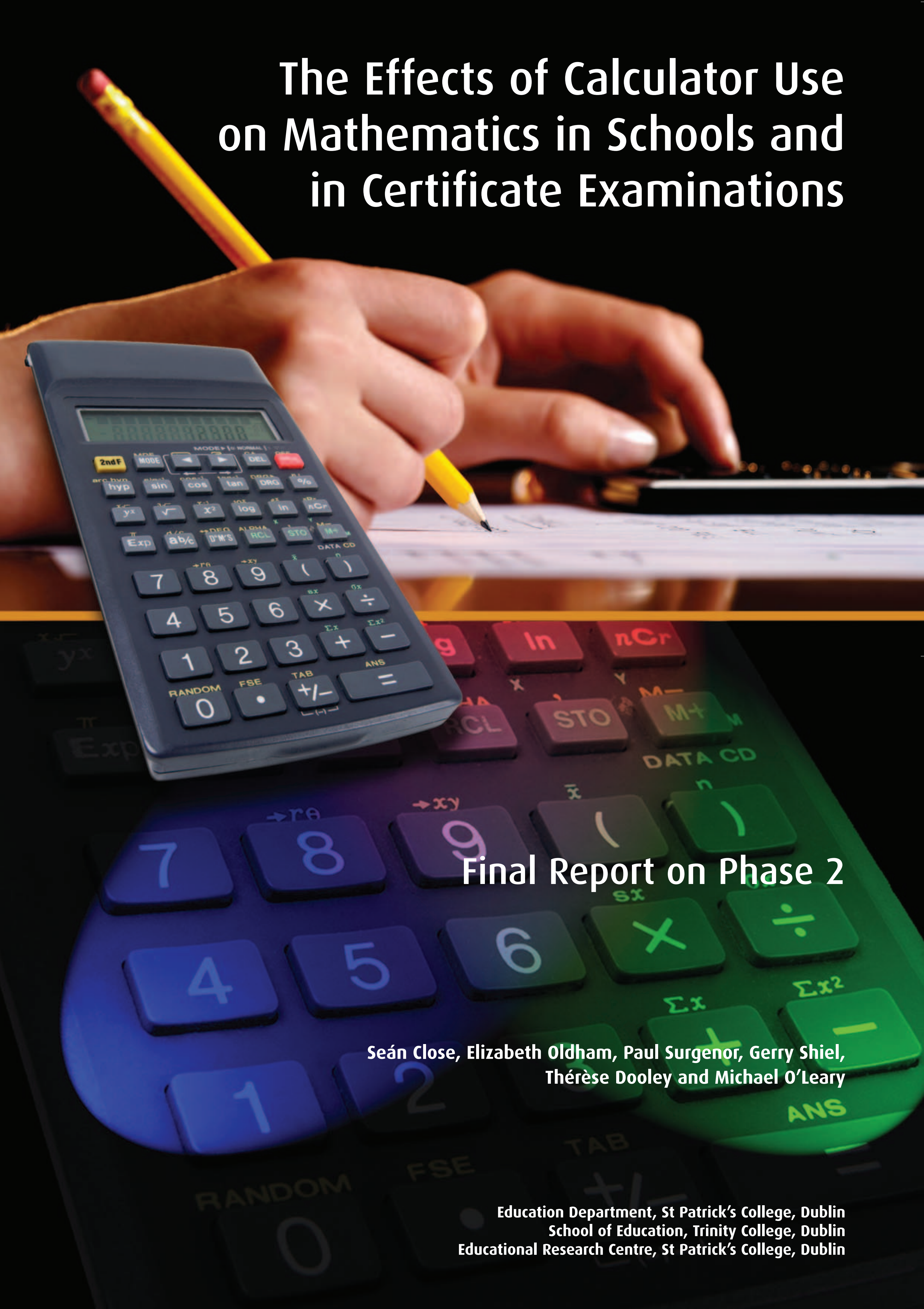

The Effects of Calculator Use on Mathematics in Schools and in Certificate Examinations

Final Report on Phase 2

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FINAL REPORT ON PHASE II

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Preface

In 1999, the Department of Education and Science awarded a contract for conducting a study on 'The Effects of Calculator Use 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 inclusion of calculators in the revised Junior Certificate mathematics syllabus (introduced in September 2000, for first examination in June 2003), 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 have to be studied over a number of years (i.e., before and after the formal introduction of calculators into the Junior Cycle mathematics syllabus/Junior Certificate mathematics examination). Phase I of the study was the subject of an earlier report (Close, Oldham, Shiel, Dooley, Hackett & O'Leary, 2004), and involved administering, in November 2001, 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 have had access to a calculator when attempting the Junior Certificate mathematics examination in June 2002. Phase II, the main focus of this report, involved administering the same tests, in November 2004, to a similar sample of students who had studied the revised Junior Certificate mathematics syllabus, and who would have access to a calculator when sitting the Junior Certificate mathematics examination in June 2005.

Research Questions

In Phase II of the study, when students had experience in using calculators in their mathematics programmes in line with the revised Junior Cycle mathematics syllabus, and would have access to calculators in the Junior Certificate mathematics examination, the following research questions were addressed:

- Will the levels of performance without calculators be maintained from 2001 to 2004?
- Will the level of performance with calculators improve between 2001 and 2004?
- Of the content areas and skills assessed in the tests, which benefit most, and which least, from calculator access?
- To what extent are calculators being used in Junior Certificate mathematics classes in 2004?
- What kinds of calculator use are taking place in these classrooms?
- What are teachers' and students' experiences of increased calculator use, and what are their attitudes in the light of these?
- How do teachers' and students' attitudes relate to performance in mathematics?

- What policies govern calculator use in schools?
- What links are there between performance on the calculator-based tests and performance on the 2005 Junior Certificate mathematics examination?

Organisation of the Report

This report is divided into nine chapters. The first chapter sets the context of the study. Chapter 2 is a review of the national and international literature on calculators in mathematics that builds on Close et al.'s (2004) review. In Chapter 3, the framework for the calculator tests is outlined and revisions to the student and teacher questionnaires used in 2001 are described. In Chapter 4, the sampling of schools and students is discussed, as are procedures used to scale and analyse the data. Chapter 5 provides a description and analysis of the performance of students in 2004 on the calculator tests and compares the performance of students in 2001 and 2004. It also examines the effects of calculator access on performance on key test items. In Chapter 6, the focus is on student perceptions of, and attitudes to, calculators and calculator use and the relationship of these to performance on the tests. Chapter 7 addresses relationships between teacher perceptions and attitudes to calculators and calculator use and student performance on the tests. Chapter 8 looks at the relationship between students' performance on the calculator tests and their performance on the Junior Certificate mathematics examination. Chapter 9 provides some discussion of findings and sets out recommendations arising from them.

Acknowledgements

The research team wishes to acknowledge with thanks the many teachers and students who participated in the different elements of the 2004 study. Without their co-operation, it would not have been possible to conduct the study.

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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 revised test booklets and questionnaires. The work of the Third-year mathematics students from St. Patrick's College, who assisted with the scoring of tests and questionnaires, is also acknowledged.

Executive Summary

In September 2000, a revised Junior Certificate mathematics syllabus was implemented in post-primary schools, for first examination in June 2003. Unlike its predecessor (the 'pre-2000' syllabus), the revised syllabus explicitly included the use of calculators in mathematics classes. In line with this, students were permitted to use calculators in the Junior Certificate mathematics examination from June 2003 onwards. In the context of introducing calculators to the syllabus and to the Junior Certificate mathematics examination, the Department of Education and Science commissioned a research study on 'The Effects of Calculator Use on Mathematics in Schools and in the Junior Certificate Examination' (henceforth called 'The Calculator Study). The study was conducted over two phases. Phase I (2000-2003) involved a cohort of Third-year students and their teachers, who worked under the pre-2000 syllabus where calculators were not mentioned in the syllabus, and were not permitted in the Junior Certificate mathematics examination. Phase II (2003-05) involved a cohort that had studied the revised syllabus, and expected to have access to calculators in the Junior Certificate mathematics examination. Phase I of the study, for which fieldwork was conducted in November 2001, involved five key elements: completion of a literature review on the effects of calculators on students' mathematical achievement; administration of three calculator tests to a representative sample of students in Third year in post-primary schools; administration of a questionnaire about calculator usage at home and at school to these students; administration, to their teachers, of a questionnaire about use of and attitude towards calculators in Junior Certificate mathematics classes; and comparison of the performance of the students on the calculator tests and on the 2002 Junior Certificate mathematics examination.

Phase II, for which fieldwork was conducted with a new cohort of students and their teachers in November 2004, also involved five elements: an updating of the literature review; administration of the three calculator tests; administration of a revised student questionnaire; administration of an expanded questionnaire for teachers; and a comparison of performance on the calculator tests and on the 2005 Junior Certificate mathematics examination.

The Literature Review

The Phase I literature review established 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 emphasised that instruction in mental arithmetic and estimation takes on added importance in classes where calculators are routinely available during instruction. The follow-up review in Phase II draws on the outcomes of recent international assessments of mathematics to show that access to a calculator is just one factor among several associated with test performance. It also shows that, despite the inclusion of calculator objectives in the

1999 Primary School Mathematics Curriculum (for which implementation began in September 2002), calculator usage in Fourth class mathematics classes is limited (with one-third of students 'hardly ever or never' using a calculator), and is largely confined to routine computation and checking answers (see NCCA, 2005a; Shiel, Surgenor, Close & Millar, 2006). The review also identifies use of graphics calculators as likely to improve understanding of function and graph concepts, problem solving skills, and readiness for the study of calculus (see Dunham, 2000).

Overall Performance on the Calculator Tests

Three calculator tests were administered to students in both 2001 and 2004:

- A *Calculator Inappropriate* test consisting of items that could (and should) be done without use of a calculator – this test was 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 was taken by all students, but only half had access to a calculator, while the other half did not
- A *Calculator Appropriate* test, consisting of items for which access to a calculator was deemed necessary – all students took this and all had access to a calculator.

The results indicate that overall performance on the Calculator Inappropriate and Calculator Optional (without calculators) tests declined slightly between 2001 and 2004, but not significantly so, whereas overall performance on the Calculator Appropriate test improved significantly between the two years. The findings for 2001 and 2004 on the Calculator Inappropriate test suggest that the performance of students in 2004 on basic mathematical skills was not significantly affected by the revised Junior Certificate mathematics syllabus where they had access to calculators, compared with 2001 students. The improvement in performance on the Calculator Appropriate test suggests that students' ability to make use of a calculator in solving problems improved over the three years, although the low performance on this test in both 2001 and 2004 (35% and 41% correct, respectively) is of some concern.

On the Calculator Appropriate test, students scoring at the 10th, 50th, and 75th percentiles achieved significantly higher scores in 2004 than in 2001. These results suggests that performance on questions for which the use of a calculator is most appropriate were most affected by the impact of calculator access over the three-year period of the study and that this effect was not confined to any particular mathematical ability group.

The difference in overall achievement between students with and without access to a calculator on the Calculator Optional test was three-tenths of a standard deviation in 2001, and over four-fifths in 2004, in favour of the students with access. Both of these differences are statistically significant, showing clearly the advantage conveyed to students with access to calculators compared to those with no access, at the two test points. Although the difference in performance between 2001 and 2004 on the calculator optional test with access (favouring students in 2004) was not statistically significant, there was a significant difference in 2004 in favour of students scoring at the 50^{th} percentile. Similarly, the difference in performance on the calculator optional test without calculator access between 2001 and 2004 (favouring students in 2001) was not statistically significant, but there was a significant difference at the 50th percentile in favour of students in 2001 on the non-calculator access condition. These outcomes suggest that, at the level of performance represented by the 50th percentile, students in 2004 benefited more than students in 2001 from calculator access, but were less able than students in 2001 to cope without calculator access.

Performance on Mathematics Content Areas

The Junior Certificate syllabus contains eight content areas[1]. Two of these (Number Systems, and Applied Arithmetic & Measure) were examined in detail, and two (Algebra and Statistics) were considered to a lesser extent. On the Calculator Inappropriate test, the differences between 2001 and 2004 for the two main content areas (Number Systems, and Applied Arithmetic & Measure) were not significant – a finding in keeping with previous research which showed the lack of any negative effects of calculator use on the use of basic number skills.

An analysis by content area for each calculator condition on the 2001 and 2004 Calculator Optional tests revealed that the 2004 group who had access to calculators when taking the test did significantly better than the 2001 group who also had access to calculators, on both Number Systems and Algebra; and slightly better, though not significantly so on Applied Arithmetic & Measure and Statistics. There was a significant drop in performance on the Number Systems component of the same test between 2001 and 2004 for students without access to a calculator; no significant differences were observed in the other three areas. On the Calculator Appropriate test, students in 2004 scored significantly higher than did students in 2001 on Number Systems. No significant differences were recorded in two other content areas – Statistics and Applied Arithmetic & Measure (there were no Algebra items on the Calculator Appropriate test).

Students' Use of Rough Work

In 2001, a study of students' written work was undertaken using a selection of 200 scripts in total. Findings indicated that the students were more likely to show their work when they did not have access to a calculator than when they had access. In 2004, this aspect of the study was extended and the scripts of all students in the sample were analysed in terms of rough work usage. Also, samples of items were chosen for further analysis to examine the relationship between rough work usage and achievement. The highest proportion of rough work was done by students on the Calculator Optional test where there was no access to calculators, as the items on this

[1] Sets, Number Systems, Applied Arithmetic & Measure, Algebra, Statistics, Geometry, Trigonometry, and Functions and Graphs

test were designed on the basis that most students would probably use pen and paper calculations to do them, in the absence of a calculator. On tests for which calculators were available, there was a substantial reduction in the amount of rough work shown, with relatively small amounts in evidence for the Calculator Optional test (with calculator) and the Calculator Appropriate test. In general, significant positive correlations were found between rough work use and performance on the tests, with the highest correlation occurring between rough work use and performance on the Calculator Optional test with no access to calculators. Even when calculators were available, high levels of rough work were associated specifically with items involving fraction operations, operations with measures of time, and operations with square roots and exponents. These results suggest that many students were unable to, or chose not to, use the calculator for these kinds of operations and, where appropriate, need to be taught the relevant skills.

Students and Calculators

In both 2001 and 2004, male students did somewhat better than females on the Calculator Inappropriate test, and female students outperformed males on the Calculator Appropriate test. However, none of these differences was statistically significant. In both years, students in the upper socio-economic groups (SEG) (those in the top third of the SES distribution) significantly outperformed students in the low SEG (those in the bottom third) on the three tests, while in 2004, but not in 2001, there was a significant difference on the three tests in favour of students in the medium SEG (those in the middle third) over students in the low SEG.

Whereas usage of calculators in mathematics classes was low in 2001 (2% of students reported that they used them often), over four-fifths (81%) said that they 'often' used them in 2004, and less than 1% indicated that they never did so. "Fractions, decimals & percentages" and "Length, area, volume & time" (Measurement) emerged as the two areas in which over one-half of students reported using their calculator 'a lot' in 2004, while calculator usage was lower in Algebra, Statistics and Geometry. Almost one quarter of students (23%) reported that they had learned to use a calculator while in Primary school, 34% in First year, 5% in Second year, and 2% in Third year. The remainder (37%) said that they were self-taught. Calculator usage in Business Studies classes was about the same in 2001 (63% reported often using one) as in 2004 (62%). There is evidence of increased occasional use of calculators in Science classes, with 3% using them 'often' and 52% using them 'sometimes' in 2004, compared with 2% and 17% respectively in 2001.

There was a noticeable improvement in students' attitudes towards calculators in mathematics classes between 2001 and 2004. In 2004, more students believed that a calculator could help them to get good marks in school mathematics, while fewer believed that a calculator made them lazy at school mathematics. In 2004, 86% of students believed that they could solve a problem better if they had access to a calculator.

Teachers and Calculators

Teachers of students who participated in the 2001 and 2004 studies completed questionnaires that sought information on their attitudes towards and views about calculators in Junior Certificate mathematics classes and in the Junior Certificate mathematics examination. In addition, teachers in 2004 were asked additional questions about school policy on calculators and about the extent to which they carried out specific calculator-related activities with their students.

About three in four students in 2001 were taught by teachers who were in favour of allowing the use of calculators for mathematics classwork and homework, and for the Junior Certificate mathematics examination, where the calculator was relevant to the work at hand. However, in practice, most students were taught by teachers who did not allow the use of calculators for classwork or homework. By 2004, when students were permitted to use calculators in the Junior Certificate mathematics examination, 86% were taught by teachers who were in favour of calculator use for mathematics classwork and homework. The content areas in which teachers said calculators were used most were Trigonometry and Applied Arithmetic & Measure.

In 2004, teachers were asked about the use of calculators in their teaching. The percentages of students whose teachers allowed use of calculators in mathematics classes ranged from 38% in First year to 79% in Third year. Those students whose teachers did not allow use of calculators unless given permission fell from 29% in First year to 11% in Third year. Teachers of 25% of students said they had calculator-free days when teaching First years; the corresponding figure for Third years was 9%. Methods advocated by teachers for checking answers obtained with a calculator included: checking if the answer is reasonable (90% of students); estimating before calculating (88%); doing the calculation twice (83%); and doing the calculation by hand (79%). While most students were taught about the more familiar features of calculators such as the percent, fraction, power, brackets, and positive/negative keys by their teachers, as well as interpreting the display and using exponential and scientific notation, only a minority were taught to use the constant function and memory keys. About 22% of students in 2004 were taught by teachers who said that their school had a policy on calculators

Also in 2004, teachers commented on both positive and negative effects of calculator availability. Positive effects included greater confidence and independence for students, particularly lower-achieving students; improved accuracy in computation; and greater ease of teaching some concepts and procedures (negative numbers, fractions and decimals, trigonometry, statistics, complicated multiplication and division). Negative effects included a perceived decline in various aspects of numeracy (mental arithmetic, estimation, concepts, tables, computational skills); over-reliance on the calculator; practical and technical drawbacks (loss, breakage, missing calculators, different makes/models, confusion about mode); and difficulty in using calculators effectively (using features/functions incorrectly, lack of awareness of sources of error). A majority of the teachers of the students in the 2004 study indicated that they used calculators differently with lower-achieving than with other students, and students of these teachers scored significantly higher than students whose teachers said they did not make this differentiation.

Calculators and the Junior Certificate Mathematics Examination

The effects of calculator availability on performance on the Junior Certificate mathematics examination can be looked at only indirectly. One reason for this is that the proportions taking different levels of the examination vary from year to year. Between 2001 and 2005, the percentage taking Higher level mathematics increased from 36% to 42%, at a time when the overall size of the cohort declined from 59,184 to 55,813. Between the same years, the proportion taking Foundation level dropped gradually from 13% to 11%.

In 2001 and 2002, the percentages achieving grades A to C on Higher level mathematics were 77% and 74% respectively. In 2003, the first year in which calculators were permitted in the examination, 79% achieved grades A to C. However, in 2004, this fell back to 73%, only to increase in 2005 to 76%. At Ordinary level, the percentages achieving Grades A to C increased from 68% in 2001 to 72% in 2003 and 75% in 2004, but fell back to 73% in 2005. At Foundation level, the percentage of A to C grades increased from 73% to 86% between 2001 and 2004, only to fall back to 77% in 2005. Hence, the introduction of the revised Junior Certificate syllabus, and the availability of calculators in the Junior Certificate mathematics examination, coincided with an initial increase in the proportions of A to C grades awarded at all levels, though, by 2005, the percentage of students achieving A to C grades had dropped, and, in the case of Higher level, slightly fewer such grades were awarded in 2005 (76%) than in 2001 (77%).

In both 2001 and 2004 the performance of students on the Calculator tests was examined with reference to the level of the Junior Certificate mathematics examination they intended to sit, and the level they actually they sat (in 2002 and 2005 respectively). Predictably, in both years, students taking Higher level outperformed students taking Ordinary and Foundation levels. Of particular interest, however, is the finding that in 2004 the mean score of Ordinary level students taking the Calculator Optional test with a calculator was close to the mean score of Higher level students taking this test without a calculator. This reflects the benefits of calculator access to lower-achieving students in answering basic mathematics questions. As expected, correlations between performance on the calculator tests and performance on the Junior Certificate mathematics examination were high (in the range of 0.66 to 0.70).

Recommendations

Recommendations based on the two phases of the study are presented. These address the need to continue to monitor performance on basic mathematical processes (such as those measured by the Calculator Inappropriate test), and to raise performance in problem solving items (such as those included on the Calculator Appropriate test).

The recommendations also put forward suggestions for improving use of calculators, including better alignment between mathematics programmes in primary and post-primary schools, professional development for post-primary teachers that includes use of calculators to develop specific concepts and procedures, estimation skills, and use of real-life problems and data, and broader use of graphics calculators to teach algebra and functions. A need to identify ways in which calculator usage can be promoted to address the varying needs of low-achieving students is also noted. The importance of establishing clear school-level policies on calculator use is stressed.

Chapter 1: Context of the Study

The Calculator Study addresses the effects of the introduction of calculators into the Irish Junior Certificate mathematics syllabus. It monitored Junior Certificate 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 revised syllabus formally incorporated calculators into Junior Certificate mathematics. 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, and also by an overview of some of the current issues in Irish mathematics education. The discussion of calculator policy and practice is presented in the first section of this chapter. The second section outlines the origin and structure of the Calculator Study, and identifies some key issues for examination. The third section provides an overview of current issues relevant to the study.

CALCULATORS IN IRISH MATHEMATICS EDUCATION[2]

At the time of the introduction of the revised Junior Certificate mathematics syllabus (September 2000), the mathematics curriculum operating in Irish primary schools was *Curaclam na Bunscoile* (Primary School Curriculum) (Department of Education, 1971). Not surprisingly, as it pre-dates the widespread availability of calculators, it made 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 primary 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). Classroom implementation of the revised *Primary School Curriculum* began in Autumn 2000 on a phased basis, with the mathematics element being implemented in Autumn 2002 – that is, after the introduction of the revised Junior Certificate mathematics syllabus. However, the Junior Certificate syllabus was designed to take into account the impending changes at Primary level.

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[3] in 1973 (for first examination in 1976), and the Leaving Certificate syllabus in 1976 (for first

[2] 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), *Calculator Guidelines for Second-level Schools* (DES/NCCA, 2001), and accounts published at the time (e.g., Oldham 1992). The discussion here is an updated version of that presented in Close et al. (2004).

[3] 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).

examination in 1978). In neither case was calculator use a matter for 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.

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 calculation. In practice, however, use of a scientific calculator appears to have become the norm.

The explicit introduction of the calculator into Leaving Certificate mathematics came in 1990 with the inception of the Ordinary Alternative syllabus.[4] 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

[4] The Ordinary Alternative syllabus was introduced as an interim measure to follow on from the Intermediate Certificate Syllabus C (later Foundation level Junior Certificate). It was replaced by a Foundation level syllabus in 1995.

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 a 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 its 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. It was also 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 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 placed on estimation. As intended, this too is being assessed by questions in the state examinations. Benefits with regard to these examinations include the fact that questions can now include more real-life data and – a minor but not insignificant point – a more accurate value of π can be utilised.

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 idea was rejected; the difficulty of monitoring students in the usual examination settings would make such a policy hard to implement, as indicated above. This position might need to be revisited in the future, especially after the first cohorts of students experiencing the revised Primary curriculum complete their Junior Certificate examinations, 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 state 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 in these examinations. However, as was the case for less powerful machines in the 1980s and 1990s, there is no embargo on their employment as teaching and learning tools. While the availability of graphics calculators in mathematics classes remains limited, some schools have small sets, acquired in the context of data-logging in science; moreover, individual teachers have borrowed class sets from commercial providers or the National Centre for Technology in Education for short-term use. Some pioneering work has been done using powerful calculators equipped with computer algebra and dynamic geometry systems. It should be noted also that students can (and some do) experience the benefits of such packages by using computers rather than handheld devices.

THE CALCULATOR STUDY

The introduction of calculators into a mathematics curriculum provides opportunities for improvements in performance and in attitudes to mathematics, and allows for exciting developments in teaching and learning. However, it also raises concerns about the maintenance of computational skills without the aid of a calculator. Trends in all these respects need to be monitored. In 1999, in view of the forthcoming implementation of the revised Junior Certificate syllabus, the Department of Education and Science invited applications for undertaking a research project into the effects of calculator use in schools and in the Certificate examinations. The statement of requirements for the project specified that the proposed research was to assess the impact of the changed role of calculators on students' basic numerical skills and related concepts and understanding. General objectives were specified as follows:

- To assess present [before the introduction of the revised syllabus] levels of students' skill and understanding in the areas of:
    - mental and written arithmetic skills
    - calculator skills
    - understanding of number
    - data analysis skills
- 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
- To identify the effects on the above of a comprehensive school policy on calculators and arithmetic skills.

A contract for the study was awarded 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.

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 Certificate mathematics syllabus and the Junior Certificate mathematics examinations). Hence, the study was implemented in two phases, each involving the administration of mathematics tests and questionnaires to nationally-representative samples of Third year students. Phase I, testing for which was carried out in November 2001, examined the final cohort studying the pre-2000 Junior Certificate mathematics syllabus. Phase II, testing for which was carried out in November 2004, examined the third cohort studying the revised Junior Certificate syllabus. The third such cohort was chosen, in preference to an earlier cohort, in order to allow the revised syllabus to "settle down" and teachers and students to gain familiarity with its new aspects, in particular with regard to calculator use.

The structure of the instruments used in the study is described more fully in Chapter 3. A short account is given here in order to highlight results obtained in Phase I and issues raised for Phase II. Three tests were developed to test different aspects of students' numerical and calculator skills:

- A *Calculator Inappropriate* test to be taken without access to a calculator by all students in the sample, consisting of items that could (and should) be answered mentally or with minimal written work;
- A *Calculator Optional* test to be taken by half the sample with access to a calculator and by the other half without such access, consisting of items for which use of a calculator was reasonable but not necessary;
- A *Calculator Appropriate* test to be taken with access to a calculator by all students, consisting of items requiring more challenging calculations for which such access was deemed necessary.

In addition, questionnaires for students and their teachers were developed, in order to investigate the extent of calculator usage and to examine teachers' and students' attitudes to mathematics and calculator use.

The test results from Phase I of the study (Close et al., 2004) provided base-line data on the performance of students following the pre-2000 Junior Certificate syllabus. In addition, the results from the Calculator Optional test allowed comparison of performance with and without calculator access for students in this cohort. The group with calculator access scored significantly higher than the group without such access (whereas no significant difference was found between the scores of these two groups on the other two tests). This occurred despite the fact that teachers and students reported very little use of calculators in mathematics classes. Greatest differences in scores tended to occur on items testing aspects of the Number Systems content area of the syllabus, such as division of a four-digit by a two-digit number. A further result with regard to the Calculator Optional test emerged from consideration of the students' performance in the Junior Certificate mathematics examination in summer 2002. The mean score of those students with access to calculators who took the examination at Ordinary level approached the mean score of students without access to calculators who took the examination at Higher level (though the difference in favour of the latter was statistically significant); calculator use appeared to help Ordinary level students to avoid calculation errors on the easier items, though it may have had less effect for more difficult ones. A similar result obtained for Foundation level students with access to calculators vis-à-vis Ordinary level students without such access. Another finding of interest from the scores on the three Calculator Study tests was that there were no significant differences between the mean scores of boys and those of girls.

Attitudes of teachers and students to calculator use were generally positive. While many teachers did not allow calculator use in their classes – presumably reflecting the fact that calculators would not be available to their students in the Junior Certificate mathematics examinations – most reported that they were in favour of calculator use in the examinations. However, a few were opposed to use of a calculator in Junior Certificate mathematics for any purpose. These and other findings are presented fully in the report on Phase I of the study (Close et al., 2004).

In the light of these findings, broad research questions were formulated for Phase II of the study as follows:

- Will the levels of performance without calculators (hence, on the Calculator Inappropriate test and, for the no-calculator condition, on the Calculator Optional test) be maintained from 2001 to 2004?
- Will the level of performance with calculators (hence, on the Calculator Appropriate test and, for the calculator condition, on the Calculator Optional test) improve?
- Of the content areas and skills assessed in the tests, which benefit most, and which least, from calculator access?
- To what extent are calculators now being used in Junior Certificate Mathematics classes?
- What kinds of calculator use are taking place in these classes?
- What are teachers' and students' experiences of increased calculator use, and what are their attitudes in the light of these?
- How do teachers' and students' attitudes relate to performance in Mathematics?
- What policies govern calculator use in schools?
- What links are there between performance on the calculator-based tests and performance on the 2005 Junior Certificate mathematics examination?

These and further questions of interest are addressed in this report.

CURRENT ISSUES IMPINGING ON THE STUDY

The two phases of the Calculator Study were carried out at a time of great interest for mathematics education in Ireland: a time at which some problematic issues were being identified, and hence the entire mathematics curriculum was becoming the focus of reflection and critique to an extent not experienced since the 1960s (DES/NCCA, 2002). Evidence emerged over several years to suggest that the performance of some Irish school students in mathematics was not satisfactory and that the mathematical knowledge and skills that some students take with them to third level courses were insufficient. Difficulties were encountered in particular with relational understanding and problem solving and with reproducing basic skills in unfamiliar contexts (DES, 2000, 2001; Morgan, Flanagan, & Kellaghan, 2001; Shiel, Cosgrove, Sofroniou, & Kelly, 2001; Lyons, Lynch, Close, Sheerin, & Boland, 2003; Close et al., 2004; Cosgrove, Shiel, Sofroniou, Zastrutzki, & Shortt, 2005; Cleary, 2007; Gill & O'Donoghue, 2007; Eivers, Shiel & Cunningham, 2008). A discussion paper produced by the NCCA identified a wide range of possible factors, including not only the traditional targets of syllabus and examinations but also problematic issues previously often overlooked: approaches to teaching and learning, and aspects of classroom and general culture (NCCA, 2005b). Publication of the discussion paper was followed by a national consultation process that brought wide-ranging debate on mathematics education into the public domain.

The themes emerging from this debate have informed subsequent developments. The main outcome has been "Project Maths", an initiative that will be phased in over several years starting in Autumn 2008 (NCCA, 2008). The project involves some revision of the Junior and Leaving Certificate syllabus content, but pays particular attention to teaching, learning and assessment:

> This development will see much greater emphasis being placed on student understanding of mathematics concepts, with increased use of contexts and applications that will enable students to relate mathematics to everyday experience.
>
> The initiative will also focus on developing students' problem-solving skills. In parallel with changes in curriculum, there will be changes in the way mathematics is assessed, to reflect the different emphasis on understanding and skills in the teaching and learning of mathematics. (http://www.ncca.ie/eng/index.asp?docID=289)

It is noteworthy that many of the goals of the project are similar to ones cited as aims for calculator use or reasons for introducing calculators to the school curriculum. Relevant aspects include problem solving (with students' minds freed from routine calculations so as to be able to concentrate on problem analysis and solution), investigative approaches to mathematical situations, and the use of real-life data, as well as enhanced proficiency in computation (see for example Close et al., 2004).

While the implementation of Project Maths makes the findings from the Calculator Study especially timely, changes that have taken place during the course of the study provide some challenges in interpreting its results. In comparing findings from Phase I and Phase II of the study, several factors must be taken into account.

First, and most obviously, there are changes related to the revised syllabus and its implementation. Changes in the syllabus were not limited to those involving calculator usage. The tests for the study focused on areas for which the introduction of the calculator appeared to constitute the only significant change; however, other alterations may have affected teachers' approaches to the syllabus, students' learning, and hence student performance in general. Introduction of the syllabus was accompanied by a programme of teacher professional development – with emphasis on teaching for understanding (DES/NCCA, 2002; Oldham & English, 2005) – and it might be expected that this would lead to some improvements in teaching and learning. On the other hand, a perception that the Higher level syllabus had been 'shortened' seems to have led to some reduction in the time allocated to Junior Cycle mathematics in some schools; this could counteract such improvements.[5]

A second point of interest is that the proportion of the candidates for the Junior Certificate mathematics examination who opt for the Higher level has been growing in recent years, with a notable increase occurring when the revised syllabus was first examined (Table 1.1). For the two examination cohorts sampled for the study, the proportions were 36.8% in 2002 and 41.9% in 2005. This is a welcome trend, but raises some difficulties, especially for level-specific comparisons between the cohorts.

Table 1.1 *Proportion of Students at Each Junior Certificate Examination Level for Mathematics, by Year*

Level	2001		2002		2003		2004		2005	
	n	%	n	%	n	%	n	%	n	%
Foundation	7909	13.4	7886	13.3	7324	12.5	6584	11.8	5907	10.6
Ordinary	30162	51.0	29588	49.9	27383	46.9	26347	47.1	26518	47.5
Higher	21113	35.7	21821	36.8	23734	40.6	23006	41.1	23388	41.9
Total	59184	100	56705	100	58441	100	55937	100	55813	100

Source: State Examinations Commission (http://www.examinations.ie)

A third factor stems more generally from the time elapsing between the two phases of the study. It was pointed out above that Phase II examined students from the third cohort following the revised syllabus, and hence that testing for Phase II was carried out three years after that for Phase I. This had the intended outcome of allowing teachers to become a familiar with the revised syllabus, and teachers and students to do likewise with regard to the style of the Junior Certificate examinations; it therefore provided a truer reflection of the implemented syllabus than would have been the case if the first cohort had been examined. It also allowed for more impact from the teacher professional development programme. An inevitable consequence of the passage of time, however, is that any underlying demographic, cultural or other trends affecting student performance (such as the negative influences noted in the NCCA discussion paper) may have had a stronger effect on the 2004 cohort than on those preceding it.

A fourth factor (minor in itself, but illustrative of the previous one) is that when the revised syllabus was designed, scientific calculators in general did not have 'fraction keys'. Such keys have become increasingly usual during the intervening period. The extent of teachers' and students' familiarity with the feature – and of students' willingness to engage with the concepts underlying computation with fractions when perhaps they can obtain correct answers without doing so – is not known. The issue highlights the importance of estimation skills in the presence of

[5] The *content* was reduced in order to allow more time for learning with understanding. Reducing the time allocation for mathematics effectively negates the intended change.

technology (as well as the fact that any study involving technology is likely to have to cope with rapid changes in the power of that technology).

Especially in the light of these factors, several areas can already be identified for further investigation. It should be noted that the professional development programme supporting the revised syllabus – with limited time in which to address a wide range of issues – did not prioritise calculator usage. The present study can act as a diagnostic tool to indicate what aspects might be addressed. Moreover, the effects of changes in the revised Primary Schools mathematics curriculum, especially with regard to calculator usage, did not impinge on the cohort examined in Phase II of the study. This therefore addressed a situation in which the revised Junior Cycle syllabus was not yet building on its intended Primary foundation. Many students who first experienced the revised Primary curriculum in Sixth Class (in the academic year 2002-2003) took their Junior Certificate examinations in Summer 2006; it can be expected that the effect of full implementation of the primary curriculum will not emerge for several years). The introduction of Project Maths will provide for changes that also should impact on students' learning. Additional phases of the study would allow these effects to be examined.

Chapter 2: Calculators in Mathematics – A Review of Recent Literature

In the literature review presented in the report on Phase I of the study (Close et al., 2004), reference was made to short-term and long-term studies on the effects of calculator usage on mathematical achievement. Relevant information was also drawn from international studies such as the Second International Assessment of Educational Progress study in 1991 (IAEP II) and the Third International Mathematics and Science Studies (TIMSS) in 1995 and 1999 (Beaton et al, 1996; Mullis et al, 2000). Some research on the attitudes of students and teachers to calculator usage was described and consideration was given to issues surrounding the use of calculators in assessment. The main purpose of this chapter is to give a description of the findings of more recent national and international studies on calculator availability and usage and on the effects of non-graphics and graphics calculators on tests of mathematical achievement.

CALCULATOR AVAILABILITY AND USAGE

Primary Level

The revised Irish Primary School Mathematics Curriculum provides for the use of calculators in mathematics from Fourth to Sixth classes (DES/NCCA, 1999a, 1999b). Reports on the implementation of this curriculum give some information on the extent of calculator usage. A review, conducted by the NCCA in 2003, was based on data from 719 completed teacher questionnaires and case study data from 6 schools, gathered from September 2003 to September 2004 (NCCA, 2005a). One item on the questionnaire concerned the types of activities for which children used calculators. This was answered by 269 teachers as it was directed at those teaching Fourth to Sixth classes only. It was found that the most commonly used calculator activity was the prediction and checking of results (79.9% of teachers) and the least common activity was the exploration of the number system and discovery of facts and relationships (48.3% of teachers). However, no indication was given about the frequency with which calculators were used by the pupils in these classes. Some information on this is given in the report on the *2004 National Assessment of Mathematics Achievement* (Shiel, Surgenor, Close & Millar, 2006). This report (referred to hereon as NAMA 2004) was based on the results of tests administered to a sample of Fourth class pupils in Irish schools (n = 4171) and of questionnaires completed by school principals, teachers, pupils, parents and inspectors. As reported by Fourth class teachers, calculators are used by 17.4% of pupils once or twice a week and by 44.5% of pupils once or twice a month. One third (33.4%) of Fourth class pupils are in classes where the teacher stated that the calculator is ‘hardly ever or never’ used. However, as shown in Table 2.1, this shows a marked increase from the situation that obtained in

1999 when the calculator was practically never used by Fourth class pupils in mathematics lessons (Shiel & Kelly, 2001).

