Mean Score	Percent of Students	Mean Score	Percent of Students	Mean Score
Belgium	39	577	23	572	14	584	24	571
Canada	5	489	3	515	12	518	80	533
England	0	~	2	~	15	479	83	523
France	4	537	3	565	19	538	74	537
Hungary	29	533	5	512	6	534	60	540
Ireland	68	535	7	490	13	515	11	521
Japan	79	603	16	609	4	620	2	~
Korea	76	613	16	608	8	585	1	~
Singapore	1	~	5	617	12	636	82	647
Sweden	7	495	21	523	37	520	35	521

Source: Beaton et al. (1996)

High performing countries in this study include Singapore, Japan and Korea. But the profiles of these countries in terms of calculator usage contrast sharply. Approximately three quarters of students in Japan and Korea report that they ‘never or hardly ever’ use the calculator at Grade 8 while in Singapore over 80% of students report using the calculator almost every day. The mean achievement of students in France and Ireland across categories is broadly similar and yet extent of calculator usage is markedly different in these countries. In their report on the TIMSS Repeat study in Grade 8 in 1999 (in which Ireland did not participate), Mullis et al. (2000) reported that, since several high-performing countries had restricted calculator use, and large percentages of students indicated low use of calculators, the relationship between calculator use and performance was difficult to interpret. However, they did observe that, within countries where emphasis on calculator use was high, such as England and the United States, there was a positive association between calculator use and achievement.

In 2000, the first cycle of the *Programme for International Student Assessment (PISA)*, an international assessment involving 15-year old students in second-level schools, was conducted. Twenty-eight OECD countries, including Ireland, participated in the assessment in that year. Comparative international data on students' achievements in reading literacy (the major domain), mathematical literacy (a minor domain) and scientific literacy (a minor domain) were generated. On the test of mathematical literacy, students were permitted to use a calculator if their principal teachers had indicated that they normally used a calculator during mathematics lessons. Just over one quarter of Irish students for whom responses were available stated that they used the device in the assessment. The mean score of students with access to a calculator (see Table 1.2) is significantly higher than that of students who said that they did not have access to a calculator (Shiel et al., 2001). However, no information is given on the characteristics of students with/without a calculator. Furthermore, information on usage of calculators during testing is not available for other countries in PISA 2000.

Table 1.2 Performance of Irish Students on the OECD/PISA 2000 Assessment of Mathematical Literacy, by Access to a Calculator during Testing

Calculator Availability	Percent of Students	Mean	Standard Error
Yes	27.3	526.9	4.47
No	72.7	501.8	3.10

ATTITUDE TOWARDS CALCULATORS

Attitudes Among Students

Hembree and Dessart (1992) cite data from the Second International Mathematics Study (SIMS) conducted in 1981 where only one-third of Grade 8 students felt that calculators would make mathematics more fun and would enhance their learning of other subjects. In the same survey, 83% of Grade 12 students agreed with statements on these matters, suggesting that students may develop more positive attitudes towards calculators as they progress through their schooling. In a study by Bitter and Hatfield (1991), middle-grade students expressed more positive attitudes towards calculators, though they were wary of using them in test situations, and still felt the need to demonstrate their work on paper (see Table 1.3).

Table 1.3 Percent of Grade 12 Students Responding 'Agree' or 'Strongly Agree' to Calculator Attitude Items in Bitter and Hatfield (1991)

Attitude Item	Percent of Students
Calculators make mathematics fun	79.1
Mathematics is easier if a calculator is used to solve problems	86.3
It is important that everyone learn how to use a calculator	85.6
I would do better in math if I could use a calculator	72.7
I prefer working word problems with a calculator	69.6
I would try harder in math if I had a calculator to use	49.3
Students should not be allowed to use a calculator while taking math tests	28.3
The calculator will hinder students' understanding of the basic computation skills	36.6
Since I will have a calculator, I do not need to learn to do computation on paper	12.7

In a study by Ruthven (1995), a questionnaire was administered to 327 students who had just entered their First year of secondary education in two 11-16 comprehensive schools in the South Cambridgeshire area of England. There were two groups of items on the questionnaire. The first group consisted of items comparing modes of calculation (calculator, mental and written). The second group addressed more general attitudes towards working with numbers and calculators. It was found that the calculator mode was most favoured and the mental mode least favoured in terms of perceived difficulty, incidence of mistakes and time taken. However, there was a degree of scepticism about the value of the calculator as a learning tool; over 50% of the students agreed or strongly agreed with the statement that 'If you use a calculator you learn less about numbers' and about 40% of the students supported the statement that 'Using a calculator to do number problems is a kind of cheating'.

Attitudes Among Teachers

Given that calculators have been more readily accepted in second-level than in primary schools (Mullis et al., 1997), it seems likely that primary teachers regard the calculator with a greater degree of scepticism than do teachers at second level. In a study by Schmidt and Callahan (1992), the most common element identified by elementary teachers and principals was fear – fear that calculators would become a crutch, replacing students' mathematical thinking, reasoning, mental computational abilities, and basic skills. Schmidt (1999) conducted a study in which she compared the beliefs of middle grade teachers before and after participating in a project designed to teach them how to connect calculators to their mathematics teaching. Before and after the project there was broad acceptance that the calculator should be integrated into mathematics education but there remained a commitment to student learning of basic facts and the use of traditional paper-and-pencil algorithms. Table 1.4 indicates how teachers responded to a selection of statements following the intervention.

When asked 'in what ways do students in your classes use calculators?' the most frequent responses were 'problem-solving' and 'checking'. However, whereas in the pre-questionnaire, there was a tendency to name a particular topic such as 'decimals' or 'fractions', a common post-questionnaire response was 'for exploring mathematics'.

Table 1.4 Summary of Teacher Responses to Statements about the Effects of Calculator Usage on Student Performance in Mathematics (Schmidt, 1999)

Statement	Pre-Project	Post-Project	Direction of Change
If calculators are used in school mathematics programs, students no longer need to know paper-and-pencil computing techniques	SD*	SD	+
Extensive use of calculators makes estimation and mental calculation increasingly important skills to be taught	A	SA	+
Calculators are tools that allow students to focus more attention on mathematics concept development and understanding	SA	SA	+
Using calculators helps students learn, retain and internalise number facts	U	U	+
Students who use calculators learn mathematics better than those who do not	U	U	–
Calculator use benefits student achievement in problem solving	A	A	+
If calculators are used in middle school mathematics programs, pencil computing techniques that promote understanding should have precedence over techniques that are 'speedy' and efficient	U	U	–

* SA - Strongly Agree; A- Agree; U- Uncertain; D - Disagree; SD – Strongly Disagree; + Post-test mean moves towards stronger agreement or disagreement; – post-test mean moves towards lesser agreement or disagreement: Source: Schmidt (1999)

CALCULATORS AND TESTING

Item Type and Format

The integration of the calculator into mathematics instruction has implications for assessment in terms of objectives and item format. In the mid to late 1980s, pilot projects took place in many states in the U.S. to research some of these implications. A pilot project was completed during 1989-90 by the state of Florida to investigate the feasibility of using calculators in the assessment of students' mathematical proficiency (Hopkins, 1992). The increased acceptability of the use of calculator in the assessment of mathematics was based on the premise that its incorporation would:

- Ensure that students do not spend a disproportionate amount of time on computation during testing
- Allow the inclusion of realistic problems on the test, thus making them a more reliable measure of students' conceptual understanding as opposed to their computational proficiency
- Promote a shift in the mathematics curriculum away from computation to problem solving and reasoning.

Hopkins (1992) maintains that objectives tested with calculators fall into two categories: (i) calculator specific objectives; and (ii) mathematics objectives. Calculator specific items assess a student's ability to manipulate the device, e.g., recognition of appropriate key sequences, interpretation of the calculator display, and identification of specific calculator keys. Mathematics objectives deemed appropriate for assessment with a calculator include exploration of number patterns, use of guess-and-check strategies for problem solving, the process of hypothesis formation, and verification and solution of problems using realistic data. Calculators are normally prohibited for assessment of basic computation skills. Given that the calculator allows inclusion of realistic data in word problems but that its use in the classroom demands that greater attention be paid to mental arithmetic and estimation, a distinction may be made between calculator active and calculator inactive items. In 1984, the Connecticut General Assembly agreed to develop a new Grade 8 mastery test (Leinwand, 1992). It was decided that calculators would be available for objectives on problem-solving/applications and measurement/geometry. At the time of development of the pilot test, it was not certain that calculators would be available to all students and therefore items were developed 'where a calculator would be helpful but not indispensable'. For the purpose of this test, calculator active items were defined as those that tested basic knowledge of how to use a calculator (e.g., in the computation of sums, differences, products and quotients), as well as word problems, where large numbers made the problems more realistic and the calculator more helpful.

In describing the use of calculators in U.S. College Board standardised tests, Greenes and Rigol (1992) make the following distinctions:

- *Calculator inactive* problems are those for which there is no advantage (perhaps even a disadvantage) to using a calculator, e.g., finding the area of a parallelogram
- *Calculator neutral* problems can be solved without a calculator but a calculator may be used, e.g., Sin (Arcsin 1/10) = (a) 0; (b) $^1/_{10}$; (c) $^1/_9$; (d) $^9/_{10}$; (e) 1
- *Calculator active* problems require the use of a calculator for their solution, e.g.,
  The diameter and height of a right circular cylinder are equal.
  If the volume of the cylinder is 2, what is the height of the cylinder?
  (a) 1.37; (b) 1.08; (c) 0.86; (d) 0.80; (e) 0.68

Early in 1986, it was decided that the Michigan state assessment that was administered annually at the beginning of Grades 4, 7 and 10 would be revised to take the integration of the calculator in instruction and testing into account (Payne, 1992). The test was first administered in Autumn of 1991 and included sections on mental arithmetic and estimation, paper-and-pencil computation with no calculators allowed, and paper-and-pencil computation with calculators permitted. In early tryouts of the test, it was found that student performance under timed administration of printed items with multiple choice format was indistinguishable from untimed, oral presentations. It was also found that the multiple choice format was much better for estimation items because in the open-ended format students had great difficulty in knowing how close their estimates should be.

Preliminary test results of the Michigan state assessment suggested that time needed to be allocated to developing calculator literacy skills as the results on certain computation items with calculator available were poor, e.g., items such as 1.18% of 3.4 or 4.56 x $^{18}/_{25}$ were answered correctly by fewer than 50% of Grade 10 students (Payne, 1992). In the Florida project, a frequent comment made by Grade 8 and 11 students during the post-test interview was that the calculator slowed them down (Hopkins, 1992). This finding had also emerged in the 1977-78 National Assessment of Educational Progress (NAEP) study in which some students were allowed to use calculators on all items. The students who had been allowed to use a calculator spent more time on test items than those who were not allowed to use one. However, it was not clear at the time whether students required extra time because of unfamiliarity with the calculator or because of the type of problems appearing on the test. Hopkins (1992) suggests that there is a direct relationship between student performance on the calculator-based tests and familiarity with the calculator. For example, in Grade 5, students who indicated that they never used a calculator in school made more errors than their counterparts who had used a calculator in school.

Effect of Calculator Type

Of the 25% of Irish students who used a calculator in the 2000 PISA survey, the majority reported using either a simple arithmetic calculator or a scientific calculator. The table below, which is based on the Irish PISA database, shows the type of calculator used:

Table 1.5 Types of Calculators Used by Irish 15-Year Olds in PISA 2000

Calculator type	Percent of students
None	64.45%
Simple	13.18%
Scientific	10.72%
Programmable	0.30%
Graphics	~

It seems, however, that complexity of a student's calculator has little effect on student performance (Hanson et al., 2001). Fifty students in Grade 8 completed a set of problems from NAEP, a set of timed computation tests with their own calculators and comparable sets of problems with a standard calculator. The type of calculator used did not affect their performance as measured by problem-solving accuracy and time taken to complete the test. Furthermore, the complexity of the students' calculators did not have an effect on the main finding, i.e. students with simple calculators and students with complex calculators showed no performance differences on NAEP problem-solving items.

CONCLUSION

Since its debut in the 1970s, the hand-held calculator has increased in complexity to the extent that there is a growing convergence between it and the microcomputer. However, given their general affordability, the types of calculators sanctioned for use in Irish second-level schools are the four function arithmetic and scientific machines. In most countries, over 90% of Grade 8 students report personal ownership of a calculator (Beaton et al., 1996). However, there are differences among countries in the degree to which there is acceptance of the calculator as a tool for teaching and learning mathematics. Some teachers of these students report using the calculator 'almost every day' while others state that they 'hardly ever or never' use the device. While this might be related to state or school policy on calculator use in assessment, the literature suggests that there is a degree of scepticism on the part of some teachers and students towards the calculator. There are concerns that calculator usage will cause a diminution of basic skills but most studies suggest that such a diminution does not occur. In the oft-cited meta-analyses of Hembree and Dessart, calculator usage was not found to cause an erosion of paper-and-pencil skills (except at Grade 4), and, in fact, improved these skills for students of average ability. However, calculator availability in the testing situation is a crucial factor in assessing its impact on mathematical achievement.

The rationale for the incorporation of the calculator in assessments is based on the premise that it promises a shift in emphasis away from computation to problem solving and mathematical reasoning. However, calculator usage also demands that more time be spent on mental arithmetic and estimation. Therefore, issues around assessment include the development of items that test basic computation and estimation skills and the need to make distinctions between calculator inactive, calculator neutral and calculator active items. In the construction of items for the assessment of estimation, a multiple-choice format has been found to give accurate feedback on students' competencies in this area. Student familiarity with a calculator appears to be a key factor in performance on tests.

The effect of the calculator on achievement in word problems has been found to be mainly computational although there is some evidence that it can also affect choice of correct operation, particularly if used over a long period of time. There is also evidence that its use can improve understanding of number concepts. In most studies where groups are compared, calculator groups outperform non-calculator groups, especially in tests on computation and solution of word problems. An important caveat here is that while this occurs within countries, it does not appear to be the case between countries. For example, high scoring countries in TIMSS have very different profiles on calculator usage, though within countries where calculator usage is high, students who use calculators more frequently tend to do better. It might be safely concluded that while the calculator does not harm acquisition of mathematical skills, it is merely one of several factors that should be considered in improving performance on tests of mathematical achievement.

2 Framework for the Study

This chapter discusses the framework for the Calculators in Mathematics Study, including the rationale underlying the cognitive tests and the Teacher and Student questionnaires. In Chapter 3, the piloting of these instruments and the implementation of the main study are addressed.

DEVELOPMENT OF THE CALCULATOR TESTS

This section describes the development of the framework underpinning the calculator tests administered to Third-year students in a representative sample of second-level schools, as part of the study. It also describes the compilation of the tests.

Research Requirements

The research requirements specified by the Department of Education and Science (DES) for the cognitive testing component of the project were:

- To assess present levels of students' skills and understanding in the areas of:
  - mental and written arithmetic skills
  - calculator skills
  - understanding of number
  - data analysis skills; and
- To identify any significant changes relative to the above base-line data when students experience a greater level of calculator use in learning and assessment.

These requirements determined the research paradigm and contributed greatly to the development of the framework for the study. The requirement to assess 'present levels of students' skills and understanding' and identify any significant change in 'base-line data' pointed clearly to a large-scale study using nationally representative samples of students. Hence, the brief would be best addressed by the construction of appropriate tests and by their administration to a suitable sample of Third-year students on two occasions: the first before the revised courses came into operation (hence, to a cohort which would not use calculators in the Junior Certificate mathematics examination) and the second when the new courses were established (hence, to a cohort that had been prepared to use calculators in the Junior Certificate examination). The extent to which there was a change in the students' experience of calculator use for *learning* (as opposed to assessment) between the two phases could be assessed by use of questionnaires which would ask students and their teachers about the ways in which calculators featured in the teaching/learning process (see below).

For the design of the cognitive tests, a number of questions needed to be answered. These fall into three categories. The first category deals with questions arising from the literature review with regard to such tests, and hence can be considered as addressing *calculator issues*; the second category addresses matters germane to the content of the questions, and hence focuses on *curricular issues*; the third category focuses on the actual test design, and so deals with *testing issues*. Once these issues had been addressed, items needed to be chosen or written and assembled into appropriate tests. This is discussed under the heading of *compiling the tests*.

Calculator Issues

The following questions arise from the literature review:

1. Should calculator-specific skills (those concerned with operating the calculator rather than solving mathematical problems) be tested?
2. For what parts of the tests should calculator use be allowed, for what parts should it be optional, and for what parts (if any) should it be required?
3. In the light of this, what balance should be struck between the number of items that are calculator inactive (a calculator conveys no advantage and may constitute a disadvantage), calculator neutral (can be done with or without a calculator) and calculator active (a calculator is necessary); and how should these items be grouped?

With regard to the first question, it was decided not to test calculator-specific skills. Such testing would typically involve observing individual students as they worked, and recording their key depressions and/or the contents of their calculator display screens. To do this for all students in a nationally representative sample would be prohibitively expensive. (It is more suited to a small-scale study, and might profitably be addressed in the future in classroom-based research.) Thus, the phrase 'calculator skills' as mentioned in the research requirements was interpreted as meaning skills in using a calculator for computational purposes and for solving mathematical problems.

A provisional answer to the second question is dictated by the research requirements. For the assessment of mental and written arithmetic skills, at least one section of the test should be done without the aid of calculators. For the assessment of calculator skills, at least one section of the test should be done with calculators available. However, *compulsory* use of calculators would require a high level of supervision, and again would be more appropriate in a small-scale study in which student activity could be observed. Hence, use of calculators for the sections of the test for which they were available would be left to the students' discretion.

This leads to an answer to the third question. One section of the test, in which calculator use would not be allowed, should consist of items that are either calculator inactive or calculator neutral. Another section should consist of calculator-active items and/or calculator-neutral items for which availability of a calculator, albeit not strictly necessary, might be regarded as advantageous; for this section, calculators should be available to all students.

Reference can be made again at this point to the difficulties in classifying items as calculator inactive, calculator neutral or calculator active. Instead, it may be appropriate to view items as lying on a continuum. For example, the calculation (3 × 4) / 2 can (and, in terms of the aims of mathematics education, perhaps should) be done mentally. However, it can also be done using pencil and paper or with the aid of a calculator. Strictly, therefore, it is calculator neutral, but it is close to being calculator inactive in that – for second-level students who are to any degree competent at arithmetic – there should be 'no advantage' in using a calculator. The calculation (3.1 × 24) / 2 can reasonably be done with or without a calculator (though use of a calculator for at least part of the computation might be expected to enhance both speed and accuracy); the calculation can therefore be classified as calculator neutral. The calculation (3.12 × 24.75) / 0.2052 could, if necessary, be carried out without use of a calculator, at least by students who have learned long division, but the process would be very laborious. Again, therefore, the item is technically calculator neutral, but this time it is close to being calculator active.

Moreover, one of the reasons for introducing calculators into the curriculum and examinations for mathematics is to obviate the need to carry out such calculations manually (and hence to save time[1] and divert emphasis to higher-level objectives) (DES / NCCA, 2001, p. 4). With regard to the aims of mathematics education, it is *appropriate* to use a calculator for such an item. The term 'appropriate' is particularly relevant here because in the revised Junior Certificate syllabus (DES, 2000, p. 7, 19, 29) it is specified that calculators are assumed to be available 'for appropriate use', and the issue of appropriateness is identified as being 'crucial' in the *Guidelines for Teachers* (DES / NCCA, 2002, p. 15), which complement the syllabus.

This leads to a reformulation of the emerging framework for the tests. One section (done without access to calculators) should consist of items for which use of calculators is deemed *inappropriate*. Another section (for which calculators would be provided) should consist of items for which use of a calculator is deemed *appropriate.* It remains to consider the placement of items for which the use of a calculator might be considered as *optional*: they could be tackled sensibly using either a calculator or pencil and paper. Ascertaining how students perform on such items in each case is of particular interest. Inclusion of a section consisting of items of this type would allow a cross-sectional element to be added to the test design. Half the sample would be supplied with calculators, while the other half would not, allowing the level of performance on the items in the two cases to be compared.

The final design, therefore, specified three sections to the cognitive test (see Figure 2.1):

- Calculator Inappropriate Test – calculators not available
- Calculator Optional Test – calculators available to half the cohort and not available to the other half.
- Calculator Appropriate Test – calculators available.

Figure 2.1 Summary of Tests Developed

Calculator Inappropriate Test –
No Calculator Available –
All Students

Calculator Optional Test –
No Calculator Available –
One-half of Students

Calculator Optional Test –
Calculator Available –
One-half of Students

Calculator Appropriate Test –
Calculator Available –
All Students

[1] For the rather simple sequence of keystrokes required here, many students would be sufficiently familiar with calculators to gain rather than lose time through their use.

Curricular Issues

So far, discussion has focused on issues of relevance to tests involving calculators, but has not – except in introducing the term 'appropriate' – dealt with the specific aims, objectives, content and usual forms of assessment of the Junior Certificate mathematics course. In this context, two questions need to be answered.

1. What mathematical topics and skills should be tested?
2. How should these relate to the Junior Certificate mathematics syllabus?

In addressing the first question, the research requirements provide an initial answer: they specify mental and written arithmetic, understanding of number, and data analysis; and they also specify calculator skills, defined above as meaning use of a calculator for computation and problem-solving. Since one of the main arguments for encouraging calculator use in schools is to allow students to address problems containing realistic data (DES / NCCA, 2001), topics involving such data should be covered.

It should be noted here that another main argument for encouraging calculator use is that it facilitates certain aspects of exploratory or investigational work (as referred to in Chapter 1): for example, exploring patterns, investigating functions, finding maximum and minimum values of areas and volumes, and so forth. However, this type of work has not been emphasised in the Irish school mathematics curricula, and the revised syllabus (DES / NCCA, 2000) and *Guidelines for Teachers* (DES / NCCA, 2002) do not focus on change in this respect. Test questions on these areas, therefore, would test students' familiarity (or unfamiliarity) with the basic methodology of investigational approaches rather than their skill in using the calculator as an exploratory tool. Consequently it would make sense to restrict the content and skills being tested to those that are familiar as part of the old syllabus (and from featuring in examination papers) augmented by those that are specifically being emphasised in the revised version – in particular, estimation and calculator-assisted computation. This provides an initial answer to the second question posed above.

With these general guidelines for inclusion and exclusion in mind, it remained to locate the exact content areas that should be included in the tests. A useful distinction can be made here between areas of the course that are *calculator sensitive* and those that are not. The term 'calculator sensitive' is introduced here to avoid the problems encountered above in clarifying the more usual terminology (calculator active / neutral / inactive). Topics involving numbers and numerical calculation are calculator sensitive: for test items in these areas, it is often possible (though not necessarily advantageous) to use a calculator – or at least to consider its use – in order to arrive at an answer. Topics involving deduction, or the proof of a general statement, are usually not calculator sensitive; the presence or absence of a calculator is irrelevant. To achieve the objectives outlined above, the tests could be restricted to calculator-sensitive areas of the Junior Certificate mathematics syllabus.

In the revised syllabus, eight content areas are listed for the Higher and Ordinary courses. These are:

- Sets
- Number Systems
- Applied Arithmetic and Measure
- Algebra
- Statistics
- Geometry
- Trigonometry

- Functions and graphs

For the Foundation course there are seven content areas – trigonometry is omitted (and the titles of two others being amended to reflect the different thrust of the work for this course). The content areas Number Systems, Applied Arithmetic and Measure, and Statistics (Statistics and Data Handling for the Foundation course) are primarily calculator sensitive. They are also the areas that most immediately correspond to the requirement for assessing 'understanding of number' and 'data analysis skills' as specified in the research requirements. By contrast, much of the Geometry section of the syllabus, which involves concepts and skills such as classification, deduction and proof, is not calculator sensitive. The same can be said for the topic Sets, which focuses on classification and logical reasoning. For the other topics in the syllabus – Algebra, Trigonometry and Functions and Graphs – the degree of calculator sensitivity depends on the type of calculator available. For a user of a graphics calculator, functions are calculator sensitive; to a user of a calculator with symbolic manipulation facilities, algebra is calculator sensitive; but these topics are not notably calculator sensitive for the user of a scientific or four-function calculator, the types of machine allowed in the examinations for the revised syllabus. Trigonometry constitutes a special case. Introductory work in the area typically involves much numerical computation; moreover, the availability of a scientific calculator rather than four-figure tables for obtaining trigonometric ratios was a powerful argument in favour of introducing calculators into the course and the examinations. However, Trigonometry is not included in the Foundation course, so questions on this topic would be meaningless for students following that course. Moreover, the use of a calculator to obtain trigonometric ratios is a *calculator skill* rather than a computational or problem-solving use of the machine; thus, it lies outside the chosen scope of the tests.

The situation is complicated by the fact that problems involving some numerical calculation can be set in almost any area of the course. In Algebra, for example, solution of an equation of form $ax + b = c$ (where a, b and c are numbers) requires some computation; if a (the coefficient of x) is not an integer, the final stage of the computation may be made easier by use of a calculator. In Geometry, an item may require a candidate to calculate the measure of one angle of a triangle when the measures of the other two are given. Similar examples can be given in other content areas. However, not all of these areas are enhanced or made more interesting by the use of 'realistic' data. The two areas which are perhaps most naturally enhanced in this way are ones which have already been highlighted as being calculator-sensitive: Applied Arithmetic and Measure, and Statistics. The former, in particular, has the twin advantages that many of its basic concepts figure in all three courses (and so are meaningful, albeit perhaps very difficult or, in practice, impossible, for Foundation students) and that typical problems are easily made 'realistic' and calculator appropriate. For the latter (Statistics), it might seem that the same advantages apply. In practice, however, many of the statistics questions appearing in examination papers are either calculator inappropriate (for example, compiling frequency or cumulative frequency tables) or restricted to the Higher course (for example, finding the mean of a grouped frequency distribution); the topic is also given rather little weight in the syllabus. It was decided that Statistics should also be accorded lower priority in the tests. In the revised Foundation course, statistics is coupled with a topic 'data handling' (DES / NCCA, 2000, p. 31) which might appear particularly relevant to 'data analysis' as mentioned in the research requirements. However, 'data handling' refers specifically to elementary work intended to prepare students for 'the sections [of the course] on algebra and functions' (DES / NCCA, 2002, p. 54). As it would probably be unfamiliar to all students following the old syllabus and to Higher- and Ordinary-level students following the revised syllabus, it was not targeted for inclusion.

A decision was taken initially to omit algebraic questions from the test. However, so many problems end with the solution of an algebraic equation that it was felt advisable to investigate if the presence of a calculator made any difference to the success rate in solving simple equations, and a few such questions were added to the Calculator Optional test during the pilot-testing period (described in Chapter 3).

Altogether, therefore, the following principles were used in determining the content and skills to be examined in the tests:

- Material would be restricted to that found in the Junior Certificate mathematics courses
- As far as possible, questions should be *meaningful* and their general style familiar to students following any of the three courses
- The tests would focus chiefly on the content areas of Number Systems, Applied Arithmetic and Measure, and Statistics
- The topic Applied Arithmetic and Measure would be given particular weight because of its relevance for the use of realistic data
- A few questions on Algebra, focusing on the solution of simple equations, would be included.

Testing Issues

The third category of questions relating to the design of the cognitive tests to be used in the study has to do with issues of item format, scoring, sequence, classification, and difficulty level. Thus, five questions need to be answered:

1. What item format should be used?
2. Should partial credit be given in marking the items?
3. How should items be distributed over the tests?
4. Should items be categorised by cognitive category as well as by content area?
5. How would the tests accommodate students who not only were of different abilities but also were taking quite markedly different courses (Higher, Ordinary or Foundation level)?

As regards the first question (item format), it was decided that the tests should consist mainly of short, discrete items rather than long questions or series of related questions. This would facilitate analysis of the specific skills involved. Such items can be written in one of two formats: multiple-choice or constructed-response (with the latter involving students supplying a short answer rather than choosing from among a number of options). The Junior Certificate mathematics examination papers used to contain a short multiple-choice section, but this was dropped when a slightly revised course was introduced in 1987 for first examination in 1990. However, students typically are reasonably familiar with the format, for example from taking standardised achievement tests in their primary school days; and it has the advantage of facilitating the scoring and analysis of results. Short constructed-response items are much closer in style to those customarily used in the classroom and examination papers; moreover, this format has advantages in not guiding students towards particular answers and perhaps in being more natural in cases in which, because of the complexity of the questions, it would not be easy to formulate a short list of good distractors. Hence, some items of each type would be used, with constructed-response being favoured for more complex questions and for ones in which multiple-choice options might (for example) allow the candidates to ‘work backwards’ to find the answer, rather than exercising the skill which the item was intended to test.

The use of constructed-response items leads to discussion of the second question posed above: the issue of awarding partial credit for incorrect answers. Partial credit is usual in the state examinations. Even simple parts of questions (for example, solving an equation such as $3x + 4 = 13$) are usually marked on a partial-credit basis; students are penalised minimally for, say, a minor arithmetic slip, and are given an ‘attempt mark’ (about one-third of the number of marks available for the question part) if they make a reasonably relevant but flawed attempt to provide an answer. However, the award of partial credit adds to the burden involved in marking tests, and hence to the cost of the operation. Moreover, traditional scaling procedures use dichotomous (right/wrong) scoring, though a limited partial-credit item response theory model was used in scaling the mathematical literacy test in the recent OECD Programme for International Student Assessment (PISA). However, there is some evidence that the use or otherwise of partial credit may not make a substantive difference to the properties of a test for research purposes (R. Turner, personal communication, May 2001). It is, of course, likely to affect individual students’ scores and the mean scores for the test as a whole; this needs to be borne in mind when results are being communicated. As the tests in this instance are being used for research purposes, the option of giving no partial credit was chosen.

The third question posed above referred to the distribution of items over the tests. This covers both the placement of a particular item in one of the three tests and its position within that test. Three issues arise here. The first and most immediate is that of calculator appropriateness as described above. A second issue is expected item difficulty. It was decided that the three tests as a whole should display a ‘gradient of difficulty’, allowing candidates to progress from a comparatively easy start to a challenging conclusion. Thus, items in the Calculator Inappropriate test (which would be taken by all students first) should not only be calculator inappropriate but should be easy enough to be done mentally or with a minimum of writing. Items on the Calculator Optional test (the second test), as well as being calculator optional, should in general be of intermediate difficulty level. However, some easy items should be incorporated at the beginning of and at intervals throughout each test as this would help candidates to get started and might keep them from becoming discouraged and giving up. Most items in the Calculator Appropriate test, as well as being calculator appropriate, should require some degree of problem analysis before they could be solved. The third issue to be taken into account in item distribution is item format. Within each test, it is simpler for candidates if items of like format are grouped together. Hence, in a test including both multiple-choice and constructed-response items, those in constructed-response format (the format used for more complex items) would be grouped together at the end, preserving the general ‘gradient of difficulty’.

The ‘gradient of difficulty’ over the three tests can be compared with that used typically in questions in the state examinations in mathematics. Such questions are usually divided into three sections, designated as ‘parts (a), (b) and (c)’. The three parts normally aim to test different assessment objectives specified in the syllabus. In general, part (a) of a question tests straightforward recall of facts or simple instrumental understanding (ability to execute simple procedures); part (b) tests instrumental understanding (ability to carry out routine procedures such as those required in solving an equation, for example) or relational understanding (say, interpreting a graph in such a way as to show understanding of the concepts involved); part (c) tests application (typically translation from verbal into mathematical form, selection of appropriate formulae or techniques, and interpretation of results) or higher-order objectives (see DES / NCCA, 2002, p. 92, 96ff.). Moreover, the three parts of the question are intended to be of increasing difficulty. In this respect the assessment objectives – interpreted for examination purposes – can be contrasted with the 'competency classes' used in the mathematics element of the PISA assessment of mathematical literacy (OECD, 1999, 2001). In PISA, it is emphasised that an item in the 'reproduction' class is not necessarily easier than one in the 'connections' class, though this is often the case.

The foregoing discussion raises the question of whether items for the tests should be classified not only by content (as described earlier), but also by cognitive category. Such classifications are useful in trying to ensure that tests address the full range of relevant objectives in appropriate proportions. As indicated above, the main assessment objectives used in the syllabus can be summarised as:

- Recall
- Instrumental understanding
- Relational understanding
- Application

However, a major issue arises here: the intrinsic difficulty of making such categorisations in a reliable way. For example, a simple item about money (such as 'what change do I get from a five-euro note if I buy a newspaper costing €1.30?') might be classified as testing both 'instrumental understanding' and 'application'. Since the item involves minimal 'translation' prior to its solution by the routine procedure of subtracting, it would probably be considered as chiefly testing instrumental understanding. *A fortiori*, a problem on finding the area of a rectangular garden of given dimensions might be seen as testing instrumental understanding of the 'measure' section of the syllabus rather than the (somewhat) higher-level skill of application. However, the categories vary with the prior experience of the candidate. A routine exercise for one candidate may be a hard problem for another; in particular, for a lower-achieving Foundation-level student, the 'application' element in the two examples may be far from trivial. Thus, classification using cognitive categories is not likely to be sufficiently robust for purposes of analysis.

It should be noted here that the 'application' objective in the syllabus does not refer specifically to application to 'real-life' settings, but also covers intra-mathematical application. In view of the interest in seeing if the calculator helps students deal with 'realistic' or 'quasi-realistic' data, a more appropriate classification might be in terms of 'pure' and 'applied' mathematics. Hence, the following categories were identified:

- Knowledge of mathematical facts, procedures and concepts
- Knowledge of applications to 'real-life' contexts.

An analysis of recent Junior Certificate examination papers in mathematics revealed that the cognitive category "knowledge of applications to 'real-life' contexts" constituted about one-third of tasks on the Higher-level papers (the complement – two-thirds – being 'knowledge of mathematical facts, procedures and concepts'), about a third of tasks on Ordinary-level papers, and about two-thirds of those at Foundation level. The analysis also revealed that the content areas tested in the current study (Number Systems, Applied Arithmetic and Measure, and Statistics) represent about one-third of tasks on Higher-level papers, about half of those on Ordinary-level papers, and about four-fifths of those on Foundation-level papers. Most of the applications tasks on the examination papers are in the areas of Number Systems, Applied Arithmetic and Measure, and (to a lesser extent) Statistics, reflecting the topics prioritised in the study. The two categories 'knowledge of mathematical facts, procedures and concepts' and 'knowledge of applications to "real-life" contexts' would therefore be used as guidelines to produce an appropriate balance between 'pure' and 'applied' aspects in the tests.

The fifth question raised above – the problem of coping with the wide ability range and different mathematical backgrounds of candidates who are taking differentiated mathematics courses at Junior Certificate level – has already been addressed at intervals throughout the foregoing discussion. It was deemed important that students taking the Foundation course should not find taking the tests an unduly negative experience; hence, the tests would be restricted to content areas likely to be meaningful to them (as noted under the heading of 'curricular issues'). For lower-achieving or less-confident students in general, each test would start with some easy questions, and a few easy questions would be placed at strategic intervals in order to provide encouragement. However, in order to assess some of the calculator-sensitive Higher-level material in the Junior Certificate syllabus, questions beyond the scope of some students would have to be included.

Altogether, therefore, the following principles were used in constructing the tests:

- The two categories 'knowledge of mathematical facts, procedures and concepts' and 'knowledge of applications to "real-life" contexts' would be used as guidelines to produce an appropriate balance between 'pure' and 'applied' aspects in the tests
- The tests would display an overall 'gradient of difficulty', with the Calculator Inappropriate test being devoted chiefly to questions that could be done mentally, the Calculator Optional test to questions requiring limited analysis and computation, and the Calculator Appropriate test to more complex questions
- However, each test would start with easy questions, and some easy questions would be incorporated at intervals to provide encouragement, especially to less-able students
- Both multiple-choice and short constructed-response formats would be used, with the latter being associated with the more complex questions
- In marking the tests, partial credit would not be given.

Compiling the Tests

Against this background, it remained to select or construct a pool of items from which tests for the pilot-testing and data collection phases of the study could be compiled. Items were located by looking at four types of source:

- Junior Certificate materials
- standardised tests developed in Ireland
- international tests of mathematics achievement in which Ireland had taken part
- test questions from other countries

Details of the process of item identification for the pre-pilot study are given below. The numbers of items from each source are approximate, as some items were merged or split at a later stage during the test construction process.

The Junior Certificate materials are obviously relevant to the project. Some 43 items were constructed by amending parts of questions from the 1997 Foundation-level paper and the 1998 Ordinary- and Higher-level papers. A further ten items were drawn from current Junior Certificate textbooks. A couple of highly calculator-appropriate computational items were based on questions in the draft sample assessment materials for the revised Junior Certificate course.

The most relevant Irish standardised test was the mathematics component of the *Drumcondra Attainment Test – Level VI* (Educational Research Centre, 1978). Difficulty levels on this test for the relevant population (students in Third year, second-level) are known, though somewhat dated. While the items are somewhat easy for the better Junior Certificate students, they are suitable for the weaker Ordinary- and Foundation-level candidates. Some 24 of these items were selected.

Items drawn from cross-national tests in which Ireland had participated could be used to provide linkage with performances on those tests. This would incorporate an extra element of comparison into the project. From the sets of items released into the public domain, some 14 items were drawn from IAEP II (Lapointe et al., 1992), and some 32 from TIMSS (Beaton et al., 1996). The relevant parts of the two studies had focused on slightly younger age groups than the Junior Certificate cohort (thirteen-year-olds in IAEP II, and – in Irish terms – First and Second year students in TIMSS). However, the selected items were appropriate in style and content for the less-able students in the Calculators in Mathematics study. Finally, some 20 items were purpose-written based on specifications for the PISA study.

Another type of source was material developed for use in calculator-sensitive areas of courses, or calculator projects, in English-speaking countries. Sample questions for the General Certificate of Secondary Education (GCSE) in Northern Ireland were useful because they were designed for a somewhat similar population to the Junior Certificate cohort (albeit typically one year older) and for a test with calculator and non-calculator sections. Some 15 items were selected. Finally, some 20 questions were based on test items used in calculator studies in the United States.

The items were assembled into tests using the principles devised above. Details of the number and type of items for each component of the pilot tests and the main test are given in Chapter 3. For the Calculator Appropriate test, all items selected were of the constructed-response format, reflecting the greater degree of complexity obtaining in general for this test. Thus, all the multiple-choice items were placed in tests which would be taken – by some or by all candidates – without the aid of a calculator. This obviated having to develop responses that would match specific calculator errors rather than paper-and-pencil computation errors (see Chapter 1). Also, the Calculator Appropriate test contained items predominantly of the 'applied' type (emphasising the use of the calculator with 'realistic' data), while a high proportion of those in the Calculator Inappropriate test were 'pure', emphasising basic numerical skills. Finally, and particularly for the main tests, some heed was paid to the placement of items by content area. Where appropriate, items testing a given content area were grouped together, to avoid arbitrary shifts of focus from one topic to another.

DEVELOPMENT OF THE QUESTIONNAIRES

Discussion so far has addressed the research requirements dealing with cognitive issues, and so has covered research design and test construction. To investigate variables that might be associated with student performance on the tests, background data on participating students and teachers would be required. Moreover, the brief for the study also specified that the effects of 'a comprehensive school policy on calculators and arithmetic skills' should be identified. This latter issue is relevant chiefly to Phase II of the study, but baseline data on current classroom practice with regard to calculators could be collected in Phase I. For Phase I of the study, therefore, research questions were formulated as follows:

1. What are the attitudes and beliefs about the teaching and learning of mathematics held by students and teachers?
2. What are the attitudes to calculators held by students and teachers?
3. How does performance on the Calculator tests relate to such factors as general ability, gender, pupil attitude towards calculator usage, teacher attitude and other background factors?
4. What emphasis is there in the Junior Certificate mathematics programmes on mental mathematics and estimation, routine skills and applications, non-routine applications, problem-solving, and mathematical investigation?
5. To what extent are calculators used by students for mathematics work at home and for mathematics work at school?

In order to address these issues, two short questionnaires were developed – a Teacher questionnaire and a Student questionnaire.

The Teacher Questionnaire

In line with the purposes of the study, the Teacher questionnaire was designed to address the following:

1. General background information on teachers, including gender and number of years experience teaching mathematics
2. Information and views on calculator usage in mathematics classes, including the following:
   - teachers' approval of calculator usage by students for classwork in mathematics
   - frequency with which teachers allowed calculator usage in class
   - frequency with which calculators are used in class, by mathematical content area
   - teachers' views regarding whether or not students should be allowed to use a calculator in mathematics class, for classwork in other subjects, and in the Junior Certificate examination
   - teachers' views on whether or not a calculator could be used as a tool for teaching and learning mathematics, and not simply for computational work
3. Information and views on calculator usage for homework, including the following:
   - proportion of students who own a calculator
   - teachers' approval of use of a calculator for mathematics homework
   - estimated proportion of students using a calculator for homework
   - frequency with which students might use a calculator for mathematics homework, by mathematics content area
   - teachers' views regarding whether or not students should be allowed to use a calculator for mathematics homework, and for homework in other subjects

4. Level of emphasis placed by the teachers on various aspects of school mathematics, including developing basic arithmetic and estimation skills, teaching basic mathematical procedures, developing mathematical understanding, developing mathematical application, and developing mathematical problem solving.
5. Rank ordering of areas of school mathematics from most difficult to least difficult for students
6. Teacher's policy regarding use of calculators in mathematics classes during the weeks and months prior to the Junior Certificate mathematics examination (if calculators are used in mathematics classes at all)
7. Teacher's philosophy with regard to the teaching of mathematics, focusing on the teacher's role during mathematics classes, relationships between content and process during mathematics teaching, relationship between basic skills instruction and mastery of complex mathematical ideas and skills, role of interest and motivation during mathematics classes, and whole-class vs. group work in mathematics classes (Becker & Anderson, 1998).

Student Questionnaire

The Student questionnaire was designed to access information on the following:

1. Background information including student's age, gender, and socio-economic status
2. Level of the Junior Certificate mathematics examination that the student intended sitting
3. Access to a calculator at home, and use of a calculator for homework in mathematics, business studies, science and technology
4. Frequency of calculator usage at school, and type of calculator used
5. Frequency of calculator usage at school, by subject area
6. Frequency of calculator usage during homework, by subject
7. Frequency of calculator usage in mathematics classes
8. Attitudes towards mathematics – including engagement in mathematics and preferences for different mathematics content areas
9. Attitudes towards calculators, including attitude towards calculator usage in mathematics classes, in other subjects, and in the Junior Certificate mathematics examination.

CONCLUSION

The purpose of the current chapter was to outline the framework underpinning the Calculator in Mathematics Study. The framework for the Calculator tests described the content and structure of three tests – the Calculator Inappropriate test, the Calculator Optional test, and the Calculator Appropriate test. No students would have access to calculators for the Calculator Inappropriate test, one half would have access for the Calculator Optional test, and all would have access for the Calculator Appropriate test.

In identifying and developing items for inclusion in the Calculator tests, a distinction was made between items that were deemed to be calculator sensitive (i.e., items for which access to a calculator was relevant) and those that were not. Content areas selected for inclusion in the test, because they were particularly appropriate for calculator sensitive items, were Number Systems, Applied Arithmetic and Measure, and Statistics. In addition, some Algebra items, which required students to solve equations, were included. In developing the items, a distinction was made between items that tapped aspects of ‘pure’ mathematics, and those that were based on ‘real-life’ applications. Whereas the Calculator Inappropriate test included just a few ‘real-life’ applications, and focused mainly on ability to perform mental operations in mathematics, the Calculator Appropriate test consisted mainly of ‘real-life’ applications. The Calculator tests consisted of a combination of multiple-choice and short constructed response items.

Teacher and Student questionnaires were developed in order to generate contextual information with which to interpret the performance on students on the Calculator tests. The Teacher questionnaire sought to ascertain teachers’ attitudes towards calculator usage by students in a variety of contexts, including the home, the classroom, and the Certificate examinations. In addition, the questionnaire sought information about the relative emphasis that teachers placed on various aspects of school mathematics.

The Student questionnaire sought information on students’ calculator usage at home and at school, in a range of subjects, including mathematics, and asked about students’ attitudes to mathematics in general and towards calculator usage in particular.

3 Implementation of the Study

This chapter describes the implementation of the Calculators in Mathematics study in second-level schools. The chapter is divided into five sections. The first section describes the pilot studies that were conducted to generate information about the performance of test items, and to finalise the Student and Teacher questionnaires. The second section describes the sample for the main study. The third describes the implementation of the main study. The fourth describes the scaling of the calculator tests. The final section describes the approaches taken to analysing data gathered during the main study.

THE PILOT STUDIES

Prior to implementing the main study in November 2001, a pre-pilot study was undertaken in March 2000, and a pilot study in October 2000. Both are described below.

The Pre-pilot Study – March 2000

The purpose of the pre-pilot study was to obtain some initial feedback on the performance of Third-year students on the set of items identified for possible inclusion in the current study. As indicated in Chapter 2, Calculator Inappropriate, Calculator Optional and Calculator Appropriate tests had been developed for the study.

The pre-pilot study involved 7 schools, including 2 that were designated disadvantaged. Four of the schools were in the Secondary sector, and 3 were in the Community/Comprehensive sector. Due to the timing of the study (just before Easter), there was a preponderance of students taking the Ordinary level course in the sample. Schools were generally unwilling to let students taking the Higher-level course to participate because of the time demands of their course.

A further difficulty was that schools were unable to allocate a fixed block of time (about 2 hours) for administration of the tests. Instead, tests were administered during mathematics classes. Hence, probably due to the shortness of the class periods used for testing (c. 35 minutes), there was a high level of omissions towards the end of the tests.

Since a large number of items had been prepared for the Calculator Optional and Calculator Appropriate tests, two versions of each were developed. Within each version of the Calculator Optional test, two forms were identified – one to be administered to students with access to a calculator, and the second (covering the same items) to be administered to students without access (see Table 3.1). As indicated in Chapter 2, both multiple-choice and short constructed-response items were developed.

Table 3.1 Number of Items in Pre-pilot Test Booklets, by Format

Test Booklet	Total Number of Items	Number of Multiple Choice Items	Number of Short Constructed Response Items
Calculator Inappropriate	52	30	22
Calculator Optional 1 (Forms A and B)*	33	13	20
Calculator Optional 2 (Forms A and B) *	28	12	16
Calculator Appropriate 1	38	0	38
Calculator Appropriate 2	28	0	28
Totals	179	55	124

*Form A was designated as a Calculator Available Form, and Form B as a No Calculator Form.

Notwithstanding concerns about lack of balance between the numbers of students taking the Higher- and Ordinary-level courses in the sample, the shortage of calculators in some schools (which was rectified), and the unavailability of large blocks of time for testing, much useful information was obtained from the pre-pilot study. For example, in accordance with the study design, it was confirmed that the Calculator Appropriate tests were more difficult for students than the Calculator Inappropriate test (see Table 3.2). Perhaps because the groups were not directly comparable, no obvious pattern emerged with regard to the performances of students with and without access to calculators on the Calculator Optional test.

Table 3.2 Descriptive Statistics – Pre-pilot Study (March / April 2000)

Test	No. of Items	No. of Students	Mean Score	Std. Dev.	Mean Percent Correct	Reliability (Alpha)
Calc. Inappropriate	52	123	20.92	12.41	41.02	0.95
Calc. Optional 1 (No Calc)	33	112	12.10	6.32	36.67	0.88
Calc. Optional 1 (W/ Calc)	33	75	14.24	8.16	43.15	0.93
Calc. Optional 2 (No Calc)	28	64	17.84	5.23	63.71	0.85
Calc. Optional 2 (W/ Calc)	28	103	15.76	5.98	56.29	0.88
Calculator Appropriate 1	38	90	10.93	5.50	28.76	0.87
Calculator Appropriate 2	28	100	10.52	6.05	37.57	0.90

As students had been encouraged to show their work, the 'rough work' for these items was examined by members of the project team. As a result of this qualitative analysis, it was decided to rephrase certain items, and, in some cases, to give additional information in the stems of items. It was also found that students using a calculator were less likely than others to show 'rough work', and that they would need to be explicitly directed to do so.

The Pilot Study – October 2000

Following a consideration of the outcomes of the pre-pilot study, and a revision of some of the test items, it was decided to mount a pilot study in a more representative sample of schools in October 2000. A total of 15 schools – 8 Secondary, 6 Community/Comprehensive and 1 Vocational – took part. In schools with one or two Third-year mathematics classes, all classes were invited to take part. In schools with more than two classes, two were selected at random. In all, 685 different students participated, with most completing 2 of the 7 tests. Students were asked to complete 2 rather than 3 tests, as the pilot versions of the tests included more items that students would be expected to complete in the main study. Table 3.3 shows the numbers of students at each course level who attempted the different tests. The project team was satisfied that the sample was more representative than that involved in the pre-pilot study, and that it targeted the full range of mathematics achievement among Third-year students in schools.

In the course of attempting the tests, students were directed to indicate the last item they had completed after 15, 20, 25 and 30 minutes. This was done so that estimates could be made of the time that most students would require to complete tests of various lengths. Additional relevant information was obtained by inspecting the percentages of students attempting each item on the different tests.

Table 3.3 Numbers of Pupils in Pilot Study (October, 2000) by Level of Junior Cycle Mathematics Course Studied and Tests Attempted

Test	Higher	High/Ord	Ordinary	Ord/Fndt	Foundation	Total
Calc. Inappropriate	74	19	58	26	13	190
Calc Optional 1 – Calc	74	0	18	65	13	170
Calc Optional 1 – No Calc	54	27	105	0	0	186
Calc Optional 2 – Calc	100	0	93	0	0	193
Calc Optional 2 – No Calc	72	0	63	47	0	182
Calc Appropriate 1	33	44	102	11	0	190
Calc Appropriate 2	61	0	115	15	0	191
Totals	468	90	554	164	26	1302

Item-level data from the pilot study were generally satisfactory (see Table 3.4). Mean percent correct scores were again lowest for the Calculator Appropriate tests (26.81% and 26.66% respectively for the two versions). In this study, students who took the calculator versions of the Calculator Optional tests did somewhat better than their counterparts who took the non-calculator versions of the same tests. In the case of Calculator Optional test 1, the difference between the two groups was just 3.19%, while on test 2, it was 10.45%.[1] Finally, the mean percent correct score of (all) students on the Calculator Inappropriate test was 50.1%.

Table 3.4 Descriptive Statistics – Pilot Study (October 2000)

Test	No. of Items	No. of Students	Mean Score	Std. Dev.	Mean Percent Correct	Reliability (Alpha)
Calc. Inappropriate	46	190	23.05	12.04	50.10	.95
Calc. Optional 1 (No Calc)	34	186	14.30	6.79	41.97	.89
Calc. Optional 1 (W/ Calc)	34	170	15.35	8.88	45.16	.94
Calc. Optional 2 (No Calc)	29	181	10.91	5.83	37.62	.88
Calc. Optional 2 (W/ Calc)	29	193	13.94	5.09	48.07	.84
Calculator Appropriate 1	31	190	8.31	4.80	26.81	.84
Calculator Appropriate 2	27	191	7.20	3.86	26.66	.80

Using item-level statistics from the pilot study, it was possible to identify sets of items that could be included in the main study. The process of selecting items involved re-estimating average percent correct scores for each test after particular items had been omitted, either because they were too easy or too difficult, or because too few students attempted them. In addition, the selection process took into account

[1] Caution should be exercised in interpreting these percentages as the groups were not directly comparable.

the need to assess the different mathematical content areas in the framework for the study. In the course of selecting items for the main study, the Calculator Optional tests 1 and 2 were combined to form a larger pool of items. It was decided that that two forms of the Calculator Appropriate test (each consisting of 16 items) should be developed in order to achieve broader content coverage than would be possible with one form. Moreover, since all students would have calculators for this test, one-half of the cohort would complete each form. A final consideration in deciding to develop two forms of the Calculator Appropriate test was that individual items on this test tended to take longer to complete than items on the Calculator Inappropriate test (where 25 were selected for the main study) or on the Calculator Optional test (where 32 were selected). Table 3.5 indicates the number of items in each test, by mathematics content area. Examples of the types of items included in the final version of the test are given in Appendix 3B.

Table 3.5 Numbers of Items on the Calculator Inappropriate, Calculator Optional and Calculator Appropriate Tests, by Mathematics Content Area – Main Study (November, 2001)

	Number of Items				
Test	Number	Applied Arithmetic and Measure	Algebra	Statistics	Total
Calculator Inappropriate	13	10	1	1	25
Calculator Optional	11	15	4	2	32
Calculator Appropriate*	9	17	-	6	32

*Refers to both forms combined.

In selecting items for the main study, there was also an attempt to ensure a balance between multiple-choice and short constructed-response items (Table 3.6). All items on the Calculator Appropriate test were of the short constructed-response type.

Table 3.6 Numbers of Multiple-Choice and Short Constructed-Response Items on the Calculator Inappropriate, Calculator Optional and Calculator Appropriate Tests – Main Study (November, 2001)

	Number of Items	
Test	Multiple Choice	Short Constructed Response
Calculator Inappropriate	16	9
Calculator Optional	13	19
Calculator Appropriate*	0	32

*Refers to both forms combined.

Six teachers whose classes were involved in the Pilot Study were asked to read through the Teacher questionnaire, with a view to identifying any areas of possible difficulty. These teachers expressed satisfaction with the content of the questionnaire, and with the overall length – 7 pages. A small number of second level students were asked to read through the Student questionnaire. These students expressed satisfaction with the content and length (3 pages) of the Student questionnaire.

SAMPLING FOR THE MAIN STUDY

It had been planned to conduct the main study in the Spring of 2001. However, an industrial dispute affecting some second-level schools at the time meant that difficulties might arise in implementing the study as planned. It was therefore decided to postpone the main study until the Autumn of 2001. This section describes the sampling of schools and students for the main study.

Sample Design

In drawing a sample to represent the population of Third-year students in Irish second-level schools, the principal concerns were to avoid bias, to represent each section of the relevant population, and to keep sampling error as low as possible.

A first stage of sampling involved whole schools as the sampling units. A simple random selection of schools would not have guaranteed proportionate representation of schools of different kind (type) and size – categories which are known to differ in terms of the average achievement of enrolled students. Consequently, schools were first grouped into strata which were defined by type and size.

Target Population

The target population consisted of students in Third-year in schools on the Department of Education and Science's post-primary schools database. Students in special schools or in special classes in ordinary schools were excluded. The Department of Education and Science's second-level schools database for 2000-01 provided a listing of schools, and the numbers of male and female students in the Junior Cycle programme in each school. Unfortunately, a breakdown by year level within the Junior Cycle was not available. Small schools, defined as those with fewer than 100 students enrolled at Junior Cycle level, were excluded from the database, leaving 632 schools from which to select the sample.

Stratification and Selection of Schools

Schools were stratified by type (stratum) – Secondary (large/small), Vocational (large/small) and Community/Comprehensive – and by size within stratum (see Table 3.7). Large schools were defined as those with more than 200 students at Junior Cycle level, while small schools were defined as those with 200 or fewer students. Within strata, schools were ordered by the percentage of female students enrolled in Junior Cycle classes. Therefore, student gender composition operated as an implicit stratifying variable. Within strata, schools were selected with probability proportional to size. The number of schools selected in each stratum is given in Table 3.7 in the first column under 'Selected Sample'.

Table 3.7 **Population, Selected Sample, and Achieved Sample of Schools, by Stratum – Main Study (November 2001)**

	Population*			Selected Sample*			Achieved Sample***		
Stratum	Schools	Students	p**	Schools	Students	p**	Schools	Students	p**
Secondary – Large	265	86830	50.5	45	15640	53.55	34	792	53.91
Secondary – Small	122	19031	11.07	10	1632	5.59	7	132	8.99
Vocational – Large	85	26310	15.3	14	5003	17.13	8	175	11.91
Vocational – Small	80	11482	6.68	6	858	2.94	3	60	4.08
Community/ Comprehensive	84	28306	16.46	15	6072	20.79	14	310	21.10
Total	636	171959	100.00	90	29205	100.00	66*	1469	100.00

Large: > 200 students at Junior Cycle level; Small ≤ 200 students, but at least 100 at JC level.
*Includes First-, Second- and Third-year pupils
**Proportions of students
***Includes Third-year students only

Selection of Students within Schools

A letter was sent to the principal teacher of each school in the sample in October 2001, inviting the school's participation in the study. The letter was accompanied by a 'School Form' which invited the principal teacher (or his/her nominee) to list all the Third-year classes in the school. On receipt of this form, one Third-year class was selected at random to participate in the study.

Response Rates

Of the original 90 schools invited to participate in the study, 62 indicated a willingness to participate, giving an initial response rate of 69%. Four of 6 replacement schools contacted before the deadline of October 31, 2001 also agreed to participate, giving a total of 66 schools in the study, and an overall response rate of 73%. As one of the original classes subsequently split into two, there were 67 classes in the sample.

Some schools that were unwilling to participate indicated that they were involved in other projects, and did not have time to allocate to the study. A few cited time lost during the previous school year, due to industrial relations problems. A couple of schools indicated that they would not take part because their Third-year students were not allowed to use calculators in mathematics classes or in the Junior Certificate mathematics examination.

In all, 1469 students completed the Calculator tests. Of these, 1418 students provided completed Student questionnaires. Of the 67 teachers whose classes were tested, 64 provided completed Teacher questionnaires. These were mapped to the responses of 1416 students. Hence, there were no Student questionnaire data available for 51 students who completed the Calculator Tests, and no teacher information for 53 students who completed the same tests.

Weights

Weights were computed to compensate for the somewhat unequal distribution of students in the different strata in the sample, using procedures applied in conjunction with the Third International Mathematics and Science study (TIMSS), which also involved the sampling of intact classes in schools (see Foy, 1997). First, a school weight was computed for each school in the sample by obtaining the inverse of the number of Junior Cycle students in the stratum in which the school fell over the product of the number of Junior Cycle students in the school by the number of participating schools in the stratum. Second, a class weight was computed for each participating class. This was the inverse of the number of Third-year mathematics classes in a school selected to participate in the study (1 in all but one case) over the number of Third-year classes in the school. Third, an adjustment for non-response within each class was computed. This was the inverse of the number of students present during testing over the number of students in the class. Fourth, each class weight was multiplied by the corresponding school weight and the adjustment for non-response within the class to yield an individual student weight. Finally, each student weight was multiplied by the total number of students in the achieved sample over the total number in the population so that the total number of students in the weighted sample corresponded to the number in the unweighted sample.

IMPLEMENTATION OF THE MAIN STUDY

The main study was implemented in November, 2001. When a school indicated its agreement to participate, the school principal was asked to name a co-ordinator – usually the senior mathematics teacher – to liaise with the Educational Research Centre during the study. Each school co-ordinator was sent a box containing a Test Administration Manual, test booklets, School and Teacher questionnaires, and calculators (loaned by the Junior Cycle Mathematics Support Service). It was suggested to the co-ordinators that they themselves might administer the Calculator tests, or that they might nominate a different teacher.

Testing was conducted during the two-week period, November 5-17, though a few schools administered the tests during the week of November 20-24. All schools that agreed to participate returned their materials to the Educational Research Centre by early December, 2001.

In all cases, the Calculator Inappropriate test was administered first. The time limit for this test was 30 minutes. Students did not have access to calculators. After a short break, students were administered the Calculator Optional test. The time limit for this test was 40 minutes. The calculator and non-calculator versions of the test were distributed to alternate students. Then, calculators were provided to students with the calculator version. After a short break, the Calculator Appropriate test was administered to students. The time limit for this test was 25 minutes. Test administrators were asked to distribute the two forms of this test at random within classes, first among students who had access to calculators for the Calculator Optional test, and then among the others. Additional calculators were then distributed so that all students had access to one. Following a third short break, the Student Questionnaire was distributed.

Scoring of Calculator Tests and Questionnaires

Students of mathematics at St Patrick's College, Drumcondra were recruited to score the test booklets using marking schedules developed by the project team. For short constructed-response items, markers were sometimes provided with more than one response to account for small differences that might arise if the student used/did not use a calculator. Markers were encouraged to consult with a member of the project team in relation to any response about which they were uncertain.