Table 2.1 *Percentages of Pupils Whose Teachers Reported that Calculators Had Been Used for Various Purposes in Mathematics Classes (2001 and 2004)**

	Daily		Weekly		Monthly		H. Ever/Never	
	1999	2004	1999	2004	1999	2004	1999	2004
Routine computation	0.4	3.3	0.0	10.5	0.7	34.1	98.9	52.2
Checking answers	0.4	5.5	1.8	16.7	0.9	36.5	97.0	41.3
Exploring number concepts	0.0	0.5	0.0	3.9	0.0	40.0	100	55.6
Solving 1 & 2 step problems	0.4	1.0	0.0	10.4	0.0	30.7	99.6	57.9
Tests and exams	0.0	0.0	0.0	2.7	0.0	5.5	100	91.7

** Data from 2004 National Assessment of Mathematics Achievement* (Shiel et. al., 2006); *1999 n = 4693; 2004 n = 4157*

In cases where there is frequent use of the calculator (daily or weekly), the purposes for which it is most frequently used are those of checking answers and doing routine computations; it is least often used in the exploration of number concepts.

Internationally, there is a wide range in the frequency of calculator usage at primary level. Of the twenty eight countries for which results were presented at the Fourth grade in TIMSS 2003[6] (in which Ireland did not participate), 14 report that there are statements advocating calculator usage in their national or regional mathematics curriculum (Mullis, Martin, Gonzalez, & Chrostowski, 2004). On average, 57% of the Fourth grade students were taught by teachers who do *not* permit them to use calculators. Countries in which widespread use of calculators was reported by teachers include Australia, Cyprus, England, New Zealand and Scotland. It would appear that, if permitted, the calculator is used most often at this grade level for checking answers, solving complex problems and exploration of number concepts and, in contrast with Ireland, least often for doing routine computations.

Second Level

Before its introduction in the Junior Certificate examination in 2003, the calculator was used on an infrequent basis in Junior Certificate Mathematics classes. For example, in TIMSS 1995 it was found that 68% of the sample of the 13-year old students in Ireland were in classes whose teachers reported that they 'hardly ever or never' used a calculator in mathematics classes (Beaton, Mullis, Martin, Gonzalez, Kelly & Smith, 1996). This was corroborated by the findings of Phase I of this study where it was reported that 77% of the sample of students were taught by teachers who did not permit use of calculators in mathematics classes and only 3% of the students surveyed indicated that they 'often' used a calculator for mathematics homework (Close et al., 2004). Not surprisingly, there appears to be some change in this situation.

[6] By 2003, TIMSS had become the Trends in International Mathematics and Science Study.

For example, 78% of students in Ireland surveyed for another international study, the Programme for International Student Assessment (PISA), said that they had used a calculator during the mathematics component of the assessment in 2003 (OECD, 2004), whereas only 24.2% reported having done so in 2000 (Cosgrove et al., 2005).

On the international front, the 1999 TIMSS report found that there was a small but significant decrease between 1995 and 1999 in the percentage of students who reported that they 'almost always' used calculators in mathematics lessons in Eighth grade (Mullis, Martin, Gonzalez, Gregory, Garden, O'Connor, Chrostowski & Smith, 2000). This was true for Cyprus, the Czech Republic, England, Hong Kong, Latvia, Romania, the Russian Federation and the Slovak Republic. However, the Netherlands and Singapore showed increases in this category for the same period. In TIMSS 2003, results were presented for fifty countries at the Eighth grade level (Mullis et al., 2004). Of these, 33 countries report that there are policy statements about calculator usage in official curriculum documentation. As might be predicted, uptake of the calculator is greater at Eighth grade than at Fourth grade. Calculators are used least often in Bahrain where 69% of students do not have access to them during mathematics lessons. The countries where virtually all students are permitted to use calculators to some degree include England, Hong Kong, Lithuania, Morocco, Netherlands, Norway, the Palestinian National Authority, Scotland, and Sweden. The extent of calculator usage does not appear to be related to statements in the curriculum. For example, in Ghana where there is a policy statement promoting calculator usage, 61% of students are taught by teachers who do not permit the device to be used. This contrasts with Hong Kong where 98% of students use calculators in mathematics lessons despite the fact that there seems to be no official policy about calculators in the curriculum. As was the case in TIMSS 1999, the calculator is used most often in Eighth grade for solving complex problems, routine computations, and checking answers, and least often for the exploration of number concepts.

CALCULATORS AND ACHIEVEMENT

Calculator Usage during Assessment

The most frequently cited report regarding the effect of the non-graphics calculators on mathematical achievement is that of Hembree and Dessart (1986, 1992). They conducted meta-analyses of 79 studies over a 15 year period. One finding of their study was that, on tests of problem solving where access to calculators was permitted, there were positive effects for students of all ability levels. The results of Phase I of this study support the finding that calculator availability during assessment is a key factor in producing better results. On the Calculator Optional test, those students who did not have access to a calculator attained a mean score of 47%, while those who had access achieved a mean score of 59%; a difference that was statistically significant (Close et al., 2004). In PISA 2003, students who reported that they had used a calculator during the assessment had a significantly higher mean score than those who reported that they had not (Cosgrove et al., 2005). However, access to a calculator during assessment can affect performance in a negative way if students are not familiar with its use (Hopkins, 1992), or if they have not had prior experience in using it in mathematics tests (Bridgeman, Harvey & Brasswell, 1995). This may account for the relatively poor performance of Irish primary pupils on the 25 calculator appropriate items in NAMA 2004, where the overall percent score on these items was just under 40% compared to an average of 55% across all sections of the test[7]. It should be noted that the computations involved in the calculator appropriate items were purposely designed to be more difficult than those in non-calculator items. However, it does point to the need for greater integration of the calculator into the assessment of mathematical achievement at primary level, particularly in view of the finding that over 90% of Fourth class pupils 'hardly ever or never' use the calculator for tests and examinations (Shiel et al., 2006, Table 7.16).

Calculator Usage in Mathematics Instruction

One of the key findings of the meta-analyses conducted by Hembree and Dessart (1986 and 1992) was that, with the exception of those in Fourth grade, students of average ability performed better on pen and paper tests after exposure to four-function calculators during mathematics instruction. In the final report of Phase I of the current study, reference was made to several studies that showed the beneficial effects on students of exposure to the hand-held calculator during mathematics instruction (e.g., ARK (Hedrén, 1985), CAN (Shuard, 1992) and CPM (Groves & Stacey, 1998)). In these studies, project children demonstrated a better ability to solve word problems, and a superior understanding of topics such as place-value in large numbers and decimal numbers than their non-project peers; on tests of basic skills they performed as well as or better than those who did not have exposure to the calculator. In NAMA 2004, no correlation was found between frequency of calculator usage and pupils' mathematics achievement. Possible reasons include the observation that the calculator is not used for the exploration of number concepts and that it might be used most frequently by pupils who experience difficulty with mathematics. However, although the calculator appears to be a tool that can facilitate understanding of key mathematical concepts, it is only one of several factors that impinge on performance on tests of mathematical achievement. This was illustrated in TIMSS 2003 where the frequency of calculator usage at Eighth-grade differs across the eight top-scoring countries as shown in Table 2.2. For example, the average scale score for Hong Kong and that for Chinese Taipei differ by a mere one point despite the fact that the countries have dissimilar patterns of calculator usage.

[7] There were 125 non-calculator items and 25 calculator items in the NAMA 2004 test. The items were distributed over five booklets. Each pupil was randomly assigned one booklet. The calculator items were included as the last section in one booklet and in the first section in another booklet.

Table 2.2 *Calculator Usage in High-Scoring Countries in TIMSS 2003*

Country	% of Students Whose Teachers Reported That Calculators Are Permitted	Average Scale Score (2003)
Singapore	100	605
Rep. of Korea	65	589
Hong Kong	98	586
Chinese Taipei	66	585
Japan	63	570
Belgium (Flemish)	97	537
Netherlands	100	536
Hungary	81	529

On the other hand, average scale scores of students in countries where there is frequent use of calculators in Eighth grade is at or above the international average of 467 (see Table 2.3) while for those countries where calculators are least used, average scores tended to be below the international mean. This at least suggests that exposure to the calculator during mathematics instruction does not impede mathematical performance.

Table 2.3 *Countries with High Levels of Calculator Usage in TIMSS 2003*

Country	% of Students Whose Teachers Reported That Calculators Are Permitted	Average Scale Score (2003)
Belgium (Flemish)	97	537
Hong Kong	98	586
Lithuania	99	502
Singapore	100	605
Netherlands	100	536
Norway	100	461

Recent studies bode well for graphics calculators. Reviews of research demonstrate that students who use these tools display better understanding of function and graph concepts, improved problem solving performance and greater readiness for the study of calculus (Dunham, 2000). Owens (1995), for example, found that use of the TI-80 graphics calculator by Eighth-grade students improved their performance on basic order-of-operation problems involving integers and signed rational numbers and that the effects were strongest for low-achieving students. However, positive effects of both graphics and non-graphics calculators for low-achieving students tend to be limited to the avoidance of computational errors rather than to improvements in performance on difficult conceptual items (Bridgeman et al., 1995).

ATTITUDES TOWARDS CALCULATORS

Students' attitudes towards calculators are mixed. Ruthven (1995) found that, while First-year secondary students were positively disposed towards calculators in terms of perceived reduction in difficulty, lower incidence of mistakes and reduced time taken, they were quite sceptical about their value as learning tools and they associated calculator usage with 'laziness'. Similar findings emerged from Phase I of this study (Close et al., 2004). Over seven-tenths (70.6%) of students 'strongly agreed' or 'agreed' that that the calculator could help them to achieve better marks in school mathematics. On the other hand, a lower percentage (46.7%) expressed similar levels of agreement with the statement, 'I think a calculator could help me get better at mathematics'. Interestingly, a negative correlation was found between attitude towards calculators in mathematics and performance in the calculator tests. The explanations suggested for this were that higher-achieving students might be less positively disposed towards calculator usage or that students may have felt that, as they did not have access to calculators for the Junior Certificate mathematics examination, neither should students in future years.

Few studies have been conducted on teachers' attitudes towards calculators. Primary or elementary teachers seem to be particularly dubious about their integration into the curriculum, believing that they prevent children from engaging in mathematical thinking and reasoning (Schmidt & Callahan, 1992). Schmidt (1999) found that, while teachers at this level accepted that the calculator might have a role in mathematical problem solving and concept development, there was a strong commitment to pen and paper computing techniques. This attitude is reflected in the responses of the sample of secondary teachers surveyed in Phase I of this project (Close et al., 2004). Most teachers agreed that the calculator should be used in mathematics lessons, especially for checking answers and for topics such as trigonometry and statistics. However, some reservations were expressed. Many teachers stressed the importance of students being able to carry out basic operations mentally. Some felt that calculators should be used by low-achieving students whereas others indicated that they should be used by high-achieving students. There was a small minority of teachers who believed that the calculator was detrimental to students' mathematical progress.

SUMMARY

In recent years, calculators have become increasingly sophisticated and functionally advanced (Ruthven, 1996; DES/NCCA, 2001). Indeed, international research on the effects of calculators on secondary-level mathematics now concerns the graphics calculator rather than the scientific calculator (see Dunham (2000) for a review of research). Calculators are widely available in the homes of primary and secondary students in Ireland (Shiel et al., 2006; Close et al., 2004). The frequency of the usage of the scientific calculator among secondary students has increased, arising from the fact that it is now part of the Junior Certificate syllabus and examination. On the other hand, the uptake of calculators in primary-level mathematics classes in Ireland, although showing improvement since 1999, is disappointing. It is possible that the inclusion of calculator appropriate items in primary mathematics tests will promote the integration of the calculator in senior primary mathematics lessons.

The purposes for which the calculator is used in mathematics instruction also warrant attention. It had been hoped that calculator usage in mathematics classes would promote a growth in problem solving and investigative work and a decreased emphasis on pen and paper calculations but this seems not to have been the case as yet (Close et al., 2004; Shiel et al., 2006). Although research points to the positive effects of the calculator on the development of higher order mathematical skills, the calculator is used most often in Irish primary and post-primary schools for checking answers and for routine operations. Moreover, the failure to exploit the device to its full potential may reinforce negative attitudes towards it on the part of teachers. This could account for a noticeable decline in ‘frequent’ calculator usage among Eighth grade students as reported in TIMSS 1999 (Mullis et al., 2000). Professional development courses have been found to have a positive effect on teachers' beliefs about the potential of the calculator as a tool for exploration of mathematics (Schmidt, 1999) and should be made available to both primary and secondary teachers. The calculator is not a panacea that cures all mathematical ills but, used appropriately, it is one of several factors that contribute to mathematical achievement and to the flexible mathematical thinking that is required in today's society.

Chapter 3: Study Framework and Instrument Development

This chapter describes the assessment framework for the two phases of the Calculator Study. It also outlines the development of the instruments used in Phase I of the study and the modifications made for Phase II.

CALCULATOR TESTS

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

- To assess present [that is, prior to the implementation of the revised syllabus] 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.

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 carried out over a number of years using nationally representative samples of students. Thus, tests were constructed for administration to a suitable sample of Third-year students on two occasions: the first before the revised courses came into operation (therefore to a cohort that would not use calculators in the Junior Certificate mathematics examination), and the second when the new courses were established (therefore to a cohort that was being prepared to use calculators in the Junior Certificate mathematics examination).

For the design of the cognitive tests, three types of issues needed to be addressed: *calculator issues*, *curricular issues*, and *assessment issues*. Also, suitable items had to be chosen or written and assembled into tests. The process is described briefly below; a fuller account is provided in the main Phase I report (Close et al., 2004). Amendments made to the tests for Phase II of the study are then outlined.

Calculator Issues

Three calculator issues were identified:

- Consideration of the possible need to test calculator-specific skills – those concerned with operating the calculator rather than carrying out computations and solving mathematical problems
- Determination of which parts of the tests should be done without access to calculators, and which should be done with calculators available

- In the light of this, creation of a balance between test questions for which a calculator is appropriate and questions for which it is not.

It was decided not to test calculator handling skills, as this would typically involve either observing individual students as they worked, which was outside the scope of a study of a nationally representative sample, or asking students to record their calculator operations in great detail, which would limit the time available for computation and problem solving. It was also decided that one section of the test (done without access to calculators) should consist of items for which use of calculators is deemed *inappropriate* (for example (3 × 4) / 2), and another section (for which calculators would be provided) should consist of items for which use of a calculator is deemed *appropriate* (for example (3.12 × 24.75) / 0.2052). It remained to consider the placement of items for which the use of a calculator might be considered *optional* (for example (3.1 × 25) / 2: this could be tackled sensibly using either a calculator or pen and paper). Inclusion of a section consisting of items of this type would allow an internal comparative 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 for the cognitive test:

- Calculator Inappropriate test – calculators not available to any students
- Calculator Optional test – calculators available to half the cohort and not available to the other half
- Calculator Appropriate test – calculators available to all students.

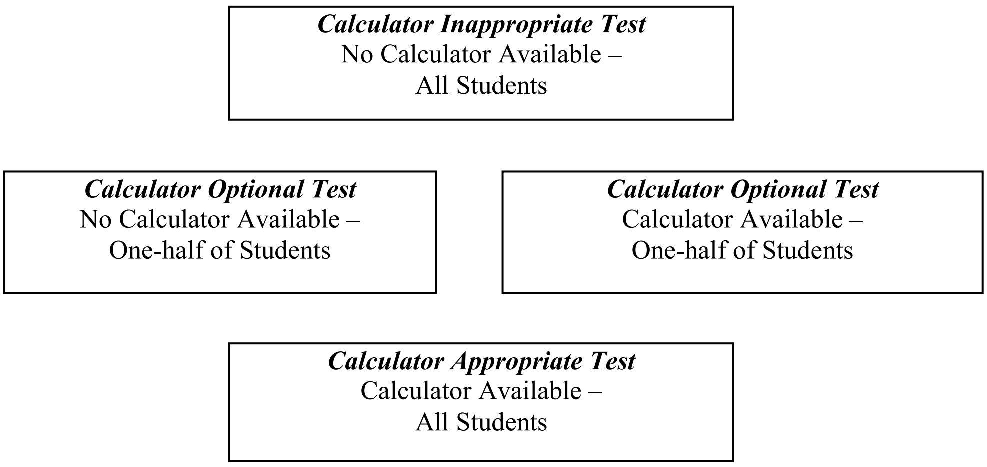


Figure 3.1 *Summary of Tests Developed*

Curricular Issues

With regard to curricular issues, two questions needed to be answered:

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

The research requirements provided an answer to the first question. There was a requirement to test mental and written arithmetic, understanding of number, and data analysis; there was also a requirement to test calculator skills, considered here (in the light of the discussion above) as meaning use of a calculator for computation and problem solving rather than calculator-handling skills. Since one of the main arguments for encouraging calculator use in schools is to allow students to address problems containing real-life data (Close et al, 2004), topics involving such data should be covered.

Another argument for encouraging calculator use is that it facilitates certain aspects of investigational work: for example, exploring patterns, investigating functions, and finding maximum and minimum values of areas and volumes (see Close et al., 2004). 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 assess students' familiarity (or unfamiliarity) with the basic methodology of investigational approaches rather than their skill in using calculators as exploratory tools. Consequently, it made 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 and problem solving.

This provides an initial answer to the second question posed above. Material would be restricted to that found in the Junior Certificate syllabus. As far as possible, questions should be *meaningful,* and their general style familiar, to students following the syllabus at any of the three levels at which it is offered. (This effectively excluded Trigonometry, for example, as Foundation level students do not meet it.) However, some questions aimed at testing specifically Higher level material should be included, although they would be difficult for Ordinary level students and especially difficult for Foundation level students.

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

- the tests would focus chiefly on three of the eight content areas i.e. Number Systems, Applied Arithmetic & Measure, and Statistics, as these are the most calculator-sensitive topics accessible to all Third-year students
- The topic Applied Arithmetic & Measure would be given particular weight because of its relevance for the use of real-life data
- As many problems lead to the solution of an algebraic equation, questions on Algebra, focusing on the solution of simple equations, would also be included.

Assessment Issues

The third category of issues relating to the design of the cognitive tests used in the study has to do with issues of item type, scoring, sequence, classification, and difficulty level. Assessment issues were dealt with as follows:

- 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 lower-achieving students
- Both multiple-choice and short constructed-response item types would be used, with the latter being associated with the more complex questions.

Compiling the Tests for Phase I of the Study

Items were located, or written when necessary, and were then assembled into tests in accordance with the principles devised above. Two pilot studies were conducted: one in a convenience sample of 7 schools in March 2000, and a second in a more representative sample of 15 schools in October 2000. These studies provided valuable information on the performance of a large number of items for the tests; they also pointed to aspects of test administration that might be fine-tuned in the main study, notably the allocation of time to different tests. Further details of the pilot tests are available in the main Phase I report (Close et al., 2004).

Following the second pilot study, test booklets were prepared for Phase I of the main study. In view of time constraints identified in the pilot studies, the items for the Calculator Appropriate test were split into two forms, with half the sample taking one form and half taking the other. Having two forms of the Calculator Appropriate test (Booklets 1 and 2) allowed a substantial number of items to be used in the comparatively short time frame that could be allocated for the tests if schools were to agree to take part in the study.

The distribution of items by mathematical content area is shown in Table 3.1. As required, most of the items dealt with Number Systems and especially Applied Arithmetic & Measure, while a few addressed Algebra and Statistics.

Table 3.1 *Numbers of Items on the Calculator Inappropriate, Calculator Optional and Calculator Appropriate Tests, by Mathematics Content Area – Main Study, Phase 1 (2001)*

Test	Number of Items				
	Number	App. Arithmetic & Measure	Algebra	Statistics	Total
Calculator Inappropriate	13	10	1	1	25
Calculator Optional	11	15	4	2	32
Calculator Appropriate*	9	17	0	6	32

**Refers to both forms of the test booklet combined.*

Table 3.2 gives the distribution of items by item type (multiple-choice or short constructed-response). 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. It should be noted that this greater complexity in some cases was due only to the use of real-life (rather than conveniently rounded) numbers, whereas in other cases it was due to the amount of problem analysis required.

Table 3.2 *Numbers of Multiple-Choice and Short Constructed-Response Items on the Calculator Inappropriate, Calculator Optional and Calculator Appropriate Tests – Main Study, Phase I (2001)*

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

**Refers to both forms of the test booklet combined.*

With regard to the balance between 'pure' and 'applied' items, a high proportion of the items in the Calculator Inappropriate test were 'pure', emphasising basic numerical skills, while the Calculator Appropriate test contained items predominantly of the 'applied' type (emphasising the use of the calculator with real-life data).

Finally, 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 within the tests. Examples of items similar to those on the tests are given in Table 3.3. 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 in Phase I of the study. The following descriptors are used to interpret item difficulties: Easy (80%+ correct); Moderately easy (70%-79%); Average (50%-69%); Moderately difficult (40%-49%) and Difficult (below 40%). It should also be noted that the three tests used in the study did not allow for partial credit for work done on questions, something which is a feature of the State examinations in mathematics.

Table 3.3 *Sample Parallel Items for Each Calculator Test Booklet*

Calculator Inappropriate Items	
Which of the following numbers is equal to $^3/_{10}$? (A) 0.03 (B) 0.3 (C) 3.0 (D) 30	*Content Area: Number Systems* *Difficulty Level: Easy (87%)*
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 & Measure* *Difficulty Level: Moderately Difficult (45%)*

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 & Measure
Difficulty Level: Moderately Easy (74%)

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%)

Calculator Optional Items

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 & Measure
Difficulty Level:
With Calculator – Average (65%)
Without Calculator – Moderately Difficult (40%)
Overall – Average (53%)

Multiply: 6.4×2.5

Answer_______________

Content Area: Number Systems
Difficulty Level: With Calculator – Easy (94%)
Without Calculator – Average (64%)
Overall – Moderately Easy (79%)

Song	**Time Taken**
I need your love	3 minutes 15 seconds
You got me babe	2 minutes 55 seconds
Loving heart	4 minutes 5 seconds
My baby left me	3 minutes 22 seconds
Mama told me	3 minutes 18 seconds

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 & Measure
Difficulty Level: With Calculator – Difficult (34%)
Without Calculator – Moderately Difficult (45%)
Overall – Moderately Difficult (40%)

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 (62%)

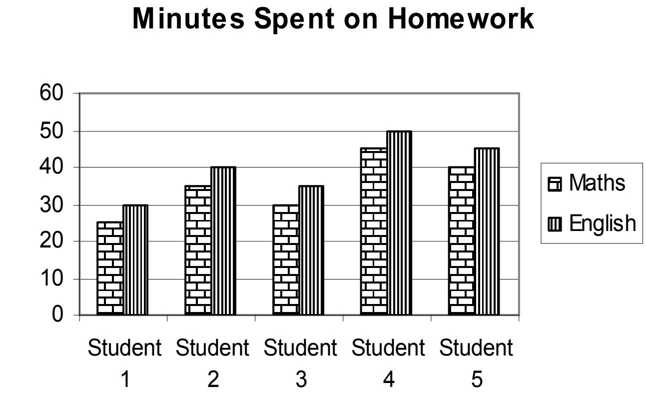
Calculator Appropriate Items

Evaluate:

$$\frac{(9.8)^3 - (29.2)^2}{0.0025}$$

Answer_______________

Content Area: Number Systems
Difficulty Level: Difficult (26%)



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_______________

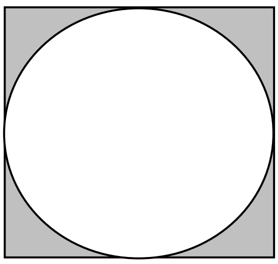
Content Area: Statistics
Difficulty Level: Average (61%)

How many 700 millilitre bottles of port can be filled from a 350 litre barrel?

Answer_______________

Content Area: Applied Arithmetic & Measure
Difficulty Level – Difficult (28%)

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 & Measure
Difficulty Level: Difficult (2%)

Revising the Tests for Phase II of the Study

After the completion of Phase I, minor changes were made to the tests in order to amend or remove items that had performed poorly. In particular:

1. Two very difficult items on simplifying a complicated numerical expression and presenting the result in standard form – one from each form of the Calculator Appropriate test – were removed, and a simpler item testing the same skill was added to the Calculator Optional test

2. Two Applied Arithmetic & Measure items – one with faulty wording and the other eliciting almost no correct responses, one from each form of the Calculator Appropriate test – were removed, and replaced by new items in Statistics, a content area which had perhaps been under-emphasised in the original tests
3. A Statistics item with potentially confusing wording in one of the Calculator Appropriate forms was re-written.

Some items with relatively poor psychometric properties (in particular, very difficult items) were retained because of their particular relevance to the revised syllabus. It was reasonable to conjecture that performance might improve as the required content or skills became more familiar.

As a result of the changes, the Calculator Optional test (for which time had not appeared to be a problem during Phase I testing) was lengthened by one item, while the Calculator Appropriate tests (the later items of which had been omitted by many students in Phase I) were shortened by one item in each form. The distributions of items by content area and item type over the revised tests are shown in Tables 3.4 and 3.5 respectively.

Table 3.4 *Numbers of Items on the Calculator Inappropriate, Calculator Optional and Calculator Appropriate Tests, by Mathematics Content Area – Main Study, Phase II (2004)*

Test	Number of Items				
	Number	App. Arithmetic & Measure	Algebra	Statistics	Total
Calculator Inappropriate	13	10	1	1	25
Calculator Optional	12	15	4	2	33
Calculator Appropriate*	7	15	0	8	30

**Refers to both forms combined.*

Table 3.5 *Numbers of Multiple-Choice and Short Constructed-Response Items on the Calculator Inappropriate, Calculator Optional and Calculator Appropriate Tests – Main Study, Phase II (2004)*

Test	Number of Items	
	Multiple Choice	Short Constructed-Response
Calculator Inappropriate	16	9
Calculator Optional	13	20
Calculator Appropriate*	0	30

* *Refers to both forms combined.*

It should be noted that the minor changes did not obviate comparisons between scores in Phase I and Phase II because IRT scaling was used, as described in Chapter 4.

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 contemporary classroom practice with regard to calculators could be collected in Phase I. Teacher and Student Questionnaires were therefore written for Phase I and developed further for Phase II.

Questionnaires for Phase I of the Study

For Phase I of the study, carried out when calculators were not mentioned in the Junior Certificate mathematics syllabus and calculator use was forbidden in the Junior Certificate mathematics examinations, research questions were formulated as follows:

1. What attitudes and beliefs about the teaching and learning of mathematics do students and teachers hold?
2. What attitudes to calculators do students and teachers hold?
3. How does performance on the calculator tests relate to such factors as general ability, gender, student attitudes towards calculator usage, teacher attitudes and other background factors?
4. In teaching the Junior Certificate mathematics courses, what emphasis is put on mental mathematics and estimation, routine skills and applications, non-routine applications, problem solving, and mathematical investigation?
5. To what extent do students use calculators for mathematics work at home and [for mathematics work] at school?

The *Teacher Questionnaire* for Phase I therefore included sections 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
3. Information and views on calculator usage for homework, including homework in subjects other than mathematics
4. Level of emphasis placed by the teachers on various aspects of school mathematics
5. Rank ordering of areas of school mathematics from most difficult to least difficult for students and from most enjoyable to least enjoyable to teach
6. Teachers' policies regarding use of calculators in mathematics classes during the weeks and months prior to the Junior Certificate mathematics examination (if calculators were used in mathematics classes at all)

7. Teachers' philosophies with regard to the teaching of mathematics, using a scale developed by Becker & Anderson (1998).

The *Student Questionnaire* for Phase I 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 in various contexts (current mathematics classes, mathematics classes in previous years, other classes, for homework)
5. Types of calculator used
6. Attitudes towards mathematics – including engagement with mathematics and preferences for different mathematics content areas
7. Attitudes towards calculators, including attitudes towards calculator usage in mathematics classes, in other subjects, and in the Junior Certificate mathematics examination.

For both questionnaires, further details are available in the main Phase I report.

Questionnaires for Phase II of the Study

For Phase II of the study it was relevant to ask about school policies with regard to calculator and arithmetic skills, as indicated above. Moreover, since teachers were now dealing with the third cohort of Third-year students to experience the revised syllabus, it was of particular interest to ascertain their views on calculators in mathematics education, to identify the parts of the course in which they were making most use of calculators, and to find out the types of usage that they were encouraging. Additional research questions were therefore formulated as follows:

1. What policies, if any, are in operation with regard to calculator and arithmetic skills?
2. At what level (school, mathematics teachers, etc.) are these policies formulated?
3. What advantages do teachers find in using calculators in the Junior Certificate curriculum, and what problems have arisen?
4. In which content areas of the syllabus has their teaching been affected, and in what way?
5. To what extent are they carrying out specified calculator-related activities with their students?
6. Are powerful calculators (graphics calculators and Computer Algebra Systems) available in schools, and to what extent are teachers using them in mathematics classes?

New sections were drafted to address these questions. They were piloted on two occasions with members of the Irish Mathematics Teachers' Association, who were invited both to critique the draft sections and to identify further issues or areas that should be included, and appropriate updates were incorporated.

To obviate excessive length, two questions, one concerning teachers' views on teaching and learning mathematics, and the other concerning teachers' philosophies of mathematics education, were omitted from the Phase II version of the questionnaire. It was felt that these views were unlikely to have changed over the three-year period between the two phases of the study. The revised *Teacher Questionnaire* (Appendix 1) for Phase II therefore included sections to address the following:

1. General background information on teachers, including gender and number of years experience teaching mathematics and year levels to which mathematics is taught by the respondent
2. Rank ordering of areas of school mathematics from most difficult to least difficult for students and from most enjoyable to least enjoyable to teach
3. Policy on calculator use
4. Information and views on calculator usage in mathematics classes, including the following:
    a. frequency with which calculators are used in class, by mathematical content area
    b. 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
    c. teachers' perceptions of whether, and when, students are formally taught calculator and other numeracy skills
    d. aspects of calculator use taught
    e. changes to teaching methodology in different content areas
5. Benefits and problems associated with calculator use in class
6. The extent of teachers' use of powerful calculators (graphics calculators and Computer Algebra Systems) at any level in the school.
7. The extent to which teachers use specified calculator and number activities in their classes (c.f. Appendix 3 for details of these activities).

The revised *Student Questionnaire* (Appendix 2) for Phase II also aimed to capture additional detail about students' experiences of mathematics education and especially of calculator use. It addressed the following:

1. Background information including student's age, gender, and socio-economic status
2. The level of the Junior Certificate mathematics examination that the student intended sitting
3. Ratings of some topics or content areas in mathematics as being easy or difficult
4. Information on calculator usage:

a. Types of calculator used
b. Frequency of use in different subjects
c. Frequency of use in mathematics classes in previous years
d. Time of first being taught to use a calculator (or indication that the student was self-taught)
e. Frequency of use in the areas of mathematics listed above
f. Aspects of calculator use liked most and least

5. Attitudes towards mathematics – including engagement in mathematics and preferences for different mathematics content areas
6. Attitudes towards calculators, including attitude towards calculator usage in mathematics classes, in other subjects, and in the Junior Certificate mathematics examination.

SUMMARY

The purpose of the current chapter is twofold. First, the framework underpinning the Calculator Study was outlined. Secondly, the development of instruments for Phase I of the study was described, and an account was given of their modification for Phase II.

The framework for the calculator tests identified 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 tests, a distinction was made between items that were deemed to be calculator sensitive (that is, items for which access to a calculator was relevant) and those that were not. Content areas selected for inclusion in the tests, because they were particularly suitable for calculator items, were Number Systems, Applied Arithmetic & Measure, and Statistics. In addition, some Algebra items, which required students to solve equations, were included. In developing the items, a balance was created between items that addressed aspects of 'pure' mathematics and those that tested applications of mathematics to 'real-life' situations. Whereas the Calculator Inappropriate test included just a few 'applied' items, and focused mainly on ability to perform mental operations in mathematics, the Calculator Appropriate test consisted mainly of items testing 'real-life' applications. With regard to item type, the tests used both multiple-choice and short constructed-response items.

Two pilot tests were carried out before versions of the tests were compiled for Phase I of the study. For Phase II, minor modifications were made to replace items that functioned badly in the first phase.

In order to generate contextual information with which to interpret the performance of students on the Calculator tests, teacher and student questionnaires were developed. 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. For Phase I of the Study, the questionnaire sought information about the relative emphasis that teachers placed on various aspects of school mathematics. For Phase II [carried out when the revised Junior Certificate mathematics syllabus (requiring appropriate use of calculators) was in operation and calculator use allowed in the Junior Certificate mathematics examination] the questions in this area were replaced by questions seeking information in two areas: school or teacher policy with regard to numeracy issues, including calculator use; and teachers' experience of aspects, benefits and problems of calculator usage.

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. In Phase II, additional questions were asked in order to investigate students' experience of calculator use under the revised syllabus.

Chapter 4: Implementation of the Study

This chapter describes implementation of the second phase of the Calculator Study. The chapter is divided into four sections. The first describes the sample for Phase II study, and compares it with the sample for the Phase I study. The second describes implementation of the study. The third outlines procedures used to scale the Calculator tests following Phase II testing. The final section summarises the approaches taken to analysing data gathered in the Phase II study.

SAMPLE OF SCHOOLS AND STUDENTS

Phase II of the Calculator Study was implemented in November 2004 – the same time of the year as the Phase I main study, so that valid comparisons could be drawn between the performances of the 2001 and 2004 samples.

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. In addition, an attempt was made to ensure that the 2004 sample was as similar as possible to the 2001 (Phase I) main study sample.

A first stage of sampling involved whole schools as the sampling unit. As in 2001, an attempt was made to ensure proportionate representation of schools of different sector (type) and size – categories that are known to differ in terms of average achievement of enrolled students. Consequently, schools were first grouped into strata which were defined by sector 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 for the 2003-04 school year. As in 2001, students in special schools, or in full-time special (resource) classes in ordinary schools, were excluded. The Department's database provided a listing of schools, and the numbers of male and female students in Third year in each school. Unlike 2001, when only numbers of male and female students in Junior Cycle were available, it was possible in 2004 to sample with respect to the numbers of students in Third year only.

Stratification and Selection of Schools

Schools were stratified by sector (Secondary, Vocational, Community/Comprehensive) and size (large, small) (Table 4.1). Schools with between 30 and 60 students in Third year were defined as small and those with more than 60 as large. Schools with fewer than 30 Third year students were not selected (in 2001, schools with fewer than 100 students in Junior Certificate were excluded). Within each stratum, schools were sorted by the percentage of female students in Third year and by school size (again, the number of students in Third year). Schools were then selected using probability proportional to size (PPS) systematic sampling. This entailed establishing a random starting point in each stratum, and selecting schools using a fixed interval (based on school size and number of schools required). Replacement schools were also selected during this procedure with the first replacement being the school immediately next in the list after the selected school and the second replacement being the school immediately prior to the selected school.

Table 4.1 *Numbers and Percentages of Schools and Third-Year Students in Database of Post-primary Schools, by Stratum – Main Study, Phase II*

Stratum	Schools		Students	
	n	%	n	%
Excluded (<30 students)	143	19.3	4187	7.4
Secondary large (61+ students)	270	36.4	27410	48.7
Secondary small (30-60 students)	95	12.8	4275	7.6
Vocational large (61+ students)	84	11.3	8229	14.6
Vocational small (30-60 students)	64	8.6	2776	4.9
Community/Comprehensive	86	11.6	9463	16.8
Total	742	100.00	56340	100.00

Table 4.2 gives the numbers and percentages of schools in each stratum in the defined population and the selected sample. Schools classified as ‘excluded’ do not appear on this table, so population percentages differ somewhat from those reported in Table 4.1. Table 4.2 indicates that, in all, 100 schools were selected to participate, and that almost one-half of these were in the large secondary stratum.

Table 4.2 *Numbers of Schools and Third-Year Students, and Percentages of Students in the Defined Population and Selected Sample, by Stratum – Main Study, Phase II*

Stratum	Defined Population				Selected Sample			
	Schools		Students		Schools		Students	
	n	%	n	%	n	%	n	%
Secondary (large)	270	45.1	27410	52.6	48	48.0	5105	49.4
Secondary (small)	95	15.9	4275	8.2	10	10.0	417	4.0
Vocational (large)	84	14.0	8229	15.8	18	18.0	2083	20.2
Vocational (small)	64	10.7	2776	5.3	6	6.0	288	2.8
Comm/Comp	86	14.4	9463	18.1	18	18.0	2431	23.5
Total	599	100	52153	100	100	100	10324	100

Selection of Students within Schools

Schools agreeing to take part in the study were asked to submit a list of Third-year mathematics classes to the Educational Research Centre, along with the number of students in each class. One class in each school was then selected at random by the Centre to participate in the study. While on psychometric grounds it would have been preferable to have selected Third-year students at random within schools, as is done with 15 year olds in the OECD Programme for International Student Assessment (PISA, OECD, 2004), this would have weakened connections between the teacher and student data.

Response Rates

Initially, 66 schools (66%) indicated their willingness to take part in the study. After the first 10 schools declined to take part, 10 replacement schools were contacted and invited to participate. Seven of these schools agreed to take part, giving 73 schools in total (Table 4.3). Given the tight time frame within which the study was conducted, it was not possible to recruit additional replacement schools.

Table 4.3 *Achieved Sample of Schools, by Stratum – Main Study, Phase II*

Stratum	Achieved Sample			
	Schools		Students	
	n	%	n	%
Secondary (large)	32	43.8	671	46.0
Secondary (small)	7	9.6	115	7.9
Vocational (large)	17	23.3	329	22.5
Vocational (small)	4	5.5	75	5.1
Community/ Comprehensive	13	17.8	269	18.4
Total	73	100	1459	100

In all, 1459 Third-year students completed the calculator tests.[8] Of these, all but 11 completed the Student questionnaire so questionnaire data and matching achievement data were available for 1448 students who completed the calculator tests. Of the 73 teachers whose classes participated in the study, 71 completed the Teacher questionnaire. This meant that teacher-level information was available in respect of most students who completed the calculator tests.