Questionnaires were also scored manually before data entry. A significant task, in the case of Student questionnaire, was the coding of the SES item. This required scorers to code parent occupations according to the International Socio-economic Index of Occupational Status (ISEI) (Ganzeboom, de Graaf & Treiman, 1992; Ganzeboom & Treiman, 1996). The comments of teachers on the Teacher questionnaire were written into a separate file for subsequent analysis.

SCALING THE CALCULATOR TESTS

This section describes the procedures used to scale the Calculator Tests using Item Response Theory methodology.

Implementation of Item Response Models for Scaling the Data.

Once data had been cleaned and verified they were scaled using Item Response Theory (IRT) methodology. An important advantage of using IRT is that it allows (within certain constraints) for changes to be made to tests from one administration to another while maintaining the integrity of the scale being used for reporting. Percents correct, for example, cannot be compared over two administrations if the tests are not exactly the same on both occasions. Item Response Models involve mathematical expressions that provide the probability of a correct response to an item as a function of the ability of the examinee. Many different models exist. Two item response models were utilised in this study: the logistic two-parameter model (2PL) and the logistic three-parameter model (3PL) (see Hambleton et al., 1991). The three parameters accounted for by the latter are (a) item difficulty, (b) item discrimination, and (c) the probability of a correct response due to guessing. The c parameter is not estimated when the 2PL model is used. Both models were implemented with the aid of the BILOG software program (Mislevy & Bock, 1990). Each of the three tests was scaled separately as a prior decision had been made not to report overall performance on the total set of items administered.

A modification of the 3PL model was chosen for scaling the Calculator Inappropriate test as it contained both multiple-choice (16) and short answer items (9). This modification was achieved by setting strong prior distributions on the c parameter for short answer items (see Allen, Johnson, Mislevy & Thomas, 1997; Mislevy, Johnson & Muraki, 1992; Johnson, Mislevy & Thomas, 1993). It should be noted that BILOG does not allow a true mix of models involving the 2PL and 3PL. It should also be noted that a test of the 2PL model for the total Calculator Inappropriate test was carried out but revealed a poorer fit to the data. In addition, a statistical test of the –2log likelihood of the converged solutions of the 2PL and 3PL models revealed that the difference was almost equal to the degrees of freedom and was not statistically significant. In other words, the effects of guessing could not be ignored in this case.

A 2PL IRT model was implemented with respect to the Calculator Optional test even thought this test contained both multiple-choice and short-answer items. There were three reasons for this decision. First, the Calculator Optional test had more short answer items (19 of 32). Second, a test of the 3 PL model revealed a poorer fit to the data than the 2PL model. Third, a statistical test of the –2log likelihood of the converged solutions of the 2PL and 3PL models revealed that the difference was more than three times the degrees of freedom and was highly statistically significant. This suggested that the effects of guessing could be ignored in this case, and a 2PL fitted. A 2PL IRT model was used to scale Calculator Appropriate test as all items included here were constructed response.

Use of Weights in Estimating Parameters

The literature is equivocal with respect to the use of case weights for item calibration. Mislevy and Sheehan (1987a) argue that 'the invariance property of IRT item parameters. . . . provides the theoretical justification for not using sampling weights during the item parameter estimation phase of an IRT calibration' (p. 300). Martin (personal communication, Jan. 21, 1999) would concur. However, Adams (personal communication, Aug, 17, 1999) and Hanson (personal communication, Aug 26, 1999) suggest that sampling weights should be used. Parameters with respect to the calculator data were estimated with and without sampling weights. The result was that the fit of items to the IRT model was slightly better when sampling weights were used. Hence, a decision was made to use them.

Approach to Estimating Item Difficulties and Examinee Abilities.

For the purposes of item calibration, a marginal maximum likelihood approach was implemented and responses that were originally coded as not-reached were recoded as not-administered. However, once item difficulties had been estimated by BILOG, the next stage of estimating examinee ability involved treating not-reached items as incorrect i.e. the same as items that were intentionally omitted. The justification for this approach is contained in Adams, Wu and Macaskill (1996, p. 121); Donahue et al., (1999, p. 136/137), and Ludlow and O'Leary (1999). In general, the choice among procedures available in BILOG for estimating ability scores is not critical when the number of items is reasonably large as it is here (all three tests had 25 items or more). However, the expected *a posteriori* (EAP) or Bayes estimator was chosen for the calculator data as this approach leads to smaller average errors in the population than any other estimator (Mislevy & Bock, 1990, p. 1-14).

A challenge posed for estimating parameters for the Calculator Optional test was that the conditions under which the examinees took the test differed in that only half of them used a calculator. As students were randomly assigned to the testing conditions, an approach to estimating item parameters making no distinction between students was considered – the assumption being that item parameter estimates should be stable across the two groups even if the calculator group now resembled a higher ability group due to calculator use (invariance assumption). However, on the basis of comments received from experts in the field (Kingston, Hombo personal communications) it was concluded that the use of calculators would make a difference in parameters associated with the items. Hence, item parameters estimates were based on the responses of those who took the Calculator Optional test without recourse to a calculator. These item estimates were then used to determine all examinee abilities.

Evaluating Item Fit

Another challenge when implementing IRT models is that there is no universally acceptable statistical test of fit for such models. BILOG uses a likelihood-ratio chi-square statistic (see McKinley and Mills, 1985 for a review of this and other goodness-of-fit statistics for IRT models). The likelihood chi-square is used to compare the observed frequencies of correct and incorrect responses to an item at various ability intervals (for example, 10 intervals) with those expected from the fitted model at the mean of the intervals (i.e. the expected proportion correct conditioned on proficiency versus the proportion correct predicted by the estimated item response function). It should be noted that the likelihood chi-square statistic is just a rough guide to determining the severity of model departures (Mazzeo et al., 1993; Mislevy & Stocking, 1997).

For the calculator data, chi-square values with probabilities less than .01 were flagged initially as potentially poor fitting items (the .01 level is a convention rather than a hard and fast rule). In the vast majority of cases, the model fit was very good. The items in Table 3.8 were flagged as having potentially poor fit (chi-square $p<0.01$ and/or extremely high difficulty (logit values ≥ 3)).

Table 3.8 Items Displaying Poor Fit to the IRT Models Utilised

Calculator Inappropriate	Calculator Optional	Calculator Appropriate (Booklet 1)	Calculator Appropriate (Booklet 2)
8	9	7	2
16	12	08b	5
19	16	10	7
24	19		9
	20		10
	25		14a
	28		

As recommended in the literature (e.g. Adams, Wu, & Macaskill, 1996; Kingston & Dorans, 1985; Mislevy and Stocking, 1987; Allen et al, 1997), the empirical versus theoretical item response curves for these items were compared. Good fitting items have empirical and theoretical curves close together (see, for example, Mislevy & Sheehan, 1987b, p. 369-371). Close inspection of the plots revealed that most of the items did not seem to depart substantially from the theoretical curves.

However, three items from Calculator Appropriate test (Booklet 1 #7, and Booklet 2 #5, #10) were identified as problematic in this respect. Other reasons for omitting items from the scale identified by Johnson (1988) and Donoghue, Isham and Worthington (1996) were detected in the data for these three items also, including large percentages of missing responses, lack of monotone increasing empirical item characteristic curves, and a percentage correct too low (< 0.02) to allow for stable estimates of item parameters. A decision was made by the project team to retain two of these items (Booklet 1 #7 and Booklet 2 #5) as they were deemed to be important in a curricular sense. However, it was agreed to review these items before the next administration of the test in 2004. In Booklet 2, #10 was deleted because there was an error in the text of the item and the project team was unsure about the impact of this error on the performance of the 32% of examinees who attempted the item and got it incorrect.

As an overall measure of fit, the correlations between the IRT scale scores and the proportion correct scores were calculated for each test. This resulted in Pearson *r*s of .97 for the Calculator Inappropriate test, .98 for the Calculator Optional test and .93 for Calculator Appropriate test. In conclusion, therefore, the data appear to be quite compatible with the assumed scaling models. It was agreed that any deviations from the models were unlikely to have a substantial impact on the outcomes of the study.

Transformation of Examinee Ability Estimates to Scale Scores

In BILOG, student abilities are estimated using logit scores which may be defined as the natural log odds for succeeding on items. Logits range in value from about –3 to +3 (see Hambleton et al., 1991) and do not provide a particularly good scale for reporting performance on tests. However, using a linear transformation, the logit scores for students on each test can be placed on a more meaningful scale. The scale chosen for reporting performance on each of the calculator tests has a mean of 250 and a standard deviation of 50. This scale was achieved by calculating a weighted average and standard deviation for the logits and applying the following formula: (Pupil Scale Score – 250)/50 = (Pupil Logit Score – Mean of All Logit Values)/SD of Logit Values.

ANALYSIS OF THE DATA

This section describes the main procedures used to analyse the data arising from the Calculators in Mathematics Study.

Computing Weighted Mean Scores and Percentages

In general, mean raw scores, scale (IRT) scores, percent correct scores, scores associated with selected percentile ranks, and percentages of students reported in Chapters 4-7 are weighted population estimates that take into account the unequal representation of students from different schools and school types in the sample. They were obtained by applying the adjusted student weights (described above) to students' scores during analysis.

Computing Standard Errors

Each mean and percentage in this report is accompanied by its standard error. A standard error is a measure of the extent to which an estimate derived from a sample (for example, a mean score) is likely to differ from the true (unknown) score in the population. In a complex sample, such as the one in the current study, in which student characteristics (such as performance on a test) are clustered in schools and classes, and are therefore likely to be correlated with each other, there is a danger that the amount of variance within the sample (and the population) will be underestimated, and hence, standard errors around estimates of mean scores and percentages are likely to be underestimated. Therefore, a specialised statistical package - WesVar (Westat, 2000) – was used. This employs a re-sampling technique to generate a standard error for each estimate that takes into account the complexity of the sample design.

A confidence interval for a statistic (consisting of the region two standard errors below the statistic to two standard errors above it) may be constructed so that, if the sampling procedure were repeated a large number of times, and the sample statistic recomputed on each occasion, the confidence interval would be expected to contain the population value 19 out of 20 times. For example, for a sample mean of

250, with a standard error of 2, it is possible to say, with 95% confidence, that the true population mean lies within two standard errors of the estimated mean, that is between 246 and 254 (250 ± 1.96 X 2).

Identifying Statistically Significant Differences Between Mean Scores

In the study, the approach taken to examining whether or not a difference between mean scores is statistically significant involved computing the standard error of the difference, identifying the relevant critical value (t-score) adjusted for multiple comparisons, and constructing a 95% confidence interval around the difference. If zero is outside the resulting confidence interval, it can be concluded that the difference between means is statistically significant.

The Bonferoni procedure (Dunn, 1961) was used to compute two-tailed alphas associated with the 95% confidence levels where more than one comparison between groups was being made. This involved dividing each alpha (.05) by the number of comparisons. Where two comparisons were being made, the adjusted alpha was .025 (.05/2). For three comparisons, the adjusted alpha was .017 (.05/3). The critical value (t) associated with the adjusted alpha was identified in a statistical table of such values, using 33 degrees of freedom (the number of variance strata in the current study associated with the balanced repeated replicate (BRR) method of variance estimation employed by WesVar).

The standard error of the difference was computed using the following formula:

$$SE_{diff} = \sqrt{SE_1^{\ 2} + SE_2^{\ 2}}$$

(SE_{diff} = Standard Error of the Difference)

where SE_1 and SE_2 are the standard errors of the two means to be compared.

Each 95% confidence interval was constructed by adding to and subtracting from each mean difference, the product of the corresponding standard error of the difference and the relevant adjusted critical value (t).

Where mean percent correct scores were compared, the procedure described above was also employed, except that the large-sample Normal (z) distribution was used instead of the t distribution, as this avoids the complexities involved in calculating the degrees of freedom corresponding to values of t (Agresti & Finlay, 1977, pp. 219-222).

Computing and Evaluating Effect Sizes

Effect sizes were computed for differences between pairs of mean scores using Cohen's (1988) *d* statistic. This statistic is the difference between the means, $M_1 - M_2$, divided by the pooled standard deviation, σ_{pooled} (assuming the variances of the two groups are homogeneous):

$$d = (M_1 - M_2)/\sigma_{pooled} \quad \text{where } \sigma_{pooled} = \sqrt{[(\sigma_1^2 + \sigma_2^2)/2]}$$

Cohen (1988) defined effect sizes as 'small, $d = 0.2$,' 'medium, $d = 0.5$,' and 'large, $d = 0.8$', but noted that 'there is a certain risk in offering conventional operational definitions for those terms for use in power analysis in as diverse a field of inquiry as behavioural science' (p. 25).

Computing Correlation Coefficients and Their Significance

Pearson correlations (r) were obtained using the square roots of the coefficient of determination (R^2) associated with the linear regression computed between an explanatory variable (e.g., socio-economic status) and test performance, and referring to the significance of the *t* statistic of the parameter estimate of the explanatory variable to ascertain significance. Again, WesVar was used as it provides a more conservative estimate of the t statistic, and hence, the statistical significance of the correlation reflects the clustered nature of the sample.

Conducting Factor Analyses

In order to improve the interpretation of students' responses to the attitude towards mathematics and attitude towards calculators scales reported in Chapter 5, it was decided to conduct factor analyses. First, an initial exploratory principal components analysis was conducted with each dataset to identify an initial factor solution. Then varimax rotation (which assumes that components share common variance) was applied to confirm the initial solution, and each factor was analysed separately to identify the optimal structure of that factor. Factor scores were then generated for each student using standard ordinary least squares (OLS) regression, and these were used in subsequent analyses.

CONCLUSION

Following pre-pilot and pilot studies, the main Calculators in Mathematics Study was implemented in November 2001. Ninety schools were invited to participate in the study. Sixty-six schools (including four replacement schools) agreed to do so, yielding a response rate of 69% before replacement, and 73% after replacement. Within each selected school, one Third-year class was selected at random to participate, with one exception, where two classes were selected.

The three calculator tests were administered to students by their mathematics teacher, or by a senior mathematics teacher in their school. First, all students attempted the Calculator Inappropriate test, without access to calculators. Then, one-half of students (half of each class) attempted the Calculator Optional test with access to calculators, while one half attempted the test without access. Third, all students attempted one of two forms of the Calculator Appropriate test, with access to calculators. Students then completed a short Student questionnaire that sought information about their use of calculators at home and at school, and their views on the role of calculators in mathematics. The students' mathematics teachers also completed a Teacher questionnaire.

Data were weighted to take into account the unequal representation of students from different schools and school types in the sample. The procedure for computing weights took into account the probability of a particular Third-year mathematics class in a school being included in a study, and incorporated a correction for non-response within classes.

The three calculator tests were scaled separately using Item Response Theory (IRT) methods. A modified three-parameter model was used for the Calculator Inappropriate test, while two-parameter models were used for the Calculator Optional and Calculator Appropriate tests. The mean and standard deviation of each test were set to 250 and 50 respectively.

All mean and average percent correct scores reported in Chapters 4-7 are weighted population estimates and are accompanied by their standard errors. The standard error provides a measure of the extent to which a mean score or percentage derived from a sample is likely to differ from the true (unknown) score in the population. Standard errors were computed using the WesVar statistical package in order to compensate for the clustering of students within classes and schools that could otherwise result in an underestimation of standard errors. In assessing the significance of differences between mean scores, Bonferoni's procedure was used to adjust the alpha levels for multiple comparisons and standard errors of the difference were computed. Effect sizes (based on Cohen's *d*) are also reported for differences between mean scores so that the reader can evaluate the size of such differences. Significance levels associated with correlation coefficients were also computed in WesVar, to take the clustered nature of the sample into account.

4 Performance on the Calculator Study Tests

As outlined in Chapter 3, students in the study were asked to complete three short tests: (i) a Calculator Inappropriate test; (ii) a Calculator Optional test; and (iii) a Calculator Appropriate test. Students did not have access to calculators for the first test; about one-half of students had access for the second; all students had access for the third.

In this chapter, the performance of students on each of the tests is described, first in terms of how they did on selected individual items, and then in terms of their overall performance. Following this, the performance of students on the different mathematical content areas covered by the tests is examined. The final section of the chapter consists of a qualitative examination of the written work recorded by students on their test booklets.

DESCRIBING STUDENTS' PERFORMANCE

This section provides an initial description of performance on the three calculator tests – the Calculator Inappropriate test, the Calculator Optional test, and the Calculator Appropriate test – in terms of the percentages of students responding correctly to particular items. In subsequent sections, the statistical significance of differences in the performance of students on the three tests, and on subsets of items within the tests, is examined.

The Calculator Inappropriate Test

The purpose of the Calculator Inappropriate test was to obtain insights into the performance of students without access to a calculator on a set of items that could (and perhaps should) be answered without a calculator. These items were mainly in the area of Number Systems (13) and Applied Arithmetic and Measure (10). There was one item each in the areas of Algebra and Statistics. Sixteen of the items were of the multiple choice variety, while 9 called for short constructed responses. The numbers with which students had to work in attempting these items were generally easy to manipulate. The overall percent correct score of students on this test was 60.0% (SE = 2.1%). The items on which students did best were all in the Number Systems area, and included:

- Identify the percentage corresponding to a fraction – Number Systems (93.9% correct)
- Convert a fraction to a decimal number – Number Systems (87.4%)
- Divide a positive integer by a negative integer – Number Systems (83.2%)
- Convert a percentage (e.g., 125%) to a fraction – Number Systems (76.0%)

Items that were at a moderate level of difficulty spanned the four mathematical content areas represented in the test, and included the following:

- Apply a scale to convert a distance from centimetres to kilometres – Applied Arithmetic and Measure (66.1%)
- Compute the mean of three numbers less than 15 – Statistics (63.7%)

- Find the value of a multiple of *x*, where *x* is a decimal number – Algebra (63.7%)
- Calculate the value of an expression representing a number written in expanded form (e.g., $5 \times 10^3 + 4 \times 10^2$) – Number Systems (59.9%)

Four of the most difficult items were in the area of Applied Arithmetic and Measure, while one was in the area of Number:

- Compute the percentage profit, given the cost price and selling price of a radio (expressed as single-digit amounts) – Applied Arithmetic and Measure (44.7%)
- Order a set of fraction and decimal numbers from smallest to largest – Number Systems (44.1%)
- Calculate the area of a rectangle, given the length and perimeter – Applied Arithmetic and Measure (31.5%)
- Calculate the average speed of a train, given the journey length and distance – Applied Arithmetic and Measure (29.6%)
- Identify the volume of a cylinder (expressed in terms of π), given the diameter and height – Applied Arithmetic and Measure (28.4%)

The Calculator Optional Test

The second test that students completed was a Calculator Optional test. As indicated in Chapter 2, items on this test could be attempted with or without a calculator. According to the design for the study, about one-half of students who attempted the Calculator Optional test had access to a calculator, while about one-half did not (see below). Items for this test were distributed over four content areas: Number Systems (11), Applied Arithmetic and Measure (15), Algebra (4) and Statistics (2). The average percent correct score of students who completed the Calculator Optional test with access to a calculator was 59.2 (SE = 2.90), while the average percent correct score of those who attempted the test without access was 47.4 (SE = 2.09). First, items at various points along the gradient of difficulty on which there were relatively small differences between students with and without access to a calculator are described (i.e., the differences are not statistically significant):

- Given the temperature at 9.00 a.m. on five consecutive days (each temperature expressed as a positive integer), find the mean temperature – Statistics (78.4% with calculator; 72.4% without calculator)
- Given an illustration of a rectangular picture pasted to a white paper, and the length and breadth of the paper and the picture, find the area of the paper not covered by the picture – Applied Arithmetic and Measure (59.0% with calculator; 55.7% without calculator)
- Find the sum of three numbers expressed as fractions (e.g., $\frac{2}{3} + \frac{9}{8} + \frac{1}{2}$) – Number Systems (56.7% with calculator; 57.8% without calculator)
- Given the capacity of a car fuel tank (e.g., 45 litres), and the fuel consumption for each 100 km drive, find the amount of fuel left in the tank following a journey of specified distance – Applied Arithmetic and Measure (42.8% with calculator; 38.7% without calculator)

Items on which there was a large and statistically significant difference in performance between students who had/did not have access to calculators included the following:

- Given the thickness of a stack of 400 sheets of paper (e.g., 2.8cm), find the thickness of one sheet – Applied Arithmetic and Measure (65.0% with calculator; 40.3% no calculator)
- Divide a decimal number by a decimal number (e.g., 2.056 ÷ .04) – Number Systems (58.9% with calculator; 44.8% no calculator)
- Find the product of two decimal numbers (e.g., 29.34 × 3.06) – Number Systems (88.1% with calculator; 46.5% no calculator)
- Divide a four-digit number by a two-digit number (e.g., 4845 ÷ 38) – Number Systems (88.7% with calculator; 28.0% no calculator)
- Calculate, in terms of π, the volume of fluid in a cylindrical container, given the radius and depth – Applied Arithmetic and Measure (24.5% with calculator, 10.9% no calculator)

Clearly, there appears to be an advantage to students with access to a calculator on items that involve non-trivial computation. This is especially apparent on items in which students need to multiply or divide decimal numbers, and on items requiring long division.

There was more non-response in the non-calculator condition than in the calculator condition on the Calculator Optional test. In the non-calculator condition, 43% of students attempted the last item, whereas in the calculator condition 65% of students did so.

Students without access to calculators outperformed their counterparts with access on three items on the Calculator Optional test. None of these differences reached statistical significance. The following is an example:

- Given the time each of five songs takes to sing (expressed in minutes and seconds), find the total time required to record all 5 songs on tape – Applied Arithmetic and Measure (34.4% with calc; 44.6% no calc)

The Calculator Appropriate Test

As indicated in Chapter 2, the Calculator Appropriate test consisted of items for which a calculator was assumed to be appropriate. Across the two forms of the test, which were randomly assigned to students, three content areas were assessed: Number Systems (9), Applied Arithmetic and Measure (17) and Statistics (6). All items were of the short constructed response variety. Students found items on this test to be particularly difficult, despite universal access to calculators. The average percent correct score was 32.5 (SE = 1.61). The test included some items that were answered correctly by a majority of students, and others that were answered by fewer than 10%. The following examples illustrate the range of items on the test. Where π was given in a formula, students were asked to use a given value of π (3.14159) or to use the value of π on their calculators.

- Given the cost of one can of lemonade, find how many can be bought for £5. – Applied Arithmetic and Measure (68.3%)
- Find the square root of a three-digit number to two decimal places – Number Systems (53.8%)
- Given the cash price for a music system, the initial down payment (expressed as a percent of the cash price), and the cost of 12 equal instalments, calculate by how much the Hire Purchase Cost is greater than the cash price – Applied Arithmetic and Measure (43.5%)

- Given the formula for calculating the circumference of a circle, find the circumference of a coin with given diameter (answer to two decimal places) – Applied Arithmetic and Measure (34.0%)
- Given the formula for the volume of a cylinder, the radius and the height, find the volume in cm^3 (correct to two decimal places) – Applied Arithmetic and Measure (26.5%)
- Read a graph and calculate the percentage decrease in sales of audiotapes between two given years – Applied Arithmetic and Measure (8.3%)

There was some non-response towards the end of the Calculator Appropriate test. For example, just 54% of students attempted the last item on Form A of this test.

OVERALL PERFORMANCE ON THE CALCULATOR STUDY TESTS

As outlined in Chapter 3, the three tests were scaled separately using Item Response Theory methods, and the mean score and standard deviation for each was set at 250 and 50 respectively. In this section, all scores are scale scores unless otherwise stated. Means, standard deviations, and standard errors for the tests are given in Table 4.1.

Table 4.1 Mean Scores, Standard Deviations and Standard Errors on the Calculator Inappropriate, Calculator Optional and Calculator Appropriate Tests

Test	N	Mean	Standard Dev.	Standard Error[1]
Calculator Inappropriate	1456	250.0	50.0	4.45
Calculator Optional	1463	250.0	50.0	3.89
Calculator Appropriate	1454	250.0	50.0	4.45

Table 4.2 gives the scores of students at key markers on the Calculator Appropriate, Calculator Optional and Calculator Inappropriate tests. Again, no distinction is made here between the scores of students who had or did not have access to calculators while attempting Calculator Optional test. Scores can be used as baseline data when the Calculator Study is replicated at the end of 2004.

[1] Mean scores reported in this report are estimates, and are subject to sampling error. The standard error can be used to identify the interval in which the actual ('true') score lies with 95% probability. To identify this interval, 1.96 times the standard error should be added to and subtracted from the estimated mean score. In the table, we are 95% confident that the mean score for students on the Calculator Inappropriate test is in the range 241.28-258.72. The standard error is important if one wishes to compare the significance of differences between mean scores.

Table 4.2 **Scale Scores (Standard Errors) at the 10th, 25th, 50th, 75th and 90th Percentiles on the Calculator Inappropriate, Calculator Optional and Calculator Appropriate Tests**

Percentile Rank	Calculator Inappropriate	Calculator Optional	Calculator Appropriate
10th	178.5 (5.79)	182.9 (5.4)	175.6 (5.13)
25th	220.0 (5.34)	217.3 (3.14)	216.7 (6.84)
50th	256.9 (9.36)	255.2 (6.79)	252.5 (4.86)
75th	277.2 (3.89)	279.4 (7.19)	281.6 (3.85)
90th	318.8 (4.38)	312.3 (4.04)	314.4 (6.42)

Performance on the Calculator Optional Test, With and Without Access to Calculators

This section addresses differences in performance on the Calculator Optional Test between students who did/did not have access to a calculator.

It is established that the two groups of students taking the Calculator Optional test were of equal overall ability in mathematics. It will be recalled that students were assigned at random to either the calculator or no calculator conditions (see Chapter 3). Students who had access to a calculator for the Calculator Optional test achieved a mean score on the Calculator Inappropriate test of 249.5 (Weighted N = 731; SD = 39.23, SE = 4.25), while students who did not have access to a calculator for the Calculator Optional test achieved a mean score on the Calculator Inappropriate test of 250.4 (Weighted N = 732, SD = 50.79, SE = 4.84). Students who had access to a calculator for the Calculator Optional test achieved a mean score on the Calculator Appropriate test of 250.5 (Weighted N = 731, SD = 50.32; SE = 4.49) while those who did not have access to a calculator for the Calculator Optional test achieved a mean score on the Calculator Appropriate test of 249.5 (Weighted N = 732, SD = 47.71, SE = 4.62). The very small differences between the mean scores of students on the Calculator Inappropriate and Calculator Appropriate tests who had/did not have access to calculators for the Calculator Optional test indicates that the two groups were similar in terms of overall performance in mathematics.

The difference in overall achievement between students with and without access to a calculator on the Calculator Optional test is 25.7 scale points (Table 4.3). This difference is statistically significant (Standard Error of the Difference = 1.88; 95% Confidence Interval: 21.8 to 29.5). The effect size (Cohen's *d*) is .53, which can be considered to be in the medium range (Cohen, 1988).

Table 4.3 **Mean Scores, Standard Deviations and Standard Errors on the Calculator Optional Test, by Access to Calculator**

Calculator Optional Test	N*	Mean	Standard Dev.	Standard Error
With Calculator	731	262.9	47.52	4.09
Without Calculator	732	237.2	49.14	4.78

*Weighted.

Table 4.4 gives the scores at the 10th, 25th, 50th, 75th and 90th percentiles on the Calculator Optional Test for two groups – students who had access to a calculator during the test, and students who did not have access.

Table 4.4 **Scale Scores (Standard Errors) at the 10th, 25th, 50th, 75th and 90th Percentiles on the Calculator Optional Test for Students with/without Access to a Calculator during the Test**

Percentile Rank	Calculator Optional – Access to Calculator	Calculator Optional – No Access to Calculator
10^{th}	208.4 (7.20)	174.9 (4.82)
25^{th}	222.5 (4.52)	222.5 (4.52)
50^{th}	263.7 (1.78)	232.9 (7.43)
75^{th}	298.6 (7.28)	268.2 (4.25)
90^{th}	323.5 (7.48)	312.3 (4.04)

When the scores of students at the 10th, 25th, 50th, 75th and 90th percentile ranks were compared across the calculator access/no access conditions, it was found that the difference in performance between students at the 90th percentile with and without access to calculators (16.04 points) was statistically significant (Table 4.5). Significant differences were observed between those with and without access to calculators at the 10th, 25th, 50th and 75th percentiles. It appears that higher-achieving students (those scoring at the 90^{th} percentile) may not benefit from access to a calculator when attempting the Calculator Optional items to the same extent as students with lower levels of performance.

Table 4.5 **Comparisons of Mean Score Differences at the 10th, 25th, 50th, 75th and 90th Percentiles on the Calculator Optional Test, by Calculator Availability**

Comparison (Access to Calculator – No Access) / Percentile Rank	Scale Score Difference	SE Diff	95% Confidence Interval*
10^{th}	33.5	8.29	**16.7 to 50.4**
25^{th}	18.1	5.18	**7.57 to 28.66**
50^{th}	30.9	6.55	**17.5 to 44.2**
75^{th}	30.4	3.27	**23.8 to 37.1**
90^{th}	16.04	7.84	**0.09 to 32.0**

*Confidence Intervals associated with statistically significant differences are indicated in bold.

PERFORMANCE ON MATHEMATICS CONTENT AREAS

Consideration is given in this section to the performance of students on different mathematics content areas on the Calculator Inappropriate, Calculator Optional and Calculator Appropriate tests. As indicated in Chapter 2, each item was categorised by two raters according to the mathematics content area it addressed – Number Systems, Applied Arithmetic and Measure, Algebra, and Statistics. An item-by-item breakdown of the three tests by content area is given in Appendix 3a (Tables A3.1 to A3.3).

Content on the Calculator Inappropriate Test

Average percent correct scores on subsets of items on the Calculator Inappropriate test ranged from 53.1% (Applied Arithmetic and Measure) to 67.6% (Statistics) (Table 4.6). It should be noted, however, that there was just one item each in Algebra and Statistics, so, for these areas, the data represent item statistics.

Table 4.6 **Percent Correct Scores on Mathematics Content Areas – Calculator Inappropriate Test**

Content Area	N of Items	N of Students*	Mean Percent Correct	Std. Dev.	Std. Error
Number Systems	13	1453	64.5	23.81	2.09
Applied Arithmetic and Measure	10	1453	53.1	25.87	2.14
Algebra	1	1453	63.7	48.11	3.10
Statistics	1	1453	67.6	46.82	4.80
Total	25	1453	60.0	24.02	2.10

*Weighted; Students with imputed scale scores on the Calculator Inappropriate Test are not included.