Weights

Weights were computed to compensate for the somewhat unequal distribution of students in different strata in the sample, using procedures applied in TIMSS 1995 (the Third International Mathematics and Science Study), which also involved sampling of intact classes in schools (see Foy, 1997). A separate weight was computed for each school/classroom based on the product of four components:

[8] In fact, 1463 test booklets were returned for each test, but, in the case of 4 students, no responses were filled in for any of the tests.

- A school base weight, which was the inverse of the number of Third-year students in a stratum, over the number of Third-year students in the population
- A school-level correction for non-response, which was the inverse of the number of schools in a stratum in the original sample, over the number of schools in the stratum that participated
- A class weight, which was the inverse of the number of Third-year classes in a school, over the number of classes in the school in the study (i.e., 1)
- A student-level correction for non-response, which was inverse of the number of students in the class according to the School Form, over the number that completed the Calculator tests.

The resulting weights were multiplied by the number of students in the sample, over the number in the population, so that the total number of students in the weighted sample corresponded with the total number in the unweighted sample.

Comparison of the 2001 and 2004 Samples

While every effort was made to ensure that the Phase II sample (November, 2004) was representative of the population of students in Ireland, it was also important to ensure that it was broadly equivalent with the Phase I main study sample (November, 2001) so that valid comparisons could be made between student performance in the two phases. Table 4.4 compares the achieved main study samples for Phases I and II. The table shows that, across the two phases, the achieved samples are broadly similar, though there were proportionately fewer large Secondary schools (and students) and proportionately more large Vocational schools (and students) in the Phase II sample, relative to the Phase I sample.

Table 4.4 *Numbers of Schools and Students in Achieved Sample, by Stratum – Phase I (2001) and Phase II (2004) Main Studies*

Stratum	Phase I (2001)				Phase II (2004)			
	Schools		Students		Schools		Students	
	n	%	n	%	n	%	n	%
Secondary (large)	34	51.5	792	53.9	32	43.8	671	46.0
Secondary (small)	7	10.6	132	9.0	7	9.6	115	7.9
Vocational (large)	8	12.1	175	11.9	17	233	329	22.5
Vocational (small)	3	4.5	60	4.1	4	5.5	75	5.1
Comm/Comp	14	21.2	310	21.1	13	17.8	269	18.4
Total	66	100	1469	100	73	100	1459	100

The two samples can also be compared with respect to the gender of students. Table 4.5 shows that, across the two phases, the proportions of male and female students were broadly similar. Whereas data on gender were unavailable for 4% of students in Phase I, they were unavailable for just 1% in Phase II. Comparable data on the proportions of male and female students sitting the Junior Certificate examination in the population and the selected sample in 2004/2005 are given in Appendix Table 4.1.

Table 4.5 *Distribution of Achieved Sample, by Gender (Unweighted) – Phase I (2001) and Phase II (2004) Main Studies*

	Phase I (2001)		Phase II (2004)	
	n	%	n	%
Male	637	43.4	659	45.2
Female	773	52.6	789	54.1
Missing	59	4.0	11	0.8
Total	1469	100	1459	100

The Phase I and II samples can be compared with respect to the proportions intending to take the Junior Certificate mathematics examination at Higher, Ordinary and Foundation levels in the November preceding the Junior Certificate proper in each Phase. Table 4.6 indicates that, in broad terms, the Phase I and Phase II main study samples are equivalent in terms of the Junior Certificate mathematics level that students intended to sit, some 7 months before the examination proper. Again, data were missing for this variable for 4.2% of students in 2001, and for 1.4% in 2004. In relation to the Junior Certificate examination that students actually sat, the large proportion of missing data in 2001 (13%) makes it more difficult to draw comparisons between the two phases, though there does appear to be an increase in the proportion of Higher level students sampled.

Table 4.6 *Distribution of Achieved Sample, by Intended and Actual Junior Certificate Mathematics Level (Unweighted) – Phase I (2001) and Phase II (2004) Main Studies*

	Phase I (2001)				Phase II (2004)			
	Intended		Actual		Intended		Actual	
	n	%	n	%	n	%	n	%
Higher	808	55.0	594	40.6	885	60.7	773	53.0
Ordinary	567	38.6	638	43.6	503	34.5	611	41.9
Foundation	33	2.2	45	3.1	51	3.5	60	4.1
Missing	61	4.2	185	12.7	20	1.4	15	1.0
Total	1469	100	1462	100	1459	100	1459	100

IMPLEMENTATION IN SCHOOLS

The Phase II main study was implemented in November 2004. 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 and Teacher and Student questionnaires.

Unlike 2001, it was not necessary to supply schools with calculators, as these were now readily available in schools. It was suggested to co-ordinators that they administer the test themselves, or ask the students' mathematics teacher to do so.

Testing was conducted during a two-week period, November 8 - 19, 2004. All schools that agreed to participate returned their materials to the Educational Research Centre by early December, 2004.

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 a calculator for this test. After a short break, students were administered the Calculator Optional test. The calculator and non-calculator versions of the test (only the directions with respect to calculator usage were different) were distributed to alternate students. Then students with the calculator version were directed to take out their calculators. The time limit for this test was 40 minutes. After another short break, the Calculator Appropriate test was administered. The time limit for this test, for which all students had access to a calculator, was 25 minutes. Test administrators distributed the two forms of the test within classes, first alternately to students who had access to a calculator for the Calculator optional test, and then, alternately to those who had not. Then all students were asked to take out their calculators. Following another short break, the Student questionnaire was administered. Teachers were encouraged to complete the Teacher questionnaire at the same time as students were working on their questionnaire.

Scoring of Calculator Tests and Questionnaires

Students of mathematics at St Patrick's College, Drumcondra, were recruited to score the test booklets using marking schemes developed by the project team. In the case of short constructed-response items, markers were encouraged to consult with a member of the project team in relation to any student response about which they were unsure. Responses were marked as either correct or incorrect. Unlike the Junior Certificate in mathematics examinations, no partial credit was allowed.

Questionnaires were also marked manually before data entry. A significant task, in the case of the Student questionnaire, was the coding of the socioeconomic status item. Coders were asked to code parent occupations according to the International Socioeconomic 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 compare the performances of students taking the 2004 version of the Calculator Tests with the performance of students who took the 2001 version of the tests.

Using Item Response Modelling to Adjust for Changes to the 2004 Tests

In 2001, Item Response Theory (IRT) methodology was used to derive scores for each examinee on the Calculator Inappropriate, Calculator Optional and Calculator Appropriate tests. A full discussion on the IRT models employed and on the approaches used to evaluate item fit, to estimate item difficulties, and to transform examinee abilities to scale scores is contained in the main 2001 report (Close et al., 2004).

Analyses carried out on the 2001 data indicated that a small number of items were problematic and it was agreed that these needed to be deleted, replaced or improved for the 2004 administration, as discussed in Chapter 3 of this report. Exact details about the changes made are provided below. However, while these changes were carried out to improve the validity of the calculator tests as measures of mathematics performance, they also had the effect of making comparisons across the two administrations of the test problematic. For example, a comparison of the average percent correct across the two administrations could not be validly made if some items were different the second time around. Given this problem, one of the key reasons IRT methodology was used in this project was that it allowed changes to be made to the 2004 tests without affecting the validity of the comparisons that needed to be made between student performance in 2001 and 2004. This important advantage of using IRT derives from the fact that IRT models, when correctly applied, result in student ability estimates that are not dependent on a particular set of items, as is the case when percent correct scores are used. Discussion of the item invariance vis-à-vis a test taker's ability estimate is provided by Baker (2001) and Crocker and Algina (1986).

As outlined in Chapter 3, four items from the 2001 version of the Calculator Appropriate test (Booklet 1 item 7 and Booklet 2 items 5, 9 and 10) were identified as being problematic in terms of having poor fit statistics and/or a percentage correct score too low to allow for stable estimates of item parameters. In 2002, a decision was made by the project team to retain these items in the 2001 scale as they were important in curricular terms. As part of the preparatory work for the 2004 administration of the calculator tests, these items were reviewed again. It was decided to remove items 7 and 5 from Calculator Appropriate Booklets 1 and 2 respectively and replace them with one new item (item 29) in the Calculator Optional test covering the same material. This also had the advantage of reducing the number of items in the Calculator Appropriate test, which students found challenging first time around. In the Calculator Appropriate Booklet 1, item 8b from 2001 was rewritten to ensure that a correct response was not dependent on getting the first part (item 8a) correct. In the same booklet, an item that was faulty and not used in the scaling for 2001 (item 10) was replaced by a new item. In Booklet 2, item 9 was deleted and replaced by a new item and item 10 was retained. A small error was found in the scoring key for item 11 when scaling the 2001 data. The difficulty parameter for this item was re-estimated using 2004 data. A synopsis of the changes made is included in Table 4.7.

Table 4.7 *Summary of Changes Made to the Calculator Tests in 2004*

Test	Changes
Calculator Inappropriate	No changes 2004 test had 25 items
Calculator Optional	One item added (29) 2004 test had 33 items
Calculator Appropriate (Booklet 1)	Item 7 in 2001 deleted (content tested by Item 29 Calculator Optional Test) Item 8b in 2001 replaced by Item 7b in 2004 Item 10 in 2001 replaced by Item 9 in 2004 2004 test had 15 items
Calculator Appropriate (Booklet 2)	Item 5 in 2001 deleted (content tested by Item 29 Calculator Optional Test) Item 9 deleted in 2001 replaced by Item 8 in 2004 (Item 8 subsequently deleted from the 2004 scale due to an error in printing) Item 11 in 2001 (Item 10 in 2004) treated as new 2004 test had 15 items

Parameters for items that remained unchanged across the two administrations of the tests were fixed at their 2001 values while data from 2004 were used to estimate parameters for the new items listed in Table 4.7.

Difficulty parameters (called logit scores) for the four new items[9] were estimated through a process of holding the parameters for unchanged items at their 2001 values and using data from the 2004 administration to fit the new item difficulties to the original scale. All procedures followed in 2001 to estimate item parameters were replicated in 2004. The fit of the new items was examined and judged against the criteria used previously. One of the items (Item 29 from the Calculator Optional test) did not fit the scale well in so far as it was a very difficult item with a low percent correct (5) and a high IRT logit estimate (2.97). After due consideration, a decision was made by the project team to retain the item in the scale as it related to mathematics content that was important in a curricular sense and was not tested elsewhere in the booklet.

The difficulty values for all items used in 2004 were then used to estimate student ability logit scores in 2004. Again, the procedures used in 2001 were replicated. In 2001 student logit scores for each of the calculator tests were transformed to a scale with a mean of 250 and a standard deviation of 50 to facilitate reporting.[10] The scaling parameters used in 2001 were applied to the logit scores for test takers in 2004. In this way scores derived from both administrations of the tests can be considered comparable.

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[9] Calculator Optional Item 29; Calculator Appropriate Booklet 1 Item 7b and Item 9; Calculator Appropriate Booklet 2 Item 10c.

[10] This scale was achieved by calculating a weighted average and standard deviation for the logit scores for test takers in 2001 and applying the following formula:
(student scale score – 250)/50 = (student 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 5-8 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 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 will 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 1.96 standard errors below the statistic to 1.96 standard errors above it) may be constructed so that, if the sampling procedures 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 3, it is possible to say, with 95% confidence, that the true population mean lies within two standard errors of the estimated mean, that is approximately between 244 and 256 ($250 \pm 1.96 \times 3$).

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 (for example, between Phases I and II) 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.[11]

The Bonferoni procedure (Dunn, 1961) was used to adjust two-tailed alphas[12] 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 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 37 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). 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*).

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 6, 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.

SUMMARY

A key concern in implementing the current study was to ensure that the Phase I (2001) and Phase II (2004) samples were equivalent. The Phase I sample consisted of 66 schools and 1469 Third-year students. The Phase II sample consisted of 73 schools and 1459 students. About 45% of students in the two samples were males. About

[11] Comparisons of mean scores within the 2004 dataset (e.g., comparing the scores of males and females on the calculator tests) were done within WesVar.

[12] Alpha is the significance level used to compute the confidence level

three-fifths of students in the two samples intended to sit the Junior Certificate mathematics examination at higher level. The distribution of students across school types in the two samples was broadly similar, though large vocational schools were somewhat better represented in Phase II than in Phase I, and large secondary schools were less well represented. Overall, however, it can be concluded that the two samples are broadly equivalent.

The school-level response rate in Phase II (73 schools, 66%) is broadly adequate, and not dissimilar from the rate achieved in Phase I (66 schools, 73%). In both phases, intact classes were selected to participate following the sampling model employed in the Third International Mathematics and Science Study (TIMSS, Beaton et al., 1996).

The scaling of the Calculator Tests in Phase II capitalised on some of the strengths of Item Response Theory (IRT). In particular, it was possible to implement some minor changes to the tests without invalidating comparison across phases. The performance of students in 2004 was placed on the same scales that were developed in 2001, allowing for valid comparisons of achievement over time.

Chapter 5: Performance on the Calculator Tests

In this chapter, the comparative performance of students in 2001 and 2004 on each of the three calculator study tests is described, first in terms of overall performance, secondly in terms of performance on the different mathematical content areas tested, and thirdly in terms of performance on key items. The items used in the three tests in 2004 were the same as those used in 2001 except as detailed in Table 4.7. The final section of the chapter consists of an analysis of the written ('rough') work recorded by the 2004 students on their test booklets.

OVERALL PERFORMANCE IN 2001 AND 2004 COMPARED

As described in Chapter 4, the three tests were scaled separately in 2001 using Item Response Theory methods, and the mean score and standard deviation for each test was set at 250 and 50 respectively. To facilitate comparison between the 2001 and 2004 scores, scores on the 2004 tests were placed on the same scale as in 2001, using IRT methods. This means the two sets of scores can be compared on the same scale. Comparisons of 2001 and 2004 raw or percent correct scores involved only those items common to tests on both years. In addition to mean scale scores, mean raw scores, mean percent raw scores, standard errors, standard error of the difference, and confidence intervals are provided where appropriate.

Overall Performance on All Calculator Tests for 2001 and 2004

The mean scale scores, mean raw scores, and mean percent correct scores for the three tests for both 2001 and 2004, along with the results of tests of the significance of the differences, are given in Tables 5.1, 5.2 and 5.3 respectively. Note that, with regard to the Calculator Optional test in Table 5.1, the overall mean scale score was set at 250 in 2001, but here the means for the two calculator conditions are reported separately for each year.

Table 5.1 *Mean Scale Scores and Standard Errors on the Calculator Inappropriate, Calculator Optional (with, without Access), and Calculator Appropriate Tests (2001 and 2004)*

Test	2001		2004		04-01	SED	95%CI	
	Score	SE	Score	SE	Diff			
Calculator Inappropriate	250.0	4.54	243.2	4.48	-6.8	6.32	-5.79	19.45
Calculator Optional (Access)	266.2	3.36	271.5	4.59	5.27	4.87	-15.00	4.46
Calculator Optional (No Access)	235.8	4.68	227.1	5.35	-8.70	7.11	-5.50	22.90
Calculator Appropriate	250.0	4.45	263.4	2.39	13.4	5.05	**-23.50**	**-3.34**

Statistically significant differences are in ***bold****. SE = Standard Error; SED = SE of the Difference*

Table 5.2 *Mean Raw Scores and Standard Errors on the Calculator Inappropriate, Calculator Optional (with, without Access), and Calculator Appropriate Tests (2001 and 2004)*

Test	2001		2004		04-01	SED	95%CI	
	Score	SE	Score	SE	Diff			
Calculator Inappropriate	15.0	0.52	14.2	0.46	-0.8	0.70	-0.57	2.21
Calculator Optional (Access)	18.9	0.55	20.1	0.58	1.18	0.62	-2.42	0.06
Calculator Optional (No Access)	15.2	0.68	13.7	0.75	1.5	1.01	-0.52	3.52
Calculator Appropriate	4.9	0.23	5.5	0.14	0.6	0.27	**-1.10**	**-0.01**

*Statistically significant differences are in **bold**. SE = Standard Error; SED = SE of the Difference*

Table 5.3 *Mean Percent Correct Scores and Standard Errors on the Calculator Inappropriate, Calculator Optional (with, without Access), and Calculator Appropriate Tests (2001 and 2004)*

Test	2001		2004		04-01	SED	95%CI	
	Score	SE	Score	SE	Diff			
Calculator Inappropriate	60.0	2.10	56.8	1.80	-3.3	2.78	-2.29	8.83
Calculator Optional (Access)	59.2	1.72	62.8	1.81	3.67	1.94	-7.55	0.21
Calculator Optional (No Access) *	47.5	2.09	42.7	3.35	-4.76	3.95	-3.13	12.65
Calculator Appropriate	35.0	1.67	40.6	0.99	5.6	1.94	**-9.47**	**-1.73**

*Statistically significant differences are in **bold**. SE = Standard Error; SED = SE of the Difference*

As can be seen from the Tables 5.2 and 5.3, performance on both the Calculator Inappropriate and Calculator Optional tests (no calculator access) declined slightly between 2001 and 2004, but not significantly so. On the other hand, performance improved significantly on the Calculator Appropriate test from 2001 (35% correct) to 2004 (40.6%), though this is still low relative to performance on the other two tests. While there was a decline in performance on the Calculator Inappropriate test over the three years (60% vs. 56.8% correct), it was not statistically significant. This can be interpreted as suggesting that students in 2004 had not lost out on basic mathematical skills while following the revised Junior Certificate mathematics syllabus with access to calculators, compared to students in 2001 who did not have access to calculators. The improvement in performance on the Calculator Appropriate test, which includes the items most likely to bring calculators into play, suggests that students' ability to make use of the calculator in solving problems improved over the three years. However, the overall low performance on this test in both 2001 (35%) and 2004 (40.6%), which arises at least partly because students did poorly on problem solving tasks, continues to be a matter of concern. Further analyses could identify which kinds of problems were solved successfully, and which were not.

Tables 5.4 gives the mean scale scores of students at key percentile points on the Calculator Appropriate, Calculator Optional and Calculator Inappropriate tests. No distinction is made in Table 5.4 between the scores of students who had or did not have access to calculators while attempting the Calculator Optional test.

Table 5.4 *Scale Scores at the Key Percentile Ranks on the Calculator Inappropriate, Calculator Optional, and Calculator Appropriate Tests (2001 and 2004)*

	Calculator					
	Inappropriate		Optional		Appropriate	
	2001	2004	2001	2004	2001	2004
10th	178.5	175.0	187.1	181.3	**175.6**	**195.5**
25th	220.0	213.0	214.3	216.9	216.8	227.0
50th	256.8	241.0	252.7	255.0	**252.6**	**265.8**
75th	277.2	274.5	286.0	283.5	**281.6**	**298.7**
90th	318.8	309.2	316.1	313.4	314.4	329.9

Significantly different scores are in ***bold***

The differences between 2001 and 2004 in terms of the scores of students at five key percentile points (10th, 25th, 50th, 75th, 90th) can be seen in Table 5.4. None of the differences at these points was significant for the Calculator Inappropriate and Calculator Optional tests. However, students in 2004 achieved significantly higher scores at the 10th, 50th, and 75th percentiles on the Calculator Appropriate test, while scores in 2004 were also higher at the 25th and 90th percentiles, but not to a significant extent. The changes across the distribution reflect the overall improvement in mean performance on the Calculator Appropriate test at the 2001 and 2004 test points compared with the other two tests. The results shown in these tables generally suggest that performance on questions for which the use of a calculator is most appropriate were most affected by the impact of calculator access over the three year period and that this effect is not confined to any particular mathematical ability group.

Effects of Access to Calculators on Performance on the Calculator Optional Test, for 2001 and 2004

This section addresses differences in performance on the Calculator Optional Test between students who did or did not have access to a calculator for the 2001 and 2004 tests.

Students had been assigned at random to either the calculator or no calculator conditions (c.f. Chapter 4). Using student scores on the Calculator Inappropriate and Calculator Appropriate tests as measures of mathematics ability, it was important to establish, first of all, that, in both 2001 and 2004, the two groups of students taking the Calculator Optional test were of equal overall ability in mathematics. In 2001 students who *had access to a calculator* for the Calculator Optional test achieved a mean score of 249.5 on the Calculator Inappropriate test, and a mean score of 250.5 on the Calculator Appropriate test, while students who *did not have access to a calculator* for the Calculator Optional test achieved a mean score of 250.4 on the Calculator Inappropriate test and a mean score of 249.5 on the Calculator Appropriate test. In 2004 students who *had access to a calculator* for the Calculator Optional test achieved a mean score of 241.6 on the Calculator Inappropriate test, and a mean score of 262.4 on the Calculator Appropriate test, while students who *did not have access to a calculator* for the Calculator Optional test achieved a mean score of 244.8 on the Calculator Inappropriate test and a mean score of 264.5 on the Calculator Appropriate test. For both 2001 and 2004, the small, insignificant differences between the mean scale scores on the Calculator Inappropriate and Calculator Appropriate tests, of those with and without access to calculators for the Calculator Optional test, indicates that the two groups were well matched in terms of overall performance in mathematics as a result of random assignment to the two calculator conditions. These data are summarised in Table 5.5.

Table 5.5 *Mean Scale Scores of Calculator Group vs Non-Calculator Group on the Calculator Inappropriate and Calculator Appropriate Tests (2001 and 2004)*

Calculator Optional	**Calculator**			
	Inappropriate		**Appropriate**	
	2001	**2004**	**2001**	**2004**
Calculator Access	249.5	241.6	250.5	262.4
No Calculator Access	250.4	244.8	249.5	264.5

*Significantly different scores are in **bold***

The difference in overall achievement between students with and without access to a calculator on the Calculator Optional test was 30.4 scale points in 2001, and 44.4 in 2004, both in favour of the calculator access group (Table 5.6). These differences are both statistically significant, showing clearly the advantage conveyed to students with access to calculators compared to those with no access at the two test points. There was a slight fall (8.7 scale points) over the three years in the performance of the non-calculator group, perhaps implying that students in this group had become less accustomed to working without access to calculators on tasks of the type on the Calculator Optional test. The increase in performance (5.3 points) of those with access to a calculator over the two years approached but did not reach statistical significance.

Table 5.6 *Mean Scale Scores and Standard Errors on the Calculator Optional Test, by Access to Calculator (2001 and 2004)*

Calculator Optional	**2001**				**2004**			
	n	**Mean**	**SE**	**Diff**	**n**	**Mean**	**SE**	**Diff**
Calculator Access	731	266.2	1.63	**30.4**	742	271.5	4.59	**44.4**
No Calculator Access	732	235.8	2.57		718	227.1	5.35	

Table 5.7 gives the scores at the 10th, 25th, 50th, 75th and 90th percentiles on the Calculator Optional Test for the two groups – students who had access to a calculator during the test, and students who did not have access – for both 2001 and 2004.

The table shows that, at the 50th percentile, the mean score of students in 2004 *with access* to calculators (267.9) was significantly higher than the mean score of the 2001 students *with access to calculators* (257.9). On the other hand, it also shows that, at the 50th percentile, the mean score of the 2001 students *without access to calculators* (240.0) was significantly higher than the mean score of the 2004 students *without access to calculators* (221.2). These data imply that, at this level of performance (50th percentile), students in 2004 with calculator access performed better than their counterparts in 2001 who had access. However they were less able than students in 2001 to function without calculator access.

Table 5.7 *Scale Scores at the Key Percentile Ranks on the Calculator Optional Test for Students With/Without Access to a Calculator (2001 and 2004)*

	Calculator Optional Test							
	Calculator Access				No Calculator Access			
	2001		2004		2001		2004	
	Score	SE	Score	SE	Score	SE	Score	SE
10^{th}	208.8	4.58	216.0	5.05	175.5	3.33	169.8	3.71
25^{th}	243.2	4.51	234.5	3.72	195.5	4.56	196.4	5.46
50^{th}	**257.9**	2.56	**267.9**	3.16	**240.0**	6.40	**221.2**	5.95
75^{th}	305.7	5.47	307.8	7.03	263.7	6.80	262.2	7.25
90^{th}	318.7	2.40	328.4	6.39	310.3	4.16	288.9	16.29

*Statistically significant differences in scores between years in **bold***

When the scores of students at the 10^{th}, 25^{th}, 50^{th}, 75^{th} and 90^{th} percentile ranks were compared across the calculator access/no access conditions within 2001 and 2004 (Table 5.8), significant differences in favour of the calculator access group were observed at the 10^{th}, 25^{th}, 50^{th} and 75^{th} percentile points in 2001 and 2004. It appears that, on Calculator Optional items in both years, higher-achieving students (those scoring at the 90^{th} percentile or above) may benefit less from access to a calculator than students with lower levels of performance (perhaps due to a ceiling level on the test). The consistency of these findings across percentile ranks and across time support outcomes from other studies that students test scores improve to a significant extent when calculators are made available to them.

Table 5.8 *Comparisons of Scale Score Differences at the 10^{th}, 25^{th}, 50^{th}, 75^{th} and 90^{th} Percentiles on the Calculator Optional Test, by Calculator Availability (2001 and 2004)*

	2001				2004			
	Access-No Access Diff	SED	95% CI		Access-No Access Diff	SED	95% CI	
10^{th}	33.3	5.66	**22.0**	**44.6**	46.2	6.27	**33.70**	**58.72**
25^{th}	47.7	6.41	**34.9**	**60.5**	38.1	6.61	**24.90**	**51.28**
50^{th}	17.9	6.94	**4.1**	**31.8**	46.8	6.74	**33.32**	**60.22**
75^{th}	42.0	8.73	**24.6**	**59.5**	45.6	10.10	**25.42**	**65.76**
90^{th}	8.4	4.80	-1.1	18.0	39.5	*	----	---

*Statistically significant differences in calculator conditions within years are in **bold**. SED = Standard Error of the Difference.*
** Standard error could not be reliably estimated.*

PERFORMANCE ON MATHEMATICS CONTENT AREAS IN 2001 AND 2004

Consideration is given in this section to the performance of students on the different mathematics content areas assessed by the Calculator Inappropriate, Calculator Optional and Calculator Appropriate tests. Each item was categorised according to the mathematics content area it addressed – Number Systems, Applied Arithmetic & Measure, Algebra, and Statistics. An item-by-item breakdown of the three tests by content area in 2004 is given in Appendix Table A5.1, while corresponding percent correct scores are given in Appendix Tables A5.2 (Calculator Inappropriate), A5.3 (Calculator Optional), and A5.4 (Calculator Appropriate). Table 5.9 (below) shows the overall results by content area for 2001 and 2004 when performance on the three tests is combined.

Table 5.9 *Comparison of Mean Percent Correct Scores, by Mathematics Content Areas (Three Tests Combined) (2001 and 2004)*

Content Area	2001		2004	
	%	SE	%	SE
Number Systems*	60.6	1.79	60.8	1.20
Applied Arithmetic & Measure**	46.4	1.87	45.7	2.00
Algebra***	46.2	2.92	48.3	1.67
Statistics****	50.1	2.11	49.8	2.04

** 32 items common to both years; ** 41 items; *** 5 items; ****9 items*

Table 5.9 shows that, when all the items in each content area on the three tests are taken together, no significant differences emerge in performance between 2001 and 2004. These results suggest that mathematical knowledge of students has not changed significantly on any of the major content areas of the combined tests over the three-year period of the study. However, a somewhat different picture emerges when the results by content area are looked at for each test separately. It should be noted that the numbers of items testing the content areas of Algebra (5 items) and Statistics (9 items) are quite small and therefore the results on these groups of items have less validity compared with those of the larger item groupings in Number Systems and Applied Arithmetic & Measure.

Content Areas on the Calculator Inappropriate Test in 2001 and 2004

Average percent correct scores on subsets of items on the Calculator Inappropriate test in 2001 were 64.5% for Number and 53.1% in Applied Arithmetic & Measure (Table 5.10). The corresponding figures for 2004 were 62.1% (Number) and 49.8% (Applied Arithmetic & Measure). The differences between 2001 and 2004 for both content areas are not statistically significant. This finding provides an affirmative answer to the research question on the effects of calculator use on basic mathematical skills. In mathematics curricula with calculator availability there is no significant loss in ability to do important basic mathematical tasks without a calculator.

It should be noted that, on this test, there was just one item each in Algebra and Statistics, so, for these areas, the data represent item rather than test statistics.

Table 5.10 *Percent Correct Scores on the Calculator Inappropriate Test, by Mathematics Content Area (2001 and 2004)*

Content Area	2001		2004		04-01	SED	95%CI	
	%	SE	%	SE	Diff			
Number Systems*	64.5	2.1	62.1	1.5	-2.4	2.6	-2.7	7.5
Arith/Measure**	53.1	2.1	49.8	2.2	-3.3	3.0	-2.8	9.4
Algebra***	63.7	3.1	56.2	0.2	-7.5	3.1	**1.3**	**13.7**
Statistics****	67.6	2.7	64.1	3.2	-3.4	4.2	-4.9	11.8

*Statistically significant differences are in **bold**. SE = Standard Error; SED = SE of the Difference*
** 13 items common to both years; ** 10 items; *** 1 item; **** 1 item*

Content Areas on the Calculator Optional Test in 2001 and 2004

Table 5.11 provides a breakdown of the performance of all students on the Calculator Optional test by content category for 2001 and 2004, while Tables 5.12 (calculator available) and 5.13 (calculator not available) report on the performance of students in each content area on the same test, by calculator access, for 2001 and 2004 respectively. Only common items across the two phases of the study are compared.

When the performance of students (regardless of calculator access) on the Calculator Optional test is compared between 2001 and 2004, no significant differences emerge for any of the content areas, with the exception of Algebra for which there were just 4 items (Table 5.11). The significant improvement in Algebra between 2001 and 2004 is considered further at the item level in a later section of this chapter.

Table 5.11 *Percent Correct Scores (All Students) on the Calculator Optional Test, by Mathematics Content Area (2001 and 2004)*

Content Area	2001		2004		04-01	SED	95%CI	
	%	SE	%	SE	Diff			
Number Systems*	63.7	1.5	62.1	1.3	-1.6	2.0	-2.3	5.6
Arith/Measure**	49.0	1.9	48.3	2.4	-0.7	3.0	-5.4	6.8
Algebra***	41.9	2.9	49.2	1.5	7.3	3.3	**-13.9**	**-0.7**
Statistics****	51.8	2.4	51.9	2.6	0.1	3.5	-7.1	6.8

*Statistically significant differences are in **bold**. SE = Standard Error; SED = SE of the Difference*
** 11 items; ** 15 items; *** 4 items; **** 2 items*

Students in 2004 who had access to calculators when taking the Calculator Optional test did significantly better than students in 2001 with access to calculators, on both Number Systems and Algebra, and slightly better (though not significantly so) on the Applied Arithmetic & Measure and Statistics areas (Table 5.12). This suggests that students were able to use calculators with more effect on calculator optional tasks in 2004 than in 2001. On the other hand, this improvement was countered by a significant drop in the performance of students without access to calculators in 2004 relative to 2001 in Number Systems (Table 5.13). This latter finding suggests that this group had become more used to using a calculator on Calculator Optional tasks and did not do quite as well on them when a calculator was not available.

Table 5.12 *Percent Correct Scores on Mathematics Content Areas on the Calculator Optional Test – Calculators Available (2001 and 2004)*

Content Area	2001 %	2001 SE	2004 %	2004 SE	04-01 Diff	SED	95%CI	
Number Systems	74.1	1.1	78.2	1.1	4.1	1.6	**-7.2**	**-1.0**
Arith/Measure	52.4	1.9	54.5	2.0	2.1	2.7	-7.6	3.3
Algebra	45.4	2.9	56.8	1.8	10.5	3.4	**-17.2**	**-3.7**
Statistics	55.5	2.5	56.9	3.0	1.4	3.9	-9.2	6.3

*Statistically significant differences are in **bold**. SE = Standard Error; SED = SE of the Difference*

Table 5.13 *Percent Correct Scores on Mathematics Content Areas on the Calculator Optional Test – No Calculators Available (2001 and 2004)*

Content Area	2001 %	2001 SE	2004 %	2004 SE	04-01 Diff	SED	95%CI	
Number Systems	53.2	2.0	45.4	1.7	-7.8	2.6	**2.5**	**13.1**
Arith/Measure	45.6	1.9	41.8	2.9	-3.7	3.5	-3.2	10.7
Algebra	38.4	3.2	40.8	1.4	2.4	3.4	-9.3	4.4
Statistics	48.0	2.6	46.6	2.2	-1.3	3.4	-5.5	8.1

*Statistically significant differences are in **bold**. SE = Standard Error; SED = SE of the Difference*

The comparisons of mean percent score differences on content areas of the Calculator Optional Test, by Calculator Access, *within* 2001 and 2004 are shown in Table 5.14. There was a significant difference between students with and without access to calculators on all four content areas in both 2001 and 2004. The largest difference between the two groups in 2001 was in the area of Number Systems (20.9 percent points) as it was also in 2004 (32.8 percent points). The differences in 2004 on all content areas were greater than the corresponding differences in 2001. This suggests that access to calculators had a greater effect on performance in 2004 than in 2001. As already pointed out, it may reflect increased ability, on the part of students, to benefit from calculator access on calculator optional tasks, and, perhaps, less familiarity in working without calculators on similar tasks.

Table 5.14 *Comparisons of Mean Percent Score Differences on Content Areas – Calculator Optional Test, by Calculator Access Within Year (2001 and 2004)*

Content Area	2001				2004			
	Access-No Access Diff	SED	95% CI		Access-No Access Diff	SED	95% CI	
Number Systems	20.9	1.3	**18.4**	**23.4**	32.8	2.0	**28.8**	**36.8**
Arith/Measure	6.8	0.3	**6.2**	**7.5**	12.7	3.5	**5.7**	**19.7**
Algebra	7.0	6.7	**3.0**	**10.9**	16.0	2.2	**11.6**	**20.5**
Statistics	7.4	3.0	**1.3**	**13.5**	10.1	3.7	**2.8**	**17.5**

*Statistically significant differences are in **bold**. SED = Standard Error of the Difference.*

Content Areas on the Calculator Appropriate Test in 2001 and 2004

Table 5.15 provides the mean percent correct scores of students on the Calculator Appropriate test for 2001 and 2004. Since changes were made to the 2001 test before administering it again in 2004 (see Chapter 4 for details), only the common items were used in these comparisons. In computing the mean percent scores, the scores of students taking the two forms of the test (referred to here as Form 1 and Form 2) were combined. The mean percent correct scores for both 2001 and 2004 indicate the greater difficulty of the Calculator Appropriate test relative to the Calculator Inappropriate and Calculator Optional tests, probably due to the greater focus on items requiring more complex problem solving in real situations in this test. However, rather than being uniformly difficult, it appears that the difficulty of the Calculator Appropriate test can be attributed to the presence of a few very difficult items in the Applied Arithmetic & Measure area, as follows:

- Form 1, item 11 & Form 2, item 12. Calculate compound interest on a sum of money over two or three years (item 11, 10% and 13% in 2001 and 2004 respectively, and item 12, 4% and 10% in 2001 and 2004 respectively)
- Form 1, item 12. Find the cost of electricity given two meter readings, the cost per unit, and the VAT rate (11% in 2001 and 5% in 2004)
- Form 1, item 13. Find the radius of a wheel, given the circumference (8% in 2001 and 19% in 2004)
- Form 2, item 10. Given area of circle and area of inscribed square with diagram showing part of area shaded, find area of shaded region (2% in 2001 and 1% in 2004)
- Form 2, item 11. Given the radius of a spherical object and the percentage of water in it find the volume of water in it (5% in 2001 and 2% in 2004).

Table 5.15 *Percent Correct Scores on Mathematics Content Areas on the Calculator Appropriate Test (2001 and 2004)*

	2001		2004		04-01	SED	95%CI	
	%	SE	%	SE	Diff			
Number Systems	39.7	2.11	52.8	0.34	**13.05**	**2.14**	**-17.33**	**-8.77**
Arith/Measure	33.3	1.67	34.6	1.34	1.29	2.14	-5.56	2.98
Algebra	-	-	-	-	-	-	-	-
Statistics	43.3	2.14	46.3	0.75	2.99	2.27	-7.52	1.54

Statistically significant differences are in ***bold****. SE = Standard Error; SED = SE of the Difference*

Table 5.15 shows that Number Systems was the only content area in which performance increased significantly between 2001 and 2004. Hence, the overall improvement in performance on the Calculator Appropriate test is driven by the improvement in Number Systems.

PERFORMANCE ON KEY ITEMS IN 2001 AND 2004

This section provides a 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.

Key Items on the Calculator Inappropriate Test in 2001 and 2004

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, which were identical to those used in the 2001 study, were mainly in the area of Number Systems (13 items) and Applied Arithmetic & Measure (10 items), with one item each in the areas of Algebra and Statistics. Sixteen of the items were of the multiple-choice variety, while nine called for short constructed responses. The items were selected so that the numbers with which students had to work in attempting them were generally easy to manipulate. The overall percent correct score of students on this test was 60.0% in 2001 and 56.8% in 2004, a small and not significant drop. Most of the items on which students did best at both test points were in the Number Systems area. They almost all involved simple one-step calculation and were presented with no context. The mean percent correct on these items was much the same in 2001 as 2004, probably due to fact that there was little room for improvement (Table 5.16).

Table 5.16 *Calculator Inappropriate Test: Sample of Easy Items in 2001 and 2004*

Item	Item specification/*Content Area*	2001 % correct	2001 SE	2004 % correct	2004 SE
1	Convert a fraction to a percentage (*Number Systems*)	93.9	0.75	93.6	0.54
2	Convert a fraction to a decimal number (*Number Systems*)	87.5	0.71	87.0	1.00
3	Divide positive integer by negative integer (*Number Systems*)	83.2	2.50	83.3	1.44
14	Select a distance that is closest to 1 km (*Applied Arithmetic & Measure*)	**79.8**	**0.31**	**80.9**	**0.36**
15	Given rate of water usage per week, estimate amount used in a year (*Applied Arithmetic & Measure*)	**74.5**	**1.51**	**69.0**	**0.90**

Significantly different scores in ***bold***

Items that were at a moderate level of difficulty in 2001 and 2004 spanned the four mathematical content areas represented in the test. As with the easier items, these items involved one operation, but were often presented in a practical context, which might have added a little to the difficulty. Example items in this category are shown in Table 5.17.

Table 5.17 *Calculator Inappropriate Test: Sample of Moderately Difficult Items in 2001 and 2004*

Item	Item specification/*Content Area*	2001 % correct	2001 SE	2004 % correct	2004 SE
11	Compute the mean of three numbers less than 15 (*Statistics*)	67.6	3.23	64.2	3.19
23	Apply a scale to convert a distance from cm to km (*Applied Arithmetic & Measure*)	**66.1**	**1.08**	**69.1**	**0.88**
17	Find the value of a multiple of x, where x is a decimal number (*Algebra)*	**63.7**	**3.06**	**56.2**	**0.20**
21	Given no. of students in class and ratio of boys to girls, find how many girls are in the class (*Applied Arithmetic & Measure*)	**50.6**	**0.67**	**60.2**	**2.56**

Significantly different scores in ***bold***

Four of the most difficult items in 2001 and 2004 were in the area of Applied Arithmetic & Measure and generally involved two operations and were presented in real-life contexts (Table 5.18).

Table 5.18 *Calculator Inappropriate Test: Sample of Difficult Items in 2001 and 2004*

Item	Item specification/*Content Area*	2001 % correct	2001 SE	2004 % correct	2004 SE
12	Compute the percentage profit, given the cost price and selling price of item (*Applied Arithmetic & Measure*)	44.7	0.98	41.7	3.37
25	Calculate the area of a rectangle, given the length and perimeter (*Applied Arithmetic & Measure*)	**31.5**	**1.50**	**41.8**	**4.88**
24	Calculate the average speed of a vehicle, given the journey length and distance (*Applied Arithmetic & Measure*)	29.6	2.06	29.1	5.06
13	Identify the volume of a cylinder (expressed in terms of π), given the diameter and height (*Applied Arithmetic & Measure*)	28.4	1.98	30.8	2.14

Significantly different scores in ***bold***

In general, in both 2001 and 2004, items in Number Systems were easier than items in Applied Arithmetic & Measure, perhaps reflecting the stronger element of application in the latter. As indicated at the beginning of this chapter, there was no significant difference between performance on this test in 2001 compared with 2004. Correspondingly, at the item level, there were only 7 of the 25 items on the test that differed significantly in the percentage of correct responses across the two testing points, including items 14, 17, 21, 23, and 25 in Tables 5.16 and 5.17 above. Only two items, numbers 15 (estimation) and 17 (substitution for 'x'), showed a significant deterioration in performance between 2001 and 2004. The decline on item 15 occurred despite the fact that estimation should have been a focus of instruction.

Key Items on the Calculator Optional Test in 2001 and 2004

The second test that students completed was the 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 have access. Items for this test were distributed over the four content areas: Number Systems (12 items, 11 in 2001), Applied Arithmetic & Measure (15 items), Algebra (4 items) and Statistics (2 items). The average percent correct score of students who completed the Calculator Optional test with access to a calculator was 59.2% in 2001 and 62.8% in 2004, while the average percent correct score of those who attempted the test without access was 47.5% in 2001 and 42.7% in 2004.

Table 5.19 gives the mean percent correct scores on items on the Calculator Optional test (calculators available) which show significant change between 2001 and 2004. All these items show improvement in performance between 2001 and 2004 and, in many cases, very substantial improvement, particularly Algebra items and items involving more complex numerical calculation. Such results suggest that the 2004 students, who experienced a calculator friendly mathematics curriculum for up to three years before taking the test, were better able to benefit from calculator availability than the 2001 students who did not have such experience.

Table 5.19 *Calculator Optional Test (Calculators Available): Items on Which There Was a Significant Change in Percent Correct Scores (2001 and 2004)*

Item	Item specification *(Content Area)*	2001		2004	
		%	SE	%	SE
4	Given % of games won by a team and the no. of games played in total, find how many games were won (*Applied Arithmetic & Measure*)	**75.1**	**1.07**	**82.9**	**1.29**
6	Given lengths of two throws (decimal nos.) in a competition, find the difference (*Applied Arithmetic & Measure*)	**95.0**	**0.90**	**97.0**	**0.35**
10	Given area of circle and area of inscribed square with diagram showing part of area shaded, find area of shaded region. (*Applied Arithmetic & Measure*)	**56.7**	**1.62**	**64.5**	**0.65**
18	Divide a four-digit number by a two-digit number (*Number Systems*)	**89.9**	**0.78**	**94.0**	**0.18**
19 27	Evaluate a bracketed numerical expression (*Number Systems*) (There were 2 items of this kind)	**82.9** **80.6**	**2.55** **2.02**	**90.9** **92.6**	**0.37** **0.63**
21	Given the price of an item and the VAT rate, calculate the total price (*Applied Arithmetic & Measure*)	**57.0**	**0.93**	**71.8**	**1.91**
23 24 25 26	Substitute values for unknowns in (linear and quadratic) algebraic expressions and thus evaluate expression (*Algebra*) (There were 4 items of this kind)	**63.8** **33.8** **50.5** **33.4**	**5.17** **1.15** **1.82** **1.65**	**76.9** **48.9** **67.0** **60.7**	**0.79** **1.18** **1.75** **3.48**
28	Evaluate a complex numerical expression (*Number Systems*)	**10.4**	**1.74**	**46.6**	**2.30**
32	Calculate, in terms of π, the volume of fluid in a cylindrical container, given the radius and depth. (*Applied Arithmetic & Measure*)	**24.5**	**1.60**	**50.5**	**0.94**

*Significant differences in **bold***

Table 5.20 gives the mean percent correct scores on the 13 items on the Calculator Optional test (calculators not available) which show significant change between 2001 and 2004. Five of the items involved a significant drop in performance from 2001 to 2004 while the others showed an improvement over the period. Four of the items which showed a drop (2, 5, 15 and 17) involve operations with decimals. Such items lend themselves readily to calculator usage. Students in 2004 would be more likely to use a calculator for these tasks than students in 2001 and hence would be at more of a disadvantage than students in 2001 in doing these items in the absence of calculators. The other item showing a drop in performance (item 22) involved computation with time. Three of the four Algebra items showed substantial and significant improvement between 2001 and 2004. One explanation for this could be that teachers are giving this area more attention in the revised syllabus.

Table 5.20 *Calculator Optional Test (No Calculators Available): Items on Which There Was Significant Change in Percent Correct Scores (2001 and 2004)*

Item	Item specification/*Content Area*	2001		2004	
		%	SE	%	SE
2	Divide a four-digit decimal number by a two-digit decimal number (*Number Systems*)	**44.8**	**0.45**	**34.4**	**2.75**
5	Given the number of heartbeats in a minute, find the number for an hour. (*Applied Arithmetic and Measure)*	**80.1**	**0.33**	**75.3**	**1.68**
15	Multiply a two-digit decimal number by a two-digit decimal number (*Number Systems*)	**64.1**	**0.79**	**44.3**	**1.11**
17	Multiply a four-digit decimal number by a three-digit decimal number (*Number Systems*)	**46.5**	**3.23**	**36.6**	**1.01**
22	Given the length of time to play each of a set of songs, find the total time taken (*Applied Arithmetic & Measure*)	**44.6**	**0.36**	**39.1**	**0.44**
27	Evaluate a bracketed numerical expression $(3.9 + 4.5) \times 7$ (*Number Systems)*	**48.6**	**3.41**	**64.4**	**1.27**
21	Given the basic price of a purchase and the VAT rate calculate the total price (*Applied Arithmetic & Measure)*	**40.2**	**1.16**	**46.1**	**1.59**
24	Substitute values for unknowns in (linear and quadratic)	**35.0**	**0.68**	**47.8**	**1.79**
25	algebraic expressions and thus evaluate expression	**38.8**	**1.82**	**45.2**	**2.33**
26	(*Algebra)* (There were 3 items of this kind)	**23.9**	**1.75**	**35.0**	**3.74**
28	Evaluate a complex numerical expression *(Number Systems*)	**2.2**	**0.74**	**7.5**	**1.77**
29	Evaluate an numerical expression and write result in scientific notation (*Number Systems*)	**24.6**	**2.38**	**36.8**	**1.50**
32	Calculate, in terms of π, the volume of fluid in a cylindrical container, given the radius and depth. (*Applied Arithmetic & Measure*)	**10.9**	**0.71**	**27.4**	**5.69**

Significantly different scores in ***bold***

In general, the students with access to a calculator tended to find items on Number Systems relatively easier than did the students without access. These items all involve non-trivial computation. Students without access to calculators outperformed their counterparts with access on just three items (1, 22, and 24) on the Calculator Optional test in 2001 and one (item 22, involving time) in 2004. None of these differences was statistically significant. It may be that factors such as the new syllabus, the in-career development provided to teachers, and the *Junior Certificate Mathematics Guidelines for Teachers* contributed to the observed differences.

Table 5.21 *Calculator Optional Test: Items with Substantive Differences in Average Percent Correct Scores between Students With/Without Access to Calculators Within Years (2001 and 2004)*

Item	Item Specification *(Content Area)*	2001		2004	
		% Correct Calc.	% Correct No Calc.	% Correct Calc.	% Correct No Calc.
2	Divide a four-digit decimal number by a two-digit decimal number *(Number Systems)*	**58.9**	**44.8**	**57.7**	**34.4**
6	Given lengths of two throws (decimal nos.) of a discus in a competition find the difference *(Applied Arithmetic & Measure)*	**95.0**	**87.1**	**97.0**	**84.7**
12	Given the thickness of a stack of sheets of paper and the no. of sheets, find the thickness of one sheet (*Applied Arithmetic & Measure)*	**65.0**	**40.3**	**63.9**	**43.4**
14	Find the sum of three decimal numbers (e.g., 145.3 + 0.08 + 24.7) (*Number Systems)*	**93.6**	**79.1**	**92.3**	**79.0**
15	Multiply a two-digit decimal number by a two-digit decimal number (*Number Systems)*	**93.7**	**64.1**	**94.2**	**44.3**
16	Identify the missing number in a subtraction sentence (e.g., 2005 – x = 180). (*Number Systems)*	**85.0**	**74.7**	**88.3**	**74.6**
17	Multiply a four-digit decimal number by a three-digit decimal number *(Number Systems)*	**88.1**	**46.5**	**88.8**	**36.6**
18	Divide a four-digit number by a two-digit number (e.g., 4845 ÷ 38) (*Number Systems)*	**90.0**	**28.0**	**94.0**	**29.9**
19	Find the value of a bracketed numerical expression (e.g., (3.9 + 4.5) × 7) (*Number Systems)*	**82.9**	**69.3**	**90.9**	**73.4**
27	(There were two items of this kind)	**80.6**	**48.6**	**92.6**	**64.4**
21	Given the price of a item and VAT rate calculate the total price (*Applied Arithmetic & Measure)*	**57.0**	**40.2**	**71.8**	**46.1**
28	Evaluate a complex numerical expression (e.g., $1/\sqrt{0.25} + (.5)^2$) *(Number Systems)*	**10.4**	**2.2**	**46.6**	**7.5**
30	Find the average speed of a bus journey in km/hour, given the distance covered in 3.5 hours. *(Applied Arithmetic & Measure)*	**30.8**	**16.6**	**40.5**	**22.9**
32	Calculate the volume of fluid in a cylindrical container, given the radius and depth. *(Applied Arithmetic & Measure)*	**24.5**	**10.9**	**50.5**	**27.4**

Significantly different scores in ***bold***

Table 5.21 brings together 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 within each year (see also Appendix Table A5.3). As indicated earlier, most of the items on which students with access to calculators outperformed their counterparts without access in both 2001 and 2004 were in the area of Number Systems. On item 2, for example, there was a difference of 14% between students with/without access to a calculator in 2001 and 24% in 2004. 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 62% was observed between those with and without a calculator in 2001 and 64% in 2004.

Substantive differences were also observed on a few items in the Applied Arithmetic & 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 17% in 2001 and 26% in 2004, students were asked to calculate VAT on the price of a laptop computer.

The differences in mean percent correct scores between the calculator and non-calculator groups, on 25 out of the 32 items on the test in 2004, were substantially greater than the differences in 2001 (in favour of the calculator groups). This could in part be attributed to an improvement, over the three years, in students' ability to use calculators in computation while other skills remained almost the same. This is further evidence to support the view that experience with a mathematics curriculum that utilises calculators improves students' performance

Key Items on the Calculator Appropriate Test in 2001 and 2004

The Calculator Appropriate test consisted of a total of 27 valid items for 2001/2004 comparison purposes, for which a calculator was deemed to be appropriate. Across the two forms of the test, to which students were randomly assigned, three content areas were assessed: Number Systems (6 items common to 2001 and 2004), Applied Arithmetic & Measure (16 items common to 2001 and 2004) and Statistics (5 items common to 2001 and 2004). All items were of the short constructed-response variety. As mentioned earlier in this chapter, students in both 2001 and 2004 found many items on this test to be particularly difficult, despite access to calculators. The average percent correct score in 2001 was 35% and in 2004 was 40%. The test included some items that were answered correctly by a majority of students, and others that were answered correctly by fewer than 10%, with these items usually coming towards the end of the test when fatigue may have been a factor. The examples in Table 5.22 illustrate the range of difficulty of items on the test. Difficulty level was not associated with any content area in particular.

Table 5.22 *Calculator Appropriate Test: Sample of Items with Varying Difficulty Levels in 2001 and 2004*

Item	Item Specification (*Content Area)*	2001		2004	
		Mean	SE	Mean	SE
1*	Convert a sum of money from euros to dollars given an exchange rate . (*Applied Arithmetic & Measure)*	**76.1**	**2.59**	**83.4**	**0.51**
5*	Find the square root of a three-digit number to two decimal places. (*Number Systems)*	**53.8**	**2.86**	**73.1**	**0.25**
12**	Given the price of an item, the down payment (as a percent of price), and cost of each of 12 instalments, calculate by how much the Hire Purchase price is greater than the cash price. (*Appl. Arithmetic & Measure)*	**43.5**	**2.60**	**55.9**	**3.77**
7**	Given the formula for calculating the circumference of a circle, find the circumference of an object with given diameter (two decimal places). (*Applied Arithmetic & Measure)*	27.5	2.16	32.5	3.65
14b**	Read a sales graph and calculate the percentage decrease in sales over two given years. (*Applied Arithmetic & Measure)*	**8.4**	**0.21**	**16.4**	**2.57**
13**	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 & Measure)*	**4.2**	**0.0**	**10.2**	**2.42**

Significantly different scores in ***bold;*** ** = Form 1; ** = Form 2*

Overall, students did significantly better on this test in 2004 than in 2001 and this is reflected in the numbers of items (17) on which there was a significant improvement between 2001 and 2004, comprising 7 items on Form 1 and 10 items on Form 2. Despite this improvement and despite the greater familiarity of the 2004 students with calculators, the continued low scoring on so many items on this test suggests that students may not be getting much experience with the kind of problems included in this test, although the scores would be considerably higher if partial credit had been available as in the Junior Certificate mathematics examination. This finding seems to have more to do with curriculum and teaching and less to do with effects of calculator availability. The 10 items on which there was no significant improvement between 2001 and 2004 are listed in Table 5.23

Table 5.23 *Calculator Appropriate Test: Items on Which There Was No Significant Difference in Percent Correct Scores (2001 and 2004)*

Item	Item Specification (*Content Area)*	2001		2004	
		Mean %	SE	Mean %	SE
3*	Calculate the number of seconds in a given number of weeks. (*Applied Arithmetic & Measure)*	52.1	0.08	54.9	3.70
7**	Given the formula for calculating the circumference of a circle, find the circumference of an object with given diameter (two decimal places) (*Applied Arithmetic & Measure)*	27.5	2.16	32.5	3.65
8a*	Read two values from a double bar chart and find sum. (*Statistics)*	60.6	0.81	63.7	2.18
8c*	Use the data on a double bar chart to calculate mean. (*Statistics)*	49.8	3.44	47.6	1.49
9*	Given the area in sq. m. and cost per month of letting office space in two buildings, find the lowest cost for a given area. (*Applied Arithmetic & Measure)*	49.0	0.40	50.7	3.80
11*	Calculate the compound interest on a sum of money for two years given the annual interest rate. (*Applied Arithmetic & Measure)*	10.3	2.66	12.8	2.64
1**	Find the cost of a set of grocery items and use it to calculate change from a 20 Euro note. (*Applied Arithmetic & Measure)*	85.7	2.74	91.1	0.51
7**	Find the number of containers of a given no. of mls that can be filled from a container of a given no. of litres. (*Applied Arithmetic & Measure)*	27.5	2.16	32.5	3.65
10**	Find the area of a circle inscribed in a square given the radius of the circle. (*Applied Arithmetic & Measure)*	1.9	0.13	0.8	0.86
11**	Given the radius of a spherical object and the % of water in it find the volume of water in it. (*Applied Arithmetic & Measure)*	4.9	0.53	2.4	2.10

** = Form 1; ** = Form 2*

One of the items (Form 2, item 1) was very easy and hence there was little scope for improvement. Four of the items (Form 1, items 3, 8a, 8c, and 9) were of moderate difficulty, and five (Form 1, items 7 and 11, and Form 2, items 7, 10, and 11) were very difficult and therefore less likely to reflect any general trends over time.

INVESTIGATION OF STUDENTS' WORK

It was pointed out in Chapter 3 that the items in the Calculator Inappropriate test were intended to be done mentally or with only a small amount of written work. As in 2001, students were instructed that they could work out the answers to the questions on this test with or without pen and paper, and a 'rough 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, Calculator Optional and Calculator Appropriate, were unlikely to be done successfully by mental methods alone. For these tests, the directions at the beginning indicated that work should be shown, and the instruction 'Show your work' was repeated on each page, under the 'work column' heading.

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, it should be noted that instructions such as 'show your work' may be ignored, especially where partial credit is not obviously given. Moreover, for multiple-choice items, there has been no tradition of students benefiting from displaying work. In the revised Junior Certificate 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, it was anticipated that students would make more use of the 'work column' in Phase II of this study than was the case in Phase I.

Procedures Used in 2001

In 2001 a study was undertaken using a small selection of the scripts (Close et al, 2004). For each of the tests, 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 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 there was access to calculators, recorded any work in the column that was provided for this purpose on their test booklets. Of particular interest was the finding that on items on the Calculator Inappropriate test requiring estimation, students tended to find exact answers using pen and paper, or, for items in multiple-choice format, to state that the correct answer was not given. Also, on fraction items on the Calculator Optional test, students who had access to calculators used rough work to the same extent as those students who did not have access, perhaps due to lack of familiarity with the fractions feature of scientific calculators (or possession of calculator without such a feature). This contrasted with items requiring simple decimal computation, where students with access to calculators did substantially less rough work than did those who did not have access. For items requiring more complex decimal calculations, there were similar patterns in rough work display in both groups.

Procedures Used in 2004

In 2004 it was decided to examine the rough work data of all students in the study, rather than selecting a sample. In the initial marking of responses, the number of items for which rough work was displayed by students was recorded on the cover of each test for every student. Subsequently, the actual items for which rough work was used were identified and coded.[13] The patterns of rough work across tests, and across items in each test, were then examined. Samples of items were also chosen for further analysis to examine the relationship between rough work usage and achievement.

Rough Work Patterns Across Tests

Arising from the rough work count for each test booklet, Table 5.24 gives the mean number and percent of rough work records per student per test. The highest proportion of rough work (56.9% of items) was found for students who took the Calculator Optional test without access to calculators. This is predictable, as the items were designed on the basis that most students would probably use pen and paper calculations to do them in the absence of a calculator. Where calculators were available, there was a substantial reduction in the amount of rough work shown. This was the situation for the Calculator Optional test with access to calculators (30.3%), and for both forms of the Calculator Appropriate tests (26.1% and 28.3%). In the case of Calculator Inappropriate test, the items were designed to be done mentally or with limited use of pen and paper. The rough work results for this test (32.2%) indicate that this seems to have been the case.

Table 5.24 *Extent of Rough Work Usage by Students on the Calculator Tests (2004)*

Test	No. of Items	No. of Students taking the test	Mean no of RW records/student	Mean % of RW records/student
Calculator Inappropriate	25	1460	8.1	32.2
Calculator Optional (Access)	32	743	9.7	30.3
Calculator Optional (No Access)	32	720	18.2	56.9
Appropriate (Form 1)	15	737	3.9	26.1
Appropriate (Form 2)	15	721	4.3	28.3

Rough Work Patterns Across Items in the Calculator Inappropriate Test

Figure 5.1 shows the distribution of rough work in the Calculator Inappropriate test. A preliminary examination of the trends in Figure 5.1 indicate that multiple-choice items attracted less rough work than did constructed-response items (the first 16 items were of multiple-choice type, while the following 9 items were of short constructed-response type). However, there were a few exceptions to this trend, in particular items 6, 9, 13 and 15. An analysis of these items suggests that, whereas item 6 (addition of mixed

[13] For any item, a rough work incident was recorded if calculations or drawings that clearly related to the item appeared in the Rough Work column. Calculations could be full or partial solutions and could be as little as one or two numbers relating to an item. Drawings could be labelled or unlabelled sketches.

numbers) and item 13 (identifying the volume of a cylinder (expressed in terms of π), given the diameter and height) could require some pen and paper recording, items 9 (conversion of exponential notation to standard notation) and 15 (estimation of a product) should be readily done mentally. This finding raises the question as to whether or not the students had sufficient understanding of the processes involved in the latter two questions. The two constructed-response items for which the least rough work was done, i.e. items 18 (division of a whole number by a unit fraction) and 23 (interpretation of scale), were not computationally demanding and therefore were easily done mentally.

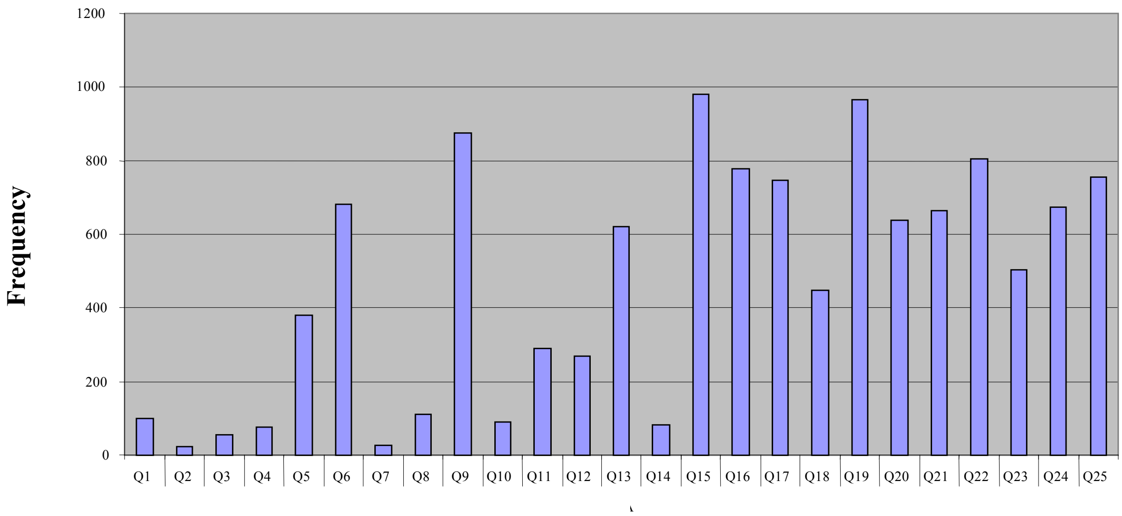

Figure 5.1 *Distribution of Rough Work on the Calculator Inappropriate Test*

Rough Work Patterns Across Items in the Calculator Optional Tests

As can be seen in Figure 5.2, there is a consistently high incidence of rough work for most items in the Calculator Optional test (no access to calculator), with some reduction towards the end of the test. This reduction could be attributed to the number of students who failed to complete the test. A very different pattern emerged for the Calculator Optional test (with calculator access) where, in general, there was considerably less rough work than with the Calculator Optional test (no calculator access), and where the reduction in rough work was most apparent on items around the middle of the test (Figure 5.3). Items 14 (addition of decimals), 15 (multiplication of decimals), 17 (multiplication of decimals), and 18 (long division) are particularly appropriate for, and easy to do with, a calculator, and are often regarded as tedious when done using pen and paper. The items that attracted most rough work in the Calculator Optional test (access to calculator) were item 1 (addition of fractions), item 8 (area of a rectangular border), and item 30 (interpretation of a pie chart). Items 8 and 30 were multi-step problems and thus may have warranted interim pen and paper work. Some students may have used pen and paper on item 1 because they were unfamiliar with the fraction function on their calculators. Others may have preferred to use pen and paper because they were more comfortable using that format. Hence, for some students, more attention may need to be given to doing fraction computations on a calculator.

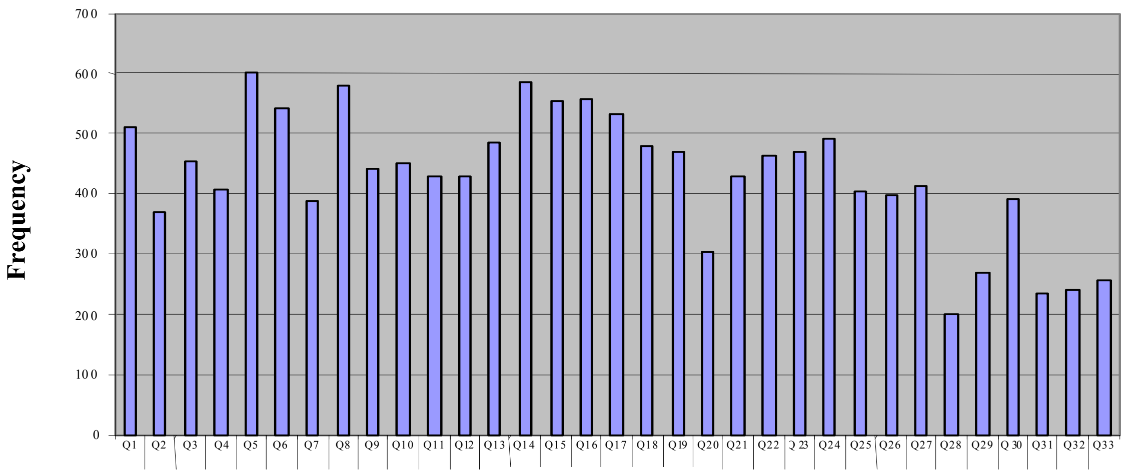

Figure 5.2 *Distribution of Rough Work on the Calculator Optional Test (No Access to Calculator)*

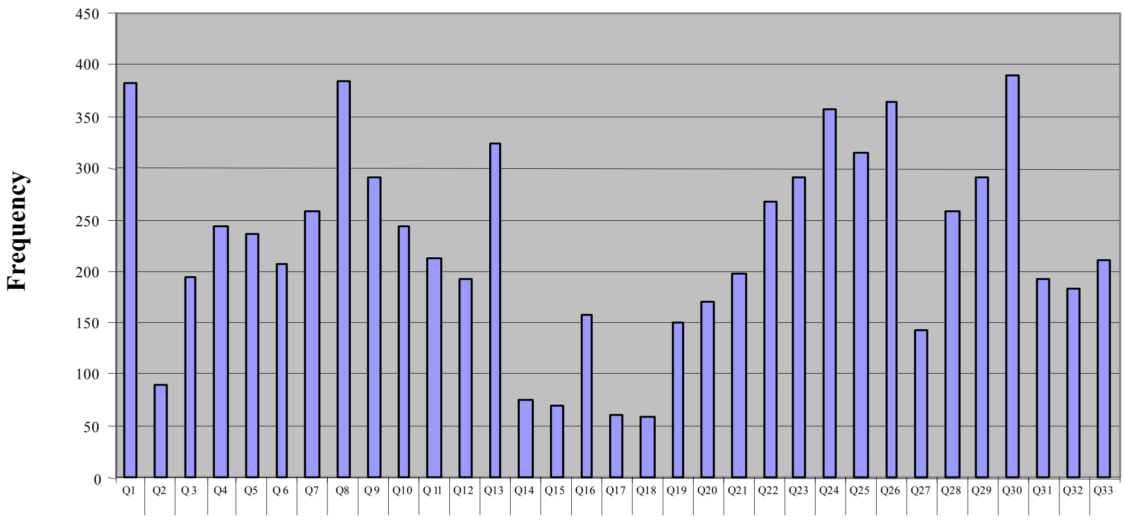

Figure 5.3 *Distribution of Rough Work on the Calculator Optional Test (Access to Calculator)*

Rough Work Patterns Across Items in the Calculator Appropriate Tests (Forms 1 and 2)

As can be seen in Figures 5.4 and 5.5, students did considerably less rough work on both forms of the Calculator Appropriate test (Forms 1 and 2) than on the Calculator Optional test (no access to calculator), and slightly less rough work than on the Calculator Inappropriate test or the Calculator Optional test (access to calculator). However it should be noted that the highest incidence of non-completed items was found in these two tests, and this may account for the relatively low levels of rough work. On one Calculator Appropriate test (Form 1), the item with the most rough work was item 6 (multi-step calculation with exponents and decimals) (Figure 5.4). Very little rough work was used for item 4 (missing operations in number sentences), and item 5 (finding the square root of a number). Both of these are particularly appropriate for calculator use. A similar trend was found in Form 2, where most rough work was shown for multi-step items such as item 11 (money and percent problem), and where there was very little rough work for the most calculator-appropriate items (Figure 5.5).

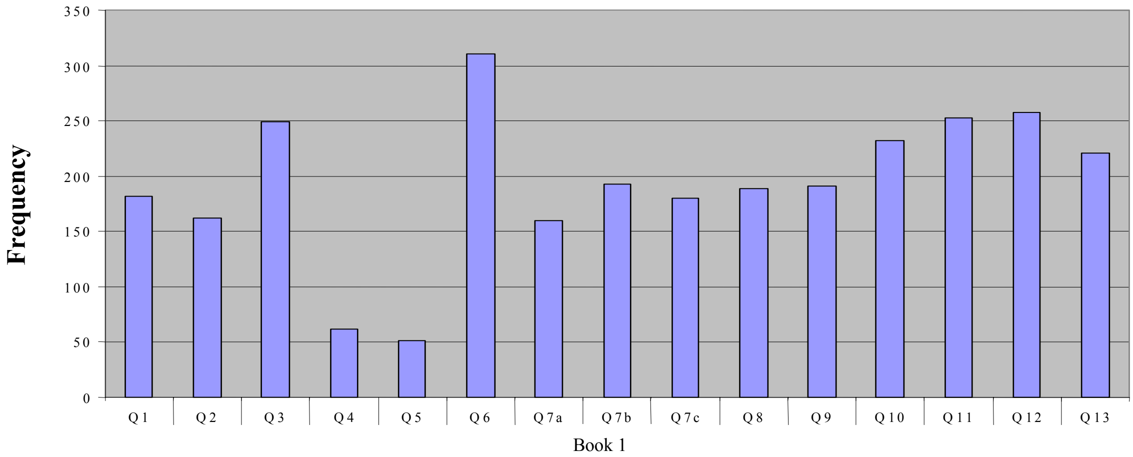

Figure 5.4 *Distribution of Rough Work on the Calculator Appropriate Test (Form 1)*

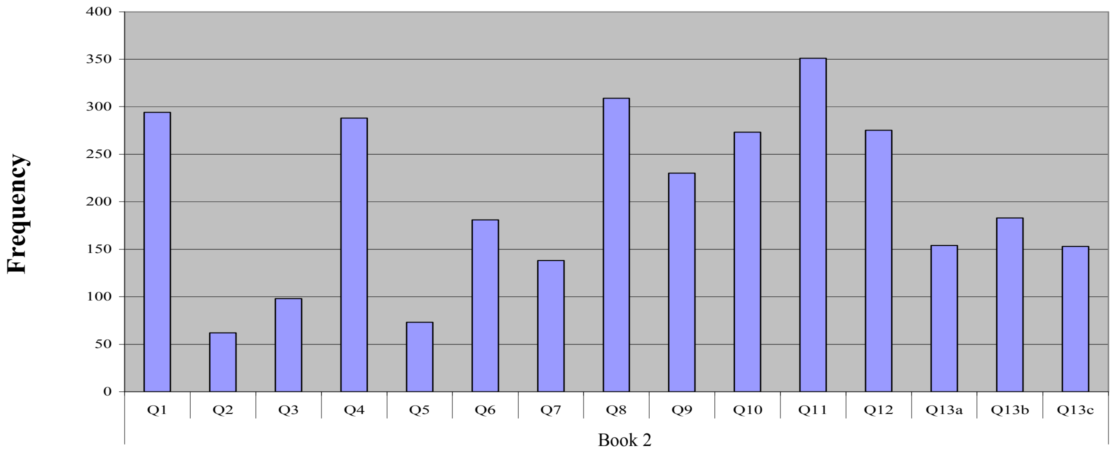

Figure 5.5 *Distribution of Rough Work on the Calculator Appropriate Test (Form 2)*

Achievement and Rough Work

Table 5.25 shows the correlations between student use of rough work and their scores on the calculator tests. The correlations (ranging from 0.36 to 0.51) are all positive and significant, indicating a modest positive relationship between rough work use and performance on the tests. The largest correlation was for the Calculator Optional test (no access to calculator) (0.51), and smallest for the Calculator Inappropriate test (0.36).

Table 5.25 *Correlations between Rough Work Usage and Performance on the Calculator Tests (2004)*

Test	r	t	p
Inappropriate	.36	7.89	**.02**
Optional (Calc)	.42	6.63	**.02**
Optional (No Calc)	.51	18.18	**.00**
Appropriate (Forms 1 & 2)	.45	34.0	**.00**

Significant correlations in ***bold****; r = Pearson correlation coefficient; t = t statistic; p = probability*

To analyse these relationships more deeply, the rough work frequency for each item was compared with the percent correct for each item (Appendix Tables A5.5 to A5.7). From these tables, sets of items were selected from each test in order to examine the relationship between achievement and levels of rough work on that test.

On the Calculator Inappropriate test, the items for which there was a high percentage of rough work and a low percentage of correct responses help to identify tasks that posed significant computational difficulty. Examples are item 13 (volume of a cylinder) and item 25 (find area given length and perimeter). Items for which there was a low percentage of rough work and a high percentage of correct responses help to identify tasks that were successfully done by mental calculation. Examples are item 2 (conversion of simple fraction to decimal), item 4 (conversion of percent to fraction), and item 14 (rounding decimal lengths).

On the Calculator Optional test, the items for which there was a similar pattern of rough work for groups with and without access to a calculator were item 26 (solve a linear equation), item 27 (order of operations), item 30 (interpretation of pie-chart), and item 31 (calculate average speed). It can be inferred that these were tasks for which students did not consider the calculator to be advantageous. Items for which there was a greater usage of rough work by students without access to calculators than by those with access included item 14 (addition of decimals), item 15 (multiplication of decimals), item 16 (completing a subtraction), item 17 (multiplication of decimals), and item 18 (long division). As the percent correct scores for these items are considerably higher for students with access to calculators than for those without calculators, it can be deduced that the calculator confers a particular advantage on such tasks involving one-step numerical operations.

On the Calculator Appropriate tests, items for which there was a low percentage of rough work and high percent correct were item 5 in Form 1 (square root of a number) and item 2 in Form 2 (fill in missing digits in a number sentence). These are tasks for which students appeared to find the calculator advantageous, or which they could do mentally. Conversely, items for which there was a high percentage of rough work and low percent correct were item 11 in Form 1 (multi-step money), and item 10 in Form 2 (volume of a sphere). These items involved complex calculations with awkward numbers. There is an implication that students could benefit from further practice with these kinds of problems, though it is acknowledged that volume of a sphere is not on the

Foundation level course. Moreover, we do not know the degree to which students' responses were incorrect, since partial credit was not provided.

SUMMARY

In this chapter, the performance of the students in 2001 was compared with that of students in 2004 on the three calculator study tests in terms of overall performance, performance on the different mathematical content areas tested, and in terms of performance on selected items. The results of an analysis of the 'rough work' recorded by the students in 2004 on their test booklets were also reported.

The results indicated that overall performance on the Calculator Inappropriate test declined slightly between 2001 and 2004, but not significantly so, whereas overall performance on the Calculator Appropriate test improved significantly between 2001 and 2004. Performance on the Calculator Optional test with calculator access increased between the two years, but the difference did not reach significance, while performance on the same test without calculator access declined, though again, the decline was not statistically significant. The outcome for the Calculator Inappropriate test suggests that students' performance in 2004 on basic mathematical skills was not significantly affected as a result of experiencing the revised Junior Certificate mathematics syllabus where they had access to calculators, compared with students in 2001 who did not have access to calculators while following the old Junior Certificate mathematics syllabus. The improvement in performance on the Calculator Appropriate test suggests that students' ability to make use of the calculator in doing more complex computations and/or solving problems improved over the three years, although the low performance on this test in both 2001 and 2004 is of particular concern, given the more problem solving orientation of the test.

The scale scores for 2001 and 2004 on the Calculator Appropriate test at five key percentile points showed substantial differences in favour of the 2004 students, with the difference for three (10^{th}, 50^{th}, and 75^{th} percentiles) of the five percentile points being significant. There were no significant differences at any of the percentile points for the other two tests. These results suggests that performance on questions for which the use of a calculator is particularly appropriate were most affected by the impact of calculator access over the three year period of the study and that this positive effect was not confined to any particular mathematical ability group.