Content on the Calculator Optional Test

Table 4.7 provides a breakdown of the performance of students on the Calculator Optional test by content category, while Tables 4.8 (calculator available) and 4.9 (calculator not available) report on the performance of students in each content area on the same test, by calculator access.

Table 4.7 **Percent Correct Scores on Mathematics Content Areas on the Calculator Optional Test – All Students**

Content Area	N of Items	N of Students*	Mean Percent Correct	Std. Dev.	Std. Error
Number Systems	11	1453	63.7	22.7	1.50
Applied Arithmetic and Measure	15	1453	49.0	23.1	1.87
Algebra	4	1453	44.6	33.7	2.79
Statistics	2	1453	51.8	33.9	2.38
Total	32	1453	53.3	21.5	1.86

*Weighted; Students with imputed scale scores on the Calculator Optional Test (N = 16) are not included

The largest difference between the two groups is found in the area of Number Systems (20.9 percent points) (Table 4.10). Indeed, this was the only content area on which there was a significant difference between students with and without access to calculators. Although students with a calculator did somewhat better than their counterparts without a calculator on items in Applied Arithmetic and Measure, the difference between the two groups did not reach statistical significance. This suggests that access to calculators did not 'release' students from basic computation to the extent that they could focus attention on the problem solving required for some of these items. Against this, however, it should be noted that some students with access to calculators may not have been particularly skilled in using them (given that they may not have received instruction in their use in mathematics), and hence may not have derived maximum benefit from their availability, except in Number Systems.

Table 4.8 **Percent Correct Scores on Mathematics Content Areas on the Calculator Optional Test – Calculators Available**

Content Area	N of Items	N of Students*	Mean Percent Correct	Std. Dev.	Std. Error
Number Systems	11	731	74.1	16.8	1.51
Applied Arithmetic and Measure	15	731	52.4	23.5	3.65
Algebra	4	731	45.6	33.4	5.88
Statistics	2	731	55.5	34.7	4.50
Total	32	731	59.2	20.0	2.90

*Weighted; Students with imputed scale scores on the Calculator Optional test (N = 8) are not included.

Table 4.9 **Percent Correct Scores on Mathematics Content Areas in the Calculator Optional Test – No Calculators Available**

Content Area	N of Items	N of Students*	Mean Percent Correct	Std. Dev.	Std. Error
Number Systems	11	722	53.2	23.0	2.05
Applied Arithmetic and Measure	15	722	45.6	22.2	1.91
Algebra	4	722	43.6	34.0	3.12
Statistics	2	722	48.0	32.7	2.64
Total	32	722	47.4	21.4	2.09

*Weighted; Students with imputed scale scores on the Calculator Optional test (N = 8) are not included.

The finding that students did not benefit from access to a calculator on the four Algebra items can also be interpreted from at least two points of view. First, it may be that solving Algebra problems (e.g., solving an equation such as $5x - 1 = 18$, or finding the value of $4x + 7y$, where the values for x and y are given) does not benefit from calculator access. Second, it may be that students are not able to derive maximum benefit from access to a calculator because of lack of practice in using calculators to carry out computations and solve problems in Algebra and in other areas.

Table 4.10 **Comparisons of Mean Percent Score Differences on Mathematical Content Areas – Calculator Optional Test, by Calculator Access**

Comparison (Access/No Access during Testing)	Difference	SE Diff	95% Confidence Interval*	Effect Size (d)
Number Systems	20.9	2.55	**14.2 to 27.6**	1.04
Applied Arithmetic and Measure	6.8	4.12	-4.1 to 17.7	0.38
Algebra	2.0	6.66	-15.6 to 19.6	0.06
Statistics	7.5	5.22	-6.3 to 21.3	0.22

*Confidence Intervals associated with significant differences are indicated in bold.

Table 4.11 provides descriptions of items on the Calculator Optional test on which the difference between the percentages of students with and without access to a calculator was statistically significant (see also Table A4.11, Appendix 4). As indicated earlier, most of the items on which students with access to calculators outperformed their counterparts without access were in Number Systems. On Item 2, for example, there was a difference of 14.1% between students with/without access to a calculator (Table 4.11). The item required students to divide a decimal number by a decimal number. The largest difference between the two groups occurred on Item 18 (dividing a four-digit number by a two-digit number). On this item, a difference of 61.9% was observed between those with and without a calculator.

Substantive differences were also observed on a few items in the Applied Arithmetic and Measure area. However, when the content of these items is considered, it is clear that they also call for computation, which may involve decimals and percentages. On Item 21, for example, where the difference in mean percent correct scores between students with and without access to calculators was 16.8%, students were asked to calculate VAT on the price of a laptop computer.

It is not possible to say, without further analysis, if wrong answers resulted from computational slips or inappropriate problem analysis.

Table 4.11 Descriptions of Items on the Calculator Optional Test with Substantive Differences in Average Percent Correct Scores between Students with/without Access to Calculators

Item	Content Area	Content	Percent Correct (SE) –Calc.	Percent Correct (SE) – No Calc.
2	Number Systems	Divide a decimal number by a decimal number (e.g., 2.056 ÷ .04)	58.9 (2.68)	44.8 (2.85)
6	Applied Arithmetic and Measure	Subtract two decimal numbers set in a real-life problem (e.g., 71.50 – 49.55)	95.0 (0.91)	87.1 (1.66)
12	Applied Arithmetic and Measure	Given the thickness of a stack of 400 sheets of paper (e.g., 2.8cm), find the thickness of one sheet	65.0 (2.82)	40.3 (2.55)
14	Number Systems	Find the sum of three decimal numbers (e.g., 145.3 + 0.08 + 24.7)	93.6 (1.08)	79.1 (2.38)
15	Number Systems	Find the product of two decimal numbers (e.g., 9.5 × 2.6)	93.7 (1.86)	64.1 (2.73)
16	Number Systems	Identify the missing number in a subtraction problem (e.g., 2005 – x = 180).	85.0 (1.55)	74.7 (2.34)
17	Number Systems	Find the product of two decimal numbers (e.g., 29.34 × 3.06)	88.1 (1.05)	46.5 (3.02)
18	Number Systems	Divide a four-digit number by a two-digit number (e.g., 4845 ÷ 38)	89.9 (1.64)	28.0 (2.36)
19	Number Systems	Find the value of an expression (e.g., (3.9 + 4.5) × 7)	82.9 (1.69)	69.3 (3.23)
21	Applied Arithmetic and Measure	Compute VAT on the price of a laptop computer	57.0 (2.75)	40.2 (3.67)
27	Number Systems	Find the value of an expression (e.g., 4.5 + (3.9 × 8))	80.6 (2.12)	48.6 (3.13)
28	Number Systems	Evaluate an expression (e.g., $1/\sqrt{0.25} + (.5)^2$)	10.4 (2.00)	2.18 (0.62)
30	Applied Arithmetic and Measure	Find the average speed of a bus journey in km/hour, given the distance covered in 3.5 hours.	30.8 (2.48)	16.6 (2.33)
32	Applied Arithmetic and Measure	Calculate, in terms of π, the volume of fluid in a cylindrical container, given the radius and depth.	24.5 (3.02)	10.9 (2.13)

See Table A4.11 (Appendix 4), for details of comparisons.

Content on the Calculator Appropriate Test

Finally, Table 4.12 provides the mean percent correct scores of students on the Calculator Appropriate test. In computing these percentages, the scores of students taking the two forms of the test were combined. One item, which had been omitted from the scaling of the Calculator Appropriate test (see Chapter 3), was also omitted in computing the percent correct scores reported here. Mean percent correct scores ranged from 30.8 (Number Systems) to 36.9 (Statistics). Clearly, these mean scores indicate the greater difficulty of the Calculator Appropriate test relative to the Calculator Inappropriate and Calculator Optional tests. However, rather than being uniformly difficult, it appears that the difficulty of the Calculator Appropriate test can be attributed to the inclusion of a few very difficult items, including the following:

- Simplify and write a numeric expression in standard form [(e.g., $(9.7 \times 10^{-3}) + (1.8 \times 10^{-2})$] (0.64% correct)
- Calculate compound interest on a sum of money over two years (10.3%)
- Find the cost of electricity (VAT included) between meter readings (10.6%)

- Find the radius of a wheel, given the circumference and the value of π (8.3%)

Table 4.12 **Percent Correct Scores on Mathematics Content Areas – Calculator Appropriate Test**

Content Area	N of Items	N of Students*	Mean Percent Correct	Std. Dev.	Std. Error
Number	9 (4+5)	1454	30.8	22.4	1.64
Applied Arithmetic and Measure	16 (8+8)	1454	31.7	20.5	1.63
Algebra	0	---	---	---	---
Statistics	6 (3+3)	1454	36.9	32.1	1.99
Total	31 (15+16)	1454	32.5	18.7	1.61

*Weighted

INVESTIGATION OF STUDENTS' WORK

It was pointed out in Chapter 2 that the items in the Calculator Inappropriate test were intended to be done mentally or with only a small amount of written work. Students were instructed that they could work out the answers in their heads or with pen and paper, and a 'work column' was provided on each page so that they could record calculations if they wished to do so. By contrast, most of the items in the other two tests were unlikely to be done successfully by mental methods alone. For these tests, the rubric at the beginning indicated that work should be shown, and the instruction 'Show your work' was repeated on each page, at the head of the 'work column'.

The extent and type of use made of the 'work columns' is one source of evidence as to how the students tackled the test questions. However, teachers are familiar with the fact that in cases in which students do not actually need to present intermediate calculations in order to arrive at a result, instructions such as 'show your work' are often ignored. Moreover, for multiple choice items, there has been no tradition of students benefiting from displaying work. Thus, the evidence is incomplete. It should be noted that in the revised Junior Cycle syllabus, additional emphasis is being given to students' ability to *communicate* their reasoning. The examination papers specify clearly when intermediate written work is required (and hence when its absence will be penalised) (DES / NCCA, 2002). Thus, some different patterns of use of the 'work column' might be expected in Phase II of this study.

Constraints of time and money prevented inspection of all the test papers in order to analyse the extent to which students showed their calculations and to determine what kind of calculations were represented. However, a study was undertaken using a small selection of the scripts.[2] For each of the four test forms (the Calculator Inappropriate test, the Calculator Optional test and the two forms of the Calculator Appropriate test), a judgment sample of fifty scripts was drawn. In each case, 25 of the scripts were presented by males and 25 by females; different school types and geographical locations were suitably represented. Findings for the different tests are discussed in turn.

Students' Work on the Calculator Inappropriate test

For the Calculator Inappropriate test, since each of the 50 scripts contained 25 questions, there was a total of 1250 questions altogether. The response rate was very

[2] The study was undertaken by Edel Connolly, a secondary teacher of mathematics, as part of her work for the degree of Master in Education at Trinity College Dublin.

high; all female students attempted all the questions, while male students omitted just 2% of items (i.e., no work was shown and no answer was provided). Approximately 47% of the answers (55% of the females' answers and 40% of the males' answers) were accompanied by some form of pen-and-paper calculation. Only one question did not warrant any written calculation by any of the 50 students; for this question, which was presented in multiple-choice format, a number with four places of decimals had to be rounded to two decimal places.

Of particular interest are the answers to the three questions which tested estimation rather than exact computation. The first two of these were multiple-choice questions. Many of the students – 24 females and 20 males for the first question and 25 females and 22 males for the second – had recourse to pen and paper. For both questions, several students calculated the exact answer (or what they believed to be the exact answer) and wrote it in and/or stated that the correct answer was not given, instead of identifying the best estimate. The third question, of constructed-response format, dealt with the sum of several quantities of time which were presented in hours and minutes (e.g., 1 hour, 35 minutes). In this case, only 8 of the females showed work whereas 22 of the males did so. However, attempts to examine the students' ability to estimate were confounded by their tendency to write hours and minutes in decimal format and then treat them as decimal numbers (so that, for example, 1 hour 35 minutes would become 1.35 hours – rounding down to one hour instead of rounding up to two hours, correct to the nearest hour).

Students' Work on the Calculator Optional test

For the Calculator Optional test, there were 32 questions, giving rise to 1600 possible answers from the 50 scripts sampled. The sample was chosen in such a way that 13 males and 13 females had access to calculators whereas 12 males and 12 females did not. Of chief interest in this case is the different extent to which the two groups – those with calculator access and those without – used the 'work column'. For those with calculator access, 23% of the answers of females and 26% of the ' answers of males were accompanied by written work; for those without, the figures rose to 70% for the females and 77% for the males. One male with access to a calculator answered all questions without using the 'work column'; one female with access to a calculator showed work for only one question.

A possible point of interest is the extent to which students with access to calculators chose to use pen and paper, either in preference to the calculator, in conjunction with it (to record intermediate answers), or in order to check answers after calculator use. Without observing the students as they took the test, or asking them to report on their use of the calculator, it is not possible to say if written work was done in addition to or instead of calculator use. However, some indication of reliance on written methods can be gained by looking for

- questions for which students without access to a calculator showed different response patterns with regard to written work
- questions for which the response patterns for the two groups were similar.

The first question on the paper, involving the addition of three fractions, provides an example of the latter case. It might be conjectured that students with calculator access were not familiar with (or did not have) a fraction button on their calculators. In fact, some students converted the fractions to decimals before adding. By contrast, for the second question on the paper – involving computation with decimals – fewer students with access to calculators than those without access showed written work. This may indicate that students with access to a calculator were more comfortable with using their machines for decimal calculations than for calculations involving fractions. The same pattern emerged for other simple decimal computations. However, in another decimal calculation – a much more complicated one involving division and exponentiation (including a square root) – the number of students with access to a calculator showing written work was nearly as high as for students without access: 13 compared with 16. Again, the sophisticated calculator use required for such a question may be beyond the students. Alternatively, they may have wisely decided to record partial answers as they progressed.

Students' Work on the Calculator Appropriate Test

On the Calculator Appropriate test, each of the two forms contained 16 questions, including, on each form, one 'long question' which was divided into three parts. In this small study, the three parts were treated together, reducing the number of 'questions' to 14 in each case. With 50 scripts being selected for each form of the test, there was a total of 1400 questions available for analysis. In this case, a mere 2% of these showed written work. One female answered all 14 questions without apparent recourse to pen and paper. However, in considering the paucity of responses accompanied by written work, the high rate of omitted questions must also be taken into account. Some 25% of the questions were omitted (no work was shown and no answer provided).

In conclusion, it can be said that students in the sample were more inclined to use pen-and-paper methods for calculator inappropriate questions (which might have been done mentally), and less inclined to use such methods for calculator appropriate questions (to record intermediate or partial results), than might be wished. In the former case, it is possible that the students completed some questions mentally but then checked their answer using pen and paper – a very reasonable strategy in an examination. However, it is also possible that the students were better at routine calculations than at the more intuitive skills that can be associated with mental computation. As regards the Calculator Appropriate test questions, the cohort of students tested in Phase I of the study – students following the 'old' Junior Certificate course – are perhaps unlikely to have received instruction in sensible calculator use and in the recording of intermediate working as recommended in the *Calculator Guidelines* booklet (DES / NCCA, 2001). The size and composition of the judgment samples in the small study reported here are such as to obviate generalising to the entire sample for Phase I of the study. However, it is to be hoped that a larger study can be undertaken as part of Phase II of the study. In that case, it may be possible to establish if more suitable modes of work – giving emphasis to mental and written work where suggested by the revised Junior Certificate course – have been developed.

CONCLUSION

One of the purposes of the current study was to generate baseline data on the performance of Third-year students on tests consisting of Calculator Inappropriate, Calculator Optional and Calculator Appropriate items. This was accomplished by administering such tests to a representative sample of students in Third-year, and scaling their scores on each test to a mean of 250 and a standard deviation of 50. The Junior Cycle mathematics syllabus followed by the cohort of Third-year students who completed the tests did not include instruction in calculator usage (though some teachers may have provided such instruction), nor did students in the study expect to have access to calculators at the Junior Certificate mathematics examination.

The study design also allowed for a comparison of the performance of students with and without access to calculators on the Calculator Optional test. Students with access to calculators achieved a mean score that was statistically significantly higher than that of students without access (by 25.7 scale score points). The effect size associated with this difference is in the small to medium range. More-able students (those achieving at the 90th percentile) did not appear to benefit from access to a calculator to the same extent as their less-able counterparts. The greatest differences between students with and without calculators on the Calculator Optional test occurred for items in the Number Systems content area. In particular, those with access to a calculator benefited most on items that included square roots, decimal numbers and long division. Differences were also observed on some items in the Applied Arithmetic and Measure area, including real-life problems requiring students to subtract decimal numbers and find the volume of a cylinder. It is, of course, possible that differences between students with and without calculators on the test will increase in the future as students become more proficient in the use of calculators.

In line with the test design, the mean percentage of items answered correctly by students on the Calculator Appropriate test was quite low (32.5%) in comparison with the Calculator Inappropriate (60.0%) and Calculator Optional (53.3%) tests. This seems to have arisen from the presence of a few very difficult items, which were included in the test because they were deemed to be important for students at this level in terms of curricular validity. They included items dealing with calculating compound interest, calculating VAT, and manipulating numbers expressed in standard form.

Finally, an analysis of the written work completed by a small sample of students taking the three calculator tests indicated that these students were more likely to show their work when they did not have access to a calculator than when they had access. In particular, relatively few of the students taking the Calculator Appropriate test, where calculator access was universal, recorded any work in the column that was provided for this purpose on their test booklets.

5 Students and Calculators

In this chapter, student-level variables that may be associated with performance on the Calculator Inappropriate, Calculator Optional and Calculator Appropriate tests are examined.

VARIABLES ASSOCIATED WITH ACHIEVEMENT IN MATHEMATICS

In this section, two student-level variables associated with performance on the calculator tests – gender and socio-economic status – are considered.

Gender

The scores of male and female students on the three tests administered in conjunction with the study are examined. In addition, in the case of the Calculator Optional test, interactions between gender and calculator availability are examined. The sample consisted of 54.0% female students, 41.7% male, and 4.3% missing.

On the Calculator Inappropriate test, male students achieved a mean score of 255.5, while female students achieved a mean score of 245.0 (Table 5.1). The 10.5 points difference in favour of male students was not statistically significant (Table 5.2). On the Calculator Optional Test, male students (M= 252.5) outperformed female students (M = 247.1) by a somewhat smaller margin. Again, the difference was not statistically significant. On the Calculator Appropriate test, female students (M = 251.0) outperformed male students (M = 247.4). This difference was too small to reach statistical significance.

Table 5.1 Mean Scores of Male and Female Students on Calculator Inappropriate, Calculator Optional, and Calculator Appropriate Tests

Test	Female	Male	Missing
Calculator Inappropriate	245.0 *(5.89)*	255.5 *(5.24)*	259.43 *(7.47)*
Calculator Optional	247.1 (5.61)	252.5 (5.45)	262.2 (11.0)
Calculator Appropriate	251.0 *(5.53)*	247.4 *(5.99)*	262.68 *(9.06)*

Table 5.2 Summary of Comparisons of Mean Score Differences between Male and Female Students, Standard Errors of the Difference, and 95% Confidence Intervals

Test	Difference (Females – Males)	SE Diff	95% Confidence Interval*
Calculator Inappropriate	−10.5	7.88	−30.4 to 9.4
Calculator Optional	-5.4	6.40	−7.95 to 18.45
Calculator Appropriate	3.7	8.15	−16.9 to 24.2

*Confidence intervals associated with significant differences are indicated in bold.

Effect sizes were computed for each comparison. The effect sizes for the Calculator Inappropriate, Calculator Optional, and Calculator Appropriate tests were –0.21, –0.08 and 0.07 respectively. These can be considered small (Cohen, 1988).

A regression analysis was conducted in order to ascertain if there was a statistically significant interaction between gender and calculator availability on the Calculator Optional test. The interaction was not statistically significant (F = 0.827, df

= 1, 33, p = 0.370). Effect sizes for the differences between females and males on the Calculator Optional test for the calculator available and calculator not available conditions were small: –0.06 and –0.11 respectively.

Socio-Economic Status

An item on the Student questionnaire asked students to indicate the employment of their mother/female guardian and father/male guardian. Their responses were coded using using the International Socio-economic Index of Occupational Status (ISEI), which rates occupations along a scale ranging from 0 to 90, and may be viewed as continuous (Ganzeboom, de Graaf & Treiman, 1992; Ganzeboom & Treiman, 1996). For the analysis reported here, a measure of combined parental socio-economic status was obtained by identifying and coding the higher level of SES of the student's mother or father. The distribution of SES scores was then divided into the top (high), middle (medium) and bottom (low) thirds. Table 5.3 shows the mean scores of students in the top, middle and bottom thirds of the distribution of SES scores on the Calculator Inappropriate, Calculator Optional and Calculator Appropriate tests. Performance on the tests increases as socio-economic status increases.

Table 5.3 Students' Mean Scores on the Calculator Inappropriate, Calculator Optional, and Calculator Appropriate Tests, by Socio-Economic Status

Test	High	Medium	Low	Missing
Calculator Inappropriate	263.0 (5.45)	252.2 (4.73)	236.6 (5.03)	248.2 (6.77)
Calculator Optional	260.4 (5.86)	252.8 (4.71)	236.5 (5.21)	253.5 (7.26)
Calculator Appropriate	260.0 (5.61)	253.9 (5.13)	236.7 (5.27)	250.3 (8.01)

An analysis of the differences between high- and medium-SES students, and between medium- and low-SES students on Calculator Inappropriate, Calculator Optional and Calculator Appropriate tests is given in Table 5.4. None of the differences is statistically significant. However, differences in achievement between students in the high and low SES groups are significant for each of the tests, with effect sizes ranging from .34 (Calculator Optional) to .53 (Calculator Inappropriate).

Table 5.4 Comparisons of Mean Score Differences on the Calculator Inappropriate, Calculator Optional, and Calculator Appropriate Tests, by Socio-Economic Status (SES)

Test/Comparison	Difference	SE Diff	95% Confidence Interval*	Effect Size
Calculator Inappropriate				
High – Medium	10.9	7.22	–7.3 to 29.1	0.23
Low – Medium	–15.5	6.90	–32.9 to 1.9	-0.31
High – Low	26.4	7.41	**7.7 to 45.1**	0.53
Calculator Optional				
High – Medium	7.6	4.97	2.5 to 17.7	.11
Low – Medium	-16.3	3.97	-24.4 to -8.2	-0.24
High – Low	39.9	6.62	**10.5 to 37.4**	0.34
Calculator Appropriate				
High – Medium	6.1	7.60	–13.0 to 25.3	0.12
Low – Medium	–17.2	7.36	–27.6 to 20.4	-0.35
High – Low	23.3	7.70	**3.9 to 42.7**	0.48

*Confidence Intervals associated with significant differences are indicated in bold.

Pearson correlation coefficients between socio-economic status and achievement on the Calculator Inappropriate, Calculator Optional, and Calculator Appropriate tests are given in Table 5.5. *t* values are derived from regression of each test on SES, where *t* was computed by dividing β (the slope of the least-squares line) by its standard error. If *t* is significant, it can be inferred that the correlation coefficient, *r*, is significantly different from zero. The correlation coefficients for the Calculator Inappropriate and Calculator Appropriate tests are broadly similar to that reported for the association between higher parents' SES (using the same measure as in the current study) and mathematical literacy for Irish students in the PISA 2000 study (i.e. .238, Shiel et al., 2001, p. 90).

Table 5.5 Correlations between Student Socio-Economic Status and Performance on the Calculator Inappropriate, Calculator Optional, and Calculator Appropriate Tests

Test	Correlation with SES	t	p
Calculator Inappropriate	.224	5.442	0.001
Calculator Optional	.205	4.186	0.001
Calculator Appropriate	.197	4.051	0.001

A regression analysis was conducted to examine if there was a significant interaction between calculator availability and SES on the Calculator Optional test. The interaction was not statistically significant (F =0.250, df= 2, 32, p. = 0. 780).

ACCESS TO CALCULATORS AT HOME AND USE OF CALCULATORS AT SCHOOL

In the section, associations between calculator access/usage at home and at school are examined.

Access to Calculators at Home

On the Student questionnaire, students indicated whether or not they had access to a calculator at home. Nine in ten (90.78%, SE = 2.38) indicated that they had access to a calculator at home. Of the others, 5.37% (SE = 0.86) indicated that they did not have access, and 3.85 (SE = 2.27) did not respond. Mean scores for students on the three calculator tests who had / did not have access to a calculator at home are given in Table 5.6, while Table 5.7 provides a summary of the comparisons that were made between the scores of the these groups on the tests. On all the tests, students with access to a calculator at home achieved significantly higher mean scores than their counterparts without access. Effect sizes for the three comparisons were .27 (Calculator Inappropriate), .42 (Calculator Optional) and .62 (Calculator Appropriate).

Table 5.6 Mean Scores of Students on the Calculator Inappropriate, Calculator Optional, and Calculator Appropriate Tests, by Availability of Calculator at Home

Test	Calculator at Home	No Calculator at Home	Missing
Calculator Inappropriate	250.9 (5.18)	231.4 (6.36)	254.6 (10.9)
Calculator Optional	250.6 (4.55)	229.4 (7.85)	264.6 (10.35)
Calculator Appropriate	251.1(4.72)	220.4 (8.27)	264.5 (9.09)

Table 5.7 **Summary of Comparisons of Mean Score Differences on the Calculator Inappropriate, Calculator Optional, and Calculator Appropriate Tests, by Calculator Availability at Home**

Test (Calculator Available-Calculator Not Available)	Difference	SE Diff	95% Confidence Interval (Lower and Upper Limits)*
Calculator Inappropriate	19.5	7.61	**1.7 to 37.4**
Calculator Optional	21.2	6.99	**7.0 to 35.4.**
Calculator Appropriate	30.7	9.52	**8.3 to 53.1**

*Confidence intervals associated with significant differences are indicated in bold.

A regression analysis indicated no statistically significant interaction between the scores of students with/without access to calculators at home and with/without access to calculators on the Calculator Optional test (F = 0.523, df = 1, 33; p. = .475).

Use of Calculators at School

Students were also asked if they used calculators at school. The first part of this question covered use of calculators in general (i.e., across all subjects). The second part covered frequency of calculator usage in Mathematics, Business Studies, Science, Technology and other subjects.

Almost 56% of students (55.75%, SE = 3.2) indicated that they used calculators at school, 40.23% (SE = 2.96) indicated that they did not use calculators, while 4.01% (SE = 2.27) did not respond. Table 5.8 gives the mean scores on the Calculator Inappropriate, Calculator Optional and Calculator Appropriate tests for those who did/did not use calculators at school.

Table 5.8 **Mean Scores of Students on the Calculator Inappropriate, Calculator Optional, and Calculator Appropriate Tests, by Use of Calculators at School (All Subjects)**

Test	Calculator at School	No Calculator at School	Missing
Calculator Inappropriate	253.1 (5.19)	244.6 (5.79)	262.1 (5.24)
Calculator Optional	254.1 (5.17)	243.0 (5.29)	262.9 (10.67)
Calculator Appropriate	257.0 (5.75)	238.8 (4.78)	264.6 (8.81)

A comparison of the mean scores on the three tests of students who used/did not use calculators at school indicates a significant difference on the Calculator Optional and Calculator Appropriate tests in favour of those who used calculators (Table 5.9). This difference may reflect the additional practice that students who used calculators at school may have built up over their counterparts who did not use calculators. Effect sizes for the three comparisons were .17 (Calculator Inappropriate), .22 (Calculator Optional) and .37 (Calculator Appropriate) respectively.

Table 5.9 **Summary of Comparisons of Mean Score Differences on the Calculator Inappropriate, Calculator Optional, and Calculator Appropriate Tests, by Use of Calculator at School (All Subjects)**

Comparison (Used/Did Not Use Calculator at School)	Difference	SE Diff	95% Confidence Interval
Calculator Inappropriate	8.5	7.77	-9.7 to 26.8
Calculator Optional	11.1	5.18	**0.52 to 21.60**
Calculator Appropriate	18.2	7.48	**0.6 to 35.8**

Confidence Intervals associated with significant differences are indicated in bold.

A regression analysis, in which performance on the Calculator Optional test was the response variable, indicated that the interaction between use/non-use of calculators at school and calculator availability/non-availability during the Calculator Optional test was not statistically significant ($F = 1.444$, $df = 1, 33$, $p. = .293$). The effect size associated with the difference in mean scores on the Calculator Optional test (calculator available condition) between students who did/did not use calculators at school was .43. The corresponding effect size for the calculator not available condition on the same test was .31.

Use of Calculators in Selected School Subjects

In addition to the question on general usage of calculators at school, students were asked about the frequency with which they used calculators in selected school subjects: Mathematics, Business Studies, Science and Technology. Their responses are summarised in Table 5.10. Over 75% of pupils never used calculators in their Mathematics classes, while less than 1% indicated frequent usage. In Mathematics, Science and Business Studies, between 11% and 15% of students indicated that they 'sometimes' used calculators. Among those who took Technology, calculator usage was very infrequent.

Table 5.10 **Percentages of Students Indicating Various Levels of Calculator Usage in Selected Subjects during Schoolwork**

	Often	Sometimes	Never	Other*
Mathematics	0.63 *(0.63)***	11.1 *(2.09)*	76.5 *(2.49)*	11.82 *(2.19)*
Business Studies	44.9 *(3.20)*	15.7 *(1.61)*	11.2 *(1.31)*	28.26 *(3.07)*
Science	1.7 *(0.66)*	13.1 *(1.63)*	60.3 *(2.34)*	24.9 *(2.62)*
Technology	0.1 *(0.05)*	2.0 *(0.60)*	32.4 *(2.07)*	65.15 *(2.32)*

*Other includes 'Does not apply', 'Ambiguous' and 'Missing' (see Table A5.10, Appendix 5)
**Standard Errors in brackets

Students who used calculators 'often' during schoolwork in Mathematics had a lower mean achievement score (229.0) on the Calculator Appropriate test than students who used calculators 'sometimes' (241.5) and students who 'never' used them (252.3) (Table 5.11), perhaps indicating that higher-achieving students did not need to use a calculator for the types of problems they were assigned, or that lower-achieving students were encouraged to make more use of calculators. Students who used calculators 'often' during schoolwork in Business Studies achieved a mean score of 259.0, while those who did so 'sometimes' and 'never' achieved mean scores of 247.5 and 227.5, respectively.