The difference in overall achievement between students with and without access to a calculator on the Calculator Optional test was 30.4 scale points in 2001, and 44.4 in 2004. Both these differences are statistically significant, showing clearly the advantage conveyed to students with access to calculators compared to those with no access at the two test points. Differences between 2001 and 2004 on each of the two test conditions are not significant overall. However, there were significant differences at the 50^{th} percentile in favour of the 2001 students on the non-calculator access condition and in favour of the 2004 students on the calculator access condition. This suggests that, at this level of performance (50^{th} percentile), students in 2004 benefited more than the 2001 students from calculator access but were less able than students in 2001 to cope without calculator access.

An analysis of student rough work showed that the incidence of rough work was highest when students did not have access to a calculator (i.e., on the Calculator Inappropriate and Calculator Optional (no calculator available) tests, and substantially lower when they did have access (i.e., on the Calculator Optional (calculator available) and the Calculator Appropriate tests). On the Calculator Inappropriate test, more rough work was recorded for constructed-response items than for multiple-choice items, and, in general, most rough work was noted for multi-step items. Items for which a calculator was deemed advantageous included area and volume (Calculator Inappropriate), addition and multiplication of decimals (Calculator Optional), and finding the square root of a number (Calculator Appropriate). A modest but statistically significant positive correlation between the amount of rough work and performance was noted for each of the calculator tests.

Chapter 6: Students and Calculators

In this chapter, patterns of calculator usage by students at home and at school are examined. First, associations between student background variables (gender and socioeconomic status) and performance on the calculator tests are considered. Second, students' access to, and use of, calculators in home and school settings is examined. Third, students' attitudes towards mathematics in general are described. In the fourth section, their attitudes towards calculators are reviewed. Within each section, data from 2004 are reported first. Then, where relevant, data from 2001 are compared with those from 2004.

The data in this chapter are based on students' responses to the Student Questionnaire. Among the 1459 students for whom scores were available on the calculator tests in 2004, 1448 (99%) also completed the questionnaire. The average age of students who completed the questionnaire was 14.9 years (SE = 0.01).

BACKGROUND INFORMATION

Gender

The weighted sample consisted of 56.3% of female students and 42.9% male students. Information on gender was missing for less than one percent of students. The mean scores of male and female students on the calculator tests are given in Table 6.1. While female students did somewhat better than males on the Calculator Appropriate and Calculator Optional tests, and male students outperformed females on the Calculator Inappropriate test, none of these differences was statistically significant. This finding is consistent with recent trends of underachievement by males.

Table 6.1 *Mean Scale Scores of Students on the Calculator Inappropriate, Calculator Optional and Calculator Appropriate Tests, by Gender (2004)*

Gender	n	%	Calculator					
			Inappropriate		Optional		Appropriate	
			Mean	SE	Mean	SE	Mean	SE
Female	822	56.3	241.4	4.73	251.9	4.13	266.9	4.59
Male	626	42.9	245.3	4.35	246.9	4.61	258.9	4.83
Missing	11	0.8	247.1	17.53	242.5	17.33	253.6	27.27

Effect sizes were computed for each comparison by gender. The effect sizes for the Calculator Inappropriate, Calculator Optional and Calculator Appropriate tests were -0.08, 0.10, and 0.16 respectively, and can be considered small (Cohen 1988). A regression analysis was conducted to see if there was an interaction between gender and performance on the Calculator Optional test, where calculators were available/not available. The interaction between gender and calculator availability was not statistically significant ($F = 0.20$; $df = 1, 37$; $p = 0.66$).

Socioeconomic Status

Students were asked to indicate the employment of their mother/female guardian and father/male guardian. Their responses were coded using the International Socioeconomic Index of Occupational Status (ISEI), which rates occupations along a scale ranging from 16 to 90, and may be viewed as continuous (Ganzeboom, deGraaf & Treiman, 1992). For the analysis reported here, a measure of combined parental socioeconomic status was obtained by identifying and coding the higher level SES of the student's mother or father. The distribution of SES scores was divided into top (high), middle (medium) and bottom (low) thirds. These are referred to as the upper, middle and lower socioeconomic groups (SEGs).

Table 6.2 gives the mean scale scores of students in each SEG on the three calculator tests, while Table 6.3 indicates those mean score differences that are statistically significant. Students in the upper SEG achieved mean scores that were higher than those of students in the lower SEG on all three tests (Table 6.3), with differences ranging from 18.4 points (Calculator Inappropriate test) to 21.4 points (Calculator Optional test). All three differences were statistically significant. Students in the upper SEG also achieved higher mean scores on the three calculator tests than students in the middle SEG, though none of the differences was large enough to reach statistical significance. The mean scores of students in the middle SEG were greater than those of students in the lower SEG on the three calculator tests, with all three differences reaching statistical significance.

Table 6.2 *Mean Scale Scores on the Calculator Inappropriate, Calculator Optional and Calculator Appropriate Tests, by Socioeconomic Group (2004)*

SEG	n	%	Calculator					
			Inappropriate		Optional		Appropriate	
			Mean	SE	Mean	SE	Mean	SE
Upper	486	33.3	250.5	3.85	259.0	3.33	271.2	3.90
Middle	441	30.2	248.5	3.84	253.6	4.19	268.4	4.12
Lower	444	30.4	232.1	3.72	237.6	3.76	251.9	3.95
Missing	88	6.02	231.9	10.4	241.2	8.40	252.1	8.97

Table 6.3 *Comparison of Mean Scale Score Differences on the Calculator Inappropriate, Calculator Optional and Calculator Appropriate Tests, by Socioeconomic Group (2004)*

Comp	Calculator											
	Inappropriate				Optional				Appropriate			
	Diff	SED	95%CI		Diff	SED	95%CI		Diff	SED	95%CI	
Upper-Middle	2.0	2.72	-3.52	7.50	5.4	3.48	-1.67	12.43	2.8	2.91	-3.08	8.74
Upper-Lower	18.4	3.13	**12.08**	**24.78**	21.4	3.38	**14.51**	**28.21**	19.3	3.40	**12.43**	**26.20**
Middle-Lower	16.4	3.245	**9.86**	**23.01**	16.0	3.59	**8.71**	**23.25**	16.5	3.45	**9.51**	**23.47**

Diff = Difference; SED = Standard Error of the Difference; 95%CI = confidence intervals; significant differences in ***bold****.*

Regression analysis was used to assess the statistical significance of the interaction between socioeconomic status and performance on the Calculator Optional test, where calculators were available/not available. The interaction between socioeconomic status and calculator availability was not statistically significant ($F = 0.47$, $df = 1, 37$, $p = 0.50$).

Correlations between socioeconomic status (using the original continuous scale) and performance on the calculator tests are given in Table 6.4. The correlations range from 0.18 for the Calculator Appropriate test to 0.22 for the Calculator Optional (no calculator available) test.

Table 6.4 *Correlations between Calculator Tests and Socioeconomic Status*

Test	r	t	p
Calculator Inappropriate	.20	-6.45	**.00**
Calculator Optional (all)	.20	-7.21	**.00**
Calculator Optional – w/calculator	.18	-4.02	**.00**
Calculator Optional – no calculator	.22	-5.62	**.00**
Calculator Appropriate	.18	-6.59	**.00**

*Significant correlations in **bold**; r = Pearson correlation coefficient; t = t statistic; p = probability*

Comparison with the 2001 Study

As in 2001, there were no statistically significant differences between male and female students on the calculator tests in 2004. Moreover, no differences in mean scores on the calculator tests were observed between male students in 2001 and 2004, or between female students in 2001 and 2004. However, whereas females were marginally ahead of males on just one test in 2001 (Calculator Appropriate), they were marginally ahead on two in 2004 (Calculator Optional and Calculator Appropriate).

As in 2001, there were statistically significant differences between students in the high and low socioeconomic groups on all three calculator tests in 2001. However, in 2004, but not in 2001, students in the medium socioeconomic group significantly outperformed their counterparts in the low group on all three calculator tests.

STUDENTS' ACCESS TO AND USE OF CALCULATORS

In 2004, almost all students (98.5%) reported that they owned or had access to a calculator at home. Among students who reported on the type of calculator to which they had access or owned (n = 1243), 7% said they had a 'Basic' calculator, 92.8% a 'Scientific' calculator, and 0.2% a graphics calculator.

Students were also asked about the type of calculator they used in school. Among respondents (n = 1371), 4% reported using a basic calculator, 95.8% a scientific calculator, and 0.1% a graphics calculator.

Use of Calculators at School

For each of four subjects (Mathematics, Business Studies, Science, Technology), students were asked to indicate how often they used a calculator. Four response categories were offered: 'Never', 'Sometimes', 'Often', and 'Does not Apply'. Responses are summarised in Table 6.5. Among students taking mathematics who responded to the item, over four-fifths (81.1%) said that they 'often' used calculators, while less than 1% indicated that they never did so. Frequent use of calculators by a majority of students is also evident for Business Studies where over three-fifths of students (61.5%) taking the subject said that they often used a calculator. Calculators were used less frequently for Science and Technology, with 45.1% and 75.7% respectively reporting that they never used calculators in those subjects.

Table 6.5 *Percentages of Students Indicating Various Levels of Calculator Usage in Selected School Subjects (2004)*

	n*	Often	Sometimes	Never
Mathematics	1439	81.1	18.3	0.6
Business Studies	1100	61.5	27.8	10.6
Science	1216	2.9	52.0	45.1
Technology	560	5.4	18.9	75.7

**Includes only students for whom the question was applicable (i.e., they studied the subject, and responded with respect to frequency of calculator usage).*

Students were also asked about the frequency with which they used calculators in mathematics classes in primary school, and in the First and Second years of post-primary schooling. Responses are summarised in Table 6.6. Over two-thirds of students (72.2%) reported that they had never used a calculator in their mathematics classes in primary school, while 3% reported that they had 'often' used one. Just over 10% of students reported that they had never used a calculator in First year, while almost two in five students said they had 'often' used one. Fewer than 5% reported never using a calculator in Second year, while almost 70% reported having used one 'often'. The results for primary school contrast with those of the 2004 National Assessment of Mathematics Achievement, where teachers of Fourth class students reported that 33% of students hardly ever or never used a calculator in class, that 45% did so once or twice a month, that 17% did so about once or twice a week, and that 5% did so on a daily basis (Shiel et al., 2006, Table 7.14). [14]

Table 6.6 *Percentages of Students Indicating Various Levels of Calculator Usage in Mathematics Classes in Primary School, and in the First and Second Years at Post-Primary Level (2004)*

	n	Often	Sometimes	Never
Primary School	1407	2.8	25.0	72.2
First Year, PP	1422	37.8	52.0	10.1
Second Year, PP	1415	69.4	25.9	4.7

[14] Most students in the 2004 study would not have been taught under the 1999 Primary School Mathematics Curriculum, as implementation did not begin until 2002-03.

For each level (Primary, First year, Second year), tests were conducted to ascertain if mean score differences on the calculator tests were statistically significant among students reporting varying levels of calculator usage. No statistically significant differences were observed, suggesting that calculator usage may not have been the only factor impacting on achievement.

Students were also asked when they were first taught how to use a calculator, or whether they were self-taught. Among students who responded (n = 1400), 22.5% reported that they had learned in Primary school, 33.9% in First year, 5.1% in Second year, and 1.5% in Third year. The remainder (37.0%) said that they were self-taught. Although students who learned to use the calculator in Third year did less well on each of the Calculator tests than students who learned to use the calculator at an earlier stage, or were self-taught, differences were not statistically significant. This may be due, at least in part, to the large standard errors associated with mean scores of students learning to use the calculator in the Second and Third years.

Students were asked about how often they used calculators in different topic areas in mathematics. The topic area headings were modified from those in the syllabus so that students would recognise them. Predictably, Fractions, decimals & percentages, and Length, area, volume & time emerged as the two areas in which over one-half of students reported using their calculator 'a lot' (Table 6.7). Fewer than 10% reported that they 'never' used the calculator in these areas. Just 25% of students reported using the calculator 'a lot' for Algebra, 31% for Statistics, and 23% for Geometry.

Table 6.7 *Percentages of Students Indicating Various Levels of Calculator Usage in Different Areas of Mathematics (2004)*[15]

Area	**n**	**A lot**	**To some extent**	**Never**
Fractions, decimals & percentages	1409	52.0	42.6	5.4
Length, area, volume & time	1402	54.2	40.9	4.9
Algebra	1407	25.0	49.6	25.5
Statistics	1394	30.6	56.8	12.7
Geometry	1361	23.1	53.0	24.0
Trigonometry*	1332	42.3	42.9	14.8
Graphs	1398	13.9	50.2	36.0

*Foundation level students would not have known about this topic area.

Teachers reported greater usage of calculators by students than did the students themselves for some aspects of mathematics. For example, teachers of 42% of students indicated that calculators were used a lot for statistics (Table 7.9), whereas only 31% of students said they used them a lot for the same topic (Table 6.7). Such

[15] These headings, rather than the content area referred to in the syllabus, were used in the Student Questionnaire, as it was felt that they would be more interpretable to students than those in the syllabus.

differences may relate to different interpretations of the term 'a lot' held by teachers and students.

Table 6.8 shows the mean scores on the three Calculator Study tests for students reporting varying levels of calculator usage in different areas of mathematics. In some content areas, there is evidence that students who used calculators 'a lot' obtained higher mean scores than students who 'never' used them. For example, on the Calculator Appropriate test, students who used the calculator 'a lot' in Fractions, decimals & percentages achieved a mean score of 269, compared to mean scores of 261 for those who used one 'to some extent' and 249 for those who 'never' used one.

Table 6.8 *Mean Scale Scores of Students Indicating Various Levels of Calculator Usage in Different Areas of Mathematics (2004)*

	Calculator					
	Inappropriate		Optional		Appropriate	
	Score	SE	Score	SE	Score	SE
Fractions/Decimals						
A lot	245.1	2.16	253.7	2.49	269.3	1.37
To some extent	243.4	5.21	247.9	6.45	260.9	4.15
Never	241.5	23.90	241.6	16.25	248.9	11.49
Missing	214.8	5.69	223.9	6.51	227.6	2.32
Length/Area/Time						
A lot	246.6	2.68	253.7	4.01	269.7	0.94
To some extent	241.5	5.44	249.0	3.76	260.2	4.89
Never	228.8	5.11	227.8	8.73	239.2	8.39
Missing	231.3	17.16	229.2	17.31	238.3	7.47
Algebra						
A lot	221.5	7.25	230.9	4.24	245.6	2.92
To some extent	248.5	0.49	256.3	1.70	269.8	1.01
Never	255.0	7.29	258.0	9.99	270.4	7.82
Missing	236.2	12.36	229.1	11.98	248.9	1.29
Statistics						
A lot	246.4	8.50	253.0	6.89	268.4	6.95
To some extent	242.8	1.31	252.2	2.95	265.5	0.76
Never	245.3	6.75	243.3	7.43	252.0	3.62
Missing	219.9	9.49	213.9	3.58	235.3	3.02
Geometry						
A lot	235.2	2.96	241.9	5.16	258.4	2.80
To some extent	246.7	3.71	254.5	3.78	267.6	3.38
Never	247.5	11.61	252.7	10.98	263.8	7.56
Missing	228.3	3.34	228.5	7.57	246.2	10.07
Trigonometry						
A lot	245.0	1.84	251.3	2.01	265.9	3.57
To some extent	244.9	6.45	252.2	7.77	266.1	8.04
Never	244.7	11.25	246.9	8.50	256.8	4.88
Missing	224.9	5.45	234.8	2.77	250.5	4.19
Graphs						
A lot	235.0	7.41	245.2	9.26	257.2	2.54
To some extent	246.5	3.79	252.9	4.16	267.5	2.61
Never	245.1	4.87	250.6	4.96	264.0	3.58
Missing	214.3	10.63	218.7	3.93	229.7	3.57

A small number of differences are statistically significant. On the Calculator Inappropriate test, students using a calculator 'a lot' in Length, area, volume & time, outperformed students who 'never' used one (Diff = 17.8; SED = 3.56, 95% CI = 2.45 to 33.10).

Among those with access to a calculator for the Calculator Optional test, students who reported using the calculator 'a lot' in Length, area, volume and time achieved a significantly lower mean score than those who reported using one 'sometimes' (Diff = -19.7, SED = 5.04; 95% CI = -29.9 to -9.5), and those who reported that they 'never used' one (Diff = -26.2; SED = 5.92; 95% CI = -38.23 to -14.23). Similarly, among those without access to a calculator on the same test, those who reported using a calculator 'a lot' in Length, area, volume and time achieved a significantly lower mean score than those who reported using one 'sometimes' (Diff = -31.9; SED = 4.52; 95% CI = -38.23 to -14.23), and those who reported that they 'never used' one (Diff = -34.5; SED = 4.76; 95% CI = -44.13 to -24.85).

No statistical differences were observed on any of the calculator tests for students using calculators with varying levels of frequency in Fractions, decimals & percentages, Statistics, Geometry, Trigonometry or Graphs. Overall, it can be inferred that students who use calculators where appropriate (e.g., for Fractions, decimals & percentages, and/or for Length, area, volume and time) tend to do better than students who use calculators in areas where they are of less value (e.g., Algebra, Graphs).

Comparison with the 2001 Study

In 2001, students had also been asked about calculator usage at school. Not surprisingly, since the 2001-2 cohort studied mathematics under the old syllabus, fewer than one percent reported that they had used calculator 'often' in mathematics classes, while 11% reported using one 'sometimes', and 77% reported never doing so (see Close et al., 2004, Table 5.10). Hence the data for 2004 confirm that calculator usage in mathematics classrooms had increased substantially, with 81.1% reporting that they used a calculator 'often', 19.3% 'sometimes', and 0.6% 'never'.

Calculator usage in Business Studies classes was about the same in 2001 (63% reported 'often' using one) as in 2004 (62%). There is evidence of increased occasional use of calculators in Science classes, with 3% using them 'often' and 52% using them 'sometimes' in 2004, compared with 2% and 17% respectively in 2001. There is a small increase in calculator usage in Technology classes in 2004 (5% 'often' and 19% 'sometimes') compared with 2001 (0.2% and 6% respectively).

Reports of usage of calculators by students when they were in primary schools did not change between the 2001 and 2004 studies (over 70% in both cohorts reported 'never' using a calculator), though this is not unexpected, since neither the 2001 nor the 2004 cohorts would have studied under the 1999 Primary School Mathematics Curriculum, which was implemented in primary schools from 2002-03 onwards.

STUDENTS' ATTITUDES TOWARDS MATHEMATICS AND CALCULATORS

Students' Attitudes Towards Mathematics

Students were shown a series of questions about their attitudes towards mathematics, and were asked to indicate their agreement with each one. Among the statements with which students agreed the most were: 'Maths is important for getting a job' (82% 'strongly agreed' or 'agreed'); 'I like doing sums when I know the method' (83%); 'Maths is a useful subject in everyday life' (80%); and 'I get good marks at maths' (70%). Statements with which students disagreed most were: 'Doing maths is fun, I wouldn't want to give it up' (63% 'disagreed' or 'strongly disagreed'); 'Maths is one of my favourite subjects' (60%); 'I like trigonometry' (62%); and 'I like tackling maths problems' (60%) (Table 6.9). Students' responses suggest that, while they recognise the importance of mathematics for their future lives, they also prefer routine calculations to doing trigonometry or geometry, or solving problems.

Table 6.9 *Percentages of Students Indicating Various Levels of Agreement with Statements Related to Attitudes Towards Mathematics (2004)*

Statement	Mean	SE	SA	A	D	SD
Maths is important for getting a job	3.1	0.01	35.3	46.6	15.2	2.9
Maths is a useful subject in everyday life	3.0	0.02	26.0	54.3	14.5	4.7
I like doing sums where I know the method	3.0	0.01	25.4	57.9	11.0	5.8
I get good marks in maths	2.8	0.01	9.8	60.4	25.8	4.0
I like doing calculations	2.7	0.01	11.7	51.3	28.5	8.5
I have always done well in maths	2.6	0.03	12.0	43.5	36.7	7.8
I like statistics	2.5	0.01	10.0	43.1	34.4	12.5
I like algebra	2.5	0.02	12.0	39.4	30.1	18.5
When I do maths I sometimes get totally absorbed	2.4	0.01	7.1	39.3	40.8	12.8
I like arithmetic	2.4	0.03	7.0	38.1	42.9	12.0
Maths is one of my best subjects	2.4	0.01	9.9	32.7	42.5	14.8
I like everyday maths problems	2.4	0.01	6.9	37.6	41.9	13.6
Maths is one of my favourite subjects	2.3	0.03	8.5	31.8	40.9	18.8
I like tackling maths problems	2.3	0.02	8.5	31.3	41.8	18.5
I like geometry	2.3	0.03	5.1	34.5	42.4	18.0
I like doing length, area, and volume problems	2.3	0.01	5.3	34.0	41.0	19.7
Doing maths is fun, I wouldn't want to give it up	2.2	0.01	6.6	31.0	42.1	20.4
I like trigonometry	2.2	0.04	5.4	32.4	42.9	19.3

Mean scores based on: Strongly Agree (SA) = 4, Agree (A) = 3, Disagree (D) = 2, Strongly Disagree (SD) = 1.

A factor analysis (principal components, with varimax rotation) identified four factors linked to attitude towards mathematics (Table 6.10). These were: a positive attitude towards mathematics (which explained 18% of the variance in the pattern of student scores); mathematics self-efficacy (15%); enjoyment of aspects of mathematics (14%);

and sense of usefulness of mathematics (9%). The Kaiser-Meyer-Olkin measure of sampling adequacy yielded a value of 0.93, which can be considered satisfactory.

Table 6.10 *Attitudes Towards Mathematics – Rotated Components Matrix (2004)*

	Component*			
	1	**2**	**3**	**4**
I like tackling maths problems.	.75			
I like everyday maths problems.	.70			
Doing maths is fun, I wouldn't want to give it up.	.62			
I like doing calculations.	.61			
When I do maths I sometimes get totally absorbed.	.55			
I like arithmetic.	.53			
I like doing sums where I know the method.	.47			
Maths is one of my best subjects.		.81		
I get good marks in maths.		.79		
I have always done well in maths.		.73		
Maths is one of my favourite subjects.		.63		
I like trigonometry.			.78	
I like geometry.			.76	
I like statistics.			.68	
I like algebra.			.55	
I like doing length, area and volume problems.			.42	
Maths is important for getting a job.				.85
Maths is a useful subject in everyday life.				.82

**1 = Positive attitude towards mathematics; 2 = Self-efficacy in mathematics; 3 = Enjoyment of aspects of mathematics; 4 = Usefulness of mathematics.*

Four scales were constructed from the raw data – one corresponding to each identified factor. Reliabilities (alpha values) for the scales were 0.81 (positive attitude towards mathematics), 0.81 (self-efficacy in mathematics), 0.76 (enjoyment of aspects of mathematics), and 0.63 (usefulness of mathematics).

Correlations between scores on the attitude item clusters and performance on the calculator tests were computed and their statistical significance was evaluated. The resulting correlations were moderate to small, but statistically significant in all cases bar one – the correlation between usefulness and performance on the Calculator Optional test. Significant correlations ranged from 0.35 (self-efficacy and performance on the Calculator Inappropriate test) to 0.07 (usefulness and performance on the Calculator Appropriate test) (Table 6.11).

Table 6.11 *Correlations between Attitude Scores and Performance on the Calculator Tests (2004)*

	Calculator								
	Inappropriate			Optional			Appropriate		
	r	t	p	r	t	p	r	t	p
Positive attitudes	.24	7.00	**.00**	.24	8.90	**.00**	.26	8.88	**.00**
Self-efficacy	.35	13.86	**.00**	.34	13.63	**.00**	.33	13.63	**.00**
Enjoyment of aspects of maths	.16	4.55	**.00**	.18	5.44	**.00**	.18	5.58	**.00**
Usefulness	.07	3.31	**.03**	.04	2.00	.05	.08	2.62	**.01**

*Significant correlations in **bold**; r = Pearson correlation coefficient; t = t statistic; p = probability*

Comparisons were drawn between male and female students on the four attitude variables. Two of the differences were statistically significant. Females had a more positive attitudes towards mathematics than males (Diff = 0.67; SED = 0.30; 95%CI = 0.07 to 1.27). Males had a significantly stronger belief than females about the usefulness of mathematics (Diff = 1.10; SED = -2.97; 95%CI = 0.76 to 83.38).

Students' Perceptions of the Relative Difficulty of Different Aspects of Mathematics

Related to students' attitudes towards mathematics are their perceptions of the relative difficulty of various aspects of mathematics. Students were asked to evaluate those aspects of mathematics they found easy and/or difficult. The easiest aspects were Graphs (rated 'Easy' by 60.8% of students), Fractions, decimals & percentages (38%), Statistics (38%), and Algebra (31%). The most difficult areas were Trigonometry (21%), and Geometry (30%) (Table 6.12).

Table 6.12 *Percentages of Students Rating Various Aspects of Junior Certificate Mathematics, by Difficulty Level (2004)*

	n	Easy		Okay		Difficult	
		%	SE	%	SE	%	SE
Graphs	1413	60.8	2.08	30.7	1.84	8.5	1.05
Fractions, decimals & percentages	1431	37.7	1.86	52.4	1.86	9.9	1.65
Statistics	1396	37.6	2.22	48.3	1.63	14.1	2.28
Algebra	1415	31.1	2.05	42.3	1.47	26.6	1.56
Length, area, volume, time	1415	27.9	1.62	54.0	1.60	18.1	1.72
Geometry	1378	22.0	1.46	47.8	1.47	30.2	2.08
Trigonometry	1342	21.0	1.51	41.1	1.00	37.9	1.06

These ratings can be compared with those provided by teachers (Chapter 7, Table 7.4). Teachers were asked to rank order the eight syllabus content areas on the basis of their difficulty for students. Functions and Graphs, Number Systems, Statistics and Sets were identified as the easiest areas for students, while Geometry, Trigonometry, Algebra, and Applied Arithmetic & Measures were identified as the most difficult.

Hence, teachers' and students' perceptions of difficulty are broadly consistent with one another.

Students' Attitudes Towards Calculators

Students were presented with a series of statements about attitudes towards calculators, and asked to indicate their level of agreement with each one. At least 80% of students 'agreed' or 'strongly agreed' with five statements: 'a calculator could help me get better marks in school mathematics'; 'I think I should be allowed use a calculator in maths class'; 'I think I should be allowed to use a calculator for maths homework'; I think I should be allowed to use a calculator for homework in other subjects'; and 'I can solve problems better when I have a calculator to help me with the arithmetic'. On the other hand, at least 70% of students 'disagreed' or 'strongly disagreed' with two statements, 'A calculator should be used only by a student who has a lot of difficulty with school maths', and 'Since I have a calculator, I do not need to learn to do calculations with pen and paper'. Worryingly, however, 26% of students agreed or strongly agreed that, since they had a calculator, they did not need to learn to do calculations with pen and paper (Table 6.13).

Table 6.13 *Percentages of Students Indicating Various Levels of Agreement with Statements Related to Attitudes Towards Calculators (2004)*

Statement	Mean	SE	SA	A	D	SD
I think a calculator can help me to get better marks in school maths.	3.4	0.03	48.4	43.9	5.8	1.9
I think I should be allowed to use a calculator in maths class.	3.3	0.02	47.1	46.9	4.4	1.6
I think I should be allowed to use a calculator for maths homework.	3.3	0.01	42.6	51.0	4.2	2.3
I think I should be allowed to use a calculator for classwork in other subjects.	3.2	0.01	30.6	58.6	8.5	2.3
I can solve problems better when I have a calculator to help me with the arithmetic.	3.2	0.00	35.3	50.8	10.0	3.9
I think I should be allowed to use a calculator for homework in other subjects.	3.2	0.02	31.1	57.7	8.2	3.0
I think a calculator could help me get better at maths.	2.9	0.03	21.4	48.8	25.0	4.7
Maths is more fun when you can use a calculator.	2.8	0.01	21.0	47.6	23.2	8.2
You don't have to think much when using a calculator.	2.5	0.03	13.2	33.6	40.1	13.1
I think a calculator could make me lazy at school maths.	2.3	0.04	8.2	32.9	39.8	19.1
Since I have a calculator I do not need to learn to do calculations with pen and paper.	2.1	0.02	9.1	16.9	44.0	29.9
A calculator should be used only by a student who has a lot of difficulty with school maths.	1.9	0.01	6.3	12.5	48.3	32.9

Mean computed based on the values: Strongly Agree (SA) = 4, Agree (A) = 3, Disagree (D) = 2, Strongly Disagree (SD) = 1.

A principal components analysis with varimax rotation identified three factors: support for calculator usage (which explained 26% of the variance in the pattern of student scores), support for calculators to improve students' own mathematics (17%), and negative impact of calculator usage (15%). The Kaiser-Meyer-Olkin measure of sampling adequacy was 0.83, which can be considered satisfactory.

Table 6.14 *Attitudes Towards Calculators – Rotated Components Matrix*

	Component*		
	1	**2**	**3**
I think I should be allowed to use a calculator for classwork in other subjects.	.82		
I think I should be allowed to use a calculator for homework in other subjects.	.81		
I think I should be allowed to use a calculator in maths class.	.77		
I think I should be allowed to use a calculator for maths homework.	.74		
I can solve problems better when I have a calculator to help me with the arithmetic.	.57		
I think a calculator could help me get better at maths.		.73	
Maths is more fun when you can use a calculator.		.66	
I think a calculator can help me to get better marks in school maths.		.61	
I think a calculator could make me lazy at school maths.			.49
You don't have to think much when using a calculator.			.81
Since I have a calculator I do not need to learn to do calculations with pen and paper.			.70
A calculator should be used only by a student who has a lot of difficulty with maths.			.50

**1 = Support for calculator usage across subjects; 2 = Support for calculator usage to improve own maths; 3 = Negative aspect of calculator usage.*

Three scales were constructed, based on the identified factors (Table 6.14). The first, support for calculator usage, had a reliability (alpha value) of 0.84. The alpha values for support for calculator usage to improve students' own mathematics, and disadvantages of calculator usage were 0.64 and 0.55 respectively.

Correlations between each scale and performance on the calculator tests are given in Table 6.15. There was a weak non-significant association between support for calculator usage across subjects and performance on the Calculator Optional ($r = 0.04$), while the correlation between support for calculator usage across subjects and performance on the Calculator Appropriate test ($r = 0.10$) just reached significance. The correlations between support for calculators to improve students' own mathematics and performance are significant on the Calculator Inappropriate ($r = -0.14$) and Calculator Optional (-0.10) tests. The negative correlations indicate that students who are most optimistic about the potential positive effects of calculator usage on their own mathematics tend to score marginally lower than those who are less optimistic. The correlations between the negative aspects of calculator usage scale and performance on the Calculator Inappropriate ($r = -0.15$), Calculator Optional (-0.18) and Calculator Appropriate (-0.08) scales are again weak but statistically significant. These negative correlations indicate that students who feel more strongly that calculators could make them lazy, or cause them to think less, tend to do less well than students who do not hold such views.

Table 6.15 *Correlations between Attitude Scores and Performance on the Calculator Tests*

	Calculator								
	Inappropriate			Optional			Appropriate		
	r	t	p	r	t	p	r	t	p
Support for calculators across subjects	-.01	-0.39	.70	.04	1.00	.32	.10	2.81	**.01**
Support for calculators to improve own math	-.14	-4.29	**<.00**	-.10	-2.67	**.01**	-.04	-1.35	.19
Belief in negative impact of calculators	-.15	-4.50	**<.00**	-.18	-5.07	**<.00**	-.08	-2.60	**.01**

Significant correlations in ***bold****; r = Pearson correlation coefficient; t = t statistic; p = probability*

Specific Aspects of Calculator Use That Students Liked/Disliked

In an open-ended item, students were asked to identify an aspect of calculator use that they liked/disliked. Among the aspects that students liked were that calculators were easier and faster (relative to other methods) (66% of students), that they were useful when carrying out basic operations (10%), that they helped with algebra and fractions (5%), and that they generated correct answers (5%) (Table 6.16).

Table 6.16 *Aspects of Calculator Use That Students Liked Most (2004)*

Aspect	n	%	SE
Easier and faster	818	66.4	0.16
Carries out basic operations	126	10.2	1.09
Helps with algebra and fractions	62	5.0	0.40
Generates correct answers	57	4.6	0.39
Scientific functions	41	3.3	0.80
Trigonometric functions	18	1.4	0.76
Miscellaneous	45	3.7	1.34

Students were also asked to identify specific aspects of calculator use that they least liked. Almost 20% of respondents noted that it was easy to make mistakes using a calculator (Table 6.17). Sixteen percent stated that a calculator was difficult to use, while other students referred to specific topics that were difficult, including algebra (6.6%), percentages (2.3%), fractions (2.2%), addition or subtraction (1.6%) and division (1.4%). Over 12% of students indicated that there were no aspects of calculators that they liked least, while 9.6% stated that use of calculators did not engage the brain.

Table 6.17 *Aspects of Calculator Use That Students Liked Least (2004)*

Aspect	n	%	SE
Easy to make mistakes	201	19.6	0.33
Difficult to use	167	16.3	4.31
Don't use brain	96	9.4	0.36
Unable to do certain things	68	6.7	0.34
Difficulty with algebra	68	6.6	0.53
Don't know some buttons/functions	39	3.8	0.37
Trigonometry	24	2.3	1.0
Difficulty with percentages	23	2.3	0.39
Difficulty with fractions	22	2.2	0.04
Pi and volumes	17	1.7	0.39
Difficulty with addition or subtraction	17	1.6	0.46
Difficulty with division	14	1.4	0.14
Time	14	1.3	0.34
Difficulty with square root	12	1.2	1.12
2nd function	11	11	0.19
Numbers	11	1.1	0.57
Nothing	125	12.2	0.82

Comparison with the 2001 Study

Students' responses to individual attitude towards mathematics items were broadly similar in 2001 and 2004. In both years, about 80% of students 'strongly agreed' or 'agreed' that mathematics was important for getting a good job, and that mathematics is a useful subject for everyday life. In 2004 more students (40%) 'strongly agreed' or 'agreed' that mathematics was one of their favourite subjects than in 2001 (30%), and that they liked doing calculations (62% vs. 48%). In 2001, a factor analysis using the attitude towards mathematics items yielded three factors: disposition (attitude) towards mathematics, usefulness of mathematics, and mathematics self-concept. As in 2001, correlations with performance on the calculator tests were strongest for self-efficacy (self-concept in 2001), and weakest for usefulness.

Some differences are apparent in students' attitudes towards calculators in 2001 and 2004. For example, in 2001, 66% 'strongly agreed' or 'agreed' that they should be allowed to use a calculator in mathematics classes. The corresponding estimate for 2004 was over 90%. In 2001, 55% of students 'strongly agreed' or 'agreed' with the view that a calculator could make them lazy at school mathematics. In 2004, this dropped to 41% (Table 6.18). Such differences may well reflect the fact that students now routinely use calculators in mathematics classes, at home, and in examination situations.

In 2001, a factor analysis of the items on attitude towards calculators identified three factors: a general positive disposition towards calculators, a belief that calculator usage is associated with laziness or poor achievement, and a positive disposition towards calculators in areas of the curriculum other than mathematics. In 2004, three factors were also identified: the support for calculator use across subjects, support for calculators to improve one's own mathematics, and a belief in the negative affects of calculator usage. Hence, despite students being generally more supportive of the use of calculators in mathematics classes in 2004, the same factors were identified, though in a somewhat different order. Correlations between factor scores and performance on the calculator tests were somewhat weaker in 2004 than in 2001, perhaps reflecting the fact that there was less variation in students' attitudes towards calculators, particularly in mathematics classes, once they had become a feature of the syllabus.

Table 6.18 *Percentages of Students Expressing 'Strong Agreement' or 'Agreement' on Attitude towards Calculator Items (2001 and 2004)*

Statement	2001	2004
I think a calculator can help me to get better marks in school maths.	74.3	92.3
I think I should be allowed to use a calculator in maths class.	65.7	94.0
I think I should be allowed to use a calculator for maths homework.	71.5	93.6
I think I should be allowed to use a calculator for classwork in other subjects.	73.6	89.2
I can solve problems better when I have a calculator to help me with the arithmetic.	*	86.1
I think I should be allowed to use a calculator for homework in other subjects.	78.4	88.8
I think a calculator could help me get better at maths.	49.5	70.2
Maths is more fun when you can use a calculator.	*	68.6
You don't have to think much when using a calculator.	*	46.8
I think a calculator could make me lazy at school maths.	54.8	41.1
Since I have a calculator I do not need to learn to do calculations with pen and paper.	*	26.0
A calculator should be used only by a student who has a lot of difficulty with school maths.	40.0	18.8

** Question not included in 2001 Student Questionnaire*

SUMMARY

Gender differences on the calculator tests, while slightly in favour of females in two tests in 2004, and one 2001, were not statistically significant. This contrasts with the Junior Certificate mathematics examination, where females achieve higher proportions of A, B and C grades than males at Higher, Ordinary and Foundation levels, and the mathematics component of the PISA study, where males significantly outperformed females in both 2000, 2003 and 2006.

Social class differences in performance on the calculator tests were observed in both 2001 and 2004. In 2001, differences between students in the upper and lower socioeconomic groups were significant for all three tests, whereas differences between students in the middle and lower socioeconomic groups were small and not statistically significant. In 2004, differences between students in the middle and lower groups, and between students in the upper and lower groups, were statistically significant for all three calculator tests.

Not surprisingly, given that calculator usage is now a component of the Junior Certificate mathematics syllabus, fewer than 1% of students indicated in 2004 that they did not use a calculator in mathematics classes. While usage levels were about the same in 2001 and 2004 in Business Studies classes, there was a marked increase in the use of calculators ‘sometimes’ between the two years in Science classes. It is unclear if increased calculator usage in mathematics classes is responsible for this change.