Table 5.11 Mean Scores of Students on the Calculator Appropriate Test, by Level of Calculator Usage in Selected Subjects during Schoolwork

Test	Often	Sometimes	Never
Mathematics	229.0 (16.08)	241.5 (12.47)	252.3 (4.45)
Business Studies	259.0 (6.00)	247.5 (5.08)	227.5 (6.65)
Science	263.2 (10.60)	269.3 (6.37)	248.9 (4.85)
Technology	192.3 (2.97)	234.5 (10.97)	237.9 (5.40)

Students who used calculators 'often' in Business Studies classes achieved a significantly higher mean score on the Calculator Appropriate test than students who 'never' used calculators (Table 5.12). The reverse situation arose with regard to Technology, with students who 'never' used calculators outperforming those who use them 'sometimes'. The difference between the mean scores of students who 'often' or 'never' used calculators in Mathematics classes was not statistically significant. This, in part, is due to the very large standard error (16.08) associated with the mean score of students in the 'often' category (fewer than 1% of students fell into this category).

Table 5.12 Summary of Comparisons of Mean Score Differences on the Calculator Appropriate Test, by Use of Calculator during Schoolwork (Selected Subjects)

Use of Calculator During Schoolwork	Difference	SE Diff	95% Confidence Interval*
Mathematics			
Never – Sometimes	10.8	13.24	–24.2 to 45.8
Often – Sometimes	-12.2	20.35	–66.3 to 41.2
Never – Often	23.4	16.68	–20.7 to 67.5
Business Studies			
Never – Sometimes	-19.9	8.37	–42.0 to 2.2
Often – Sometimes	11.6	7.86	–9.2 to 32.3
Never – Often	-31.5	8.96	**–55.1 to –7.8**
Science			
Never – Sometimes	-20.4	8.01	–41.5 to 0.8
Often – Sometimes	-6.0	12.37	–38.7 to 26.6
Never – Often	-14.3	11.66	–45.1 to 16.5
Technology			
Never – Sometimes	3.4	12.23	–28.9 to 35.8
Often – Sometimes	-42.2	11.37	**–72.2 to –12.2**
Never – Often	45.6	6.16	**29.4 to 61.9**

*Confidence Intervals associated with significant differences are indicated in bold.

Use of Calculators during Homework

Students were also asked to indicate whether or not they used a calculator for selected subjects during homework. The subjects were Mathematics, Business Studies, Science, and Technology. Over one half of students indicated that they never used a calculator during Mathematics homework (despite the fact that calculators were available to over 90% of them). Just 2% indicated that they did so 'often' (Table 5.13). Calculator usage was somewhat more prevalent for Business Studies, with 46% of students who took part in the calculator study indicating that they 'often' used calculators. When one considers that at least a further 20% of students did not take Business Studies at all, it can be concluded that, relative to other subjects, calculator usage is quite prevalent during homework in Business Studies.

Table 5.13 Percentages of Students Indicating Various Levels of Calculator Usage in Selected Subjects during Homework

Homework	Often	Sometimes	Never	Does Not Apply	Ambiguous/ Missing
Mathematics	2.05	35.05	52.72	2.81	7.37
Business Studies	45.67	14.43	10.58	20.49	8.83
Science	1.78	14.10	57.87	16.10	10.16
Technology	0.37	2.16	32.39	50.09	14.99

The mean score on the Calculator Appropriate test of students who used calculators 'often' during mathematics homework (207.9) was lower than the mean scores of students who 'sometimes' used them (252.3) and those who 'never' used them (250.6) (Table 5.14). However, as was indicated in Table 5.13, just 2% of students are included among the group who used calculators often during Mathematics homework. In contrast, students who 'often' used calculators for Business Studies homework had a higher mean score (259.2) than students who 'sometimes' (244.4) or 'never' (226.7) used them. The small minority of students who indicated that they often used calculators during Technology homework achieved a mean score of just 212.4.

Table 5.14 Mean Scores of Students on the Calculator Appropriate Test, by Level of Calculator Usage in Selected Subjects during Homework

Test	Often	Sometimes	Never
Mathematics	207.9 (6.99)	252.3 (4.91)	250.6 (4.81)
Business Studies	259.2 (6.10)	244.4 (5.27)	226.7 (6.15)
Science	248.5 (9.85)	268.1 (7.17)	249.1 (4.64)
Technology	212.4 (18.68)	241.5 (12.58)	237.6 (5.42)

Students who 'never' used a calculator during Mathematics homework achieved a significantly higher mean score on the Calculator Appropriate test than students who often used calculators (Table 5.15). On the other hand, students who 'often' used a calculator during Business Studies homework achieved a significantly higher mean score than students who 'never' used a calculator during homework in that subject. This is consistent with the earlier finding that students who used a calculator at school achieved a higher mean score on the Calculator Appropriate test than those who did not (Tables 5.7, 5.8).

Table 5.15 Summary of Comparisons of Mean Score Differences on the Calculator Appropriate Test, by Use of Calculator during Homework (Selected Subjects)

Use of Calculators During Homework	Difference	SE Diff	95% Confidence Interval*
Mathematics			
Never – Sometimes	–1.7	6.87	–19.8 to 16.5
Often – Sometimes	–44.4	8.54	**–67.0 to –21.8**
Never – Often	42.7	83.48	**20.3 to 65.1**
Business Studies			
Never – Sometimes	–17.7	8.10	–39.1 to 3.7
Often – Sometimes	14.8	8.06	–6.5 to 36.1
Never – Often	–32.5	8.66	**–55.4 to –9.6**
Science			
Never – Sometimes	–19.0	8.53	–41.6 to 3.5
Often – Sometimes	–19.6	12.18	–51.8 to 12.5
Never – Often	0.6	10.88	–28.1 to 29.4
Technology			
Never – Sometimes	–4.0	13.7	–40.2 to 32.2
Often – Sometimes	–29.1	22.53	–88.6 to 30.4
Never – Often	25.2	19.45	–26.2 to 76.5

*Confidence Intervals associated with significant differences are indicated in bold.

Types of Calculators Used at Home and at School

Students with access to calculators at home and/or at school were also asked to indicate the type(s) of calculator to which they had access. Three options were given: a Basic calculator, a Scientific calculator, and a Graphics calculator. Across all students, 43.2% indicated they had access to a Basic calculator at home, while 46.3% indicated they had access to a Scientific calculator (Table 5.16). At school, one quarter of students said they had access to a Basic calculator while 30.8% had access to a Scientific calculator. Fewer than 1% of students in either setting reported having access to a Graphics calculator.

Table 5.16 Percentages of Students with Access to Basic, Scientific and Graphics Calculators at Home, and Percentages Using these Calculator Types at School

	Percent of Students (SE)	
Calculator Type	Access at Home	Use at School
Basic	43.2 (2.36)	25.4 (2.14)
Scientific	46.3 (2.81)	30.8 (2.80)
Graphics	0.38 (0.17)	0.6 (0.40)
Not Applicable	5.10 (0.91)	37.8 (2.96)
Missing	5.04 (2.16)	5.5 (2.08)

STUDENTS' ATTITUDES TOWARDS MATHEMATICS AND CALCULATORS

Students were presented with a series of questions about their attitudes to mathematics and calculators. First, students were asked to indicate the extent of their agreement with a series of statements about attitudes to mathematics (Table 5.17). Students were generally supportive of the view that 'mathematics is a useful subject for everyday life', with 78% indicating either 'strong agreement' or 'agreement'. Four in five students (81.5%) indicated similar levels of agreement with the view that mathematics is important for getting a job.

Four in five students (79%) 'strongly agreed' or 'agreed' that they liked doing sums when they knew the method. By contrast, just two in five students (40.4%) indicated these levels of agreement with the statement 'I like tackling problems', two in five (37.2%) with the statement 'I like everyday mathematics problems', and only three in ten (28.1%) with the statement 'I like doing length, area and volume problems'. Thus, the students favoured routine procedural work more than problem-solving activities – or, at least, problem-solving activities of the type they had experienced in their mathematics courses.

Almost one half of students (47.8%) 'strongly agreed' or 'agreed' with the statement 'I like statistics'. Smaller proportions of students indicated similar levels of agreement with the view that they liked algebra (39.3%), geometry (35.8%), and trigonometry (30.0%). For each of these three areas, over one in five students indicated strong disagreement with the view that they liked the content area.

Almost one half of students (49.5%) indicated 'strong agreement' or 'agreement' with the view that they had always done well in mathematics. Almost three in five students (59.3%) indicated 'strong agreement' or 'agreement' with the view that they get good marks in mathematics.

An initial exploratory principal components analysis indicated that three distinct factors were tapped by the attitude to mathematics item set. The analysis suggested that the items could be grouped as follows:

- A general positive attitude or disposition towards mathematics (13 items: a, b, e, i to r in Table 5.17)
- A belief that mathematics is useful in the real world (2 items: g, h)
- Mathematics self-concept or a belief in one's own mathematical ability (3 items: c, d and f)

Varimax rotation (which assumes that components share common variance) was then applied to the initial three-factor solution. When the 13 disposition items were analysed on their own, they loaded on a single factor which explained 44% of the variance in the pattern of student responses. Kaiser-Meyher-Olkin (KMO) measures of sampling adequacy indicated that all items were suitable for inclusion in the analysis (they exceeded .90). Individual items loadings were satisfactory to high (.53 - .73). A factor score for each student was generated using the standard ordinary least squares (OLS) regression method. This resulted in a distribution with a (standardised) mean of 0 and a standard deviation of 1.

The two items referring to the belief that mathematics is useful in the real world loaded on a single factor explaining 74% of the variance in students' responses.

Table 5.17 Percentages of Students Indicating Various Levels of Agreement with Statements about Attitudes to Mathematics

	Statement	Strongly Agree	Agree	Disagree	Strongly Disagree	Missing
a.	When I do mathematics, I sometimes get totally absorbed	4.5	30.9	39.4	18.0	7.2
b.	Because doing mathematics is fun, I wouldn't want to give up	3.0	20.0	45.4	25.8	5.9
c.	I get good marks in mathematics	6.5	52.8	28.8	6.5	5.4
d.	Mathematics is one of my best subjects	7.4	25.0	44.1	18.1	5.4
e.	Mathematics is one of my favourite subjects	6.1	24.3	41.4	23.0	5.2
f.	I have always done well in mathematics	9.4	40.1	35.7	9.2	5.6
g.	Mathematics is a useful subject for everyday life	29.5	48.4	10.5	6.4	5.2
h.	Mathematics is important for getting a job	34.8	46.7	9.2	3.8	5.6
i.	I like arithmetic	7.7	33.4	36.1	15.6	7.2
j.	I like doing calculations	6.8	41.2	33.1	13.2	5.6
k.	I like doing sums when I know the method	20.7	58.3	10.0	5.8	5.2
l.	I like tackling problems	7.2	33.2	37.1	16.7	5.7
m.	I like everyday mathematics problems	4.9	32.3	41.5	15.9	5.4
n.	I like doing length, area, and volume problems	4.3	23.8	39.6	26.6	5.7
o.	I like geometry	5.3	30.5	36.8	21.1	6.3
p.	I like algebra	6.7	32.6	32.2	22.5	6.1
q.	I like trigonometry	4.7	25.3	39.4	23.1	7.5
r.	I like statistics	10.1	37.7	29.9	15.3	7.0

N = 1464 (weighted); Standard Errors are given in Table A5.17 (Appendix 5).

The KMO values for this analysis (.50 for each item) are low (see Hutchenson & Sofroniou, 1999). However, since the individual item loadings were quite high (both were .86), the items were summarised using principal components analysis, and the data were again aggregated using OLS regression.

The three self-concept items were analysed in the same manner. One factor, accounting for 74% of the variance in students' responses, emerged. KMO values were again satisfactory, leading to the aggregation of the items using OLS regression.

Correlations between each factor and the Calculator Inappropriate, Calculator Optional and Calculator Appropriate tests were computed and their statistical significance evaluated using multiple-regression in WesVar. The results are given in Table 5.18. Correlations between the Disposition and Self-Concept factors and performance on Calculator tests were moderately strong and significant. For example, the correlation between Self-Concept and performance on the Calculator Inappropriate Test was .427 ($p < .001$). On the other hand, correlations between the Usefulness factor and performance on each of the tests were weak and non-significant. This confirms concerns raised earlier about the low KMO value for this factor.

Table 5.18 Correlations between Attitude towards Mathematics Scales and the Calculator Inappropriate, Calculator Optional and Calculator Appropriate Tests

Factor	Correlation with Calculator Inappropriate Test	t	p*
Disposition	.301	8.324	<0.001
Usefulness	.100	0.569	0.573
Self-Concept	.427	15.712	<0.001
	Correlation with Calculator Optional Test	t	p
Disposition	.320	8.250	<0.001
Usefulness	.045	1.162	0.254
Self-Concept	.427	12.398	<0.001
	Correlation with Calculator Appropriate Test	t	p
Disposition	.303	9.505	<0.001
Usefulness	.045	1.114	0.273
Self-Concept	.378	12.239	<0.001

*df = 1, 33 for all tests of significance

Next, the distributions of scores for each dimension of the attitude scale were divided into thirds (high, medium and low). Table 5.19 gives the mean scores on the Calculator Inappropriate, Calculator Appropriate and Calculator Optional tests for students achieving high, medium or low scores on the attitude scales. As might be expected, on the basis of the correlations reported in Table 5.18, students with high scores on the attitude towards mathematics scale tended to have higher levels of achievement on the Calculator Inappropriate, Calculator Optional, and Calculator Appropriate tests than students with medium or low attitude scores. Differences between the mean scores on these tests for students with high and low attitude scores are large enough to reach statistical significance.

Finally, a series of regression analyses was carried out to examine if performance on the Calculator Optional test might be associated with a significant interaction between attitude (high, medium, low for each scale) and calculator availability/unavailability during the test. The regressions indicated non-significant interactions for Disposition (F = 0.310; df = 2, 32; p. = 0.736), Usefulness (F = 2.092; df = 2, 32; p. = 0.140) and Self-concept (F = 0.799; df = 2, 32; p. = 0..419).

Table 5.19 Students' Mean Scores on the Calculator Inappropriate, Calculator Optional, and Calculator Appropriate Tests, by Attitude Towards Mathematics

	High	Medium	Low	Missing
Attitude Factor/Test				
Disposition (Mathematics)				
Calculator Inappropriate	269.9	251.4	239.4	235.1
Calculator Optional	270.0	252.1	238.2	235.7
Calculator Appropriate	269.4	251.3	238.9	236.7
Usefulness				
Calculator Inappropriate	252.4	250.6	247.4	242.8
Calculator Optional	252.0	251.2	246.3	246.3
Calculator Appropriate	251.7	252.3	245.3	242.9
Self-Concept				
Calculator Inappropriate	270.4	244.5	228.1	244.7
Calculator Optional	269.9	242.9	229.2	247.5
Calculator Appropriate	267.7	244.1	232.0	244.2

Standard errors are reported in Appendix 5, Table A5.19

Attitudes Towards Calculators

Students were also presented with a series of statements about attitudes towards calculators, and were asked to indicate their level of agreement with each one. Students were generally positively disposed towards calculators. For example, 70.6% 'strongly agreed' or 'agreed' with the view that calculators could help them to achieve better marks in school mathematics (Table 5.20). However, just 46.7% showed similar levels of agreement with the view that calculators could help them to get better at mathematics. Interestingly, 18.9% of students 'disagreed' or 'strongly disagreed' with the view that they should be allowed to use a calculator in the Junior Certificate mathematics examination, though, in this instance, their responses may have been influenced by the fact that they themselves would not be allowed to use calculators in that examination. Also, it may be the case that some higher-achieving students did not perceive a calculator to be particularly beneficial on the types of items they were expected to respond to on the Junior Certificate mathematics examination.

An initial exploratory principal components analysis indicated that three factors were tapped by the attitude to calculators items. The analysis suggested that the items could be grouped as follows:

- A general positive disposition towards calculator usage in mathematics (5 items: a, c, e, g and i on Table 5.20)
- A belief that calculator usage is associated with laziness or poor achievement (2 items: b, d)
- A positive disposition towards calculators in areas of the curriculum other than mathematics (2 items: f, h)

Table 5.20 Percentages of Students' Indicating Various Levels of Agreement with Statements about Attitudes to Calculators

	Statement	Strongly Agree	Agree	Disagree	Strongly Disagree	Missing
a.	I think a calculator can help me to get better marks in school mathematics	28.2	42.4	18.2	6.2	5.1
b.	I think a calculator could make me lazy at school mathematics	15.1	36.9	29.2	13.6	5.3
c.	I think a calculator could help get me better at mathematics	14.5	32.2	38.5	9.3	5.5
d.	A calculator should be used only by a student who has a lot of difficulty at school	10.3	27.4	39.5	17.2	5.6
e.	I think I should be allowed to use a calculator for mathematics homework	19.9	47.6	21.4	5.5	5.6
f.	I think I should be allowed to use a calculator for homework in other subjects	18.1	55.5	15.8	4.5	6.0
g.	I think I should be allowed to use a calculator in mathematics class	19.5	42.3	25.6	6.6	6.0
h.	I think I should be allowed to use a calculator for classwork in other subjects	16.3	52.7	20.3	4.5	6.2
i.	I think I should be allowed to use a calculator in the Junior Certificate examination	44.7	30.8	12.0	6.9	5.6

N = 1464 (weighted); Standard Errors are given in Appendix 5, Table A5.20

Varimax rotation was then applied to the initial three-factor solution and the same three-factor pattern emerged. When the five general disposition items were analysed on their own, they loaded on a single factor which explained 63% of the variance in student responses. A KMO measure of sampling adequacy indicated that all items were suitable for inclusion in the analysis (all exceeded .80). Individual item loadings ranged from .73 to .85. Factor scores for individual students were generated using standard OLS regression.

As the KMO values for the remaining factors were in the region of .50 for individual items, it was decided not to generate factor scores using OLS regression

Correlations between the Disposition factor and performance on the three calculator tests were computed using multiple regression in WesVar. The results are given in Table 5.21. The correlations between Disposition (towards calculators) and performance on the Calculator Inappropriate and Calculator Optional tests were negative, moderate in size, and statistically significant. The correlation between Disposition and performance on the Calculator Appropriate test was also negative, somewhat weaker, yet statistically significant.

Table 5.21 Correlations between Disposition Towards Calculator Usage and Performance on the Calculator Inappropriate, Calculator Optional and Calculator Appropriate Tests

Test	Correlation with Disposition	t	p*
Calculator Inappropriate	–.224	-5.140	<0.001
Calculator Optional	–.184	-4.306	<0.001
Calculator Appropriate	–.134	-2.968	<0.001

*DF = 1, 33 for all tests of significance

Next, the distribution of scores for the Disposition towards calculators scale was divided into thirds (high, medium and low). Table 5.22 gives the mean scores on the Calculator Inappropriate, Calculator Appropriate and Calculator Optional tests for students achieving high, medium or low scores on scale. As might be expected on the basis of the negative correlations reported in Table 5.21, for each of the tests, students' mean scores decrease as disposition towards calculators increases.

Table 5.22 Students' Mean Scores on the Calculator Inappropriate, Calculator Optional, and Calculator Appropriate Tests, by Disposition Towards Calculators

Disposition	High	Medium	Low	Missing
Test				
Calculator Inappropriate	239.8	248.3	264.6	245.9
Calculator Optional	242.0	248.4	262.0	245.3
Calculator Appropriate	245.2	247.4	260.2	241.9

Standard errors are reported in Appendix 5, Table A5.22

A regression analysis was carried out in order to examine the significance of any interactions between calculator availability for the Calculator Optional test (2 levels), Disposition towards calculators (3 levels), and performance on the Calculator Optional test. A significant interaction was obtained ($F = 7.824$; $df = 2, 32$; $p. < .001$). The mean scores associated with the interactions are given in Table 5.23.

Table 5.23 Mean Scores on the Calculator Optional Test of Students with Varying Levels of Attitude towards Calculators, by Availability of Calculators during the Test

Calculator	Attitude Towards Calculators			
Availability	High	Medium	Low	Missing
Yes	259.5 (3.52)	261.0 (5.48)	268.3 (4.45)	266.7 (11.49)
No	224.5 (6.49)	233.6 (5.78)	256.6 (2.54)	225.4 (13.18)

Students with a high positive attitude towards calculators who had access to a calculator during the Calculator Optional test achieved a significantly higher mean score than students with high and medium levels of (positive) attitude towards calculators, but who did not have access to a calculator (Table 5.24). The mean score difference on the same test between students with a low positive attitude towards calculators who had and did not have calculators was not statistically significant.

Table 5.24 Comparisons of Mean Score Differences on the Calculator Optional Test between Students with Varying Levels of Attitude towards Calculators, by Availability of Calculators during the Test

Comparison/Calc Availability	Difference	SE Diff	95% Confidence Interval
High (Y) - High (N)	35.0	4.03	**26.8 to 43.2**
High (Y) - Med (N)	25.9	4.80	**16.1 to 35.7**
High (Y) - Low (N)	3.0	4.57	-6.4 to 12.3
Med (Y) - Med (N)	27.4	4.15	**18.9 to 35.8**
Med (Y) - Low (N)	4.41	4.24	-4.2 to 13.0
Low (Y) - Low (N)	11.7	4.02	**3.5 to 19.9**

High, Med., Low indicates high, medium and low levels of positive attitude towards calculators
Y – indicates calculator availability during then Calculator Optional test
N – indicates non-availability of calculator during Calculator Optional test

CONCLUSION

This chapter sought to identify some of the variables associated with the performance of Third-year students on the Calculator Inappropriate, Calculator Optional and Calculator Appropriate tests.

While male students outperformed female students on two of the three tests (Calculator Inappropriate, Calculator Optional) and female students outperformed male students on the third (Calculator Appropriate), differences in mean scores were not statistically significant. Further, the interaction between gender and calculator availability on the Calculator Optional test was not statistically significant. The finding of no statistically significant gender differences is interesting to the extent that male students significantly outperformed female students in Ireland on the PISA 2000 assessment of mathematical literacy. However, an earlier international study, the Third International Mathematics and Science Study, did not indicate gender differences in overall mathematics achievement among Irish students in the First or Second years (post-primary) (Beaton et al, 1996). In the context of the present study, it is interesting that female students achieved a slightly higher (yet not significantly different) mean score than male students on the Calculator Appropriate test.

Associations between performance on the calculator tests and socio-economic status were along expected lines with high SES students (those in the top third of the SES distribution) outperforming low SES students (those in the bottom third) on the three tests. The finding that the mean scores of high and medium SES students, and the mean scores of medium and low SES students, did not differ significantly reflects the moderate association between SES and performance in mathematics reported in this and other studies of mathematics achievement.

There is some evidence from the current study that work with a calculator in school (in subjects such as Business Studies) confers an advantage on students taking a test such as the Calculator Appropriate test. Similarly, there is evidence that use of a calculator for subjects such as Business Studies during homework confers a similar advantage. This suggests that, all other thinks being equal, as calculators are used more extensively in the Junior Cycle mathematics, the majority of students should become more proficient on tests that require some practice in the use of calculators, such as the Calculator Appropriate test administered as part of this study.

Whereas associations between general attitudes towards mathematics and performance on the calculator tests were along expected lines, the negative correlations between attitude towards calculators in mathematics and performance on the calculator tests were less predictable. These may be related to the finding reported in Chapter 4, that, for higher-achieving students (those with scores above the 90^{th} percentile on the Calculator Optional test), calculator availability does not seem to have an impact on performance on the Calculator Appropriate test. Some higher-achieving students might not have felt that a calculator on the Junior Certificate Examination would be particularly beneficial (perhaps because items on the Higher-level paper were less calculator-sensitive than on the Ordinary and Foundation papers). Alternatively, some students may have felt that, because they would not have access to a calculator for the Junior Certificate examination, other students, in future years, should not have access either.

6 Calculators and the Junior Certificate Mathematics Examination

This chapter considers associations between the performance of students on the Calculator tests, and their performance on the Junior Certificate mathematics examination. First, consideration is given to associations between students' performance on the Calculator tests, and the level of the Junior Certificate mathematics examination in 2002 that students said they *intended* to sit, when asked in November 2001. Second, associations between students' performance on the Calculator tests and their *actual* level/performance on the Junior Certificate mathematics examination in June 2002 are described.

PERFORMANCE ON THE CALCULATOR TESTS BY INTENDED JUNIOR CERTIFICATE EXAM LEVEL

Students who participated in the study were asked to indicate the level of the Junior Certificate mathematics examination that they intended to take in June 2002 (i.e., some seven months later). It is likely that students' responses reflected the course they were following at the time. Over one-half of students (51.7%, SE = 6.75) indicated that they intended to take the Higher-level examination, while 44.0% (SE = 6.52) indicated an intention to take the Ordinary or Foundation levels.[1] Just under 5% of students (4.3%, SE = 2.27) did not respond to this item. It should be noted that the proportions intending to take the Junior Certificate mathematics examination at Higher, and Ordinary/Foundation levels are somewhat different from those that might have been expected on the basis of data arising from recent administrations of the Examination. In 2002, 36.8% of students took the Higher-level papers, 49.9% the Ordinary level, and 13.3% the Foundation level (Department of Education and Science, 2002). However, as indicated later, students' actual levels were closer to the national distribution than their intended levels.

Students who stated that they intended to take Junior Certificate Mathematics at Higher level achieved higher mean scores on each of the three tests than students who stated that they intended to take Ordinary/Foundation levels (Table 6.1). For each scale, the difference was about 60 score points (1.2 standard deviations). All three differences were statistically significant (Table 6.2).

Table 6.1 Students' Mean Scores on the Calculator Inappropriate, Calculator Optional, and Calculator Appropriate Tests, by Intended Junior Certificate Mathematics Examination Level

Test	Higher	Ordinary/Fndt	Missing
Calculator Inappropriate	276.9 (3.06)	217.1 (2.82)	263.4 (4.90)
Calculator Optional	276.2 (3.49)	217.8 (2.74)	264.4 (5.17)
Calculator Appropriate	275.8 (3.78)	218.4 (3.03)	264.2 (8.44)

[1] Responses / scores of students intending to take Ordinary and Foundation levels were collapsed for analysis purpose, since the percentage intending to take Foundation level was very low. Students' responses probably reflect the course they were studying at the time of the calculator tests.

Table 6.2 **Summary of Comparisons of Mean Score Differences on the Calculator Inappropriate, Calculator Optional and Calculator Appropriate Tests, by Intended Junior Certificate Mathematics Examination Level**

Test	(Higher–Ordinary/ Foundn)	SE Diff	95% Confidence Interval (Lower and Upper Limits)*
Calculator Inappropriate	59.9	4.16	**50.1 to 69.6**
Calculator Optional	58.4	4.83	**48.5 to 68.2**
Calculator Appropriate	57.3	4.84	**46.0 to 68.7**

*Confidence intervals associated with significant differences are indicated in bold.

A regression analysis was undertaken to ascertain if there might be a significant interaction between calculator availability and intended Junior Certificate level on the Calculator Optional test. The analysis indicated a significant interaction ($F = 4.75$, $DF = 1, 33$, $p. = .037$). Table 6.3 shows the mean scores on the Calculator Optional test of students with and without a calculator, by the level at which they intended to sit the Junior Certificate mathematics examination, while Table 6.4 confirms that differences between students intending to take Higher level are statistically significant for the calculator/no calculator conditions. A similar outcome was observed with respect to Ordinary/Foundation students.

Table 6.3 **Mean Scores on the Calculator Optional Test of Students Intending to Take the Junior Certificate Mathematics Examination at Higher and Ordinary/ Foundation levels, by Calculator Availability**

Junior Certificate Level /Calculator Availability	Mean (SE)
Higher Level – Calculator	287.5 (4.02)
Higher Level – No Calculator	265.1 (3.48)
Ordinary/Foundation Level – Calculator	233.1 (3.18)
Ordinary/Foundation Level – No Calculator	204.5 (3.18)

Table 6.4 **Comparisons of Mean Score Differences on the Calculator Optional Test, for Students with and without Calculators, by Intended JC Examination Level**

Comparison (Calculator vs. No Calc.)	Difference	SE Diff	95% Confidence Interval*
Higher Level	22.3	2.30	**17.6 to 27.0**
Ordinary/Fndt Levels	30.83	2.89	**24.9 to 36.7**

*Confidence Intervals associated with significant differences are indicated in bold.

In a follow-up comparison, the performance of Higher-level students without access to a calculator for the Calculator Optional test was compared with the performance of Ordinary/Foundation level students with access. The difference between the mean scores of the two groups was statistically significance (Diff = 32.0, SE Diff = 4.88, 95% Confidence Interval: 22.4 to 41.6). Hence, the performance of Higher-level students without access to a calculator is significantly higher than that of Ordinary/Foundation-level students without access.

PERFORMANCE ON THE CALCULATOR TESTS BY ACTUAL JUNIOR CERTIFICATE EXAMINATION LEVEL / RESULTS

The Department of Education and Science (DES) provided the Educational Research Centre with the Junior Certificate examination grades in mathematics of students in Third year in schools that participated in the Calculator Study, and the level at which each student took the examination. Since the names of individual students were not available, the students' dates of birth were used to effect a match between the data provided by the DES and students' scores on the calculator tests. A match was possible for all but 13% of students (Table 6.5). Students for whom it was not possible to effect a match either had not indicated their date of birth on the Student questionnaire in November 2001, shared a date of birth with another student in the same school who also took the Calculator Tests, or did not take the Junior Certificate examination in June 2002. Of students who took the Calculator Tests, 40.6% sat the Higher-level paper in their Junior Certificate. This is higher than the percentage of students in the population who took the Higher-level paper (36.8%) in the same year. Correspondingly, the percentage of students in the sample who sat the Ordinary-level paper (43.4%) is lower than the percentage of students in the population who sat the ordinary level paper (49.9%). The percentage of students in the population taking the examination at Foundation level was much greater than the percentage in the sample – 13.3% compared to 3.1%.