Students in the 2001 and 2004 cohorts reported similarly low levels of calculator usage in their primary schools. It remains to be seen whether increased levels of calculator usage in mathematics classes in primary schools, in line with the implementation of the 1999 Primary School Mathematics Curriculum, will impact on the level or quality of students’ calculator usage in mathematics classes at post-primary level.

Among the specific aspects of mathematics for which students used calculators ‘a lot’ in 2004 were Fractions, decimals & percentages (52%), Length, area, volume & time (54.2%) and Trigonometry (42.3%). Calculator usage was less extensive in Algebra, Statistics, Geometry, and Graphs.

In both 2001 and 2004, students with positive attitudes towards mathematics, those with strong belief in their own mathematical abilities, and those who enjoyed mathematics more tended to perform better on the calculator tests than those with less positive attitudes, those with less belief in their ability, and those who enjoyed mathematics less.

There was a noticeable improvement in students’ attitudes towards calculators in mathematics classes between 2001 and 2004. In 2004, more students believed that a calculator could help them to get good marks in school mathematics, while fewer believed that a calculator made them lazy at school mathematics. In 2004, 86% of students believed that they could solve a problem better if they had access to a calculator.

Chapter 7: Teachers and Calculators

A Teacher Questionnaire was administered in conjunction with Phase II of 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 Certificate mathematics classes, and in the Junior Certificate mathematics examination, and how these attitudes have changed since 2001 when a similar questionnaire was administered. Some of the questions used in 2001 were not included in the 2004 questionnaire as they were no longer relevant, while some new questions were added to it to take account the change in status of calculators in the revised Junior Certificate syllabus. Details of the changes are provided in Chapter 3.

The data for both 2001 and 2004 are reported in terms of the percentages of students whose teachers provided various responses to the questionnaire, rather than in terms of the percentages of teachers who responded. This is done to reflect the fact that the results are based on a representative sample of students and not of teachers. Seventy-one teachers responded to the questionnaires.

BACKGROUND ON TEACHERS

This section provides background and contextual information on the teachers of the classes that participated in the study. Information is provided on six aspects: the gender of teachers; their experience in teaching mathematics; their enjoyment in teaching particular topics; areas of difficulty for their students; year levels taught; and their views on the impact of the Junior Certificate examination in mathematics on their students

Teacher Gender

There was no significant difference in the gender composition of students' teachers between 2001 and 2004. Over one-half of students in the 2001 and 2004 samples (55% and 57% respectively) were taught by teachers who indicated that they were female, while about two-fifths (40% and 41% respectively) were taught by male teachers (Table 7.1). Data on gender were unavailable for the teachers of 5.4% of students in 2001 and 2.2% in 2004.

Table 7.1 *Percentages of Students Taught by Male and Female Teachers (2001 and 2004)*

	2001		2004	
	%	SE	%	SE
Female	55.0	7.13	56.6	1.39
Male	39.6	6.68	41.1	3.61
Missing	5.4	2.79	2.2	2.44

Experience Teaching Mathematics

There was some change in the experience of teachers between 2001 and 2004, with a greater number of teachers of students in 2004 being taught by more experienced teachers. As in 2001, a majority of students in 2004 were taught by teachers who reported at least 10 years teaching experience (Table 7.2). More students in 2004 had teachers with at least 16 years experience (65.1%) than in 2001 (41.0%), and fewer had teachers with up to 15 years experience (32.7% vs. 51.5%). In both 2001 and 2004, about 5% of the students were taught by teachers with no more than 5 years experience.

Table 7.2 *Percentages of Students Taught by Teachers with Varying Levels of Experience in Teaching Mathematics (2001 and 2004)*

Years experience	Percent of teachers indicating this level of experience			
	2001		2004	
	%	SE	%	SE
1-5	4.2	5.83	5.1	1.32
6-10	12.2	5.54	18.4	1.90
11-15	35.1	4.37	9.2	1.65
16-25	22.3	4.31	33.6	2.58
More than 25	18.7	5.90	31.5	6.00
Missing	7.6	2.69	2.2	2.44

Enjoyment in Teaching

Teachers in 2001 and 2004 were asked to indicate which areas of mathematics they most enjoyed teaching. The eight content areas in the syllabus were listed and teachers were asked to rank them from most enjoyable to least enjoyable. Over one-third of students in 2001 and almost one-half in 2004 were taught by teachers who indicated that Algebra was the aspect of school mathematics that they enjoyed teaching most (Table 7.3). When the percentages of students whose teachers ranked each area as most enjoyable, second most enjoyable or third most enjoyable were summed and averaged, Algebra ranked first (i.e., most enjoyable to teach) and Statistics second in 2004, whereas Statistics ranked first and Algebra second in 2001. Overall, the rank orders of content areas, in terms of enjoyment in teaching, are very similar for 2001 and 2004.

Table 7.3 *Percentages of Students Whose Teachers Rated Specified School Mathematics Content Areas as Most Enjoyable to Teach, and Rankings by Enjoyment (2001 and 2004)*

Area	2001 Most Enjoyable	2001 Overall ranking*	2004 Most Enjoyable	2004 Overall Ranking*
Sets	11.5	5	11.2	5
Number Systems	1.6	8	4.1	7
Applied Arithmetic & Measure	3.8	7	5.1	8
Algebra	36.2	2	48.9	1
Statistics	22.1	1	13.1	2
Geometry	4.9	6	7.2	6
Trigonometry	8.3	3	8.7	3
Functions and Graphs	12.1	4	5.7	4

**Based on average percentage of students whose teachers selected each area as the first, second or third most enjoyable*

Areas of Difficulty for Students

Teachers in the 2001 and 2004 studies were also asked to indicate the areas of mathematics in which their students had most difficulty by rank ordering the eight content areas from most difficult to least difficult. About thirty percent of students in 2001 and in 2004 were taught by teachers who indicated that Algebra was the aspect of school mathematics that their students found most difficult (Table 7.4). When the percentages of students whose teachers ranked each area as most difficult, second most difficult or third most difficult were taken together, Trigonometry ranked first (i.e., most difficult), with Algebra second in 2001, while Geometry ranked first and Trigonometry ranked second in 2004. As with enjoyment (Table 7.3), the rank orders of content areas for 2001 and 2004, in terms of difficulty for students, were very similar (Table 7.4), although the percent perceiving Geometry to be most difficult increased from 16% in 2001 to 32% in 2004, and Trigonometry decreased from 37% in 2001 to 15.4% in 2004. It may be relevant to note that Geometry was one of the content areas most affected by changes in the syllabus, particularly for the Higher course, and that teacher unfamiliarity may have contributed to students' perceived difficulties. The reduction in perceived difficulty with regard to Trigonometry may also reflect syllabus change, in this case with regard to use of the calculator instead of (or as well as) four-figure tables. However, these latter changes had little impact on the rank orderings in both years. As already mentioned, it is interesting to note that, while teachers hold Algebra to be the most enjoyable area to teach, they also perceive it as one of the most difficult areas for students to learn.

Year Levels Taught

Teachers were asked to indicate the levels at which they teach mathematics in the 2004-05 school year. While all students in the survey were taught by teachers with responsibility for a Third year mathematics class, about 70% were taught by teachers who also taught Fifth or Sixth years or both, while 30% were taught by teachers who also taught mathematics to Transition (Fourth) year students.

Table 7.4 *Percentages of Students Whose Teachers Rated Specified Mathematics Content Areas as 'Most Difficult' for Students, and Rank Ordering of Content Areas by Difficulty (2001 and 2004)*

Area	2001 Most Difficult	2001 Overall ranking*	2004 Most Difficult	2004 Overall Ranking*
Sets	2.1	7	0.5	8
Number Systems	1.4	6	3.4	6
Applied Arithmetic & Measure	6.0	5	10.2	4
Algebra	29.7	2	28.3	3
Statistics	1.0	8	0.0	7
Geometry	16.1	3	32.0	1
Trigonometry	36.7	1	15.4	2
Functions and Graphs	8.9	4	0.9	5

**Based on average percentages of students whose teachers selected an area as the first, second or third most difficult (combined).*

Impact of Junior Certificate Examination on Students

In order to ascertain how the effects of the Junior Certificate mathematics examination were perceived to impact on students' mathematics development, teachers in the 2001 and 2004 studies were asked to indicate the extent to which the examination hampered students' progress in mathematics. There were no significant differences between 2001 and 2004 in responses to this question. What did emerge was that, while in both 2001 and 2004 just 4% to 5% of students were taught by teachers who believed that the Junior Certificate examination hampered students' progress 'a lot', as many as 60%, in both 2001 and 2004, were taught by teachers who believed that the examination hampered students' progress 'very little' or 'not at all' (Table 7.5). In other words, the majority of students were taught by teachers who regard any negative effect of the Junior Certificate examination on students' progress in mathematics as minimal.

Table 7.5 *Percentages of Students Taught by Teachers Who Indicated Varying Levels at which the Junior Certificate Mathematics Examination Hampered Students' Progress (2001 and 2004)*

	2001*		2004**		04-01	SED	95%CI	
	%	SE	%	SE	Diff			
Not at all	31.3	6.62	35.5	5.52	4.2	8.62	-21.46	12.96
Very little	29.9	6.13	27.4	5.79	-2.5	8.43	-14.32	19.36
Some extent	30.7	5.24	24.9	6.36	-5.8	8.24	-10.70	22.22
A lot	4.2	2.97	4.9	2.18	0.7	3.69	-8.09	6.63
Missing	3.8	2.27	7.2	2.63	3.4	3.47	-10.33	3.53

** n = 1464; ** n = 1459*

SCHOOL POLICY ON CALCULATORS

The following section provides information on teachers' perspectives on various aspects of their schools' use of calculators in mathematics. Most of the findings in this section relate only to the 2004 Teacher Questionnaire as this section was revised and expanded for Phase II in the light of the subsequent revision of the mathematics syllabus to allow access to calculators (c.f. Chapter 3 for more detail on these changes) and the publication of the document *Calculators: Guidelines for Second- level Schools* (DES/NCCA, 2001).

School Policy on Calculator Provision

About one-third of students were taught by teachers who indicated that students are free to use any type of calculator. A little over one-third were taught by teachers who indicated that the school specifies the type of calculator (usually a scientific calculator), and almost three in ten by teachers who indicated that their school specifies both make and model (Table 7.6). Answering a separate question, the teachers of about 15% of students indicated that students purchased calculators from the school.

Table 7.6 *Percentages of Students in School with Various Requirements for Calculator Purchase (2004)*

	%	SE
Require particular make & model	28.7	0.78
Specify type of calculator, but not make/model	35.1	8.83
Free to use any type of calculator	31.9	6.53
Other	2.0	0.81
Missing	2.2	2.44

School Policy on Calculator Use

About 22% of students in the 2004 study were taught by teachers who said that their school had some kind of policy on calculators while 65% were taught by teachers who said their school had none. About 8% were unsure. For those schools with a policy on calculator use, only 27% of students were taught by teachers who described it as an official school policy. The policy was agreed among mathematics teachers in most cases (70%) and required that calculator use be taught in First year in the majority of cases (57%). Almost all policies forbade the use of mobile phones as calculators (89%), perhaps for reasons other than the calculating potential of the mobile phones!

Table 7.7 *Percentages of Students in Schools with Policies Relating to Various Aspects of Calculator Usage (2004)**

	Yes		No		Unsure	
	n	%	n	%	n	%
Is the policy an official school policy?	95	26.5	198	55.3	65	18.2
Is the policy agreed among teachers of subjects to which calculators are relevant?	167	49.3	142	41.9	30	8.8
Is the policy agreed among mathematics teachers only?	243	70.3	73	21.1	30	8.6
Does the policy assign responsibility for developing calculator operation skills to specific group of teachers?	47	13.7	268	77.7	30	8.6
Does the policy require that calculator use is taught in 1st Year?	212	57.1	130	34.9	30	8.0
Does the policy require that calculators are *not* used in 1st Year?	40	12.3	258	78.6	30	9.1
Does it explicitly allow the use of mobile phones as calculators?	0	0.0	345	92.0	30	7.9
Does it explicitly *forbid* the use of mobile phones as calculators?	329	88.5	13	3.5	30	8.0

*Based on responses of teachers who stated that their schools had a policy on calculators

USE OF CALCULATORS IN JUNIOR CYCLE MATHEMATICS CLASSES

This section provides information on teachers' perceptions of the use of calculators to support a number of aspects of mathematics education in their Third year classes. These aspects include: the degree of usage of calculators in different contexts and content topics; relative emphasis on important numeracy skills; specific calculator operation skills and functions taught; restrictions on calculator use; effects of calculator use on teaching methods and topic areas; and differential usage of calculators with low-achievers. The data presented also include collations of teachers' specific comments concerning calculator effects on their teaching methods and modifications in calculator use when teaching low achievers. All of the data in this section (apart from the question on calculator use in home and school contexts) refer only to the 2004 study.[16]

Calculator Use in Home and School Contexts

In both 2001 and 2004, teachers of the students in the study samples were asked whether Junior Cycle students should be allowed to use calculators in a range of home and school contexts, including the Junior Certificate mathematics examination. Teachers in 2001 were largely in favour (about 70–75% of students) of allowing the use of calculators for mathematics classwork and homework, and for the Junior Certificate mathematics examination, where the calculator is relevant to the work at hand (Table 7.8). The actual practice of teachers, at that time, of not allowing use of calculators for homework or for classwork, should therefore be interpreted in the context of students in the 2001 study not being permitted to use calculators in the

[16] Note: Teachers responded with respect to their general practice, not necessarily with respect to teaching the students in the sample

Junior Certificate mathematics examination. By 2004, when students were permitted to use calculators in the Junior Certificate mathematics examination, teachers (of 86% of students) were in favour of calculator use for mathematics classwork and homework. There remain a small percentage of students (less than 10%) who are taught by teachers who continue to feel that calculators should not be allowed in Junior Certificate mathematics work.

Table 7.8 *Teacher Views on Calculator Usage by Junior Certificate Students in a Range of Home and School Contexts – Percentages of Students (2001 and 2004)*

Question	Response	2001		2004		04-01	SED
		Mean	SE	Mean	SE	Diff	
For mathematics homework?	Yes	74.1	6.66	86.3	14.07	12.2	15.57
	No	16.3	5.45	8.8	8.70	-7.5	10.27
	Missing	9.7	4.06	4.9	5.37	-4.8	6.73
In mathematics class?	Yes	69.9	6.46	86.8	11.24	16.9	12.96
	No	18.8	5.55	8.3	5.87	-10.5	8.08
	Missing	11.3	4.35	4.9	5.37	-6.4	6.91
For homework in other subjects?	Yes	84.5	5.15	81.6	7.97	-2.9	9.49
	No	3.5	2.03	11.2	5.35	7.7	5.72
	Missing	12.0	4.75	7.2	2.63	-4.8	5.43
For classwork in other subjects?	Yes	81.8	5.57	81.6	7.97	-0.2	9.72
	No	5.2	2.64	11.2	5.35	6.0	5.97
	Missing	13.0	4.95	7.2	2.63	-5.8	5.60
In the Junior Certificate Math Examination?	Yes	72.5	6.85	87.8	12.4	15.3	14.17
	No	15.9	5.42	7.3	7.03	-8.6	8.88
	Missing	11.7	4.38	4.9	5.37	-6.8	6.93

*Diff = Difference; SED = Standard Error of the Difference; Significant differences in **bold**.*

Calculator Use in Teaching Specific Content Areas

Teachers in 2004 were asked about the extent of calculator usage for teaching and learning purposes in the different content areas of the curriculum. Of the eight content areas listed, the two in which calculators were used most were Trigonometry and Applied Arithmetic & Measure (Table 7.9). The results also indicated that limited use of calculators is made in Sets, Geometry and Algebra, areas in which there is little occurrence of more complex calculations.

Table 7.9 *Extent of Calculator Usage in Teaching/Learning Specific Content Areas in Junior Certificate Mathematics Classes (2004)*

Content Area	Mean*	SE	A lot	Some Extent	Never	Missing
Sets	1.6	0.03	2.6	46.1	44.8	6.4
Number Systems	2.1	0.03	24.9	51.4	17.2	6.6
Applied Arithmetic & Measure	2.8	0.02	72.8	20.4	0.0	6.8
Algebra	1.8	0.03	11.1	52.8	29.5	6.6
Statistics	2.5	0.01	49.7	42.3	2.3	5.7
Geometry	1.7	0.01	7.4	53.1	34.6	4.9
Trigonometry	2.9	0.02	83.3	10.7	0.0	5.9
Functions and Graphs	2.2	0.09	27.6	54.1	10.9	7.4

** Mean computed based on the values: A lot = 3; Some Extent = 2; Never = 1*

Calculator Activities

Teachers of the students in the 2004 study were provided with a list of 13 activities that can be used to develop number concepts and/or to consolidate skills. They involve calculator use but may also require estimation and mental arithmetic. (See Appendix 3 for descriptions of the activities). The teachers were asked if they used any of the activities in mathematics class. Over half (52%) of students were taught by teachers who said that they 'sometimes' used 'Estimate then check' activities (a version of which had been included in the teacher in-career development programme accompanying the introduction of the revised syllabus), and 38% by teachers who said they sometimes used the 'Square and Square Root' activity. There was little use of any of the other activities by teachers (Appendix 7, Table A7.1). However, it should be noted that the students and their teachers in this study were only the third cohort to complete a three-year Junior Certificate cycle allowing calculator access, and that – as pointed out in Chapter 1 – calculator use was not a major focus of the in-career development programme. Later cycles may make more use of the listed activities if support in the form of in-career programmes and published materials filter through to the classrooms. Interestingly, some comments were made by the teachers on the potential use of the activities described in Appendix 3.

Teaching Calculator Operations and Related Skills

In classrooms where calculators are being used as tools for mathematical work, students need to be able to use the various functions of the calculator easily, use mental arithmetic rather than the calculator when appropriate, and check their calculator-derived answers by estimation. In 2004, teachers were asked if and when they taught these skills. Almost 90% of students were taught by teachers who said they taught estimation skills and about 67% by teachers who said they taught calculator operation skills (Table 7.10). About 39% were taught by teachers who said they taught mental arithmetic skills. The teachers also indicated that much of the teaching of these skills takes place in First year and to a considerably lesser degree in Second and Third years. The relative lack of emphasis on mental arithmetic skills may be due to expectations that students coming in from primary schools would be proficient in this area – or perhaps to the fact that mental arithmetic is not explicitly tested in the Junior Certificate examinations.

Table 7.10 *Percentage of Students Whose Teacher Formally Taught Various Skills, and When They Were Taught (2004)*

	Formally taught?*				If Yes, when does it take place?**		
	Yes	**No**	**Unsure**	**Missing**	**1st Year**	**2nd Year**	**3rd Year**
JC students formally taught calculator operation skills?	66.9	22.8	5.0	5.4	55.5	33.0	24.5
JC students formally taught mental arithmetic skills?	38.8	43.5	10.9	6.8	39.6	15.0	6.7
JC students formally taught estimation skills?	89.1	0.0	6.0	4.9	78.4	39.4	33.1

** n = 1459; ** n = 1428*

The teachers of the students in the 2004 study were also asked if they ensured their students could use particular features or functions of the calculator. Most students were taught by teachers who said that they ensured use of the more familiar features of calculators such as the percent, fraction, power, brackets, and +/- keys, as well as interpretation of the display and exponential and scientific notation, whereas only a minority were taught by teachers who reported that they ensure use of the constant function and memory keys (Table 7.11). Students whose teachers ensured that they could interpret the display on the calculator scored significantly higher on the Calculator Appropriate test than those whose teachers did not (Diff = 22.5, SED = 9.34), while students whose teachers taught fraction keys also did better than students who did not, albeit not to a significant degree.

Table 7.11 *Percentages of Students Whose Teachers Ensured That Various Calculator Features Could Be Used (2004)*

	Yes		No		Missing	
	n	%	n	%	n	%
Percentage key	1019	69.8	369	25.3	71	4.9
Brackets	1213	83.1	176	12.0	71	4.9
Fraction keys	1122	76.8	266	18.2	71	4.9
Interpreting the display	1021	69.9	309	21.2	131	8.9
“Power” keys	1327	90.9	32	2.2	101	6.9
Memory	406	27.8	940	64.4	114	7.8
Constant function	308	21.1	983	67.3	169	11.6
+ / - key	1352	92.6	29	2.0	79	5.4
Exponential (scientific) form	885	60.6	441	30.2	135	9.2

Over 80% of students were taught by teachers who said they placed ‘some’ or ‘much’ emphasis on the difference between calculators following arithmetic logic versus algebraic logic. Teachers were also asked if they encouraged students to record or write down intermediate results when using calculators. Almost 90% of students were taught by teachers who said they gave ‘some’ or ‘much’ emphasis to encouraging students to record intermediate results (for instances on paper). This finding may be related to the fact that students sitting the Junior Certificate examinations in mathematics are asked to show their intermediate workings on many of the questions on the examination papers.

Rules Regarding Calculator Use

Table 7.12 provides percentages of students in 2004 whose teachers indicated that they placed various kinds of restrictions and requirements on calculate use in mathematics class. Care should be exercised in interpreting the data, owing to high levels of missing data and overlap across categories.

Teachers of 38% of students said they allowed use of calculators at all times in First year; the corresponding figure for Third year was 79% (Table 7.12). The proportion of students who were not allowed to use calculators unless given permission fell from 29% in First year to 11% in Third year. The percentage of students whose teachers said they had calculator-free days decreased from 25% in First year to 9% in Third year. The general pattern in the results across the three years suggests that there are some limited restrictions on calculator use in many First year classrooms but that by Third year these have been lifted in the vast majority of classrooms.

Table 7.12 *Percentage of Students Whose Teachers Placed Various Restrictions on Calculator Usage (2004)*

Frequency of Calculator use	1st Year Yes	No	Missing	2nd Year Yes	No	Missing	3rd Year Yes	No	Missing
Can use at all times	37.7	38.5	23.8	64.2	17.6	18.2	78.8	7.0	14.1
Can use unless told otherwise	55.6	20.5	23.9	59.7	9.1	31.1	65.8	2.7	31.5
Not allowed to unless given permission	29.0	36.6	34.4	12.1	50.5	37.4	10.6	54.9	34.5
There are calculator free days	25.1	39.4	35.5	6.6	56.3	37.1	9.4	54.9	35.7

n = 1459; Although it was expected that the first three rows in each 'yes' columns would sum to 100%, in practice this did not happen.

Most students in 2004 were taught by teachers who indicated that they encouraged (or required in some cases) students to use some sort of method to check the answers they obtained with their calculators including: checking if the answer is reasonable (89%); estimating before calculating (88%); doing the calculation twice (83%); and doing the calculation by hand (79%) (Table 7.13). Some teachers referred to the difficulty of getting students to carry out such checks.

Table 7.13 *Extent to Which Teachers Required Students to Use Various Methods to Check Calculator Computations (Percentage of Students in 2004)*

	Require		Encourage		Don't Mention		Missing	
	n	%	n	%	n	%	n	%
Do the calculation twice	163	11.1	1045	71.5	196	13.4	57	3.9
Do it a different way	54	3.7	645	44.2	602	41.2	159	10.9
Use answer to check	156	10.7	694	47.5	390	26.7	220	15.1
Do it by hand	223	15.2	936	64.1	126	8.6	176	12.0
Estimate before calculating	429	29.4	843	57.7	131	9.0	57	3.9
Check if the answer is reasonable	510	35.0	786	53.8	92	6.3	72	4.9

Effects of Calculators on Teaching Methods

The teachers of students in the 2004 study were asked about the effects of calculator availability on their teaching methods. About 56% of students were taught by teachers who stated that the availability of calculators in class had affected their teaching methods, while for 40% it had no effect (Table 7.14).

Table 7.14 *Percentages of Students Whose Teachers Felt That the Availability of Calculators Had Affected Their Teaching Methods (2004)*

	n	%	SE
Yes	823	56.4	2.3
No	578	39.6	2.5
Missing	59	4.0	4.4

The same teachers were also asked what mathematical content areas were affected and in what ways. The areas they considered to be most affected included Statistics, Trigonometry, Sets, and Applied Arithmetic & Measure. The areas they considered to be least affected were Geometry and Algebra. Analysis of teachers' comments on how the calculator had affected the different areas of mathematics found that substantial numbers of teachers included the following:

- It enabled students to check answers
- It allowed for quicker and more accurate calculations
- It helped weaker students
- Log tables were no longer needed
- There is more time to address student methods of obtaining answers
- It helps with signs

More detail on these comments classified by content area can be found in Appendix Table A7.2.

Almost two-thirds of students were taught by teachers who said they made different use of calculators with lower-achieving students than with other students, though the types of use varied: for example, instances were reported of greater use by lower-achieving students (to allow focus on aspects other than computation) and of less use (to allow for practice of basic skills). The students of these teachers had a significantly higher mean score on the Calculator Appropriate test than students of teachers who said they did not make differentiated use of calculators (266.2 versus 256.7; Diff = 9.48, SED = 1.11, 95%CI = 4.69 to 14.27).

PERCEIVED ADVANTAGES AND DISADVANTAGES OF CALCULATOR ACCESS IN JUNIOR CERTIFICATE MATHEMATICS

This section presents an analysis of the perceptions of teachers of students in the 2004 study about the benefits and drawbacks of calculator availability in Junior Certificate mathematics classrooms.

Advantages of Calculator Access

The two main areas in which these teachers indicated that the calculator was beneficial to a major or minor degree were improved accuracy in students' work (teachers of 90% of students), and increased ability to move through topics (81%). Almost 50% of the students were taught by teachers who saw no benefit in calculator access for the explanation of concepts and procedures (Table 7.15; see also Appendix Table A7.3). The latter finding may result from teachers' lack of experience in using calculators to develop understanding of concepts and procedures.

Table 7. 15 *Percentages of Students Whose Teachers Identified Various Aspects of Classwork as Having Benefited from Calculator Availability (2004)*

Aspect of Classwork	n	Major Benefit	Minor benefit	No benefit	Missing
Explanation of concepts and procedures	1459	10.0	34.5	48.1	7.4
Improving accuracy in students' work	1459	55.5	34.8	7.5	2.2
Moving more quickly through topics	1459	43.7	37.4	11.0	7.8

When further asked to specify what they found to be the greatest benefit of calculator availability, teachers' responses fell into three categories of benefits:

1) Aspects of time saving and time management
2) Greater ease of teaching some topics (trigonometry, statistics, fractions and decimals, negative numbers, complicated multiplication and division)
3) Greater confidence and independence for students, particularly lower-achieving students.

Apart from those covered by the third category, the specific comments of the teachers are broadly equivalent to the aspects of classwork listed in Table 7.15 above.

Disadvantages of Calculator Access

The two main areas in which the teachers of students in 2004 indicated that the calculator was problematic to a major or minor degree were coping with missing calculators (teachers of 82% of students), and students in class having different makes of calculators (73%). Ninety percent of the students were taught by teachers who had little or no problem in teaching how to use the calculator within each mathematics topic (Table 7.16; see also Appendix Table A7.4).

Table 7.16 *Percentages of Students Whose Teachers Identified Various Aspects of Calculator Availability as Problematic (2004)*

	n	Major Problem	Minor Problem	No Problem	Missing
Teaching how to use the calculator within each topic	1459	0.0	35.6	55.0	9.3
Coping with missing calculators (lost, stolen, forgotten)	1459	30.1	52.4	15.3	2.2
Change in calculator types or models from year to year	1459	11.7	53.6	28.3	6.4
Students in your class having different makes of calculator	1459	21.0	51.9	23.5	3.6

When asked to specify what they found to be the greatest drawback of calculator availability, teachers' responses fell into four categories:

1) Practical and management issues (loss, breakage, missing, make/model, mode)
2) Inappropriate use of or over-reliance on the calculator
3) Difficulty in using calculators effectively (using features/functions, lack of awareness of sources of error)
4) Decline in various aspect of numeracy (mental arithmetic, estimation, concepts, tables, computational skills).

Use of Graphics Calculators and Computer Algebra Systems

Graphics calculators and computer algebra systems (CAS) were rarely used at Junior Certificate level in Ireland. Indeed, only 5% of students were taught by teachers who said that the school had a set of graphics calculators, while 11% were taught by teachers who said that, while the school did not have a full set of graphics calculators, it did have one or more. Eight percent of students were taught by teachers who said their schools had at least one CAS calculator.

TEACHERS' GENERAL COMMENTS

Teachers were invited to add further comments at the end of the questionnaire. Perhaps because of the extensive nature of the instrument and the fact that teachers in the Irish Mathematics Teachers Association had been asked to suggest areas that might be addressed, additional comments were sparse. Moreover, some echoed comments made elsewhere in the questionnaire. The main themes addressed were as follows:

1. General attitudes to calculator use, ranging from the zeal of the convert via grudging acceptance to general disapproval
2. Recognition of specific advantages (less drudgery, support for lower-achieving students, benefits for particular topics, and so forth) and disadvantages (such as loss of mental arithmetic and computational skills) of calculator use
3. Attribution of blame for problems to primary schools
4. Recognition that calculators are a feature of everyday life
5. Policy issues (non-use of calculators in First year, calculator free days).

SUMMARY

The Phase II Teachers' Questionnaire was used to obtain information on: (i) school policy on calculators; (ii) the teaching of calculator skills; and (iii) changes in teaching and learning mathematics resulting from the introduction of the calculator into the Junior Certificate mathematics syllabus.

The 2004 findings on school policy on calculators indicate that most students obtain their own calculators (based on school-designated specifications) with only about 15% purchasing them from the school. With regard to policy, the 'comprehensive policies' anticipated in the Department's requirements for this research study were notable for their absence. Less than a quarter of the students were taught by teachers who said that their schools had a policy. In many cases, such policy was agreed by the mathematics teachers (rather than being a 'comprehensive' policy agreed or decreed at school level), and included, in a majority of schools, the requirement that calculator skills be taught in First year.

Many of the teachers of the students in the 2004 sample indicated that they taught calculator skills and mental arithmetic and estimation, mainly in First year and to a lesser degree in the Second and Third years. An interesting finding in 2004 was that students whose teachers taught them how to interpret the display on the calculator scored significantly higher on average on the Calculator Appropriate test than students whose teachers did not teach them how to do so. Similarly, there is an association between teaching use of fraction keys and performance, though it is not statistically significant. These findings suggest that students in general may need to be taught how interpret the display and make use of the fractions keys for fraction calculations. Most teachers encouraged students to use some method of checking the calculator's answers, the most common being the practices of estimating before calculating, and doing the calculation twice on the calculator. The teachers also indicated that restrictions on calculator use decreased considerably from First year to Third year.

Most of the teachers of the students in the study saw improved speed and accuracy, and increased ability to progress through topics such as Trigonometry and Statistics, as the main benefits of calculator availability, while about half of them saw no benefit in their use for developing understanding of concepts and procedures. Responses suggested that teachers were understandably preoccupied with the practical and managerial aspects of calculator use (students forgetting to bring calculators to class, time gained or lost with regard to calculator use) and that their use in teaching and learning was largely limited to computational aspects. This is consistent with the fact that other approaches were not emphasised in the professional development programme accompanying the introduction of the revised curriculum.

Teachers in 2004 were generally positive about calculators, more so than teachers in 2001. However, there are concerns about inappropriate use of calculators and about loss of basic numeracy knowledge and skills. Teachers reported difficulties in persuading students to use mental or other appropriate methods and to check their calculator-assisted work. Some teachers indicated that they encouraged greater use of calculators by lower-achieving students to allow them to focus on aspects other than computation, while others encouraged less use in order to allow for practice of basic skills, suggesting differing emphasis by teachers on understanding versus computational proficiency.

There was little evidence of availability or use of graphics calculators among teachers of the students in the study. This finding should be of concern as it has been established that graphics calculators can be effective tools in supporting the teaching of Algebra and Functions, areas for which scientific calculators have only very limited use.

Chapter 8: Calculators and the Junior Certificate Mathematics Examination

The relationship between the performance of students on the calculator tests and their performance on the Junior Certificate mathematics examination is considered in this chapter. Mean achievement scores on the calculator tests are considered by the Junior Certificate level that students intended to sit when the calculator tests were administered in November 2004, and the actual level taken in June 2005. Results are considered by both the intended examination level and actual level taken, to reflect potential differences between the course level at which students were being taught, and the level at which they actually sat the examination. (As was noted in the Phase I report (Close et al., 2004), there is normally a considerable discrepancy between students' intentions with regard to level to be taken several months before the examination, and the actual level they sit.) This is followed by an analysis of the correlations between calculator test performance and Junior Certificate grades in mathematics. The results of these analyses are compared with those of the 2001 study. Finally, the distributions of Junior Certificate grades in mathematics between 2001 and 2005 are considered.

PERFORMANCE ON THE CALCULATOR TESTS BY INTENDED AND ACTUAL JUNIOR CERTIFICATE EXAMINATION LEVEL TAKEN

Performance by Intended Junior Certificate Mathematics Examination Level

Students who completed the calculator tests in November 2004 were asked to specify the level at which they intended to sit the 2005 Junior Certificate mathematics examination. Almost two-thirds (63.4%) of students indicated that they intended to sit the examination at Higher level, just under one-third (32.5%) at Ordinary level, and 4.2% indicated that they intended to sit the Foundation level mathematics examination. In Table 8.1, scores achieved by students on each calculator test (i.e. Calculator Inappropriate, Optional, and Appropriate) are considered by the Junior Certificate level students intended to sit.

Table 8.1 *Mean Scale Scores on the Calculator Inappropriate, Calculator Optional, and Calculator Appropriate Tests, by Intended Junior Certificate Mathematics Examination Level (2004-05)*

Intended Level	n	%	Calculator					
			Inappropriate		Optional		Appropriate	
			Mean	SE	Mean	SE	Mean	SE
Higher	903	63.4	265.4	6.30	271.7	5.22	285.6	3.14
Ordinary	462	32.5	209.4	2.07	215.8	1.67	229.1	1.72
Foundation	59	4.2	175.7	0.28	188.1	3.90	198.8	7.71

Students intending to take Higher level achieved significantly higher scores on each Calculator test than students intending to take Ordinary and Foundation levels (Table 8.2).

Table 8.2 *Differences in Mean Scale Scores on the Calculator Inappropriate, Calculator Optional, and Calculator Appropriate Tests, by Intended Junior Certificate Mathematics Examination Level (2004-05)*

Calculator Test	Higher – Ordinary Comparison Diff	SED	95%CI		Higher – Foundation Comparison Diff	SED	95%CI	
Inappropriate	56.0	8.37	**20.00**	**92.04**	89.7	6.04	**63.74**	**115.69**
Optional	56.0	3.54	**40.73**	**71.21**	83.7	8.75	**46.01**	**121.33**
Appropriate	56.5	4.85	**35.62**	**77.38**	86.9	8.96	**48.31**	**125.40**

Diff = Difference; SED = Standard Error of the Difference; 95%CI = confidence intervals; significant differences in ***bold****.*

Since these levels are, in effect, groupings by mathematical ability, they confirm an association between grouping and performance on the calculator tests.

Performance by Actual Junior Certificate Mathematics Examination Level

Information relating to the actual Junior Certificate examination levels they sat and their Junior Certificate examination results in mathematics were obtained for the students who participated in the calculator study. Students' 2005 Junior Certificate results were matched to their calculator test results. Only 1.8% of students in the sample could not be matched to their Junior Certificate results. Of those matched, over half (54.3%) sat the Higher level, 40.7% sat the Ordinary level, and 5% sat the Foundation level paper.

Mean student scores on the three calculator test booklets by the Junior Certificate level they sat are presented in Table 8.3.

Table 8.3 *Mean Scale Scores on the Calculator Inappropriate, Calculator Optional, and Calculator Appropriate Tests, by Actual Junior Certificate Mathematics Examination Level (2004-5)*

JC Level	n	%	Calculator Inappropriate Mean	SE	Optional Mean	SE	Appropriate Mean	SE
Higher	783	54.3	270.6	5.58	276.1	4.28	291.0	1.90
Ordinary	587	40.7	216.0	2.42	223.2	0.80	235.5	2.04
Foundation	73	5.0	171.5	1.82	183.8	3.34	194.6	7.32

The mean scores achieved by students sitting the Higher level papers are compared with those sitting the Ordinary level and the Foundation level papers in Table 8.4.

Table 8.4 *Differences in Mean Scale Scores on the Calculator Inappropriate, Calculator Optional, and Calculator Appropriate Tests, by Actual Junior Certificate Mathematics Examination Level (2004-05)*

Calculator	Higher – Ordinary Comparison				Higher – Foundation Comparison			
	Diff	SED	95%CI		Diff	SED	95%CI	
Inappropriate	54.5	8.00	**20.14**	**88.93**	99.1	4.81	**78.37**	**119.78**
Optional	52.9	3.47	**37.96**	**67.83**	92.3	5.15	**70.08**	**114.41**
Appropriate	55.5	3.94	**38.51**	**72.42**	96.4	7.80	**62.79**	**129.94**

*Diff = Difference; SED = Standard Error of the Difference; 95%CI = confidence intervals; significant differences in **bold**.*

These data indicate that Higher level students achieved significantly higher scores on each test (i.e. Calculator Inappropriate, Optional, and Appropriate). As with the intended Junior Certificate level, for the Higher-Ordinary level comparison, differences were broadly similar within each set of comparisons. Again, the results suggest that the three Junior Certificate examination levels are effective as mathematics performance groupings as measured by the Calculator Study tests.