Table 6.5 Percentages of Students Taking the Junior Certificate Mathematics Examination at Higher, Ordinary and Foundation Levels (June, 2002) – Calculator Study Sample and Population of Third-Year Students

	Percent of Students	
Level	Sample	Population
Higher	40.6	36.8
Ordinary	43.4	49.9
Foundation	3.1	13.3
No JC Level	13.0	-
Total	100.0	100.0

Performance on the Calculator Tests

Calculator Inappropriate Test

The mean scale scores and mean percent correct scores for students in the Calculator Study on the Calculator Inappropriate tests are given in Table 6.6, according to the level of the Junior Certificate mathematics examination that they took. Students taking Higher level achieved a mean score of 282 on this test, while Ordinary level students achieved a mean score of 229. When the mean scale scores are compared, it is seen that the Higher-level students performed significantly better than the Ordinary-level students, who, in turn, performed significantly better than the Foundation level students (see Table 6.7). The group for whom no Junior Certificate level could be established had a mean score between those of Higher- and Ordinary-level students (245 scale score points). The difference between the mean scale scores of Ordinary-level students and the students for whom information on Junior Certificate mathematics examination level was unavailable was not statistically significant.

Table 6.6 **Mean Scores of Students on the Calculator Inappropriate Test, by Junior Certificate Mathematics Examination Level**

		Calculator Inappropriate Test			
JC Level	N	Mean Score	Std. Dev	Std. Error	Mean % Correct
Higher	570	282.2	39.51	3.38	75.0
Ordinary	648	229.0	40.93	2.57	50.0
Foundation	55	181.5	38.7	6.61	28.5
No JC level	191	244.9	49.3	6.59	56.4
Total	1464	250.0	50.0	4.45	60.0

Table 6.7 **Comparison of Mean Score Differences on the Calculator Inappropriate Test, by Junior Certificate Mathematics Examination Level**

	Diff	*SE Diff*	95% Confidence Interval*
Higher–Ordinary	53.2	4.25	**42.8 to 63.6**
Foundation–Ordinary	-47.5	7.09	**-64.8 to -30.2**
Missing–Ordinary	15.9	7.07	-1.4 to 33.2

*Significant differences indicated in bold

Calculator Appropriate Test

The mean score on the Calculator Appropriate test of students who took the Junior Certificate mathematics examination at Higher level was 281 (Table 6.8). This was some 50 points (one standard deviation) higher than the mean score of students taking the test at Ordinary level. The mean percent correct scores reported in the last column in Table 6.10 indicate that, in general, students found the Calculator Appropriate test to be quite challenging. Higher-level students got an average of 43% of items correct, while Ordinary-level and Foundation-level students got 25% and 11% of items correct, respectively.

Table 6.8 **Mean Scores of Students on the Calculator Appropriate Test, by Junior Certificate Mathematics Examination Level**

		Calculator Appropriate Test			
JC Level	N	Mean Score	Std. Dev	Std. Error	Mean % Correct
Higher	570	280.6	42.59	4.47	43.0
Ordinary	648	230.4	40.22	2.61	25.2
Foundation	55	187.0	31.74	5.28	11.2
No JC level	191	243.6	52.03	7.20	30.5
Total	1464	250.0	50.00	4.45	32.5

Again, Higher-level students performed significantly better than Ordinary-level students, who, in turn, performed better than Foundation level students (Table 6.9). The group for which no Junior Certificate level was established had a mean score that was not significantly different from that achieved by Ordinary-level students.

Table 6.9 **Comparisons of Mean Score Differences on the Calculator Appropriate Test, by Junior Certificate Mathematics Examination Level**

	Diff	*SE Diff*	95% Confidence Interval*
Higher–Ordinary	50.2	5.18	**37.5 to 62.9**
Foundation–Ordinary	-43.4	5.89	**-57.8 to -29.0**
Missing–Ordinary	13.2	7.66	-5.5 to 31.9

*Significant differences indicated in bold

Calculator Optional Test

Table 6.10 provides the mean scores and percent correct scores on the Calculator Optional test (with or without calculator access) for students taking the Junior Certificate mathematics examination at Higher, Ordinary and Foundation levels, and for students for whom no information on Junior Certificate level was available. In the case of Higher-level students, for example, those with access to a calculator achieved a mean score of 292, while those without achieved a mean score of 270 (a difference of 23 scale score points or one-half of a standard deviation). The mean scores of Ordinary-level students with and without calculators were 245 and 213 scale points respectively (a difference of 32 points). Hence, the difference between Ordinary-level students with and without calculators is somewhat greater than that between Higher-level students with and without calculators.

Table 6.10 **Mean Scores of Students on the Calculator Optional Test, by Junior Certificate Mathematics Examination Level**

		Calculator Optional Test			
JC Level	N	Mean Score	Std. Dev	Std. Error	Mean % Correct
Higher					
With Calculator	278	292.8	39.86	4.51	47.1
Without Calculator	292	270.2	49.36	3.57	39.1
Ordinary					
With Calculator	320	245.0	39.06	2.95	36.7
Without Calculator	328	212.7	38.21	2.98	25.2
Foundation					
With Calculator	31	204.9	26.46	6.13	28.6
Without Calculator	24	187.6	32.29	6.29	17.8
No JC level					
With Calculator	102	255.0	46.22	6.77	39.2
Without Calculator	98	233.7	56.25	7.65	28.3

For each Junior Certificate level, the students who had access to a calculator for the test performed significantly better than the students who did not have access (Table 6.11). There was also a significant difference between the mean scores of students with no Junior Certificate level who did the test with or without a calculator.

Comparisons were also drawn between some cross-level groups, including Higher-level students who took the Calculator Optional test without a calculator and Ordinary level students who took the same test with a calculator (Table 6.12). The difference between these two groups was 25.2 points, which was statistically significant. This corresponds to a finding reported earlier regarding the difference in mean scores on the Calculator Optional test between students intending to take the Higher-level Junior Certificate mathematics paper who did not have a calculator, and students expecting to take the Ordinary or Foundation level papers who did. It is also interesting that the mean percent correct scores of students in these groups (39.1% vs. 36.7%) are quite close (Table 6.10).

Table 6.11 Comparison between Mean Scores of Students Taking the Calculator Optional Test, with and without Calculators, by Junior Certificate Mathematics Examination Level

	Diff	*SE Diff*	95% Confidence Interval*	
Higher Level (Calc–No Calc)	22.6	3.05	**16.4**	**28.8**
Ordinary Level (Calc–No Calc)	32.3	3.33	**25.5**	**39.1**
Foundation (Calc– No Calc)	23.3	7.5	**8.0**	**38.6**
No JC Level (Calc– No Calc)	21.3	6.48	**8.13**	**34.5**

*Significant differences indicated in bold

Table 6.12 Comparison between Higher- and Ordinary-level Junior Certificate Mathematics Students Taking the Calculator Optional Test, with and without Calculators

	Diff	*SE Diff*	95% Confidence Interval*	
Higher Calc– Ordinary Calc	47.8	5.89	**35.8**	**59.8**
Higher No calc– Ordinary calc	25.2	4.29	**16.5**	**33.9**
Ordinary No calc– Ordinary calc	-39.6	3.33	**-39.1**	**-25.5**
Higher No Calc – Ordinary No calc	-57.5	4.78	**-67.2**	**-47.8**

*Significant differences indicated in bold

Performance of JC Students on the Calculator Tests

It was possible to place the performance of all students for whom Junior Certificate mathematics examination results were available on the same underlying scale. Junior Certificate Overall Performance Scores (OPS) in mathematics were obtained by assigning the following scores to students' grades: Higher Level – A (12), B (11), C (10), D (9), E (8), F (7); Ordinary Level – A (9), B (8), C (7), D (6), E (5) and F (4); and Foundation Level – A (6), B (5), C (4), D (3), E (2), and F (1). No score was assigned to students who achieved a 'no grade' (NG). The scale had been used in an earlier study to equate the performance of students across levels of Junior Certificate mathematics in analyses of the Irish PISA 2000 data (Shiel et al., 2001).

Table 6.13 shows the proportions of Higher, Ordinary and Foundation level students at each of four intervals on the Calculator Inappropriate test. It can be seen that there is some overlap in performance across levels of the examination. For example, 18.2% of Higher-level students achieved scores at or below the mean (250 points or fewer) on this test, while 32.1% of ordinary level students achieved scores that were higher than the mean (more than 250 points)

Table 6.13 Percentages of Students Achieving Various Scores on the Calculator Inappropriate Test, by Level of Junior Certificate Mathematics Examination Taken

Scale Score by Level	Higher Level	Ordinary	Foundation	Level Not Known
Below 200	2.9	22.4	66.7	16.2
200-250	15.3	45.4	22.2	35.1
251-300	48.0	27.9	11.1	33.5
Above 300	33.9	4.2	0.0	15.2
Total	100.0	100.0	100.0	100.0

Finally, Table 6.14 gives overall correlations between Junior Certificate grades in mathematics (on the OPS scale) and performance on the calculator tests, for students taking each Junior Certificate examination level. The overall correlation between performance on the Calculator Inappropriate test and performance on the Junior Certificate mathematics examination is .69. The corresponding correlations for the Calculator Optional (with calculator), Calculator Optional (without calculator) and Calculator Appropriate tests and the OPS scale are .70, .71 and .63 respectively.

Table 6.14 Correlations between OPS Scores and Performance on the Calculator Tests

	N	OPS Scale
Calculator Inappropriate		
Higher Level	596	.484*
Ordinary Level	636	.419
Foundation Level	45	.345
All	1277	.686
Calculator Optional – with Calculator		
Higher Level	278	.530
Ordinary Level	320	.469
Foundation Level	31	.526
All	629	.702
Calculator Optional – without Calculator		
Higher Level	292	.449
Ordinary Level	326	.470
Foundation Level	24	.356
All	642	.713
Calculator Appropriate		
Higher Level	596	.401
Ordinary Level	636	.355
Foundation Level	45	.317
All	1277	.637

* $r < .001$, unless otherwise indicated;

Correlations between OPS scores and performance on the Calculator Inappropriate test were weaker for each level of the Junior Certificate examination than when all levels were combined (the pooled correlation). Again, this reflects the distribution of performance at different Junior Certificate levels on the Calculator Inappropriate test, including the fact that some Ordinary level students outperformed their Higher level counterparts on this test.

CONCLUSION

In this chapter, the performance of students in the Calculators in Mathematics Study was linked to their performance on the Junior Certificate mMathematics Examination. First, associations between performance on the calculator tests, and the level of the Junior Certificate mathematics examination that students said they expected to sit (when asked in November 2001) were examined. Second, associations between performance on the calculator tests and actual performance on the Junior Certificate mathematics examination were examined.

Students planning to take the Higher-level paper in the Junior Certificate mathematics examination achieved significantly higher mean scores on the three calculator tests in comparison with students planning to take the Ordinary or Foundation levels. The mean score of students intending to take Higher level who did not have access to a calculator was significantly higher on the Calculator Optional test than the mean score of students with a calculator who intended to take the Junior Certificate mathematics examination at Ordinary/Foundation levels.

In a second series of analyses, the performance of students on the calculator tests was compared with their actual performance on the Junior Certificate mathematics examination, though, unfortunately, data on Junior Certificate performance were unavailable for 13% of subjects. The results were broadly similar to those arising from the analyses based on intended Junior Certificate level. Access to a calculator on the Calculator Optional test allowed Ordinary level students to approach the performance of Higher level students without access to a calculator, though the difference in favour of the latter group was again statistically significant. The percent correct scores of students in the two groups were also quite close. These findings may be interpreted as suggesting that calculators can help Ordinary level students to avoid computation errors on the easiest items, with perhaps less effect on their performance on the more difficult ones.

An additional finding was that, whereas 18% of Higher-level students achieved scores on the Calculator Inappropriate test that were lower than the mean score on the test, 32% of Ordinary level students achieved scores that were higher than the mean. Correlations between performance on the Calculator tests and grades on the Junior Certificate mathematics examination were nevertheless reasonably strong when the grades of students taking different levels of the Junior Certificate mathematics examination were placed on the same underlying scale. For example, the correlation between performance on the Calculator Inappropriate test, and performance on the Junior Certificate mathematics examination was .69, while that between performance on the Calculator Appropriate test (where calculators were available to all students) and the examination was .64. These correlations are perhaps not unexpected given that the Junior Certificate mathematics examination assesses a broad range of content, whereas the Calculator tests assess a subset of that content – those areas of the syllabus most likely to be calculator sensitive, including Number and Applied Arithmetic and Measure. Differences in marking styles between the Junior Certificate mathematics examination (where partial credit is offered) and the Calculator tests (which no partial credit was available) may have also impacted on the strength of the obtained associations between the two assessments.

7 Teachers and Calculators

A Teacher Questionnaire was administered in conjunction with the Calculators in Mathematics Study. The purpose of the questionnaire was to ascertain teachers' attitudes towards and views about the use of calculators in Junior Cycle mathematics classes, and in the Junior Certificate mathematics examination.

The data are reported in terms of the percentages of students whose teachers provided various responses rather than in terms of the percentages of teachers.

Teachers were asked to respond to all questions (except those dealing with their own backgrounds) with reference to students currently in Third year (i.e., students who had studied a mathematics syllabus that did not suggest the use of calculators, and who would not have had access to a calculator when attempting the Junior Certificate mathematics examination in June, 2002).

BACKGROUND ON TEACHERS

This section provides background information on the teachers of classes that participated in the study. Information is provided on the gender of teachers, and on their experience in teaching mathematics.

Teacher Gender

Over one-half of students in the sample (55%) were taught by teachers who indicated that they were female, while almost two-fifths (39.6%) were taught by teachers who said that they were males (Table 7.1).

Table 7.1 Percentages of Students Taught by Male and Female Teachers

	What is your gender?
Female	55.0 *(7.13)**
Male	39.6 *(6.68)*
Missing	5.4 *(2.79)*

*Standard error of the mean in brackets

Experience Teaching Mathematics

A majority of students were taught by teachers who reported at least 10 years teaching experience (Table 7.2). Under 5% were taught by teachers with fewer than 5 years experience.

Table 7.2 Percentages of Students Taught by Teachers with Varying Levels of Experience in Teaching Mathematics

No of Years	How many years of experience in teaching mathematics do you have?
1-5	4.2 *(5.83)**
6-10	12.2 *(5.54)*
11-15	35.1 *(4.37)*
16-25	22.3 *(4.31)*
More than 25	18.7 *(5.90)*
Missing	7.6 *(2.69)*

*Standard error of the mean in brackets

OWNERSHIP AND USE OF CALCULATORS BY STUDENTS

This section provides information on teachers' perspectives on the use of calculators by students in their Third-year classes for homework and classwork.

Ownership of Calculators

First, teachers were asked to estimate the level of ownership of calculators by students. Nineteen percent of students were taught by teachers who indicated that 'all' of their students owned a calculator (Table 7.3). Sixty-five percent were taught by teachers who believed that 'some' students owned a calculator.

Table 7.3 Teacher Estimates of Ownership of Calculators by Students

	About how many of your students own a calculator?
All	18.9 *(5.65)**
Some	64.5 *(6.95)*
None	3.6 *(2.32)*
Don't Know	9.3 *(4.04)*
Missing	3.8 *(2.27)*

*Standard error of the mean in brackets

Calculators and Mathematics Homework

Just over two-thirds of students were taught by teachers who did not approve of students using a calculator for homework in mathematics. One quarter of students were taught by teachers who indicated their approval (Table 7.4).

Table 7.4 Teacher Approval of Calculators for Mathematics Homework – Percentages of Students

	Do you approve of your students using a calculator for homework in mathematics?
Yes	25.0 *(5.39)**
No	66.8 *(5.78)*
Missing	8.3 *(3.46)*

*Standard error of the mean in brackets

A comparison of the mean scores on the Calculator Inappropriate, Calculator Optional and Calculator Appropriate tests of students whose teachers approved/did not approve of using calculators for mathematics homework indicated that the differences were small (Table 7.5). On the Calculator Inappropriate test, the mean scores of students whose teachers did not approve of the use of calculators for homework was slightly higher (by 1.9 points) than that of students whose teachers approved. The difference was not statistically significant (Diff. = – 1.9; 95% CI: –24.2 to 20.4). Differences between the mean scores of these groups on the Calculator Optional test (Diff. = –2.50, 95% CI: –20.0 to 15.0) and Calculator Inappropriate test (Diff. = 0.00; 95% CI = –24.4 to 23.4) were not statistically significant either. A regression analysis indicated that the interaction between teacher approval/disapproval of calculator usage during mathematics homework and calculator availability on the Calculator Optional Test was not statistically significant ($F = 0.39$, $df = 2, 32$, $p = .536$).

Table 7.5 Students' Mean Scale Scores on the Calculator Inappropriate, Calculator Optional and Calculator Appropriate Tests, by Teacher Approval of Calculator Usage during Homework

Test	Mean Scores (Standard Errors) Approve Calculator (Homework)	Do Not Approve Calculator (Homework)	Missing
Calculator Inappropriate	249.0 *(7.69)*	250.9 *(5.58)*	246.1 *(10.8)*
Calculator Optional	248.6 (7.59)	251.1 (5.33)	245.7 (12.2)
Calculator Appropriate	250.6 *(8.49)*	250.6 *(5.21)*	242.7 *(14.03)*

Almost two-thirds of students were taught by teachers who indicated that 'a few' students in their classes used a calculator during mathematics homework (Table 7.6). This outcome is broadly consistent with the finding reported in Chapter 5 that over one-half of students reported that they never used a calculator during mathematics homework (see Table 5.9).

Table 7.6 Teacher Estimates of Calculator Usage by Students during Mathematics Homework

	About how many of your students might use a calculator for mathematics homework?
None	8.4 *(3.56)*
A Few	64.5 *(5.84)*
Half	14.5 *(4.54)*
All	4.8 *(3.18)*
Missing	7.9 *(3.71)* *

*Standard error of the mean in brackets

Related to this, teachers were asked to estimate the level of usage of calculators at home by students, for each of eight mathematics topics. The topics on which the largest proportions of students could use a calculator were in the areas of: Applied Arithmetic and Measure, Statistics, Trigonometry and, to a lesser extent, Number Systems (Table 7.7) – the areas identified in Chapter 2 as being the most 'calculator sensitive'. In Applied Arithmetic and Measure, it was estimated that the calculator could be used at least to some extent by 78% of students to complete homework.

Table 7.7 Teacher Estimates of Student Calculator Usage during Homework, by Mathematics Topic – Percentages of Students

Topic	For which topics in mathematics might a calculator be used by your students at home?			
	A lot	To some extent	Never	Missing
Sets	0.0	13.8	76.5	9.8
Number Systems	10.8	46.5	30.2	12.6
Applied Arithmetic and Measure	32.7	44.3	11.2	11.8
Algebra	4.3	26.4	57.6	11.7
Statistics	22.4	47.6	19.2	10.8
Geometry	2.9	26.9	58.9	11.4
Trigonometry	29.4	38.8	21.2	10.7
Functions and Graphs	7.0	40.6	41.4	11.0

Standard errors are given in Appendix 7, Table A7.7

Calculators and Classwork in Mathematics

Teachers were also asked to indicate whether or not they allowed the use of calculators for classwork in mathematics. Just 14% of students were taught by teachers who approved the use of calculators during mathematics lessons (Table 7.8).

Table 7.8 Teacher Approval of Calculator Usage during Classwork in Mathematics – Percentages of Students

	Do you approve use of a calculator by students in class?
Yes	13.6 *(4.43)**
No	77.1 *(5.35)*
Missing	9.4 *(3.94)*

*Standard error of the mean in brackets

Differences between the mean scores on the Calculator Inappropriate, Calculator Optional, and Calculator Appropriate tests of students whose teachers approved/did not approve calculator usage in mathematics classes range from 7 to 10 scale score points in favour of students in classes of teachers who approved calculator usage (Table 7.9). Differences were not statistically significant on the Calculator Inappropriate (Diff. = –7.8; 95% CI: –11.5 to 39.3), the Calculator Optional (Diff. = –13.5; 95% CI: –39.1 to 12.2), or the Calculator Appropriate (Diff. = –7.6; 95% CI = –43.6 to 28.4) tests. A regression analysis in which the response variable was student performance on the Calculator Optional test indicated that the interaction between teacher approval of calculator usage in mathematics classes and calculator availability on Calculator Optional test was not significant (F = 0.91, DF = 2, 32, p. = .347).

Table 7.9 Students' Mean Scale Scores on Calculator Inappropriate, Calculator Optional and Calculator Appropriate Tests, by Teacher Approval of Calculator Usage during Classwork

Test	Approve Calculator (Classwork)	Do Not Approve Calculator (Classwork)	Missing
Calculator Inappropriate	242.6 *(12.34)**	250.5 *(5.17)*	256.6 *(9.49)*
Calculator Optional	237.7 (12.65)	251.2 (5.03)	257.7 (9.63)
Calculator Appropriate	243.0 *(14.55)*	250.6 *(4.77)*	255.7 *(12.13)*

*Standard error of the mean in brackets

When asked how often they allowed their Third-year students to use calculators during mathematics classes, teachers indicated that they allowed infrequent usage, with just 16.5% of students being allowed to use calculators 'sometimes' (Table 7.10).

Table 7.10 Teacher Reports of Frequency of Calculator Usage in Class – Percentages of Students

Frequency	How Often Do You Allow Students to Use a Calculator in Class?
Never	76.7 *(6.02)**
Sometimes	16.5 *(5.16)*
Often	1.1 *(1.14)*
Missing	5.7 *(2.95)*

*Standard error of the mean in brackets

Teachers were asked to give an indication of calculator usage by students in their classes for each of 8 mathematics content areas. Where calculators were used at all during classwork, they tended to be used in such areas as Number Systems, Applied Arithmetic and Measure, Statistics, and Trigonometry (Table 7.11). This is broadly in line with responses of teachers to an earlier question concerning the areas in which students used calculators at home (Table 7.7).

Table 7.11 Teacher Reports of Calculator Usage in Mathematics Classes, by Mathematics Topic – Percentages of Students

Topic	For which topics in mathematics is the calculator used in class?			
	A lot	To some extent	Never	Missing
Sets	0.0	2.2	91.2	6.6
Number Systems	1.4	13.7	77.6	7.3
Applied Arithmetic and Measure	12.7	8.6	73.1	5.7
Algebra	0.0	8.0	85.4	6.6
Statistics	8.6	13.4	72.3	5.7
Geometry	0.0	6.7	86.0	7.3
Trigonometry	10.5	7.0	76.8	5.7
Functions and Graphs	4.7	3.6	84.4	7.3

Standard errors are given in Appendix 7, Table A7.11

Teachers were asked whether Junior Cycle students should be allowed to use calculators in a range of contexts, including the Junior Certificate mathematics examination. Teachers were largely positive about the use of calculators for mathematics homework, and for the Junior Certificate mathematics examination, though there was a tendency to approve the use of calculators in other subjects to a greater extent than in mathematics (Table 7.12). Almost three-quarters of students were taught by teachers who approved the use of calculators in the Junior Certificate mathematics examination. The decision of teachers not to allow very much use of calculators for homework (Table 7.4) or for classwork (Table 7.8) should therefore be interpreted in the context of students in the current study not being permitted to use calculators in the Junior Certificate mathematics examination.

Table 7.12 Teacher Views on Calculator Usage by Junior Cycle Students in a Range of Home and School Contexts – Percentages of Students

Context	Do you think Junior Cycle students should be allowed to use a calculator (where a calculator is relevant to the task at hand)?		
	Yes	No	Missing
Mathematics Homework	74.1 *(6.66)**	16.3 *(5.45)*	9.7 *(4.06)*
Mathematics Class	69.9 *(6.46)*	18.8 *(5.55)*	11.3 *(4.35)*
Homework in Other Subjects	84.5 *(5.15)*	3.5 *(2.03)*	12.0 *(4.75)*
Classwork in Other Subjects	81.8 *(5.57)*	5.2 *(2.64)*	13.0 *(4.95)*
Junior Certificate Maths Exam	72.5 *(6.85)*	15.9 *(5.42)*	11.7 *(4.38)*

*Standard error of the mean in brackets

Teachers were also asked to make a distinction between using a calculator as a tool for teaching and learning mathematics, and using one simply for computational work. Almost three-quarters of students were taught by teachers who indicated agreement with the view that calculators could be used as a tool for teaching and learning mathematics (Table 7.13).

Table 7.13 Percentages of Students Taught by Teachers Who Agreed/Did Not Agree that a Calculator Could be Used as a Tool for Teaching and Learning Mathematics

Response	Do you think a calculator can be used as a tool for teaching and learning mathematics and not simply for computational work?
Yes	73.2 *(6.13)*[*]
No	18.4 *(5.44)*
Missing	8.3 *(3.47)*

[*]Standard error of the mean in brackets

When teachers were asked to identify those areas of school mathematics where a calculator might be used as a tool for teaching and learning, three areas in particular were referred to: Applied Arithmetic and Measure, Statistics, and Trigonometry. For example, over four-fifths of students were taught by teachers who felt that a calculator could be used as a tool for teaching Trigonometry (Table 7.14).

Table 7.14 Areas of School Mathematics in which Teachers Feel that Calculators Could be Used as Tools for Teaching and Learning – Percentages of Students

Area	In which areas of school mathematics do you think a calculator might be used as a tool for teaching and learning mathematics, and not simply for computational work?			
	A lot	To some extent	Never	Missing
Sets	1.4	35.8	33.0	29.8
Number Systems	14.9	47.4	13.8	23.9
Applied Arithmetic and Measure	56.7	28.5	1.5	15.3
Algebra	1.4	49.3	17.4	31.9
Statistics	50.9	32.6	0.0	16.6
Geometry	5.7	43.8	22.1	28.5
Trigonometry	58.3	26.4	0.0	15.3
Functions and Graphs	20.8	42.9	9.6	26.7

Standard errors are given in Appendix 7, Table A7.14

TEACHERS' PERSPECTIVES ON THE TEACHING AND LEARNING OF MATHEMATICS

In addition to asking teachers about their views on calculator usage, teachers were asked some general questions about the aspects of Junior Cycle mathematics syllabus on which they placed most emphasis, and about aspects of school mathematics which they enjoyed teaching most. Where possible, links between achievement on the calculator tests and teacher perspectives on teaching and learning mathematics are provided.

Teachers were asked to indicate the level of emphasis they placed on five aspects of school mathematics. Eighty-two percent of students were taught by teachers who indicated that they placed 'a lot' of emphasis on basic mathematical procedures, while 53% were taught by teachers who placed a similar level of emphasis on developing mathematical understanding (Table 7.15). It is apparent that problem solving (whether routine or non-routine) is emphasised to a lesser degree than basic procedures. In light of the introduction of calculators into Junior Cycle mathematics, it is interesting to observe that, while all almost all students were taught by teachers who reported that they emphasised mental arithmetic and estimation skills to some degree, just over one-third were taught by teachers who emphasised this aspect of mathematics ‘a lot’. As outlined in Chapter 1, the development of mental arithmetic and estimation skills is likely to take on an even greater importance in the future as calculators become more widely used.

Table 7.15 Emphasis Placed by Teachers on Various Aspects of School Mathematics – Percentages of Students

Aspect	Approximately how much emphasis do you place on the following aspects of school mathematics?			
	A Lot	Some	Very Little	Missing
Mental Arithmetic and Estimation Skills	33.8	62.4	0.0	3.8
Basic Mathematical Procedures (e.g., procedures related to operations with whole numbers, plotting graphs, solving equations)	81.9	10.3	4.0	3.8
Developing mathematical understanding (e.g., having student verbalise his/her method)	52.8	38.3	5.1	3.8
Developing mathematical applications (e.g., routine problems)	22.9	58.7	14.6	3.8
Developing mathematical problem solving (e.g., non-routine problems, mathematical investigations)	16.3	45.3	34.6	3.8

Standard errors are given in Appendix 7, Table A7.15

The mean achievement scores on the Calculator Inappropriate and Calculator Appropriate tests were compared for students whose teachers indicated differing levels of emphasis on each of the five aspects of school mathematics (see Table 7.16). In general, mean scores differences between adjacent levels (e.g., ‘A lot’ – ‘Some’) were small and not statistically significant (see Appendix 7, Table A7.16). This, in part, arises from the relatively large standard errors associated with several of the mean scores. However, a statistically significant difference was observed on the Calculator Inappropriate test between the mean scores of students whose teachers placed ‘very little’ emphasis on developing mathematical understanding, and those who placed ‘some’ emphasis on this area (in favour of the former). Statistically significant differences were observed on the Calculator Appropriate test between students whose teachers placed ‘very little’ emphasis on developing mathematical understanding, and students whose teachers placed ‘some’ emphasis on this area (in favour of the former), and between students whose teachers placed ‘a lot’ of emphasis on developing mathematical applications, and students whose teachers placed ‘some’ emphasis on this area (again in favour of the former). The extent to which these findings can be generalised should be considered in the context of the small number of teachers representing the students in these analyses.

Table 7.16 Mean Scale Scores of Students on the Calculator Inappropriate and Calculator Appropriate tests, by Levels of Teacher Emphasis on Aspects of School Mathematics

	Mean Score (Standard Error)	
	Calculator Inappropriate	Calculator Appropriate
Mental Arithmetic/Estimation Skills		
A lot	251.8 *(8.78)*	252.0 (8.96)
Some	248.3 *(5.26)*	248.0 (5.20)
Very Little	-----	-----
Missing	263.3 *(5.26)*	265.0 (9.13)
Basic Mathematics Procedures		
A lot	252.5 *(5.33)*	251.6 (5.37)
Some	239.3 *(6.13)*	243.2 (6.35)
Very Little	213.7 *(27.61)*	220.4 (28.8)
Missing	263.3 *(5.26)*	265.0 (9.13)
Developing Mathematical Understanding		
A lot	257.6 (4.79)	256.9 (5.66)
Some	234.9 (6.76)	236.0 (5.71)
Very Little	275.6 (12.85)	272.9 (15.76)
Missing	263.3 (5.26)	265.0 (9.13)
Developing Mathematical Applications		
A lot	259.5 (8.93)	260.5 (9.75)
Some	242.6 (6.14)	243.2 (5.98)
Very Little	261.6 (6.43)	257.1 (6.93)
Missing	263.3 (5.30)	265.0 (9.13)
Developing Mathematical Problem Solving		
A lot	259.2 (8.98)	260.3 (10.63)
Some	257.6 (6.47)	256.9 (6.49)
Very Little	234.3 (6.73)	234.5 (6.02)
Missing	263.3 (5.30)	265.0 (9.13)

*Standard error of the mean in brackets

It may be the case, of course, that these outcomes are influenced in some way by students' level of ability. Since information was available on whether individual students intended to take the Junior Certificate examination at Higher or Ordinary/Foundation levels, it was possible, using regression, to ascertain if, for performance on the Calculator Inappropriate and Calculator Appropriate tests, significant interactions occurred between expected Junior Certificate examination level (2 levels) and emphasis on specific aspects of school mathematics (3 levels). No significant interactions were observed.