OVERALL 2005 JUNIOR CERTIFICATE PERFORMANCE IN MATHEMATICS BY CALCULATOR TEST

In this section, the scores of students on the calculator tests are compared with their performance on the Junior Certificate mathematics examination. For each test, the mean scale score, overall performance score, and percentage correct for that particular test is presented. The overall mathematics performance score (OMPS) is used to place the performance of all students for whom Junior Certificate mathematics examination results were available on the same underlying scale. This was achieved by assigning scores to students' grades (Table 8.5), as in the 2001 study.

Table 8.5 *Overall Mathematics Performance Score (OMPS) Conversion Table*

Examination Level	Grade					
	A	B	C	D	E	F
Higher	12	11	10	9	8	7
Ordinary	9	8	7	6	5	4
Foundation	6	5	4	3	2	1

Note: No score was assigned to students who achieved no grade.

Calculator Inappropriate Test

The mean OMPS, mean percentage correct scores, and scales scores on the Calculator Inappropriate test are presented in Table 8.6. Mean scores on each test are higher for students who sat the Higher level examination.

Table 8.6 *Mean Scale Scores, Percent Correct Scores, and OMPS on the Calculator Inappropriate Test by Actual Junior Certificate Mathematics Examination Level (2004-05)*

Level	n	%	Scale	SE	% Correct	SE	OMPS	SE
Higher	783	54.3	270.6	5.58	69.9	2.08	10.3	0.04
Ordinary	587	40.7	216.0	2.42	43.5	1.11	7.3	0.08
Foundation	73	5.0	171.5	1.82	25.1	1.52	4.7	0.10

The proportions of Higher, Ordinary, and Foundation level students at each of four score categories on the Calculator Inappropriate test, and the mean OMPS for each, is presented in Table 8.7. Almost three quarters of students who sat the Higher level examination scored 250 or more on the Calculator Inappropriate test, compared to one fifth of those who sat the Ordinary level, and 3% who sat the Foundation level. As expected, the overall mean OMPS was highest for students who scored in the top category (10.9), and lowest for those who scored in the bottom category (6.6).

Table 8.7 *Mean OMPS and Percentage of Students in Each Score Category on the Calculator Inappropriate Test, by Actual Junior Certificate Mathematics Examination Level (2004-05)*

Score	Higher			Ordinary			Foundation			Mean	
Category[17]	n	%	SE	n	%	SE	n	%	SE	OMPS	SE
< 199	21	2.7	0.15	200	34.5	0.42	57	78.1	1.75	6.6	0.11
200 – 249	199	25.5	1.45	260	44.8	0.86	14	19.2	0.55	8.3	0.13
250 – 299	388	49.8	0.95	114	19.7	0.28	2	2.7	0.18	9.7	0.05
≥ 300	171	22.0	3.30	6	1.0	0.09	0	0.0	0.00	10.9	0.03

Calculator Optional Test

Scores for students who had/did not have access to a calculator on the Calculator Optional test are presented in Table 8.8. Mean scale scores and percentage correct scores were significantly higher at each examination level when students had access to a calculator than when they did not. OMPS differences, however, were not statistically significant (see Appendix Table 8.1). Differences between the performance of students sitting the Higher and the Ordinary levels, and those sitting the Ordinary and Foundation levels were greater for students who had access to a calculator, than for those who did not. Further, when Ordinary level students had access to a calculator, their mean percent correct score (49.0%) approached that of Higher level students who did not have access to a calculator (51.7%).

[17] Categories in the Phase I report indicated proportions of students scoring one standard deviation above and below the mean. These categories have been kept the same for comparative purposes.

Table 8.8 *Mean Scale Scores, Percent Correct Scores, and OMPS on the Calculator Optional Test, by Calculator Availability (2004-05)*

Calculator	Level	n	%	Scale		% Correct		OMPS	
				Mean	SE	Mean	SE	Mean	SE
Yes	Higher	396	27.5	300.6	3.20	73.6	1.05	10.3	0.06
Yes	Ordinary	295	20.5	243.4	0.69	49.0	0.37	7.2	0.15
Yes	Foundation	38	2.6	199.7	8.24	30.8	3.94	4.7	0.11
No	Higher	387	26.8	250.9	4.56	51.7	1.89	10.3	0.02
No	Ordinary	292	20.2	202.8	3.81	30.8	1.75	7.3	0.01
No	Foundation	35	2.4	166.5	6.06	17.6	1.92	4.6	0.10

Calculator Appropriate Test

Mean scale scores and percent correct scores on the Calculator Appropriate test for Higher, Ordinary, and Foundation level students, as well as their OMPS scores, are presented in Table 8.9. As before, Higher Level students achieved the highest mean score for each.

Table 8.9 *Mean Scale Scores, Percent Correct Scores, and OMPS on the Calculator Appropriate Test, by Actual Junior Certificate Mathematics Level Taken (2004-05)*

Level	n	%	Score	SE	% Correct	SE	OMPS	SE
Higher	783	54.3	291.0	1.9	48.5	0.77	10.3	.04
Ordinary	587	40.7	235.5	2.0	27.3	0.79	7.3	.08
Foundation	73	5.0	194.6	7.3	14.2	2.37	4.7	.10

As expected, there were greater proportions of Higher level students than Ordinary or Foundation level students, in the upper score categories on the Calculator Appropriate Test (Table 8.10), with 41% of students taking Higher level achieving a score that was greater than 300, and a further 44% achieving scores between 250 and 299. The scores of just over three in 10 students taking Ordinary level also fell into the 250 to 299 interval.

Table 8.10 *Mean OMPS and Percentage of Students in Each Score Category on the Calculator Appropriate Test, by Actual Junior Certificate Mathematics Examination Level (2004-05)*

Score	Higher			Ordinary			Foundation			Mean	
Category	n	%	SE	n	%	SE	n	%	SE	OMPS	SE
< 200	15	2.0	0.32	109	19.0	0.76	49	68.0	1.23	6.3	0.09
200 – 249	102	13.3	0.13	255	44.3	0.31	18	24.6	0.92	7.7	0.08
250 – 299	335	43.6	0.54	182	31.7	1.36	5	7.4	0.38	9.1	0.07
$\geq$ 300	317	41.2	2.30	29	5.0	0.20	0	0.0	0.00	10.6	0.02

CORRELATIONS BETWEEN CALCULATOR TEST PERFORMANCE AND 2005 JUNIOR CERTIFICATE GRADES IN MATHEMATICS

Correlations between performance on the calculator tests and the 2005 Junior Certificate mathematics examination results (OMPS) are presented in Table 8.11. Total correlations for each test are strong, positive, and statistically significant. Correlation values for Junior Certificate levels within each test were lower than total correlational values, possibly because of scale attenuation (i.e., a lower range of outcome scores within each Junior Certificate level).

Table 8.11 *Correlations between Calculator Test Scores and Junior Certificate Overall Mathematics Performance Scores (2004-05)*

Test	Level	r	t	p
Calculator Inappropriate	Higher	0.43	33.04	**0.00**
	Ordinary	0.36	6.66	**0.02**
	Foundation	0.10	6.19	**0.03**
	Total	0.70	25.48	**0.00**
Calculator Optional	Higher	0.43	37.37	**0.00**
	Ordinary	0.38	20.69	**0.00**
	Foundation	0.32	9.66	**0.01**
	Total	0.66	20.31	**0.00**
Calculator Appropriate	Higher	0.45	91.73	**0.00**
	Ordinary	0.39	7.42	**0.02**
	Foundation	0.00	0.04	0.98
	Total	0.69	34.43	**0.00**

p values in bold indicate statistical significance of correlation coefficients. r = Pearson correlation coefficient; t = t statistic; p = probability

For each calculator test, correlations were strongest between calculator test performance and OMPS for Higher level students. Again this may reflect the degree of variation in performance within each level, with Higher level students performing more consistently. Furthermore, the difference in the correlations may reflect the discriminative difference of the three Junior Certificate examination levels

On the Calculator Optional test, the correlation between OMPS scores and calculator scale scores was stronger when students had access to a calculator ($r = 0.8$, $t = 22.3$, $p < 0.05$) than when they did not ($r = 0.7$, $t = 11.2$, $p < 0.05$). The stronger correlation may arise because of the availability of a calculator for both the Calculator Optional test and the Junior Certificate examination.

These correlations support the use of the calculator tests as valid instruments for assessing aspects of the taught Junior Certificate course.

COMPARISON WITH THE 2001 STUDY

The 2004 student scale scores at each Junior Certificate level (based on levels students intended to sit, and levels they actually sat) were compared with those from the 2001 study.

Comparisons Based on Students' Intended Junior Certificate Level

The mean scores for each calculator test by Junior Certificate examination level and year are presented in Table 8.12. For comparative reasons, in this section the Ordinary and Foundation categories were collapsed, as per the 2001 study, since the numbers of students indicating that they intended to sit the Junior Certificate mathematics examination at the Foundation Level were very low in both years.

Table 8.12 *Mean Scale Scores on the Calculator Inappropriate, Calculator Optional, and Calculator Appropriate Tests, by Intended Junior Certificate Mathematics Examination Level (2001 and 2004)*

Test	2001				2004			
	Higher		Ord/Foundation		Higher		Ord/Foundation	
	Score	SE	Score	SE	Score	SE	Score	SE
Inappropriate	276.9	3.06	217.1	2.82	265.4	6.30	205.6	1.91
Optional	276.2	3.49	217.8	2.74	271.7	5.22	212.6	1.57
Appropriate	275.8	3.78	218.4	3.03	285.6	3.15	225.6	1.40

Based on the Junior Certificate level that students expected to sit, Ordinary/ Foundation level students in 2001 achieved significantly higher scale scores on the Calculator Inappropriate test than students who intended to sit the examination at the same levels in 2004 (Diff = 11.5, SED = 3.40, 95%CI = 4.73 to 18.33).

On the Calculator Appropriate test, however, students in 2001 who intended to sit mathematics examinations at either the Higher or the Ordinary/Foundation levels achieved significantly lower scale scores than those intending to sit at the Higher (Diff = 9.8, SED = 4.91, 95%CI = -19.63 to -0.01) or Ordinary/Foundation (Diff = 9.2, SED = 3.34, 95%CI = -13.91 to -0.57) levels in 2004. In the case of Higher level, the difference just reached statistical significance.

Table 8.13 shows the mean scale scores for the Calculator Optional test in 2001 and 2004, by the examination level students intended to sit.

The mean scale scores of students in 2004 who had access to a calculator were not significantly different from those of students in 2001. For students without access to a calculator, however, mean scale scores were significantly lower in 2004 than in 2001 for both Higher and Ordinary/Foundation level students.

Table 8.13 *Mean Scale Scores on the Calculator Optional Test, by Calculator Access and Intended Junior Certificate Mathematics Level (2001 and 2004)*

Calculator	Level	2001		2004		04-01 Diff	SED	95%	
		Score	SE	Score	SE				
Yes	Higher	287.5	4.02	295.7	4.62	8.16	6.12	-20.39	4.07
	Ord/Found	233.1	3.18	230.8	1.29	-2.31	3.43	-4.55	9.17
No	Higher	265.1	3.48	247.0	6.10	-18.11	7.02	**4.09**	**32.13**
	Ord/Found	204.5	3.18	194.2	2.32	-10.30	3.94	**2.43**	**18.17**

Diff = Difference; SED = Standard Error of the Difference; 95%CI = confidence intervals; significant differences in ***bold***.

Comparisons Based on Junior Certificate Examination Level Students Had Actually Taken

Comparisons of student performance in 2001 and 2004 on the calculator test are considered below. In interpreting these data, it should be noted that no information was available for the Junior Certificate examination level taken by 13% of students in the 2001 sample who took the Junior Certificate mathematics exam in 2002. The corresponding figure for the 2004 sample that took the Junior Certificate mathematics exam in 2005 was 1%.

Calculator Inappropriate Test

A comparison of the mean scores achieved on the Calculator Inappropriate test in 2001 and 2004 indicate only one significant difference (Table 8.14). Students who sat the Ordinary level mathematics examination achieved a significantly higher scale score in 2001 than those in 2004.

Table 8.14 *Mean Scale Scores on the Calculator Inappropriate Test, by Actual Junior Certificate Mathematics Examination Level (2001-02 and 2004-05)*

Level	2001		2004		04-01	SED	95%CI	
	Score	SE	Score	SE	Diff			
Higher	282.2	3.38	270.6	5.58	-11.65	6.52	-1.37	24.67
Ordinary	229.0	2.57	216.0	2.42	-12.98	3.53	**5.93**	**20.03**
Foundation	181.5	6.61	171.5	1.82	-10.02	6.86	-3.67	23.71

Diff = Difference; SED = Standard Error of the Difference; 95%CI = confidence intervals; significant differences in ***bold***.

Calculator Optional Test

Performance on the Calculator Optional test (Table 8.16) is considered by calculator availability, and by Junior Certificate examination level taken. For students who had access to a calculator, there was no significant difference in performance, at any level, between 2001 and 2004. Higher, Ordinary, and Foundation Level students who did not have access to a calculator, however, achieved significantly higher scores in 2001 than in 2004.

Table 8.15 *Mean Scale Scores on the Calculator Optional Test, by Actual Junior Certificate Mathematics Examination Level (2001 and 2004)*

Calculator	Level	2001		2004		04-01	SED	95%CI	
		Score	SE	Score	SE	Diff			
Yes	Higher	292.8	4.51	300.6	3.20	7.84	5.53	-18.89	3.21
Yes	Ordinary	245.0	2.95	243.4	0.69	-1.63	3.03	-4.42	7.68
Yes	Foundation	204.9	6.13	199.7	8.24	-5.22	10.27	-15.29	25.73
No	Higher	270.2	3.57	250.9	4.56	-19.26	5.79	**7.69**	**30.83**
No	Ordinary	212.7	2.98	202.8	3.81	-9.94	4.84	**0.29**	**19.60**
No	Foundation	187.6	6.29	166.5	6.06	-21.06	8.74	**3.62**	**38.51**

*Diff = Difference; SED = Standard Error of the Difference; 95%CI = confidence intervals; significant differences in **bold**.*

Calculator Appropriate Test

Mean achievement scores on the Calculator Appropriate test were not significantly different for Ordinary and Foundation level students between 2001 and 2004 (Table 8.16). For Higher level students, however, the mean scale score on the Calculator Appropriate test was significantly higher in 2004 than in 2001.

Table 8.16 *Mean Scale Scores on the Calculator Appropriate Test, by Actual Junior Certificate Mathematics Examination (2001and 2004)*

Level	2001		2004		04-01	SED	95%CI	
	Score	SE	Score	SE	Diff			
Higher	280.6	4.47	291.0	1.90	10.39	4.86	**-20.09**	**-0.69**
Ordinary	230.4	2.61	235.5	2.04	5.12	3.31	-11.74	1.50
Foundation	187.0	5.28	194.6	7.32	7.62	9.03	-25.64	10.40

*Diff = Difference; SED = Standard Error of the Difference; 95%CI = confidence intervals; significant differences in **bold**.*

PERFORMANCE ON JUNIOR CERTIFICATE MATHEMATICS (2001 TO 2005)

It was of interest to examine patterns of performance on the Junior Certificate mathematics examination, following the implementation of the revised syllabus in schools. A summary of performance on the Junior Certificate mathematics examination from 2000 to 2005 is presented in Figures 8.1 to 8.3 (see Appendix Tables 8.2 to 8.4 for associated data).

In 2003, when the revised Junior Certificate mathematics syllabus was assessed for the first time, a slightly higher percentage of students achieved an 'A to C' grade (79.4%) at Higher level, compared with the previous year (74.1% in 2002) (Figure 8.1). By 2005, however, the percentage of students achieving Grades A to C at this level had reverted to a percentage (75.6%) similar to that of 2002 (74.1%), as had the percentage of students achieving a 'D' grade (19.8% in 2002, and 20% in 2005).

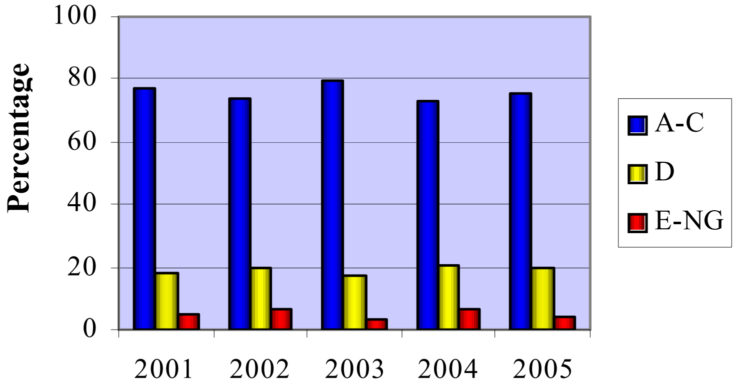

Figure 8.1 *Performance on the Higher Level Junior Certificate Mathematics Examination (2001 to 2005)*

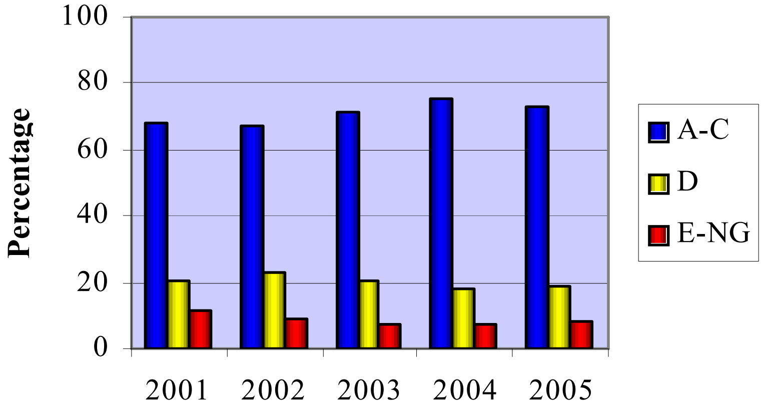

Figure 8.2 *Performance on the Ordinary Level Junior Certificate Mathematics Examination (2001 to 2005)*

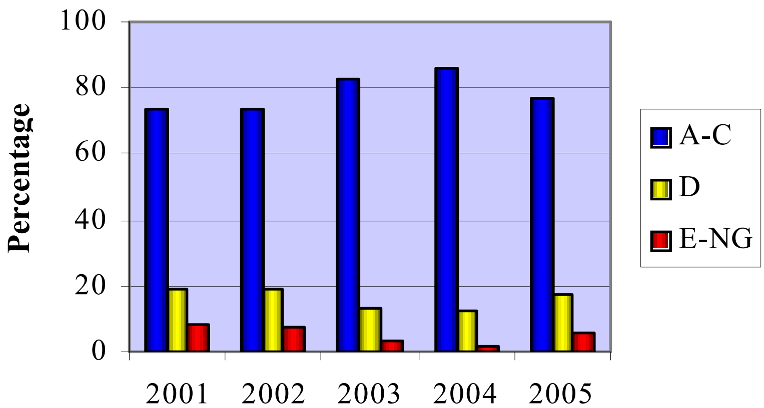

Figure 8.3 *Performance on the Foundation Level Junior Certificate Mathematics Examination (2001 to 2005)*

The proportion of students at the upper grades (i.e., A to C) on the Ordinary level mathematics paper (Figure 8.2) likewise increased between 2002 (67.5%) and 2003 (71.5%), but continued to remain high (73% in 2005). Fewer students also achieved a 'D' or an 'E to No Grade' in 2005 (18.8% and 8.2% respectively) than in 2002 (23.2% and 9.3% respectively).

The greatest apparent change following implementation of the revised Junior Certificate mathematics syllabus was noted at the Foundation level (Figure 8.3). The percentage of students attaining an 'A to C' grade increased between 2002 and 2003 (74% and 83% respectively). Although the percentage achieving these grades dropped in 2005 (from 86% to 77%), this proportion is higher than the proportion achieving in this grade range in 2001 and 2002 (approximately 73% in each year).

To examine overall performance further on the Junior Certificate mathematics examination between 2001 and 2005, grades were converted to OMPS scores (c.f. Table 8.5 for conversion table). The distributions of scores for each year are summarised in Figure 8.4.

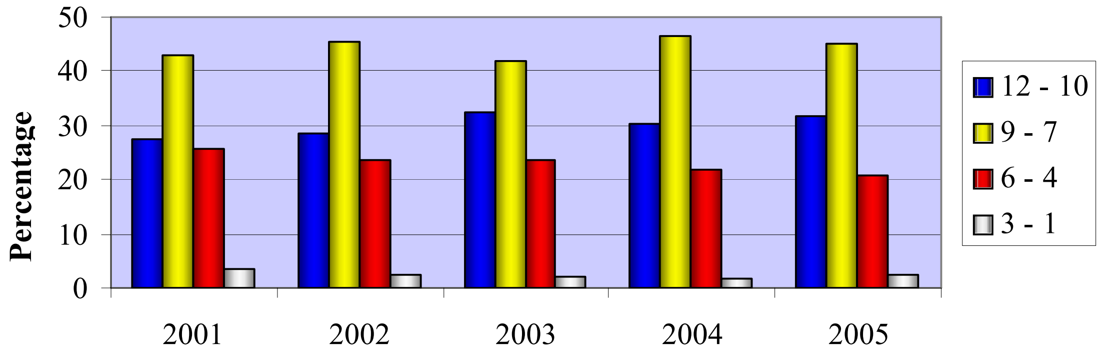

Figure 8.4 *OMPS Scores on the Junior Certificate Mathematics Examination (2001 to 2005)*

The data in Figure 8.4 show an increase in the percentage of students achieving at the upper end of the OMPS scale between 2001 (27.6%) and 2005 (31.7%). The general increase in performance is noted in the smaller proportion of students in the lower two categories. In 2001 25.8% and 3.6% of students achieved 4-6 points and 1-3 points respectively, while in 2005, those figures were down to 20.9% and 2.4%.

SUMMARY

In this section, mean achievement scale scores on the calculator test booklets were considered both by students' intended Junior Certificate mathematics level, and by the examination level they actually took. Scores achieved by Higher level students in 2004 on each calculator test did not vary significantly when considered either by their intended or by their actual examination levels. Mean scale scores of Ordinary level students on each test were higher when based on the examination level they actually sat, rather than the level they intended to sit, and, for Foundation level students, mean scores were significantly lower on one test only (Calculator Inappropriate) when considered by the examination level they actually sat. These differences may reflect a shift of students between courses from November (when the Calculator tests were administered) to June (when they sat the Junior Certificate mathematics examination).

In comparing Higher and Ordinary level students on the calculator tests, based on the actual Junior Certificate level taken in June 2005, differences in favour of Higher level students were large (about 50 points, or one standard deviation) on all three calculator tests. The mean scores of students who sat the Junior Certificate mathematics exam at Ordinary level were also significantly higher than the mean scores of those taking the examination at Foundation level, on all three calculator tests.

The scale scores of students on the Calculator Optional test in 2004 were considered with reference to calculator availability. Differences were greatest for Higher level students with and without calculator access, and least for Foundation level students. This may be interpreted as indicating that Higher level students benefit more from access to calculators than Foundation level students.

The mean score on the Calculator Inappropriate test in 2004 was significantly lower for students who sat the Junior Certificate mathematics examination at Ordinary level compared with the corresponding mean score in 2001. On the Calculator Appropriate test, the mean score was significantly higher in 2004 for students who sat the JC mathematics examination at higher level. On the Calculator Optional test, again, there was no significant difference in performance at any examination level when students had access to a calculator, though students at all levels who did not have access achieved significantly lower mean scores in 2004 than in 2001. As noted earlier, these data should be interpreted with reference to the incomplete information on actual Junior Certificate levels in the 2001 study.

A consideration of the proportion of students achieving ‘A to C’ grades, ‘D’ grades, or ‘E to No Grade’ between 2001 and 2005 suggest that Foundation level students have changed most since the introduction of the revised syllabus (and, by implication, the calculator). Scores on the OMPS scale over the five years for this group indicate a general increase in performance, with more students achieving at the upper end of the scale (9-to-12 points), and fewer at the lower end (1-to-3 points). While an initial increase in the proportions achieving ‘A to C’ grades was observed at Higher and Ordinary levels in 2003 and 2004, following implementation of the revised syllabus, by 2005, the proportions of ‘A to C’ grades awarded at these levels had started to fall.

Chapter 9: Conclusions and Recommendations

The main goal of Phase I of the study, implemented in 2001, was to assess Junior Certificate students' performance on key areas of numeracy in the mathematics syllabus that was in place at the time and in which calculators played no part in either curriculum or assessment. These areas included Number Systems, Applied Arithmetic & Measure, Statistics and some Algebra. Phase II of the study was carried out in 2004 to obtain data in the same key areas for comparison with data from Phase I. This was done to determine if any changes in performance had occurred since the introduction of calculators into the Junior Certificate mathematics syllabus and examinations. The results of Phase II, including comparisons with Phase I, are described in Chapters 5-8 of this report.

PERFORMANCE IN 2001 AND 2004 COMPARED

This section provides an overview of performance on the three calculator tests, a summary of performance on key mathematics content areas, and a review of students' rough work.

Overall Performance on the Three Tests

As was the case in 2001, performance in 2004 on the Calculator Inappropriate test was stronger than performance on the Calculator Optional test, and performances on both these tests was stronger than performance on the Calculator Appropriate test, supporting the validity of the study design and the stability of the tests.

Overall performance on the Calculator Inappropriate test, a test containing items that could be done mentally or with minimal pen-and-paper work and would not normally be facilitated by access to a calculator, declined slightly between 2001 and 2004, but not significantly so. However, if this downward trend continues, it may become significant; therefore, it is desirable to administer the Calculator tests again in the next few years. There was a similar non-significant decline on the version of the Calculator Optional test for which a calculator was not available. The test contains items that might or might not be done more successfully with a calculator, depending on a number of student and curriculum factors. Hence, based on the performance of the 2004 cohort on the two non-calculator tests, it can be concluded that, for now at least, there has not been a decline in basic computation skills.

On the other hand, overall performance on the Calculator Appropriate test, a test containing items for which availability of a calculator would very probably provide a distinct advantage, improved significantly between 2001 and 2004.[18] This is in keeping with the findings of the international literature described in Chapter 2. The significant improvement in performance on the Calculator Appropriate test suggests that students' ability to make use of the calculator in solving problems improved over the three years of the study as a result of experiencing the revised Junior Certificate mathematics syllabus. However, the generally low performance on this test in both 2001 and 2004 is of particular concern, given the problem solving orientation of the test. The items on this test were designed to be somewhat similar to those on the OECD PISA test (Cosgrove et al., 2005), a test on which Irish 15 year-olds scored about average compared to other OECD countries. These findings highlight, among other things, the need to give more attention to how calculators can be used with these types of problems and non-routine applications in the Junior Certificate mathematics curriculum and examination.

In order to look at the influence of ability on the improvement in performance between 2001 and 2004 on the Calculator Appropriate test, the scale scores for 2001 and 2004 at five key percentile ranks were analysed. They showed differences in favour of the 2004 students at all points, with the difference for three (10^{th}, 50^{th}, and 75^{th} percentiles) of the five percentile points being statistically significant. There were no significant differences between 2001 and 2004 at any of the percentile points for the Calculator Inappropriate or Calculator Optional tests. These results suggest that performance on a test for which the use of a calculator is most appropriate was most affected by the impact of calculator access over the three year period of the study and that this effect was not confined to any particular mathematical ability group.

Effects of Access to Calculators

On the Calculator Optional test, one-half of the 2001 and 2004 samples were randomly assigned access to calculators and the other half had no access. The difference in overall achievement between students with and without access to a calculator on the Calculator Optional test was 30.4 scale points in 2001, and 44.4 in 2004. Both these differences are statistically significant, reflecting the advantage conveyed to students with access to calculators compared to those with no access. Although it might be expected that students in 2004 in the calculator access condition would benefit from experience with calculators in the revised Junior Certificate syllabus, and therefore significantly increase the difference over the equivalent 2001 sample, this was not the case. The differences between 2001 and 2004 on each of the two test conditions were not significant overall (though, in the calculator condition, the difference approached significance). However, there were significant differences at the 50^{th} percentile in favour of students in 2001 on the non-calculator access condition, and in favour of students in 2004 on the calculator access condition. This finding suggests that, at the level of performance represented by the 50^{th} percentile rank, students in 2004 benefited more than students in 2001 from calculator access,

[18] Performance on the Calculator Optional test, with calculator access, also improved, but not significantly so.

but were less able than the 2001 students to complete the items on the Calculator Optional test without access to calculators.

When the mean scores of students at five key percentile ranks were compared across the calculator access/no access conditions *within* 2001 and 2004, significant differences in favour of the calculator access group were observed at all ranks, apart from the 90th percentile in both 2001 and 2004. It can be concluded from these results that, in both years, while most students benefit substantially from calculator access, higher-achieving students (those scoring at the 90th percentile) may benefit to a lesser extent from access to a calculator when attempting the Calculator Optional items due to a 'ceiling effect'. Here, again, the consistency of these findings support outcomes from other studies (e.g. Hembree and Dessart, 1992) reporting that students' test scores improve substantially when calculators are made available to them.

Performance by Content Area and Key Items

When scores on all three tests were combined and analysed in terms of the four content areas tested (Number Systems, Applied Arithmetic & Measure, Algebra, and Statistics), no significant differences were noted between 2001 and 2004. However when the results by content area were looked at separately for each of the three tests, some differences were evident.

On the Calculator Inappropriate test, there were no significant differences for any of the four content areas between 2001 and 2004. That the differences on the two main content areas (Number Systems, and Applied Arithmetic & Measure) were not significant is in keeping with previous research which showed the lack of any negative effects of calculator use on the acquisition of basic number skills. In both 2001 and 2004, items in Number Systems on this test were generally answered better than items in Applied Arithmetic & Measure in terms of percent correct. (There was just one item each in Algebra and Statistics on this test).

An analysis of the 2001 and 2004 Calculator Optional test results by content area for each calculator condition revealed that the 2004 group who had access to calculators when taking the test did significantly better than the 2001 group who also had access to calculators, on both Number Systems and Algebra; and slightly better, though not significantly so, than the 2001 group on the Applied Arithmetic & Measure and Statistics areas. All the items in these content areas involved considerable computation. This finding suggests that students were better able to make use of calculators on the Calculator Optional test tasks in 2004 than in 2001. On the other hand, between 2001 and 2004, there was a significant deterioration in performance on Number Systems by students who did not have access to a calculator, suggesting that this group had become used to using a calculator in school on calculator optional type tasks, and did not do as well on the same types of tasks when a calculator was not available during the 2004 testing. These results support the view that providing access to calculators for tasks that require moderate or difficult computations leads to improved performance on the tasks while also indicating that it may lead to some degree of dependence on calculators for such tasks.

The comparisons of mean percent score differences on content areas of the Calculator Optional Test, by calculator access *within* 2001 and 2004, showed that there was a significant difference between students with and without access to calculators on all four content areas in either year. However, the differences between access and no access in 2004 on all content areas were somewhat larger than the corresponding differences in 2001. This suggests that access to calculators had a greater effect on performance in 2004 than in 2001, particularly on Number Systems where the items generally required substantial calculation. As already noted, this may reflect increased ability, on the part of students in 2004, to benefit from calculator access on tasks on the Calculator Optional test.

On the Calculator Appropriate test, students in 2004 scored significantly higher than students in 2001 on Number Systems. No significant differences were recorded in the other two content areas (there were no Algebra items). Many of the items on this test proved to be particularly difficult in 2001 and 2004, though less so in 2004. The improvement across the two testing points could be attributed to the 2004 students' greater familiarity and experience with calculators compared to 2001 students.

Students' Rough Work

Items in the Calculator Inappropriate test were intended to be done mentally or with only a small amount of written work. Students in the 2001 and 2004 assessments were instructed that they could work out the answers to the questions on this test with or without pen and paper, and a 'rough 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 on the other two tests, Calculator Optional and Calculator Appropriate, were unlikely to be done successfully by mental methods alone. For these tests the instruction 'SHOW YOUR WORK' was repeated on each page, under the 'ROUGH WORK COLUMN' heading.

In 2001, a study of students' written work was undertaken using a selection of 50 scripts. Findings 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 2004, this aspect of the study was extended and the scripts of all students in the sample were analysed in terms of rough work usage. Also, sample items were chosen for further analysis to examine the relationship between rough work usage and performance.

Predictably, results of the analysis showed that the highest proportion of rough work was done by students on the Calculator Optional test without access to calculators, as the items on this test were designed on the basis that most students would probably use pen and paper calculations to do them, in the absence of a calculator. Where calculators were available there was a substantial reduction in the amount of rough work shown, compared with that for the Calculator Optional test done without calculator access. Similarly, students produced less rough work for the Calculator Appropriate test. In the case of the Calculator Inappropriate test, where the items were designed to be done mentally or with limited use of pen and paper, the extent of rough work was also relatively low. Significant positive correlations were found between rough work use and performance on the tests, with the highest correlation occurring between rough work use and performance on the Calculator Optional test with no access to calculators.

Further analysis of these trends at the item level led to identification of items that were particularly sensitive to calculator effects. On the Calculator Inappropriate test, constructed-response items generally evoked greater rough work than did multiple-choice items. Perhaps the presence of the answer students obtained mentally (often involving just one step or operation in the case of the Calculator Inappropriate test) among the four multiple-choice responses reassured students, whereas they resorted to pen and paper to check mental answers in the case of constructed-response items. This could be attributed to lack of confidence and lack of ability to estimate answers that should be obtained by calculators. However, this was not the case on the Calculator Optional test. This may be because the multiple-choice items would not be done mentally to anything like the same degree as on the Calculator Inappropriate test. Items in the former were generally more complex computationally (often involving two or more steps or operations), and were often set in problem contexts. Other noticeable trends were the high levels of rough work associated specifically with items involving fraction operations, operations with measures of time, and operations with square roots and exponents.

STUDENTS AND CALCULATORS

The student questionnaire used in Phase II of the study was similar to that used in Phase I but contained two additional questions relating to usage of calculators in mathematics. As with Phase I, questionnaire responses were used to examine important student variables and their relationship to achievement on the calculator tests. These included student gender, socio-economic status, calculator usage in mathematics and other subjects, attitude to mathematics, and attitude to calculators.

As in 2001, there were no significant gender differences in performance on the calculator tests in 2004. This result contrasts with results for the Junior Certificate mathematics examinations, where females achieve higher proportions of A, B and C grades than males at Higher, Ordinary and Foundation levels, and with the results of the OECD PISA 2000, 2003 and 2006 studies, where males significantly outperformed females in mathematics. The mathematics component of the 1995 TIMSS study (Beaton et al., 1996), where the test was more like the calculator study than the PISA mathematics test or the Junior Certificate mathematics examination, found no overall differences between male and female students in Ireland in Grade 8 (second year).

Predictably, differences in performance on the calculator tests were observed by socioeconomic group in both 2001 and 2004. In both phases, students in the upper SEGs (socio-economic groups) achieved significantly higher scores than lower SEG students, while in 2004 (but not in 2001), students in the middle SEG significantly outperformed those in the lower SEG. In general, there were moderate but significant positive correlations between socioeconomic status and performance on the three tests. These findings are similar to findings on the SEG variable from other studies of school achievement in Ireland (e.g. Cosgrove et al., 2005; Surgenor et al., 2006).

Calculator Usage

Now that calculator usage is allowed in the Junior Certificate mathematics syllabus and examinations, over 99% of the 2004 students indicated that they used a calculator in mathematics classes. While usage levels were about the same in 2001 and 2004 in Business Studies classes, there was an increase in the use of calculators in Science classes between the two years. With regard to calculator usage within mathematics content areas, there was a tendency for students who used calculators a lot in specific content areas to perform better on the three tests than students who never used them, apart from Algebra, where students who used calculators a lot obtained a significantly lower score than students who never used them. This could be interpreted as indicating that lower-achieving students are more likely than higher-achieving students to resort to calculator use in areas like Algebra to make up for their lack of confidence or knowledge in these areas. This finding can be seen to support the use of calculators in mathematics in general.

Students in 2001 and 2004 reported similarly low levels of calculator usage in their primary schools in both years. It remains to be seen whether any future increases in levels of calculator usage in mathematics classes in primary schools, in line with the advice provided in the Teacher Guidelines for the implementation (beginning in the 2002-03 school year) of the revised Primary School Mathematics Curriculum, will have any effect on the level or quality of students' calculator usage in mathematics classes at post-primary level. In this regard, there is a case for bringing the results of this study to the attention of primary teachers, some of whom appear to be slow to embrace the widespread appropriate use of calculators in their mathematics classes.

Attitudes to Mathematics and Calculators

Consistent with international findings, significant positive correlations were found in 2001 and 2004 between student responses to attitude item clusters and performance on the three calculator tests. The clusters were: (i) positive attitude towards mathematics, (ii) self efficacy in mathematics, and (iii) usefulness of mathematics. There was also a noticeable improvement in students' attitudes towards mathematics classes between 2001 and 2004; this may or may not be related to the advent of calculator availability in these classes. As in 2001, students in 2004 indicated that they found Trigonometry, Geometry, Measure and Algebra to be the most difficult topics, and Graphs, Number and Statistics topics to be the easiest.

Students were generally positive about calculators in both 2001 and 2004 but more so in 2004, perhaps owing to their greater familiarity with them and their benefits in doing mathematics.

TEACHERS AND CALCULATORS

The Teacher Questionnaire used in Phase I of the study was revised for Phase II to obtain information on school policy on calculators, on the teaching of calculator skills, and on changes in teaching, learning and assessment, resulting from the introduction of the calculator into the mathematics curriculum.