Teachers were also asked to indicate the areas of mathematics in which their students had most difficulty. Eight areas were listed and teachers were invited to rank these areas from most difficult to least difficult. Almost 37% of students were taught by teachers who indicated that Trigonometry was the most difficult content area, while almost 30% were taught by teachers who indicated that Algebra was the most difficult (Table 7.17). Just 1% of students were taught by teachers who rated Statistics as the most difficult area. When mathematics areas were ordered in terms of their relative difficulty (i.e., based on the proportions of students whose teachers rated a topic as 'most difficult', 'second most difficult' or 'third most difficult'), Trigonometry was confirmed as the most difficult area (ranked 1), and Statistics as the least (ranked 8).

Table 7.17 Percentages of Students Whose Teachers Indicated Specified Levels of Probable Difficulty for Students, by Mathematics Area

Area**	With which areas of mathematics do your students have most difficulty? Most Difficult	Second Most Difficult	Third Most Difficult	Overall Ranking*
Sets	2.1	3.4	3.1	7
Number Systems	1.4	2.7	8.5	6
Applied Arithmetic /Measure	6.0	1.0	15.8	5
Algebra	29.7	21.5	19.6	2
Statistics	1.0	4.0	3.0	8
Geometry	16.1	23.8	21.7	3
Trigonometry	36.7	28.7	11.4	1
Functions and Graphs	8.9	13.7	29.9	4
Missing	5.8	5.8	5.8	---

Responses were 'missing' for 5.8% of students for each area of mathematics
*Based on average percentages of students whose teachers selected an area as the first, second or third most difficult.

Teachers were also asked to indicate which areas of mathematics they enjoyed teaching most. Again, eight areas were listed and teachers ranked them from most enjoyable to least enjoyable. Over one-third of students were taught by teachers who indicated that Algebra was the aspect of school mathematics that they enjoyed teaching most (Table 7.18). When the percentages of students whose teachers selected each area as most enjoyable, second most enjoyable or third most enjoyable were taken into account, however, Statistics ranked first (i.e., most enjoyable to teach), Algebra second, and Trigonometry third.

Table 7.18 Percentages of Students Whose Teachers Indicated Specified Levels of Enjoyment in Teaching Mathematics, by School Mathematics Content Area

Area	Which areas of mathematics do you enjoy teaching most?			
	Most Enjoyable	Second Most Enjoyable	Third Most Enjoyable	Overall Ranking*
Sets	11.5	15.8	7.8	5
Number Systems	1.6	5.7	8.4	8
Applied Arithmetic and Measure	3.8	6.3	6.9	7
Algebra	36.2	3.9	12.1	2
Statistics	22.1	15.0	18.1	1
Geometry	4.9	11.9	5.7	6
Trigonometry	8.3	21.1	18.9	3
Functions and Graphs	12.1	17.2	18.5	4
Missing	5.3	5.3	5.3	

Responses were 'missing' for 5.3% of students for each area of mathematics
*Based on average percentage of students whose teachers selected each area as the first, second or third most enjoyable

In order to ascertain how the effects of the Junior Certificate mathematics examination were perceived to impact on students' mathematics development, teachers were asked to indicate the extent to which the examination hampered students' progress in mathematics. While just 4% of students were taught by teachers who believed that the examination hampered students' progress 'a lot', roughly equivalent proportions were taught by teachers who believed that the examination hampered students' progress 'to some extent', 'very little' and 'not a lot' (Table 7.19). Hence, there does not appear to be consensus among teachers regarding the effect of the examination on students' progress in mathematics.

Table 7.19 Percentages of Students Taught by Teachers Who Indicated Varying Levels with which the Junior Certificate Mathematics Examination Hampered Students' Progress

	To what extent do you think children's mathematical progress is hampered by the Junior Certificate Examination?
Effect	Percentage of Students
Not at All	31.3 *(6.62)**
Very little	29.9 *(6.13)*
To some extent	30.7 *(5.24)*
A lot	4.2 *(2.97)*
Missing	3.8 *(2.27)*

*Standard error of the mean in brackets

TEACHERS' PHILOSOPHIES ABOUT TEACHING MATHEMATICS

Teachers were asked to respond to 5 items, devised by Becker and Anderson (1998), that sought to identify their beliefs/philosophies about the teaching of mathematics. Each item was presented as two statements at opposite ends of a continuum. For example, one item included the statements 'My role is that of a facilitator. I try to enable students to discover or construct concepts for themselves' and 'My role is that of explaining and showing students how to do mathematics and to assign suitable practice'. The teachers were asked to locate their relative position on each continuum by indicating their proximity to one or other of the statements at opposite ends. The percentages of students whose teachers selected each option is given in Table 7.20. The statements to the left of the table might be viewed as indicating a 'traditional' view of mathematics teaching and learning, while those at the right might be viewed as representing a more progressive view. While, in general, students were taught by teachers who leaned towards the progressive sides of the continua, this was not the case in relation to the first item. Here, 55% of students were taught by teachers who marked '1' or '2', indicating that they viewed their role as a provider of explanations and demonstrations about mathematics rather than a facilitator who enabled students to discover or construct concepts for themselves. On the other hand, teachers were strongly in agreement with the view that students should be interested and motivated when doing mathematics, rather than allowing the textbook to drive students' work.

When teachers' responses across the five continua were summed and re-arranged into quintiles (i.e., 1-5 = 1; 6-10 = 2 etc.), their aggregate scores tended to be distributed evenly around the mean (Table 7.20), except in the case of interest and motivation, where responses tended to be more 'progressive' than 'traditional'.

Table 7.20 Percentages of Students Whose Teachers Indicated Varying Degrees of Agreement with Statements Related to Beliefs About Teaching Mathematics

	Percentage of Students Whose Teachers Indicated Response (Standard Error)						
	1	2	3	4	5		Missing
My role is that of explaining and showing students how to do mathematics and to assign suitable practice.	24.9 *(5.19)*	30.1 *(5.87)*	19.7 *(4.83)*	14.7 *(4.51)*	3.1 *(2.22)*	My role is that of facilitator. I try to enable students to discover or construct concepts for themselves	7.6 *(3.29)*
The content of the mathematics curriculum is the most important thing to teach	4.2 *(2.29)*	12.2 *(4.64)*	35.1 *(6.17)*	22.3 *(4.68)*	18.7 *(5.97)*	The most important part of teaching is to encourage mathematical thinking among students; content is secondary	7.6 *(3.29)*
Students should become familiar with lots of mathematical facts and skills – later they will learn them in more depth and detail	6.3 *(4.23)*	23.0 *(5.81)*	30.1 *(5.73)*	24.6 *(5.56)*	6.6 *(3.81)*	It is better for students to understand and master a few complex ideas and skills even if breadth is limited until they are older	9.8 *(3.93)*
Interest and motivation need not drive students' work – it is more important that they learn the mathematics in textbooks	1.8 *(1.80)*	6.9 *(3.82)*	12.6 *(4.24)*	33.8 *(6.02)*	37.3 *(5.82)*	It is critical for students to become interested and motivated in doing mathematics	7.6 *(3.29)*
It is more important to give the whole class the same mathematics assignments, with clear directions and short time requirements to match attention spans and time schedules.	19.1 *(5.29)*	19.2 *(5.41)*	23.2 *(6.07)*	19.0 *(5.61)*	9.7 *(4.19)*	It is a good idea to have all sorts of activities going on in the mathematics class	9.8 *(3.93)*

Table 7.21 **Percentages of Students Whose Teachers Are at Each Quintile on the Beliefs About Teaching Mathematics Scale**

Mean Ratings of Teachers' Beliefs (SE), by Quintile					
1*	2	3	4	5	Missing
0.0	2.8	41.5	39.0	6.8	9.8
---	(1.79)	(6.57)	(5.90)	(3.62)	(3.93)

*1 indicates that students are taught by teachers holding more 'traditional' beliefs about the teaching of mathematics, while '5' indicates that they are taught by teachers holding more 'progressive' beliefs

It was of interest to ascertain if there might be differences in achievement on the Calculator Inappropriate and Calculator Appropriate tests between students whose teachers had different beliefs or philosophies about the teaching of mathematics. Table 7.22 shows the mean scores of students whose teachers were located at different points along the 'traditional-progressive' continuum (based on an average of the teacher ratings on individual items). Clearly, the mean scores on the Calculator Inappropriate test of students whose teachers are represented in quintiles 2-5 do not differ from one another. Similarly, the mean scores on the Calculator Appropriate test of students whose teachers are represented in quintiles 3 to 5 are not different from one another. While students whose teachers are represented in quintile 2 have a mean score on the Calculator Appropriate test that is almost 8 points lower than that of students with teachers in quintile 3, quintile 2 includes just 3% of students, and the standard error associated with the mean achievement of these students on the Calculator Appropriate test is very large. Hence, the mean score of students in the second quintile is not statistically significantly different from the mean scores of students in either quintile 3, 4 or 5.

Table 7.22 **Mean Scale Scores on the Calculator Inappropriate and Calculator Appropriate Tests of Students Whose Teachers Hold Varying Beliefs about the Teaching of Mathematics**

	Student Mean Scores (Standard Errors)					
	1*	2	3	4	5	Missing
Calculator Inapp.	---	249.0	250.0	248.6	249.5	256.4
		(32.79)	(6.56)	(8.72)	(11.09)	(14.54)
Calculator App.	---	241.2	248.9	250.5	250.3	255.2
		(29.94)	(6.54)	(9.00)	(12.78)	(13.74)

*1 indicates that students are taught by teachers holding more 'traditional' beliefs about the teaching of mathematics, while '5' indicates that they are taught by teachers holding more 'progressive' beliefs

COMMENTS ON TEACHER QUESTIONNAIRES

Most of the questionnaires (59 out of 64) contained at least one comment in an open comment sections. It should be recalled that teachers were asked to comment with specific regard to the target class, hence to a class following the course being tested up to the year 2002 and for which calculators were not allowed in the Junior Certificate mathematics examination. Collation and analysis of these comments suggest that the teachers' comments could be classified under a number of themes that are not mutually exclusive:

- Those that see the calculator as having some positive role or roles

- Those that see the calculator as having some negative role or roles
- Those that see the need for special emphasis to be given to development of numeracy / number sense in the light of calculator availability
- Those expressing views that are qualified with reference to context of calculator use, in areas such as curriculum, assessment and the abilities of the learners
- Those that expressed concerns about time available for teaching the course (particularly the Higher level course)

These themes are elaborated below with appropriate illustrative comments selected from the teacher questionnaires.

'The calculator has some positive roles'

One set of comments referred to the value of calculators in developing/maintaining general skills such as computation (perhaps after more basic skills had been developed), conceptual understanding, and even problem-solving ability – for example, '*Use of calculators fine for simple numerical calculations'* or *'I use it to deal with calculations so that we can focus on underlying ideas'* or *'I hope to do more problem-solving with the new syllabus – I think the use of calculators will help'*. 'Checking answers' was often mentioned as an appropriate use of calculators.

A second group of comments addressed specific topic areas for which the calculator was particularly useful. A number referred to Statistics and Trigonometry and to Applied Arithmetic and Measure – for example, '*for correction of homework in topics such as area and volume'* or *'Useful to teach BOMDAS,*[1] *inverses, standard deviation…'* or *'…using a calculator for trig would be easier than using log tables'*.

Another group of comments related to use of the calculator with particular groups of students, with some favouring use with weaker students or students with dyslexia. Others saw the calculator as having a role for the more able – e.g. '*Calculators are good for the weaker students, it improves their grades, gives them confidence in their ability to do maths. It prevents the more able student from making simple mistakes'* and '*Many students can master methods and concepts but because of constant calculation errors their confidence is undermined; hence they feel 'I can't do maths' – the calculator greatly reduces this'*.

Yet another group referred to the time saved, increased motivation, and error reduction by permitting calculator use – for example, '*Speeds up their homework, makes them more inclined to do it and cuts down on errors'* and *'Use of calculators will take the tedium out of some maths work and leave time for thinking'*.

'The calculator has negative effects'

Typical comments in this category referred to the danger of students becoming lazy or dependent on the calculator – for example, '*I think calculators make students lazy and have an adverse effect on their basic arithmetic'* or '*With frequent use of calculator pupils lose the ability to do ordinary calculations*' or '*…I feel they overuse calculators at the expense of developing mental arithmetic*'. '*They should not be allowed use it for fractions and integers'*. In contrast to the positive roles for the calculator mentioned earlier, other comments suggested that understanding would be harmed – '*It hampers their understanding of topics fully – they do procedures without understanding why'* or '*Students* [in this particular class] *are very weak, use of*

[1]Mnemonic for priority of operations: Brackets, Order, Multiply, Divide, Add, Subtract

calculator weakens their ability in numeracy – when they make mistakes they have no idea answer is wrong'. One respondent mentioned that calculator use would '*develop [unspecified] bad habits,*' and '*lower standards'.* Other comments include *'I never, ever, mention the word calculator in class – I assume pupils don't use them',* and *'Basic maths is about adding, subtracting, multiplying and dividing. I feel it is my responsibility to do these operations in class without the use of a calculator*'.

'Number sense needs to be developed'

Many teachers mentioned the importance of students developing number sense: for example, the ability to estimate, to carry out mental calculations, and to carry out basic arithmetic operations with whole numbers, fractions and decimals – for example, '*I feel students should be able to do basic mathematical operations in their heads rather than using a calculator to do them*'. Some saw these issues as highlighted by the impending introduction of calculators into the examinations. Some argued that there should be a calculator-free section in the Junior Certificate examination – '*...feel there should be some element of the exam relating to computational ability without the calculator*.'

There was little support among teachers' comments for the use of the calculator as a tool for teaching – '*I don't think they are a tool for teaching and learning but I do think they are a good aid for students when doing arithmetic calculations.'* One teacher gave an example of use of calculator as a tool for teaching and learning as follows: $25^2 + 38 = 625 + 38 = 663$ *− Turn calculator upside down − = egg*

'Calculator use should depend on the context'

Many teachers stated that they discouraged or did not allow calculator use with their current Third year classes because calculators are not permitted in the Junior Certificate mathematics examination – e.g. '*The students are not allowed to use them in the Junior Cert and hence should not depend on them for the work. I, however, do not mind them checking their work with a calculator'*. However, most of these teachers are happy to allow calculators when they are allowed in the Junior Certificate mathematics examination.

A few indicated that they do use calculators as part of the learning process; '*Once they have command of basic computational skills then use of calculator is an asset'* or '*If students are learning something new then not being allowed use a calculator can slow them down and they lose sight of the concepts being studied'*. One teacher in particular emphasised the value of graphics calculators. As indicated above, some teachers saw calculator use as appropriate for specific topics or with specific groups of students – for example, '*I believe in the use of calculators for statistics etc by very good maths students who have fully understood the concepts without calculators – this rarely applies to Third Years'*.

'There is insufficient time to teach the present course'

A concern voiced by many teachers was the shortage of time available for teaching the Junior Certificate mathematics courses, particularly the Higher-level course. '*The course is long and revision time is important – do not want to use up class time on developing mathematical problem-solving if it is not examined in Junior Cert*'. This concern was apparently independent of calculator issues. However, some teachers saw the calculator as a potential help in this respect, while others referred to lack of time in which to introduce the calculator − '*Use of calculators requires training – present syllabus is so extensive that we cannot cover it properly, hence have not used it* [calculator] *but can see possibilities'.*

The overall impression emerging from these comments is that most teachers would allow or encourage students to use calculators in mathematics work provided they were also allowed in the Junior Certificate mathematics examination, but many teachers placed conditions on this including: a separate examination paper to test numeracy skills without a calculator; calculator use for certain topics only (e.g. trigonometry and statistics), or simply for checking answers; and use with particular groups (e.g., high or low ability students only). There remain a small number of teachers who believe the calculator to be detrimental to students' mathematical development under any circumstances.

CONCLUSION

In considering the results reported in this chapter, a distinction should be made between the views of teachers regarding calculator usage for homework and schoolwork in mathematics, in the context of their students not being allowed to use calculators in the Junior Certificate mathematics examination, and the views that teachers might hold in other circumstances. Two-thirds of students were taught by teachers who did not approve of their students using calculators for homework, while just 14% were taught by teachers who approved of calculator usage in mathematics classes. On the other hand, almost three-quarters of students were taught by teachers who believed that Junior Cycle students should be allowed to use calculators for mathematics homework, while 70% were taught by teachers who believed that Junior Cycle students should be allowed use calculators in class. Significantly, 73% of students were taught by teachers who believed that calculators should be used in the Junior Certificate mathematics examination. Hence, it can be concluded that, while the majority of Third year students in 2001-02 were taught by teachers who were reluctant to endorse calculator usage for mathematics homework or in mathematics classes at school, only a small minority were taught by teachers who have more fundamental difficulties with the use of calculators for homework and classwork in mathematics, and in the Junior Certificate mathematics examination. According to teachers, the areas of mathematics in which it is most likely that a calculator would used as a tool for teaching and learning are Trigonometry, Applied Arithmetic and Measure, Statistics, and Functions and Graphs. Areas where teachers believed that a calculator might be somewhat less useful for this purpose were Sets, Algebra and Geometry.

The aspects of school mathematics that teachers regarded as being most difficult to teach to Third-year Junior Cycle students were Trigonometry, Algebra, Geometry, and Functions and Graphs. The areas regarded as being most enjoyable to teach were Statistics, Algebra, Trigonometry and Functions and Graphs. While the majority of teachers in the study tended to rate themselves as being somewhat more progressive than traditional in their approaches to and views about teaching mathematics, associations between teacher ratings and student achievement on the Calculator Inappropriate and Calculator Appropriate tests were not statistically significant.

The comments of teachers to an open-ended question at the end of the Teacher Questionnaire revealed a wide variety of views about how the calculator should (or should not) be used in school mathematics. While most teachers accepted that calculators would be used in mathematics classes in the future, many wished to attach a condition to their use – such as the use of the calculator for certain topics, by students of certain ability levels. A small minority indicated that they believed that the calculator could negatively affect students' mathematical development under any circumstances.

8 Conclusions

The main goals of Phase I of the study were to examine research related to the use of calculators in the teaching and assessment of mathematics, and to assess Junior Certificate students' mathematical knowledge in areas of the school mathematics curriculum where arithmetic or scientific calculators can have a bearing (Number Systems, Applied Arithmetic and Measure, and Statistics) – in a context in which most students did not use calculators in their mathematics classes, or in the Junior Certificate mathematics examination.

Phase I began with a review of the relevant research literature, focusing in particular on ways in which calculator usage might be expected to impact on performance, both in class settings and assessment situations. Based on this, a framework for the assessment of students' mathematics was devised. Then three calculator tests – a Calculator Inappropriate test (where calculators would not be available to students), a Calculator Optional test (where calculators would be available to some students only), and a Calculator Appropriate test (where all students would have access to a calculator) were developed and piloted. After making appropriate changes, the three Calculator tests were administered to a nationally representative sample of Third-year post-primary students in November 2001. The students and their mathematics teachers also completed short questionnaires that asked about use of and attitude towards calculators in a variety of situations. Some qualitative data were collected in the form of teachers' written comments on calculator-related issues on their questionnaire, and from students' rough work columns on the Calculator tests.

PERFORMANCE ON THE CALCULATOR TESTS

Performance on the Calculator tests was reported in terms of percent correct and scale scores. In the commentary that follows, performance is described with reference to the percent correct scores (though scale scores were also generated and used in comparisons of performance within and across tests).

The Calculator Inappropriate Test

The Calculator Inappropriate test assessed students' mathematics achievement on 25 items that could be done mentally or with minimal pen-and-paper work and would not normally be facilitated by access to a calculator. The mean score on this test was 60%. This seems a reasonable score given that there was no partial credit scoring system in operation and that the test was not part of a 'high stakes' assessment such as the Junior Certificate examination, and consequently not subject to the intense preparation usual for such tests. As predicted, the students were generally able to tackle the majority of the tasks successfully with mental methods and minimal use of pen and paper. The most difficult items on the Calculator Inappropriate test were in the area of Applied Arithmetic and Measure where the mathematics was embedded in a practical or applied context and could be considered as routine problem-solving, while the easiest items were in the area of Number Systems and involved the recall and implementation of routine computational facts and procedures.

The Calculator Optional Test

The Calculator Optional test assessed students' achievement on 32 items that might or might not be done more successfully with a calculator, depending on a number of factors including student familiarity with calculators (calculator literacy), student mathematical competence and confidence, teacher attitude to calculator use, and whether or not calculators are normally permitted in examinations. One half of the sample was randomly assigned to doing this test with access to calculators and the other half to doing the test without access. Consistent with the literature, the group with calculator access scored significantly better than the group without access (mean score: 59% versus 47%). This result establishes clearly that access to calculators has a positive effect on some aspects of mathematical achievement, even for students who have not been accustomed to using calculators for their mathematics work, at least in school. The positive effect of calculator access should prove to be even greater when students have been using calculators as a regular feature of their school mathematics classes. The qualitative data emerging from analysis of a sample of 50 student scripts indicated that a relatively small proportion of answers of students with calculator access (about 25%) were accompanied by written work while about 75% of the answers of those without calculator access were accompanied by such work.

Inspection of item difficulty levels for both calculator and non-calculator groups on the Calculator Optional test reveals that the largest differences (in favour of calculator group) were on items in the area of Number Systems in general, and involved the recall and use of routine computational procedures (for example, decimal operations), while the smallest differences were on items in Applied Arithmetic and Measure (e.g., volume of a cylinder) and in one aspect of Number Systems (i.e., fractions). It is reasonable to conclude that performance on items involving straightforward computation (for example, multiplication or division of decimals) is influenced more by calculator availability than items involving problem analysis.

The Calculator Appropriate Test

The Calculator Appropriate test assessed students' mathematical knowledge on 32 items for which availability of a calculator would be very likely to provide a distinct advantage. Most of the items involved using mathematical knowledge to solve problems set in a context involving 'realistic' data. Some questions focused on decontextualised computation in order to test efficient calculator usage. All students taking this test had access to calculators. In order to ensure adequate content coverage within limited testing time, the Calculator Appropriate test was divided into two forms and these were randomly assigned to students. Unlike the Calculator Inappropriate and Calculator Optional tests, there were no multiple-choice items on the Calculator Appropriate test. The test proved to be quite difficult for the students as reflected in the mean percent correct score across the two forms of 33%. This is not surprising given the absence of partial credit, students' typical performance on contextualised questions in the Junior Certificate mathematics examination, and their comparative unfamiliarity with calculators for non-trivial computation. The qualitative study data indicated that only 2% of students' answers in the sample of 50 scripts were accompanied by pen-and-paper work, which suggests that students availed of their calculators to help them answer the questions, but with limited success.

Variation in Achievement

Students in the high-ability range of mathematical achievement (those achieving at or above the 90th percentile) did not appear to benefit as much from calculator access on the Calculator Optional test as their lower-achieving peers. This can be attributed either to more efficient computation strategies of higher performers, or to a ceiling effect on the Calculator Optional test. In a similar vein, Hembree and Dessart (1992) noted that, in cases where skills acquisition was assessed with calculators, positive effects were found for students of low and average ability, but not for students of above average ability, on tests of computation.

STUDENTS AND CALCULATORS

The study looked at a number of relevant student variables and their relationship to achievement on the calculator tests. These included student gender, socio-economic status, calculator usage in subjects other than mathematics, attitude to mathematics, and attitude to calculators. The dependent variables were the scale scores achieved by pupils on the tests.

Gender

With regard to gender, no significant overall differences emerged between boys and girls although there were slight differences in favour of boys on the Calculator Inappropriate and Calculator Optional tests and a slight difference in favour of girls on the Calculator Appropriate test. This contrasts somewhat with the results of the recent PISA 2000 assessment of mathematical literacy where boys significantly outperformed girls in Ireland (Shiel et al., 2001). It may reflect the differing style of the PISA test from those used in the present study; the PISA mathematical literacy test focuses more on assessing how well students can use a range of mathematical competencies to solve realistic problems in a variety of contexts than on evaluating curriculum coverage. However, gender patterns in the current study concur with the somewhat earlier TIMSS study (Beaton et al., 1996) where there was no significant difference between Irish boys and girls, and in which the style of the questions was more traditional.

Socio-Economic Status

Predictably, there were positive correlations, albeit weak to moderate, between student SES and mathematics achievement on the three tests. These are similar to those obtained in other mathematics surveys including the PISA 2000 study (Shiel et al., 2001).

Calculator Use

Students in the study sample reported little use of calculators for classwork or homework in mathematics. This is not surprising given that they were preparing for an examination in which they would not be allowed access to calculators. However, students who reported regular usage of a calculator in Business Studies schoolwork and homework scored significantly higher on the three tests than students of Business Studies those who did not use a calculator for these purposes. This finding, which is consistent with outcomes reported by Hopkins (1992) and Payne (1992), highlights the value of familiarity with calculators in determining their usefulness in the hands of students engaged in mathematical tasks. On the other hand, students who never used a calculator for mathematics homework significantly outscored those who did on the Calculator Appropriate test. This may due to an interaction with mathematical ability. High-ability students may have little need to use a calculator with the kind of mathematics homework they are currently required to do.

Student Attitude to Mathematics

The three principal factors emerging from the factor analysis of the data obtained with the attitude to mathematics questionnaire – perceived usefulness of mathematics, like/dislike of mathematics, and self-concept in mathematics – are similar to the factors obtained in earlier studies of attitude to mathematics (e.g., Bitter & Hatfield, 1991; Ruthven, 1995). Correlations between the usefulness factor and performance on the calculator tests did not reach statistical significance. On the other hand, correlations between self-concept in mathematics and performance ranged from .38 for the Calculator Appropriate test to .43 for the Calculator Inappropriate test.

Student Attitude to Calculators

Factor analysis of the data on attitude to calculators produced more surprising results. The three factors emerging from the analysis were: (i) disposition towards calculator usage in mathematics; (ii) beliefs regarding an association between calculator usage and laziness or poor achievement in mathematics; and (iii) beliefs about the value of calculator use in subjects other than mathematics. There was a small but statistically significant negative correlation between disposition towards calculator usage in mathematics and achievement on the three calculator tests. This suggests that students who did well on the tests saw less value or relevance in calculators whereas those who did less well saw them as having more value and relevance for mathematics work. Teachers who foster the notion that the use of a calculator for mathematics work demonstrates lack of knowledge or incompetence could encourage this view. It is probably also related to the fact that students in the cohort surveyed would not be permitted to use calculators in the Junior Certificate mathematics examinations.

CALCULATORS AND THE JUNIOR CERTIFICATE EXAMINATION

A key aim of the study was to examine associations between calculator usage and performance on the Junior Certificate mathematics examination. This section provides some preliminary analyses of the potential impact of calculator availability on students taking different levels of the Junior Certificate mathematics examination. Phase II of the study will provide further insights into associations between performance on the calculator tests and on the Junior Certificate mathematics examination in a context in which calculators are available in the latter.

Intended Junior Certificate Level

Students planning to take the Higher-level paper in the Junior Certificate Mathematics examination (based on questionnaire responses in November 2001) achieved significantly higher mean scores on three calculator tests in comparison with students planning to take the Ordinary or Foundation levels. Although the mean score of Higher-level students who did not have access to a calculator was significantly higher than the mean score of Ordinary/Foundation level students taking the same test with access to a calculator, the difference between their respective mean scores was relatively small (about three percentage points). This finding emphasises the value of introducing calculators into the Junior Cycle Mathematics syllabus. Calculators can help improve the confidence and performance of lower-achieving students and improve the image of mathematics.

Actual Junior Certificate Level

In a second series of analyses, the performance of students on the calculator tests was compared with their actual performance on the Junior Certificate mathematics examination (taken in June 2002), though data on Junior Certificate performance was unavailable for 13% of subjects. Again, it was found that, on the Calculator Inappropriate test, Ordinary-level students with calculators approached the performance of Higher level students without calculators, though the difference in performance in favour of Higher level students was again statistically significant. An additional finding was that, whereas 18% of Higher-level students achieved scores on the Calculator Inappropriate test that were lower than the mean score on the test, 32% of Ordinary level students achieved scores that were higher than the mean, indicating some overlap in performance across these groups at the time of the year when the calculator tests were taken and on the material tested. Correlations between performance on the Calculator tests and on the Junior Certificate mathematics examination were quite strong when the grades of students taking different levels of the Junior Certificate mathematics examination were placed on the same underlying scale. For example, the correlation between performance on the Calculator Inappropriate test and performance on the Junior Certificate mathematics examination was .69, while that between performance on the Calculator Appropriate test and the Junior Certificate mathematics examination was .64.

TEACHERS AND CALCULATORS

This section summarises teachers' views about the value of calculators in teaching and learning mathematics, and their views about teaching mathematics.

Use of Calculators in Home and School

The Teacher questionnaire revealed that most teachers did not permit or approve of the use of calculators by their students for mathematics work in class or at home, at the time of the study. On the other hand, most teachers felt that students should be allowed to use calculators for mathematics work and in the Junior Certificate mathematics examination. This apparent inconsistency can be explained by the fact that the students of these teachers would not be permitted to use a calculator in their 2002 Junior Certificate mathematics examination whereas all students taking the same examination in subsequent years (2003 onwards) would be allowed to use a calculator. However, there remains a small number of teachers who are opposed to calculator use in Junior Certificate mathematics for any purpose.

Teaching and Learning Mathematics

Predictably, most teachers said they put a lot of emphasis on teaching basic mathematical procedures and relatively little emphasis on developing applications and problem solving skills – a finding also reported by Lyons et al. (2003) who found a stronger emphasis on teaching procedural knowledge than on teaching problem solving skills. Such findings probably reflect the balance of emphasis on these processes in the Junior Certificate mathematics syllabus and examination, the tendency of teachers to teach to the examinations, and teachers' perceptions of school mathematics. The questionnaire data suggested that teachers found Trigonometry and Algebra to be the most difficult areas to teach, while they considered the teaching of Statistics and Algebra to be the most enjoyable.

Teachers' Philosophies about Mathematics Teaching

A section of the Teacher Questionnaire was used to ascertain whether teachers in the study could be described as 'traditional' or 'progressive' in terms of their beliefs about mathematics teaching. The teachers' responses suggest that, in the main, they view their role in mathematics class as explaining and showing students how to do mathematics and assigning practice rather than provoking discussion and mathematical reasoning or facilitating the development of understanding through problem solving. This finding concurs with the findings of Lyons et al. (2003) study in which 20 Third-year mathematics classes in 10 schools were observed. Most teachers were heavily involved in the exposition of content followed by drill and practice. Individual interviews with the teachers revealed that they tended to equate learning of mathematics with the memorisation of formulae and procedures. These views are broadly in line with those of mathematics teachers in Ireland in the TIMSS Study (Beaton et al., 1996).

Teachers' Comments on Calculator Usage

The Teacher questionnaire included sections where teachers could supply their own comments to the main issues addressed if they so wished. Almost all teachers did, in fact, make at least one comment in the relevant sections. Many made a comment suggesting that they could see a positive role for the calculator in mathematics work and referred to activities such as checking answers. Some saw calculators as being helpful for weaker students or felt that calculators could take the drudgery out of computation. Others saw negative effects of using the calculator for mathematics, including students doing less mental arithmetic and performing procedures without understanding why. A few stated that if calculators are to be allowed in the examinations, a calculator-free section should be included. Some teachers indicated that they had had little opportunity to find out how calculators might be used in teaching and learning of mathematics. There was a small number of teachers who, if one is to judge by their comments, see no place at all for the calculator in Junior Cycle mathematics work in schools.

LOOKING TOWARDS PHASE II

The review of the literature in the earlier part of this report revealed a high degree of inconsistency among countries participating in international surveys in terms of calculator use for teaching, learning and assessment in mathematics. While mathematics teachers in some countries report regular use of the calculator for mathematics work, others report hardly any use at all. Also, degree of usage does not seem to be associated in any obvious way with achievement on the mathematics tests in these studies. Meta-analyses of controlled studies of calculator use in mathematics suggests that calculators do not have any detrimental effects on pen and paper skills and, in fact, can improve performance for some students. This was borne out by Phase I of the study when students who had access to calculators scored substantially higher than those with no access, on a test of items for which a calculator could be considered optional.

While most teachers seem not to be opposed to the introduction of calculators into mathematics work, there remains a small core of teachers who feel that calculators should not be used for mathematics work in junior secondary school. Therefore, it is timely that this study is being undertaken to provide scientific evidence on this important issue.

Phase II of the study, which is to be carried towards the end of 2004, is expected to provide insights into the effects of calculators on students' achievements in mathematics by investigating whether or not student mean scores on the calculator tests have changed. In addition, Phase II is expected to provide useful information on the actual use of calculators by teachers and students in the course of mathematics lessons, and on ways in which the Junior Certificate mathematics examination has evolved following the introduction of calculators into the Junior Certificate mathematics syllabus.

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APPENDICES

Appendix 3a – Categorisation of Test Items

Table A3.1 Categorisation of Items on the Calculator Inappropriate Test by Mathematics Content Area and Format, and Weighted Percent Correct Scores

Item	Content Area	Format	Percent Correct (SE)
1	Number	Multiple Choice	93.9 (1.01)
2	Number	Multiple Choice	87.4 (1.76)
3	Number	Multiple Choice	83.2 (1.98)
4	Number	Multiple Choice	76.0 (2.52)
5	Number	Multiple Choice	54.1 (3.14)
6	Number	Multiple Choice	54.8 (2.94)
7	Number	Multiple Choice	52.1 (3.81)
8	Number	Multiple Choice	74.3 (2.11)
9	Number	Multiple Choice	59.9 (2.18)
10	Number	Multiple Choice	44.1 (2.96)
11	Statistics	Multiple Choice	67.6 (2.69)
12	Applied Arithmetic/Measure	Multiple Choice	44.7 (2.94)
13	Applied Arithmetic/Measure	Multiple Choice	28.4 (3.05)
14	Applied Arithmetic/Measure	Multiple Choice	79.8 (1.39)
15	Applied Arithmetic/Measure	Multiple Choice	74.5 (1.51)
16	Number	Multiple Choice	57.8 (2.33)
17	Algebra	Short Con. Response	63.7 (3.10)
18	Applied Arithmetic/Measure	Short Con. Response	74.3 (2.49)
19	Applied Arithmetic/Measure	Short Con. Response	50.4 (2.59)
20	Number	Short Con. Response	50.1 (2.73)
21	Number	Short Con. Response	50.6 (2.80)
22	Applied Arithmetic/Measure	Short Con. Response	52.1 (2.73)
23	Applied Arithmetic/Measure	Short Con. Response	66.1 (2.93)
24	Applied Arithmetic/Measure	Short Con. Response	29.6 (2.73)
25	Applied Arithmetic/Measure	Short Con. Response	31.5 (3.35)

Table A3.2 Categorisation of Items on the Calculator Optional Test by Mathematics Content Area and Format, and Weighted Percent Correct Scores (Calculator and No Calculator Conditions)

Item	Content Area	Format	Percent Correct (SE) – All	Percent Correct (SE) –Calc.	Percent Correct (SE) – No Calc.
1	Number	Multiple Choice	58.3 (3.20)	56.7 (3.18)	57.8 (3.46)
2	Number	Multiple Choice	51.9 (2.38)	58.9 (2.68)	44.8 (2.85)
3	Statistics	Multiple Choice	75.5 (2.42)	78.4 (2.54)	72.5 (3.13)
4	Number	Multiple Choice	72.6 (2.45)	75.1 (2.39)	70.0 (2.99)
5	App. Arith & Meas.	Multiple Choice	81.7 (1.91)	83.2 (2.64)	80.1 (1.70)
6	App. Arith & Meas.	Multiple Choice	91.1 (1.09)	95.0 (0.91)	87.1 (1.66)
7	App. Arith & Meas.	Multiple Choice	53.4 (2.11)	53.9 (2.30)	52.9 (2.51)
8	App. Arith & Meas.	Multiple Choice	57.4 (3.12)	59.0 (3.49)	55.7 (3.08)
9	App. Arith & Meas.	Multiple Choice	31.6 (2.36)	34.4 (3.14)	28.7 (2.20)
10	App. Arith & Meas.	Multiple Choice	54.2 (2.06)	56.7 (2.95)	51.6 (2.56)
11	App. Arith & Meas.	Multiple Choice	68.0 (2.48)	69.1 (2.92)	67.0 (2.58)
12	App. Arith & Meas.	Multiple Choice	52.7 (2.36)	65.0 (2.82)	40.3 (2.55)
13	App. Arith & Meas.	Multiple Choice	40.8 (2.43)	42.8 (2.95)	38.7 (2.43)
14	Number	Short Con. Resp	86.4 (1.48)	93.6 (1.08)	79.1 (2.38)
15	Number	Short Con. Resp	79.0 (1.48)	93.7 (1.86)	64.1 (2.73)
16	Number	Short Con. Resp	79.9 (1.54)	85.0 (1.55)	74.7 (2.34)
17	Number	Short Con. Resp	67.4 (1.60)	88.1 (1.05)	46.5 (3.02)
18	Number	Short Con. Resp	59.2 (1.53)	89.9 (1.64)	28.0 (2.36)
19	Number	Short Con. Resp	76.2 (1.94)	82.9 (1.69)	69.3 (3.23)
20	App. Arith & Meas.	Short Con. Resp	60.8 (2.76)	63.7 (2.99)	57.9 (3.15)
21	App. Arith & Meas.	Short Con. Resp	48.6 (3.06)	57.0 (2.75)	40.2 (3.67)
22	App. Arith & Meas.	Short Con. Resp	39.5 (2.25)	34.4 (2.56)	44.6 (2.74)
23	Algebra	Short Con. Resp	59.9 (3.34)	63.8 (3.57)	55.9 (3.82)
24	Algebra	Short Con. Resp	34.4 (3.30)	33.8 (3.12)	35.0 (3.75)
25	Algebra	Short Con. Resp	44.7 (3.34)	50.5 (3.44)	38.8 (3.64)
26	Algebra	Short Con. Resp	28.7 (2.86)	33.4 (3.10)	23.9 (2.97)
27	Number	Short Con. Resp	64.7 (2.36)	80.6 (2.12)	48.6 (3.13)
28	Number	Short Con. Resp	6.3 (1.01)	10.4 (2.00)	2.18 (0.62)
29	Statistics	Short Con. Resp	28.1 (2.79)	32.6 (2.93)	23.6 (3.10)
30	App. Arith & Meas.	Short Con. Resp	23.7 (2.21)	30.8 (2.48)	16.6 (2.33)
31	App. Arith & Meas.	Short Con. Resp	13.9 (2.11)	16.3 (2.39)	11.4 (2.09)
32	App. Arith & Meas.	Short Con. Resp	17.7 (2.37)	24.5 (3.02)	10.9 (2.13)

Table A3.3 Categorisation of Items on the Calculator Appropriate Test by Mathematics Content Area and Format, and Weighted Percent Correct Scores

Item	Content Area	Format	Percent Correct (SE)*
C1-1 (1)	App. Arith & Meas.	Short Constructed Response	76.1 (2.21)
C1-2 (2)	App. Arith & Meas.	Short Constructed Response	68.3 (3.44)
C1-3 (3)	App. Arith & Meas.	Short Constructed Response	52.1 (2.78)
C1-4 (4)	Number	Short Constructed Response	53.9 (3.31)
C1-5 (5)	Number	Short Constructed Response	53.8 (4.56)
C1-6 (6)	Number	Short Constructed Response	26.3 (2.06)
C1-7 (7)	Number	Short Constructed Response	0.64 (0.30)
C1-8 (8a)	Statistics	Short Constructed Response	60.6 (3.53)
C1-9 (8b)	Statistics	Short Constructed Response	17.0 (2.48)
C1-10 (8c)	Statistics	Short Constructed Response	49.8 (2.60)
C1-11 (9)	App. Arith & Meas.	Short Constructed Response	49.0 (2.33)
C1-12 (10)	App. Arith & Meas.	Short Constructed Response	---
C1-13 (11)	App. Arith & Meas.	Short Constructed Response	10.3 (2.08)
C1-14 (12)	App. Arith & Meas.	Short Constructed Response	10.6 (1.81)
C1-15 (13)	App. Arith & Meas.	Short Constructed Response	26.5 (3.44)
C1-16 (14)	App. Arith & Meas.	Short Constructed Response	8.3 (1.88)
C2-1 (1)	App. Arith & Meas.	Short Constructed Response	85.7 (1.35)
C2-2 (2)	Number	Short Constructed Response	77.0 (2.24)
C2-3 (3)	Number	Short Constructed Response	18.6 (2.08)
C2-4 (4)	Number	Short Constructed Response	12.1 (1.87)
C2-5 (5)	Number	Short Constructed Response	0.71 (0.26)
C2-6 (6)	Number	Short Constructed Response	31.5 (2.96)
C2-7 (7)	App. Arith & Meas.	Short Constructed Response	27.5 (2.89)
C2-8 (8)	App. Arith & Meas.	Short Constructed Response	34.0 (3.20)
C2-9 (9)	App. Arith & Meas.	Short Constructed Response	4.2 (0.99)
C2-10 (10)	App. Arith & Meas.	Short Constructed Response	1.88 (0.57)
C2-11 (11)	App. Arith & Meas.	Short Constructed Response	4.93 (0.97)
C2-12 (12)	App. Arith & Meas.	Short Constructed Response	43.5 (3.47)
C2-13 (13)	App. Arith & Meas.	Short Constructed Response	4.24 (1.07)
C2-14 (14a)	Statistics	Short Constructed Response	57.4 (2.69)
C2-15 (14b)	Statistics	Short Constructed Response	8.40 (1.61)
C2-16 (14c)	Statistics	Short Constructed Response	28.1 (2.79)

Original Item Numbers in Brackets
Item C1-12 (10) was excluded from scaling/percent correct analysis because it contained an error.

Appendix 3B – Sample Parallel Items

The items in this appendix are similar to those that appeared on the Calculator Tests. Each item is classified according to the test from which it was drawn (Calculator Inappropriate, Calculator Optional and Calculator Appropriate) and the mathematics content area it assesses.*

<table>
<tr><th>Calculator Inappropriate Items (A)</th><th>Calculator Optional Items (B)</th></tr>
<tr><td>A1 Which of the following numbers is equal to $\frac{3}{10}$?
(A) 0.03
(B) 0.3
(C) 3.0
(D) 30

Content Area: Number Systems
Difficulty Level: Easy (87%)</td><td>B1 A pack of 120 identical cards is 3 cm thick. How thick is one card?
(A) 0.0025 cm
(B) 0.025 cm
(C) 0.25 cm
(D) 0.4 cm

Content Area: Applied Arithmetic and Measure
Difficulty Level: With Calculator – Average (65%)
Without Calculator – Moderately Difficult (40%)
Overall – Average (53%)</td></tr>
<tr><td>A2 Jane bought a CD for €5 and sold it for €7. What was her percentage profit?
(A) 2%
(B) 4%
(C) 20%
(D) 40%

Content Area: Applied Arithmetic and Measure
Difficulty Level: Moderately Difficult (45%)</td><td>B2 Multiply: 6.4 × 2.5

Answer______________

Content Area: Number Systems
Difficulty Level: With Calculator - Easy (94%)
Without Calculator – Average (64%)
Overall – Moderately Easy (79%)</td></tr>
<tr><td>A3 Aoife runs 4 km each evening in the gym. The track she runs is $\frac{1}{8}$ km long. How many times does Aoife run around the track each evening?

Answer_______________

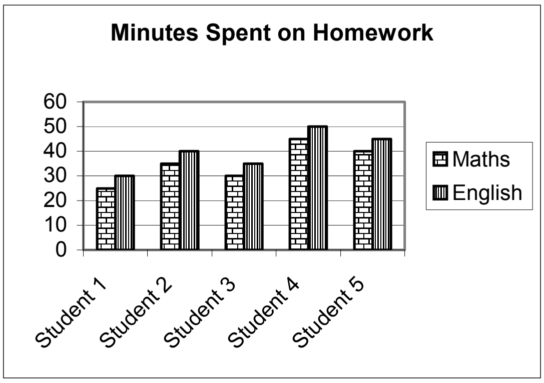
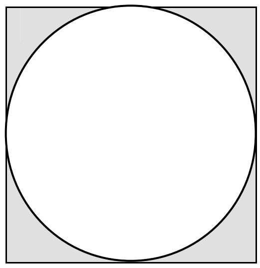
Content Area: Applied Arithmetic and Measure
Difficulty Level: Moderately Easy (74%)</td><td>B3
<table><tr><th>Song</th><th>Time taken</th></tr><tr><td>1. I need your love</td><td>3 minutes 15 seconds</td></tr><tr><td>2. You got me babe</td><td>2 minutes 55 seconds</td></tr><tr><td>3. Loving heart</td><td>4 minutes 5 seconds</td></tr><tr><td>4. My baby left me</td><td>3 minutes 22 seconds</td></tr><tr><td>5. Mama told me</td><td>3 minutes 18 seconds</td></tr></table>
Ronan plays a CD on his computer CD player. The time taken for each song is given in the table. How much time did the 5 songs take altogether?

Answer______________

Content Area: Applied Arithmetic and Measure
Difficulty Level: With Calculator – Difficult (34%)
Without calculator – Moderately Difficult (45%)
Overall – Moderately Difficult (40%)</td></tr>
<tr><td>A4 A class has 25 students. The ratio of boys to girls is 3:2 How many girls are in the class?
Answer_______________

Content Area: Number Systems
Difficulty Level: Average (51%)</td><td>B4 If a = 3 and b = $\frac{1}{4}$, find the value of 5a + 20b
Answer_____________

Content Area: Algebra
Difficulty Level: With Calculator – Average (64%)
Without Calculator – Average (60%)
Overall – Average (60%)</td></tr>
</table>

Calculator Appropriate Items (C)	
C1 Evaluate: $\frac{(9.8)^3 - (29.2)^2}{0.0025}$ Answer______________ *Content Area: Number Systems* *Difficulty Level: Difficult (26%)*	**C3** How many 700 millilitre bottles of port can be filled from a 350 litre barrel? Answer______________ *Content Area: Applied Arithmetic and Measure* *Difficulty Level – Difficult (28%)*
 **C2** The bar chart shows time (in minutes) spent on homework in Maths and English by a group of 5 students. What is the mean number of minutes spent on maths homework by the 5 students? Answer______________ *Content Area: Statistics* *Difficulty Level: Average (61%)*	**C4** A circle is inscribed in a square as shown in the diagram. The length of the diameter of the circle is 8cm. The area of a circle is πr^2.  Calculate the area of the shaded region Use π on your calculator or take $\pi = 3.14159$. Give your answer correct to two decimal places. Answer______________________ *Content Area: Applied Arithmetic and Measure* *Difficulty Level: Difficult (2%)*

*The percent correct score following each item is the weighted proportion of students in Third year who were given full credit on the corresponding item on the relevant Calculator Test. The following descriptors are used to interpret item difficulties: Easy (80%+); Moderately easy (70%-79%); Average (50%-69%); Moderately difficult (40%-49%) and Difficult (below 40%).

Appendix 4: Additional Tables – Chapter 4

Table A4.11. Comparison of Percent Correct Scores on Items on the Calculator Optional Test for Students With/Without Access to Calculators

Item	Diff	SE Diff	Confidence Interval CI 95 L to CI 95 U
1	-1.1	4.70	–16.0 to 13.8
2	14.1	3.91	**1.7 to 26.5**
3	5.9	4.03	–6.8 to 18.6
4	5.1	3.83	–7.0 to17.2
5	3.1	3.14	–6.8 to 13.0
6	7.9	1.89	**1.9 to 13.9**
7	1.0	3.40	–9.8 to 11.8
8	3.3	4.65	–11.4 to 18.0
9	5.7	3.83	–6.4 to17.8
10	5.1	3.91	–7.3 to 17.5
11	2.1	3.90	–10.2 to 14.4
12	24.7	3.80	**12.7 to 36.7**
13	4.1	3.82	–8.0 to 16.2
14	14.5	2.61	**6.2 to 22.8**
15	29.6	3.30	**19.2 to 40.0**
16	10.3	2.81	**1.4 to 19.2**
17	41.6	3.20	**31.5 to 51.7**
18	61.9	2.87	**52.8 to 71.0**
19	13.6	3.65	**2.1 to 25.1**
20	5.8	4.34	–7.9 to 19.5
21	16.8	4.59	**2.3 to 31.3**
22	-10.2	3.75	–22.1 to 1.7
23	7.9	5.23	–8.6 to 24.4
24	-1.2	4.88	–16.6 to 14.2
25	11.7	5.01	–4.1 to 27.5
26	9.5	4.29	–4.1 to 23.1
27	32.0	3.78	**20.0 to 44.0**
28	8.2	2.09	**1.6 to 14.8**
29	9.0	4.27	–4.5 to 22.5
30	14.2	3.40	**3.4 to 25.0**
31	4.9	3.17	–5.1 to 14.9
32	13.6	3.70	**1.9 to 25.3**

See also, Table 4.11, Chapter 4

Appendix 5: Additional Tables – Chapter 5

Table A5.10 Percentages/Standard Errors of Students Indicating Various Levels of Calculator Usage in Selected School Subjects

	Often	Some-times	Never	Does Not Apply	Ambiguous	Missing
Mathematics	0.63	11.1	76.5	3.13	1.19	7.5
	(0.26)	*(2.09)*	*(2.49)*	*(0.45)*	*(0.35)*	*(2.14)*
Business Studies	44.88	15.7	11.2	20.20	1.4	6.66
	(3.20)	*(1.61)*	*(1.31)*	*(3.10)*	*(0.32)*	*(2.24)*
Science	1.7	13.1	60.3	13.7	1.5	9.7
	(0.66)	*(1.63)*	*(2.34)*	*(1.73)*	*(0.36)*	*(2.27)*
Technology	0.1	2.0	32.4	49.4	0.7	15.4
	(0.05)	*(0.60)*	*(2.07)*	*(3.11)*	*(0.24)*	*(2.38)*

Refers to Table 5.10, Chapter 5

Table A5.17 Standard Errors of Percentages of Students Indicating Various Levels of Agreement with Statements about Attitudes to Mathematics

	Statement	Strongly Agree	Agree	Disagree	Strongly Disagree	Missing
a.	When I do mathematics, I sometimes get totally absorbed	*0.67*	*2.05*	*1.77*	*1.78*	*2.27*
b.	Because doing mathematics is fun, I wouldn't want to give up	*0.77*	*1.73*	*2.00*	*1.90*	*2.27*
c.	I get good marks in mathematics	*1.02*	*2.69*	*2.14*	*0.81*	*2.32*
d.	Mathematics is one of my best subjects	*1.03*	*2.30*	*2.34*	*1.71*	*2.30*
e.	Mathematics is one of my favourite subjects	*1.03*	*1.75*	*2.24*	*1.81*	*2.31*
f.	I have always done well in mathematics	*1.08*	*2.75*	*2.29*	*1.21*	*2.32*
g.	Mathematics is a useful subject for everyday life	*2.14*	*1.97*	*1.10*	*1.00*	*2.31*
h.	Mathematics is important for getting a job	*2.05*	*1.98*	*1.01*	*0.52*	*2.31*
i.	I like arithmetic	*1.28*	*2.64*	*2.19*	*1.34*	*2.28*
j.	I like doing calculations	*1.09*	*2.18*	*1.85*	*1.14*	*2.25*
k.	I like doing sums when I know the method	*1.59*	*2.51*	*1.04*	*1.07*	*2.29*
l.	I like tackling problems	*0.71*	*1.99*	*1.88*	*1.26*	*2.29*
m.	I like everyday mathematics problems	*0.75*	*1.97*	*1.97*	*1.27*	*2.31*
n.	I lake doing length, area, and volume problems	*0.77*	*1.88*	*2.03*	*1.77*	*2.30*
o.	I like geometry	*0.79*	*2.83*	*2.28*	*1.69*	*2.30*
p.	I like algebra	*0.96*	*2.15*	*2.21*	*1.51*	*2.32*
q.	I like trigonometry	*0.76*	*2.95*	*2.48*	*1.85*	*2.47*
r.	I like statistics	*1.05*	*2.34*	*1.53*	*1.51*	*2.33*

N = 1464 (weighted)

Refers to Table 5.17, Chapter 5

Table A5.19 Standard Errors Associated with Students' Mean Scores on the Calculator Inappropriate, Calculator Optional, and Calculator Appropriate Tests, by Attitude Towards Mathematics

	High	Medium	Low	Missing
Attitude Factor/Test				
Disposition				
Calculator Inappropriate	4.71	5.35	4.87	6.86
Calculator Optional	4.15	5.20	4.82	7.40
Calculator Appropriate	4.61	5.52	4.73.	6.69
Usefulness				
Calculator Inappropriate	5.89	4.67	4.95	9.98
Calculator Optional	4.76	5.00	5.53	13.97
Calculator Appropriate	5.33	5.14	5.09	11.74
Self-Concept				
Calculator Inappropriate	4.63	3.81	5.05	8.61
Calculator Optional	4.50	3.68	4.97	11.64
Calculator Appropriate	5.16	3.57	4.83	10.50

Refers to Table 5.19, Chapter 5

Table A5.20 Standard Errors for Percentages of Students' Indicating Various Levels of Agreement with Statements about Attitudes to Calculators

	Statement	Strongly Agree	Agree	Disagree	Strongly Disagree	Missing
a.	I think a calculator can help me to get better marks in school mathematics	*2.21*	*1.54*	*1.33*	*0.72*	*2.29*
b.	I think a calculator could make me lazy at school mathematics	*1.42*	*1.77*	*1.62*	*1.27*	*2.30*
c.	I think a calculator could help get me better at mathematics	*1.41*	*1.92*	*2.24*	*0.95*	*2.29*
d.	A calculator should be used only by a student who has a lot of difficulty at school	*1.07*	*1.55*	*1.87*	*1.11*	*2.30*
e.	I think I should be allowed to use a calculator for mathematics homework	*1.80*	*1.84*	*1.51*	*0.82*	*2.30*
f.	I think I should be allowed to use a calculator for homework in other subjects	*1.42*	*2.15*	*1.10*	*0.80*	*2.31*
g.	I think I should be allowed to use a calculator in mathematics class	*1.59*	*1.70*	*1.67*	*0.75*	*2.30*
h.	I think I should be allowed to use a calculator for classwork in other subjects	*1.35*	*1.99*	*1.57*	*0.64*	*2.31*
i.	I think I should be allowed to use a calculator in the Junior Certificate examination	*2.53*	*1.80*	*1.27*	*0.87*	*2.30*

N = 1464 (weighted)

Refers to Table 5. 20, Chapter 5

Table A5.22 Standard Errors for Students' Mean Scores on the Calculator Inappropriate, Calculator Optional, and Calculator Appropriate Tests, by Attitude Towards Calculators

Disposition	High	Medium	Low	Missing
Test				
Calculator Inappropriate	5.91	4.96	4.22	7.74
Calculator Optional	5.67	5.20	4.00	11.77
Calculator Appropriate	5.83	4.54	4.81	10.36

Refers to Table 5.26, Chapter 5

Appendix 7: Additional Tables – Chapter 7

Table A7.7 Teacher Reports of Student Calculator Usage during Homework, by Area of Mathematics – Standard Errors

Area of Mathematics	For which topics in mathematics might a calculator be used by your students at home?			
	A lot	To some extent	Never	Missing
Sets	---	4.99	6.34	4.28
Number Systems	4.33	5.93	6.98	4.67
Applied Arithmetic and Measures	6.63	7.80	3.51	4.65
Algebra	2.52	6.35	6.74	4.58
Statistics	6.27	6.27	5.99	4.56
Geometry	2.02	4.82	6.65	4.55
Trigonometry	7.24	7.32	5.07	4.39
Functions and Graphs	3.30	5.82	6.65	4.53

Refers to Table 7.7

Table A7.11 Teacher Reports of Calculator Usage in Mathematics Classes, by Mathematics Topic – Standard Errors

	For which topics in mathematics is the calculator used in class?			
Topic	A lot	To some extent	Never	Missing
Sets	---	2.20	3.82	3.12
Number Systems	1.36	4.92	6.08	3.35
Applied Arithmetic and Measures	4.71	3.50	6.58	2.95
Algebra	--	3.63	4.77	3.12
Statistics	3.66	5.19	6.85	2.95
Geometry	--	3.22	4.68	3.35
Trigonometry	4.11	3.24	6.01	2.95
Functions and Graphs	2.87	1.94	4.88	3.35

Refers to Table 7.11

Table A7.14 Areas of School Mathematics in Which Teachers Feel Calculators Can be Used as Tools for Teaching and Learning – Standard Errors

Area	In which areas of school mathematics do you think a calculator might be used as a tool for teaching and learning mathematics, and not simply for computational work?			
	A lot	To some extent	Never	Missing
Sets	1.43	7.71	7.45	7.83
Number Systems	4.51	7.65	6.10	7.12
Applied Arithmetic and Measures	7.42	5.96	1.53	5.31
Algebra	1.43	8.35	5.01	7.88
Statistics	7.23	7.18	---	5.51
Geometry	3.33	7.38	5.66	7.69
Trigonometry	7.06	6.62	----	5.31
Functions and Graphs	6.17	7.58	5.66	6.62

Refers to Table 7.14

Table A7.15 Teachers' Emphasis on Various Aspects of School Mathematics – Standard Errors

Aspect	Approximately how much emphasis do you place on the following aspects of school mathematics?			
	A Lot	Some	Very Little	Missing
Mental Arithmetic and Estimation Skills	6.27	6.13	---	2.27
Basic Mathematical Procedures (e.g., procedures related to operations with whole numbers, plotting graphs, solving equations)	5.25	3.60	2.85	2.27
Developing mathematical understanding (e.g., having student verbalise his/her method;	7.13	7.31	2.75	2.27
Developing mathematical applications (e.g., routine problems)	6.04	6.72	4.82	2.27
Developing mathematical problem solving (e.g., non-routine problems, mathematical investigations)	5.03	7.58	7.48	2.27

Refers to Table 7.15

Table A7.16 Differences between Students' Mean Scores on the Calculator Inappropriate test, and 95% Confidence Intervals around Mean Score Differences, by Teaching Emphasis on Selected Aspects of School Mathematics

	Calculator Inappropriate Test		
	Difference between Means	Standard Error of the Difference	95% Confidence Interval
Mental Arithmetic/Estimation Skills			
A lot-some	---	---	---
Very little-some	3.5	10.23	-22.3 to 29.3
Missing-some	15.0	7.44	-3.7 to 33.8
Basic Mathematics Procedures			
A lot-some	13.2	8.12	-7.3 to 33.7
Very little-some	-25.6	28.28	-96.6 to 45.7
Missing-some	24.0	8.07	**3.6 to 44.3**
Developing Mathematical Understanding			
A lot-some	22.7	8.28	1.8 to 43.6
Very little-some	40.7	14.52	**4.1 to 77.4**
Missing-some	28.4	8.56	**6.8 to 50.0**
Developing Mathematical Applications			
A lot-some	16.9	10.84	–10.4 to 44.3
Very little-some	19.0	8.89	–3.4 to 41.4
Missing-some	20.7	8.08	**0.3 to 41.1**
Developing M. Problem Solving			
A lot-some	1.6	11.07	–26.3 to 29.5
Very little-some	-23.4	9.34	–46.9 to 0.2
Missing-some	5.7	8.34	–15.4 to 26.7

Refers to Table 7.16