Background of Teachers

There was no significant change in the gender composition of the set of teachers in the study between 2001 and 2004, although teachers were older, and perhaps more experienced, in 2004. As in 2001, the students in the 2004 sample were taught by teachers who indicated that they enjoyed teaching Algebra and Statistics the most and Number Systems and Applied Arithmetic & Measure the least. On the other hand, the teachers in 2001 indicated that their students found Trigonometry and Algebra to be the most difficult topics while the teachers in 2004 indicated that their students found Geometry and Algebra to be most difficult. The substantial change in the ranking of Trigonometry could be explained by the fact that students in 2004 could use calculators to evaluate and compute trigonometric functions, whereas scientific calculators had little impact on Algebra. The changes to Geometry in the revised syllabus may also have contributed to the change in the ranking of Geometry across the two test points as teachers may still not be familiar with the revised version. Students in both 2001 and 2004 were taught by teachers who felt that the Junior Certificate mathematics examination had minimal negative effect on their students' mathematical progress.

School Policy on Calculators

The findings in 2004 regarding school policy on calculators suggest that most students obtain their own calculators (based on school specifications), with only about 15% purchasing them from the school. About one-fifth of students were taught by teachers whose school had a policy on calculators, usually set by the mathematics teachers, and which included, in the majority of those schools, the requirement that calculator skills be taught in First year.

Use of Calculators in Mathematics Classes

The questionnaire results also showed that in 2004 about 7.5% of students were taught by teachers who were not in favour of calculators being used for classwork and homework in mathematics; the figure for 2001 was 17.5%. This reduction between 2001 and 2004 could be attributed to the formal introduction of calculators into the Junior Cycle mathematics syllabus and suggests that the concerns of some teachers about calculators were not realised when they were introduced into their mathematics classes.

In 2004, students were taught by teachers who indicated that the content areas most affected by calculator availability were Trigonometry, Applied Arithmetic & Measure, and Statistics, with Geometry and Algebra being least affected. They made little use of calculator activities designed to develop specific concepts and skills but this may be due to the teachers' lack of familiarity with the use of calculators for teaching and learning purposes. The situation should change with appropriate professional development activities.

Many of the teachers of the students in the 2004 sample indicated that they taught calculator skills and mental arithmetic and estimation, mainly in First year and to a lesser degree in the Second and Third years. This may reflect the completion of more calculator-sensitive work in First year, and/or an assumption that, once taught in First year, calculator use has been mastered. An interesting finding in the 2004 phase was that students whose teachers taught them how to interpret the display on the calculator and use the fraction keys scored higher on the Calculator Appropriate test than students whose teachers did not teach these topics. These findings suggest that students in general may need support in interpreting displays on the calculator, and in making better use of the fractions keys for fraction calculations. Most teachers in the study encouraged students to use some method of checking calculator-derived answers, the most popular being, not surprisingly, the practice of doing the calculation twice on the calculator. Teachers also indicated that restrictions on calculator use decreased considerably from First year, where 'calculator free' days were a feature in some schools, to Third year, where there were few restrictions.

A majority of teachers of students in the 2004 study indicated that they used calculators differently with lower achieving than with other students, and students of these teachers scored significantly higher than students whose teachers said they did not make this differentiation. Some information on the contrasts in these different uses was contained in teachers' comments. Some teachers said they encouraged greater use among lower-achieving students by allowing them to focus on aspects other than computation, while others encouraged less use to allow for practice of basic skills, perhaps reflecting differing emphasis by teachers on understanding versus computational proficiency. This is an issue that may need classroom-based studies in order to identify best practice for purposes of professional development courses.

Advantages and Disadvantages of Calculators

Most teachers of students in the 2004 sample saw improved speed, accuracy, and increased ability to progress through certain topics (e.g. trigonometry, statistics, fractions and decimals, negative numbers) as the main benefits of calculator availability, while about half of them saw no benefit in their use for clarifying concepts and procedures. This could be ascribed to teachers' lack of experience in using calculators to develop understanding of concepts and procedures, and should change as teachers gain more experience with, and reflect more upon, calculator use in mathematics teaching. Again, this is something which could benefit from attention in teachers' professional development work.

When asked in 2004 about their views on the disadvantages of calculator access in mathematics classes, teachers of students in the study commented on practical or management problems such as students forgetting calculators and the problems caused by having different kinds of calculators. It is not possible to gauge the frequency of occurrence of these problems for individual teachers from the data other than that they occur frequently enough to register as significant concerns to them. Of somewhat lesser concern to the teachers was the inappropriate use of, or over-reliance on, calculators to the detriment of other skills such as mental arithmetic and computational skills, something which was, of course, a major focus of this study.

Teachers' General Comments

When further comments of a general nature were solicited from teachers of the students at the end of the questionnaire, many simply echoed comments made earlier in the questionnaire. Most of the comments fell into clusters relating to: (i) general attitudes to calculator use (for or against); (ii) recognition of specific advantages and disadvantages of calculator use; (iii) attribution of blame for the problems to primary schools; and; (iv) recognition that calculators are a feature of everyday life. It would have been helpful to have obtained more information on their concerns about primary school, but perhaps this could also be the subject of further research.

CALCULATORS AND THE JUNIOR CERTIFICATE MATHEMATICS EXAMINATION

As part of the study, the scores of students in the 2001 and 2004 samples on the three calculator tests were related to their performance on the Junior Certificate examination in mathematics, both by examination level and by performance on a common scale covering all three syllabus levels (OMPS). In both 2001 and 2004, the significant differences in performance among the three calculator tests were maintained when students were classified by the Junior Certificate mathematics examination level (Higher, Ordinary, or Foundation) they said they intended to take and by the level actually taken, further affirming the validity of the tests and the study design. As in 2001, strong positive correlations were found between 2004 students' Junior Certificate OMPS scores and their scores on the Calculator Inappropriate (0.70), Calculator Optional (0.66), and Calculator Appropriate (0.69), tests, again supporting the validity of the tests as measures of aspects of the Junior Certificate mathematics syllabus. Trends in the Junior Certificate mathematics examination performance for 2001 to 2005 were also examined. While there were increases in the percentages of students taking Higher level (with a jump in the first year of implementation), and in the percentages of grades A to C awarded across these years at all levels, these changes cannot be attributed solely to the availability of calculators to examinees, as other aspects of the Junior Certificate syllabus and examination also changed following syllabus revision.

SUMMARY OF THE STUDY

The introduction of calculators into the Junior Certificate mathematics curriculum in 2003 provided opportunities for developments in teaching and learning, and for improvements in mathematics performance. It also raised concerns about the maintenance of computational skills for which calculator use is not appropriate. It was as a result of these concerns that this study took place. The main aim of the two-phase Calculator study was to assess students' levels of performance in calculator-related areas of the mathematics curriculum both before and after the introduction of the revised Junior Certificate syllabus and examinations.

Overall Study Design and Limitations

The Calculator study was carried out in two phases. The first phase from 2000 to 2003 was structured around the administration, in 2001, of the three calculator-related mathematics tests (Calculator Inappropriate, Calculator Optional, and Calculator Appropriate) and related questionnaires to a nationally representative sample of the final cohort of Third-year Junior Certificate students to experience a mathematics curriculum in which calculators were not included. The second phase, from 2003 to 2006, which is the main focus of this report, was structured around the administration, in 2004, of the same three tests and revised questionnaires to a nationally representative sample of the second cohort of Third-year post-primary students to experience a mathematics curriculum in which (scientific) calculators were included. In this way the effects of calculator availability were studied in a quasi-controlled experiment in which the performance and attitudes of a sample of the students who experienced a non-calculator mathematics curriculum (the 'control' group) could be compared with the performance and attitudes of an equivalent group who subsequently experienced a calculator friendly mathematics curriculum (the 'experimental' group). Concerns about the validity of the comparisons between Phase I and Phase II include: (i) possible confounding effects of the minor content changes made in the revised curriculum introduced in 2000; (ii) significant changes in the numbers taking the three course levels (Higher, Ordinary, and Foundation) between 2001 and 2004; (iii) the modest school-level response rates of 73% in both phases; and (iv) any differential effects across the two phases of demographic or socio-cultural trends. Steps were taken in the analysis to allow for the second and third of these factors, including statistical weighting of data, but results of Phase II should be viewed in the light of these limitations.

Within this larger design a second experimental study was implemented in which the students taking the Calculator Optional test were randomly assigned to two test conditions, one without calculators, and the other with calculators, to examine further the effects of calculators on items for which calculators may or may not be used. Table 9.1 summarises the overall design of the study within and across the two Phases.

Table 9.1: *Overall Design of the Study*

Phase/Treatment	Calculator Test	Test Condition	
Phase I 2001 'Control' group – experienced a mathematics curriculum which did not include calculators	Calculator Inappropriate	No calculators	
	Calculator Optional	Half of sample: No access to calculators (control group)	Half of sample: Access to calculators (experimental group)
	Calculator Appropriate (Two forms - 1 and 2)	Calculators available	
Revised calculator 'friendly' curriculum introduced in 2000 and examined in 2003 for first time			
Phase II 2004 'Experimental' group – experienced revised mathematics curriculum that included calculators	Calculator Inappropriate	No calculators	
	Calculator Optional	Half of sample: No access to calculators (control group)	Half of sample: Access to Calculators (experimental group)
	Calculator Appropriate (Two forms - 1 and 2)	Calculators available	

Summary of Findings

The following is a summary of the results of Phase II of the Calculator study, as they relate to the research questions on page xiii of this report.

1. Performance on the Calculator Inappropriate test and on the Calculator Optional test for the no calculator condition declined slightly between 2001 and 2004, but not significantly so. In particular, the small negative drop (–7 scale points) between 2001 and 2004 on the Calculator Inappropriate test suggests that 2004 students did not lose out significantly on basic mathematical skills while following the revised Junior Cycle mathematics syllabus, compared to 2001 students who followed the previous syllabus. The slight fall in performance should not be of concern unless the trend continues.

2. As in 2001, the difference in overall performance between the 2004 students with access to calculators and those without access on the Calculator Optional test was significant and in favour of students with access to calculators. Additionally, the advantage of the students with access to calculators over those without access was substantially greater in 2004 (44.4 scale points in 2004 *versus* 30.4 scale points in 2001). This finding is in keeping with findings from similar controlled experiments on calculator effects in other

countries which show unequivocally the advantage conveyed to student performance in mathematics when calculators are available to them.

3. Performance on the Calculator Appropriate test, which includes the items most likely to bring calculators into play, improved significantly between 2001 and 2004 (+ 13.4 scale points), suggesting that students' ability to make use of the calculator in solving problems improved over the three years. While items in this test were intended to be somewhat challenging, the overall low performance in both 2001 and 2004 raises concerns about how well students can use their mathematical knowledge to solve realistic problems.

4. On the Calculator Optional test, students in 2004 who had access to calculators did significantly better than students in 2001 who had access, on both Number Systems and Algebra, and slightly better (though not significantly so) on Applied Arithmetic & Measure and Statistics. This finding indicates that students were able to use calculators with somewhat greater effect on calculator optional tasks in Number Systems and Algebra in 2004 than in 2001. On the other hand, students without access to a calculator for this test did significantly less well on Number Systems in 2004 than did students without access in 2001.

5. In both 2001 and 2004, items on the Calculator Appropriate test were more difficult for students than items on the other two tests, giving rise to a steeper gradient of difficulty than had been intended in the design of the study. Items that caused most difficulty were mainly in the area of Applied Arithmetic & Measure, though there was a significant improvement in percent correct scores on this content area between 2001 and 2004.

6. In 2004, incidence of rough work was highest on the Calculator Optional test with no calculator access, and substantially lower on the Calculator Optional with calculator access, the Calculator Inappropriate, and the Calculator Appropriate tests. Students who produced more rough work performed better on the calculator tests than students who produced less rough work.

7. Almost three-quarters of students in 2004 reported that they had never used a calculator in their mathematics classes in primary school, though the vast majority of these would have completed primary school before the implementation of the revised 1999 Primary School Curriculum which recommends use of calculators from 4th Class onwards.

8. There was a large increase in calculator usage in mathematics classes, from fewer than 1% using a calculator 'often' in 2001, to over 80% using one 'often' in 2004. Also, between 2001 and 2004, there was a substantial increase

in the proportion of students who believed a calculator could help mathematics performance and that it should be used in class and at home.

9. Only 22% of students in the 2004 study were taught by teachers who said that their school had a policy on calculators, and approximately a quarter of these had an 'official' policy. Nevertheless, most students (86%) were taught by teachers who were supportive of calculator use for mathematics class work and homework. The teachers also indicated that restrictions on calculator use decreased considerably from First year to Third year.

10. Just over half of students in 2004 were taught by teachers who stated that the availability of calculators in class had affected their teaching methods, particularly the areas of Statistics, Trigonometry, Sets, and Applied Arithmetic & Measure. A particularly notable finding was that students whose teachers taught them how to interpret the display on the calculator and use the fraction keys scored significantly higher on the Calculator Appropriate test than students whose teachers did not teach these topics. Little or no use is made of graphic calculators – only 5% of students were taught by teachers who said that the school had a set of graphics calculators.

11. According to teachers of students in 2004, the benefits of calculator use included saving time, greater ease of teaching some topics, and increasing confidence and independence among students, especially the weaker ones. The disadvantages of calculator use included practical management issues, inappropriate use or over-reliance on the calculator, difficulty in using calculators effectively, and a possible decline in some aspects of numeracy.

12. Students in the 2004 sample who took Higher level mathematics in 2005 achieved significantly higher scores than Ordinary or Foundation level students on each of the three calculator tests. For students taking each examination level, mean scale scores were significantly higher on the Calculator Optional test when students had access to a calculator than when they did not. Of particular interest is the finding that for the Calculator Optional test, the mean scale score of Ordinary level students with calculator access (243) approaches (and is not statistically different from) that of Higher level students without access (251). Similarly, the performance of Foundation level students with calculator access (200) is not significantly different from that of Ordinary level students without access (203). This suggests that calculator access enables students to perform at a level higher than they would otherwise attain on the types of task assessed by the test.

RECOMMENDATIONS

Recommendations based on the findings of the two phases of this study are as follows:

1. Given the small, though non-significant, fall in performance on the Calculator Inappropriate test between 2001 and 2004, it is recommended that the tests be administered again in the near future to determine if there is any further change in performance on key numeracy skills assessed by the test.

2. Given the relatively poor performance of students on the Calculator Appropriate test in 2001 and 2004 and the findings of the PISA 2003 mathematics assessment, it is recommended that more attention be given to real-life problem solving in the Junior Certificate mathematics syllabus and examinations, and in the recently launched Project Maths initiative.

3. Arising from the analysis of students' rough work across the three tests, it is recommended that students be taught more about how, when, and when not to use calculators in mathematics, and when (and when not) to support calculator work with pen-and-paper calculations.

4. Post-primary schools should be encouraged, where appropriate, to reassess the type and extent of use of calculators in First and Second years, based on the evidence of this study and in the light of calculators being included in the primary school mathematics curriculum for Fourth, Fifth and Sixth classes.

5. Given the finding that students taught how to use specific calculator keys (such as fraction keys) performed significantly better on the calculator tests than students not taught their use, students should be taught how to make intelligent use of basic calculator keys and to exploit the power provided by more sophisticated functions such as fraction and memory keys. Attention should also be given to helping students to interpret the displays on the calculator.

6. Based on the findings from the Teacher Questionnaire, more attention should be given in publications and teacher professional development initiatives to uses of calculators for developing understanding of specific concepts and procedures, estimation skills, and use of real-life problems and data, and not simply for checking answers.

7. Given the finding in this study on the benefits of use of calculators to teach lower achievers in mathematics, efforts should made through classroom studies and other means, to develop best practice for use of calculators with low-achievers.

8. Given their usefulness for teaching algebra and functions and their lack of use by teachers in this study, consideration should be given to encouraging greater use of graphics calculators in the Junior Certificate mathematics syllabus. In general, more emphasis should be given to the use of ICT tools for teaching algebra and functions.

9. Given the lack of formal school policy on calculators in many post-primary schools, all such schools should be encouraged to develop a policy.

10. The results of this and other relevant studies should be made available to primary school teachers to inform their views about the effects of calculators on student mathematical development, and the implications of calculator availability for teaching estimation and other numeracy skills.

11. A study should be carried out in the near future to assess primary teachers' views on, and extent of, calculator use in senior primary classes.

12. Further research should also focus on computation and problem solving in small groups, to investigate the strategies that students use (including their use of calculators), and their error patterns.

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APPENDIX 1 – TEACHER QUESTIONNAIRE (2004)

A. General information

1. What is your gender? (*Tick one)*

Female ☐ Male ☐

2. How many years of experience in the teaching of mathematics do you have? *(Tick one only)*

1 -5 ☐
6-10 ☐
11-15 ☐
16-25 ☐
more than 25 ☐

3. Which area of mathematics do you most enjoy teaching?
Rank-order the following from most enjoyable (1) to least enjoyable (8).

(a) Sets ☐
(b) Number Systems ☐
(c) Applied Arithmetic & Measure ☐
(d) Algebra ☐
(e) Statistics ☐
(f) Geometry ☐
(g) Trigonometry ☐
(h) Functions and Graphs ☐

4. With which area of mathematics do your students have the most difficulty, in general?
Rank-order the following from most difficult (1) to least difficult (8).

(a) Sets ☐
(b) Number Systems ☐
(c) Applied Arithmetic & Measure ☐
(d) Algebra ☐
(e) Statistics ☐
(f) Geometry ☐
(g) Trigonometry ☐
(h) Functions and Graphs ☐

5. Indicate the year levels at which you teach mathematics in the current school year.
(Tick all that apply)

(a) 1st Year ☐
(b) 2nd Year ☐
(c) 3rd Year ☐
(d) 4th Year (Transition Year) ☐
(e) 5th Year ☐
(f) 6th year ☐

B. School Policy on Calculators

(*Note*: You may need to consult colleagues or Principal before responding to these questions)

5. Which is *nearest* to the situation for Junior Cycle students in your school? (*Tick one only)*

Students are required to have a particular make and model of calculator	☐
Students are required to have a particular type of calculator (specify if other than scientific ____________________) but the make and model are not specified	☐
Students are free to use any type of calculator	☐
Other (specify) __________________________	☐

6. Which is *nearest* to the situation for Junior Cycle students in your school? (*Tick one only)*

The students' families are responsible for sourcing and buying the calculators	☐
The school buys calculators and sells them to the students	☐
The school buys calculators and lends them to the students	☐
Other (specify)____________________________________	☐

7. Is there a policy with regard to calculator use in your school? *(Tick one only)*

Yes ☐ No ☐ Unsure ☐

If the answer is yes, please answer the questions below. If the answer is no proceed to Q 9.

8. *(Tick all that apply)*

	Yes	No	Unsure
(a) Is the policy an official school policy?			
(b) Is the policy agreed among teachers of subjects to which calculators are relevant? (maths, science, business studies,….)			
(c) Is the policy agreed among mathematics teachers only? Other (please specify)____________________________________			
(d) Does the policy assign responsibility for developing calculator operation skills to specific group of teachers? If *yes,* (please specify)____________________________________			
(e) Does the policy require that calculator use is taught in 1st Year?			
(f) Does the policy require that calculators are *not* used in 1st Year?			
(h) Does it explicitly allow the use of mobile phones as calculators?			
(i) Does it explicitly *forbid* the use of mobile phones as calculators?			

The remaining questions refer to Junior Cycle mathematics We are interested in finding out if teachers are including the development of calculator operation skills and relevant numeracy skills in their plans or schemes of work, or if they teach these only in response to perceived needs in the classroom as they arise

C. Use of calculators in your Junior Cycle classes

9. To what extent is the calculator used in teaching/learning in your *Junior Cycle mathematics classes*? *(Tick one only on each line)*

	A lot	To some extent	Never
(a) Sets			
(b) Number systems			
(c) Applied Arithmetic & Measure			
(d) Algebra			
(e) Statistics			
(f) Geometry			
(g) Trigonometry			
(h) Functions and Graphs			

10. Do you think Junior Cycle students *should* be allowed to use a calculator (where the calculator is relevant to work in hand) *(Tick one on each line)*

	Yes	No
(a) for mathematics homework?		
(b) in mathematics class?		
(c) for homework in other subjects?		
(d) for classwork in other subjects?		
(e) in the Junior Cert. Maths. Examination?		

11. To what extent do you think the Junior Certificate examination hampers your students' mathematical progress?

not at all	
very little	
to some extent	
a lot	

12. This question relates to the *formal* teaching of calculator operation skills. *(Tick all that apply)*

(a) Are students in your Junior Cycle classes formally taught basic calculator operation skills?	Yes	☐	No	☐	Unsure	☐
(b) If the answer is yes, when is such teaching expected to take place?	1st Year	☐	2nd Year	☐	3rd Year	☐
(c) Are Junior Cycle students formally taught mental arithmetic skills?	Yes	☐	No	☐	Unsure	☐
(d) If the answer is yes, when is such teaching expected to take place?	1st Year	☐	2nd Year	☐	3rd Year	☐
(e) Are Junior Cycle students formally taught estimation skills?	Yes	☐	No	☐	Unsure	☐
(f) If the answer is yes, when is such teaching expected to take place?	1st Year	☐	2nd Year	☐	3rd Year	☐

13. Do you ensure that your Junior Cycle students can use the following calculator features?

	Yes	No
(a) Percentage key		
(b) Brackets		
(c) Fraction keys		
(d) Interpreting the display		
(e) "Power" keys		
(f) Memory		
(g) Constant function		
(h) + / - key		
(i) Exponential (scientific) form		

14. How much emphasis do you give to students understanding the difference between "algebraic" logic and "arithmetic" logic (e.g., typing "2" "+" "3" "×" "4" "=" and obtaining a correct answer of 14 or a wrong answer of 20, depending on the type of calculator used)? *(Tick one only)*

Much emphasis ☐ Some emphasis ☐ Little or no emphasis ☐

15. How much emphasis do you give to encouraging students to record work / write down intermediate results when using calculators? *(Tick one only)*

Much emphasis ☐ Some emphasis ☐ Little or no emphasis ☐

16. Indicate the restrictions you put on calculator use during your classes (if any). *(Tick 'yes' or 'no' wherever applicable)*

	1st year		2nd year		3rd year	
	Yes	No	Yes	No	Yes	No
(a) Students are allowed to have calculators available at all times (to use at their discretion)						
(b) Students may have calculators available unless they are told otherwise						
(c) Students are not allowed to use calculators unless given permission						
(d) There are "calculator free days" for number work						

17. Indicate the extent to which you require students to use these methods to check calculator computations. *(Tick one on each line)*

	Require	Encourage	Don't mention
(a) Do the calculation twice			
(b) Do it a different way			
(c) Use answer to check (e.g., check multiplication by dividing)			
(d) Do it by hand (if sufficiently simple)			
(e) Estimate before computing			
(f) Check if the answer is reasonable			
(g) Other (please specify) _____________			

18. (a) Has the availability of calculators affected your method of teaching?

Yes ☐ No ☐

19. If the answer to question 18 is 'yes', in what areas has the availability of calculators affected your method of teaching?

	Tick if yes	*Specify how*
(a) Sets		
(b) Number systems		
(c) Applied Arithmetic & Measure		
(d) Algebra		
(e) Statistics		
(f) Geometry		
(g) Trigonometry		
(h) Functions and Graphs		

20. Do you make different use of calculators with lower-achieving students than with other students?

Yes ☐ No ☐

If yes, please indicate the differences ______________________________

____

D. Benefits and problems

21. Indicate the extent to which calculators have led to benefits in the following aspects of your work in class. *(Tick one on each line)*

	Major benefit	Minor benefit	No benefit
(a) Exposition/explanation of concepts and procedures			
(b) Improving accuracy in students' work			
(c) Moving more quickly through topics			

(d) What have you found to be the greatest benefit of calculator availability?

____

____

22. Indicate the extent to which calculators have caused problems (if any) in your classes.
(Tick one on each line)

	Major problem	Minor problem	No problem
(a) Teaching how to use the calculator within each topic			
(b) Coping with missing calculators (lost, stolen, forgotten)			
(c) Change in calculator types or models from year to year			
(d) Students in your class having different makes of calculator			

(e) What have you found to be the greatest drawback?

____

____

23. Do you allow use of mobile phones as calculators? (e.g. if calculator is forgotten/lost)

Yes ☐ No ☐

E. Powerful calculators (graphics calculators / computer algebra systems)

24. Some schools have acquired *graphics* calculators or *CASs* (computer algebra systems), for example for data logging in science. What is the situation in your school?
(*Tick one box on each line)*

	Yes	No	Don't know
(a) The school has a class set of graphics calculators			
(b) The school does not have a set of graphics calculators, but does have one or more such calculators			
(c) The school has a special graphics calculator or panel so that the contents of the screen can be displayed from an overhead projector			
(d) The school has at least one CAS calculator			

25. Have you used graphics calculators in your mathematics classes (at any level in school)?

Yes ☐ No ☐

If 'yes' for what purpose?
____

26. Have you used CASs in your mathematics classes (at any level in school)?

Yes ☐ No ☐

If 'yes' for what purpose? ____________________________________

F. CALCULATOR ACTIVITIES

The enclosed sheet lists a number of activities that can be used to develop number concepts and/or consolidate skills. They involve calculator use but may also require estimation and mental arithmetic.

27. Do you do any of the following activities (described on pages 11-12) with calculators in mathematics class? *[Tick the appropriate box(es) on each line]*

	Sometimes	Seldom	Not at all
(1) Countdown			
(2) Broken calculator			
(3) Five steps to zero			
(4) Squares and square roots			
(5) I have … you have			
(6) Guess and press			
(7) Wipeout			
(8) Cross-numbers			
(9) Beat the calculator			
(10) Choose and use the appropriate method			
(11) Estimate then check			
(12) Missing operators			
(13) Missing digits			
(14) Other			

If other, please specify. ______________________________

____

____

____

APPENDIX 2 – STUDENT QUESTIONNAIRE (2004)

A. GENERAL INFORMATION

1. What is your date of birth?

Day	Month	Year

2. What is your gender? *(Tick one)*

Female ☐ Male ☐

3. What is your father's main job?
If he is not working now, please state his last occupation.

____

4. What is your mother's main job?
If she is not working now, please state her last occupation.

____

5. Indicate the level at which you expect to sit mathematics in the Junior Certificate Examination. (*Tick one only)*

Higher Level	
Ordinary Level	
Foundation Level	

6. Which area of Junior Certificate mathematics do you find easy/difficult, in general? *(Tick one on each line)*

	Easy	Okay	Difficult
(a) Fractions, decimals & percentages			
(b) Length, area, volume, time			
(c) Algebra			
(d) Statistics			
(e) Geometry			
(f) Trigonometry			
(g) Graphs			

B. CALCULATOR USAGE

7 (a) Do you own or have access to a calculator at home?

Yes ☐ No ☐

(b) If the answer is *yes*, what kind of calculator is it? (*Tick all that apply)*

Basic calculator	
Scientific calculator	
Graphics calculator	

8. What kind of calculator do you use in school? (*Tick all that apply)*

Basic calculator	
Scientific calculator	
Graphics calculator	

9. How often do you use a calculator for work in the following subjects? *(Tick one only) (For each subject you do not take, mark 'Does not apply'.)*

	Never	Sometimes	Often	Does not apply
(a) Mathematics				
(b) Business Studies				
(c) Science				
(d) Technology				
(e) Other subject______________				

10. How often did you use your calculator in mathematics class in *(Tick one on each line)*

	Never	Sometimes	Often
(a) Primary school?			
(b) 1st year of post-primary school?			
(c) 2nd year of post-primary school?			

11. When were you first taught how to use a calculator? *(Tick one only)*

Primary school	1st Year	2nd Year	3rd Year	I taught myself

12. To what extent do you use your calculator in the different areas of mathematics? *(Tick one on each line)*

	A lot	To some extent	Never
(a) Fractions, decimals & percentages			
(b) Length, area, volume, time			
(c) Algebra			
(d) Statistics			
(e) Geometry			
(f) Trigonometry			
(g) Graphs			

13. What aspect of calculator use do you like most?____________________________

____

14. What aspect of calculator use do you like least? ____________________________

____

C. ATTITUDE TO MATHEMATICS

15. Please *tick one* box for each of the following statements.

	Strongly disagree	Disagree	Agree	Strongly agree
(a) When I do maths I sometimes get totally absorbed.				
(b) Doing maths is fun, I wouldn't want to give it up.				
(c) I get good marks in maths.				
(d) Maths is one of my best subjects.				
(e) Maths is one of my favourite subjects.				
(f) I have always done well in maths.				
(g) Maths is a useful subject in everyday life.				
(h) Maths is important for getting a job.				
(i) I like arithmetic.				
(j) I like doing calculations.				
(k) I like doing sums where I know the method.				
(l) I like tackling maths problems.				
(m) I like everyday maths problems.				
(n) I like doing length, area and volume problems.				
(o) I like geometry.				
(p) I like algebra.				
(q) I like trigonometry.				
(r) I like statistics.				

D. ATTITUDE TO CALCULATORS

16. Please *tick one* box for each of the following statements.

	Strongly disagree	Disagree	Agree	Strongly agree
(a) I think a calculator can help me to get better marks in school maths.				
(b) I think a calculator could make me lazy at school maths.				
(c) I think a calculator could help me get better at maths.				
(d) A calculator should be used only by a student who has a lot of difficulty with school maths.				
(e) I think I should be allowed to use a calculator for maths homework.				
(f) I think I should be allowed to use a calculator for homework in other subjects.				
(g) I think I should be allowed to use a calculator in maths class.				
(h) I think I should be allowed to use a calculator for classwork in other subjects.				
(i) I can solve problems better when I have a calculator to help me with the arithmetic.				
(j) You don't have to think much when using a calculator.				
(k) Maths is more fun when you can use a calculator.				
(l) Since I have a calculator I do not need to learn to do calculations with pen and paper.				

G. Comments

Please use this space to make any general comments you wish.

Thank you for completing this questionnaire.
Please return the completed questionnaire to the co-ordinator in your school who will return it to the Educational Research Centre.

APPENDIX 3 – CALCULATOR ACTIVITIES

1. *Countdown*
Students are given a target number (e.g., 432). They use given numbers and operations, as in the TV game, to make (or get as close as possible to) the target number.

2. *Broken calculator*
Students are told to pretend that certain keys (number or operation keys or both) on their calculators are "broken," and hence cannot be used. They have to carry out given computations without using the "broken" keys (e.g., work out 738 + 872 without using the 7 or 8 keys; calculate 432 / 12 without using the division key). [Haylock, 1982].

3. *Five steps to zero*
Students are given a three-digit number less than or equal to 900. They try to reduce it to zero in at most five steps, using any of the basic operations and a single-digit number at each step. [Williams & Stephens in NCTM Yearbook, 1992]

4. *Squares and square roots*
Students are given a number that is the square of a natural number. They have to find the natural number without using the square root key on the calculator. [Williams & Stephens in NCTM Yearbook, 1992]

5. *I have … you have*
This game involves use of a set of cards each of which displays a number (e.g. 74) and a question (e.g. Who has one-eighth of this?) The teacher starts: "I have 74. Who has one-eighth of this?" The student with the appropriate card responds and poses the next question.

6. *Guess and press*
Students are given an incomplete statement, e.g. $40 \times 57 = ?$ or $34 \times ? = 600$. They have to *guess* (estimate) the missing number, record their guess, and then check it out and refine it using the calculator (i.e., *pressing* keys).

7. *Wipeout*
Students are given a multi-digit number (e.g. 35746) and must find what to subtract in order to reduce a given digit to zero (e.g. to make the number 35046).

8. *Cross-numbers*
Students are given a "crossword puzzle" in which the clues are calculations (perhaps ones demanding use of brackets or other such features) and the answers are numbers. (c.f. www.mathpuzzle.com).

9. *Beat the calculator*
Students try to beat the calculator in doing calculations that can reasonably be done mentally and/or with pen and paper.

10. *Choose and use the appropriate method*
Students are grouped into teams and each team in turn is given a question. One member must answer. More marks are awarded for an answer calculated mentally

than for one for which a calculator is used. Pen-and-paper methods can be awarded an intermediate score. Wrong answers can be penalised by deduction of marks [Tanner & Jones, 2000]

11. ***Estimate then check***
Use mental arithmetic/estimation to identify correct/incorrect solutions to complex computations and then check with calculator

12. ***Missing operators***
Find the missing operators in multi-digit operations [e.g. 43 □ 37 (4 □ 30) = 9600].

13. ***Missing digits***
Find the missing digits in multi-digit operations [e.g. □ + 37 (4 x 30) = 9600].

APPENDIX 4 – ADDITIONAL TABLES CHAPTER 4

Appendix Table A4.1 *Proportion of Students Sitting the Junior Certificate Mathematics Examination at Each Level, by Gender*

		Population (2005)		Sample (2004)	
		n	**%**	**n**	**%**
Foundation	Male	3450	58.4	30	50.0
	Female	2457	41.6	30	50.0
	Total	5907	10.6	60	4.2
Ordinary	Male	13595	51.3	315	51.6
	Female	12923	48.7	296	48.4
	Total	26518	47.5	611	42.3
Higher	Male	11179	47.8	316	40.9
	Female	12209	52.2	457	59.1
	Total	23388	41.9	773	53.5

APPENDIX 5 - ADDITIONAL TABLES CHAPTER 5

Appendix Table A5.1 *Item-by-Item Breakdown for the Calculator Inappropriate, Optional, and Appropriate Tests, by Content Area*

Calc. Inappropriate		Calc. Optional		Calc. Appropriate			
				Form 1		Form 2	
Item	**Content Area**	**Item**	**Content Area**	**Item**	**Content Area**	**Item**	**Content Area**
A01	Number	B1	Number	C1	Arith & Meas.	CC1	Arith & Meas.
A02	Number	B2	Number	C2	Arith & Meas.	CC2	Number
A03	Number	B3	Statistics	C3	Arith & Meas.	CC3	Number
A04	Number	B4	Number	C4	Number	CC4	Number
A05	Number	B5	Arith & Meas.	C5	Number	CC5	Number
A06	Number	B6	Arith & Meas.	C6	Number	CC6	Arith & Meas.
A07	Number	B7	Arith & Meas.	C7a	Statistics	CC7	Arith & Meas.
A08	Number	B8	Arith & Meas.	C7b	Statistics	CC8	Statistics
A09	Number	B9	Arith & Meas.	C7c	Statistics	CC9	Arith & Meas.
A10	Number	B10	Arith & Meas.	C8	Arith & Meas.	CC10	Arith & Meas.
A11	Statistics	B11	Arith & Meas.	C9	Arith & Meas.	CC11	Arith & Meas.
A12	Arith & Meas.	B12	Arith & Meas.	C10	Arith & Meas.	CC12	Arith & Meas.
A13	Arith & Meas.	B13	Arith & Meas.	C11	Arith & Meas.	CC13a	Statistics
A14	Arith & Meas.	B14	Number	C12	Arith & Meas.	CC13b	Statistics
A15	Arith & Meas.	B15	Number	C13	Arith & Meas.	CC13c	Statistics
A16	Number	B16	Number				
A17	Algebra	B17	Number				
A18	Arith & Meas.	B18	Number				
A19	Arith & Meas.	B19	Number				
A20	Number	B20	Arith & Meas.				
A21	Number	B21	Arith & Meas.				
A22	Arith & Meas.	B22	Arith & Meas.				
A23	Arith & Meas.	B23	Algebra				
A24	Arith & Meas.	B24	Algebra				
A25	Arith & Meas.	B25	Algebra				
		B26	Algebra				
		B27	Number				
		B28	Number				
		B29	Number				
		B30	Statistics				
		B31	Arith & Meas.				
		B32	Arith & Meas.				
		B33	Arith & Meas.				

Appendix Table A5.2 *Mean Percent Correct Scores on the Calculator Inappropriate Test (2004)*

Item	Calculator Inappropriate	
	Mean	SE
A1	94	0.5
A2	87	1.0
A3	83	1.4
A4	72	1.9
A5	54	1.2
A6	51	1.6
A7	62	1.7
A8	77	2.3
A9	52	3.0
A10	43	1.9
A11	64	3.2
A12	42	3.4
A13	31	2.1
A14	81	0.4
A15	66	0.9
A16	53	0.5
A17	56	0.2
A18	77	2.7
A19	53	2.4
A20	56	1.0
A21	60	2.6
A22	50	0.2
A23	69	0.9
A24	29	5.1
A25	42	4.9

Appendix Table A5.3 *Difference in Mean Percent Correct Scores on the Calculator Optional Test, by Calculator Access (2004)*

Item	Calc		Non-Calc		Diff	SED	95%CI	
	Mean	SE	Mean	SE				
B1	60	4.9	57	3.3	3	5.91	-8.80	14.80
B2	58	1.2	34	2.8	24	3.05	**17.92**	**30.08**
B3	80	2.6	74	3	6	3.97	-1.93	13.93
B4	83	1.3	69	3.1	14	3.36	**7.29**	**20.71**
B5	89	4	75	1.7	14	4.35	**5.32**	**22.68**
B6	97	0.4	85	2.6	12	2.63	**6.75**	**17.25**
B7	59	3.7	55	3.6	4	5.16	-6.31	14.31
B8	61	2.1	54	5.2	7	5.61	-4.20	18.20
B9	40	0.6	30	2.6	10	2.67	**4.67**	**15.33**
B10	64	0.6	55	2.1	9	2.18	**4.64**	**13.36**
B11	70	4	69	1.6	1	4.31	-7.60	9.60
B12	64	2.3	43	2.7	21	3.55	**13.92**	**28.08**
B13	48	2.2	38	6	10	6.39	-2.76	22.76
B14	92	0.4	79	1.2	13	1.26	**10.47**	**15.53**
B15	94	0.2	44	1.1	50	1.12	**47.77**	**52.23**
B16	88	4.2	75	1	13	4.32	**4.38**	**21.62**
B17	89	1.4	37	1	52	1.72	**48.56**	**55.44**
B18	94	0.2	30	3.3	64	3.31	**57.40**	**70.60**
B19	91	0.4	73	2	18	2.04	**13.93**	**22.07**
B20	69	0.9	67	2.9	2	3.04	-4.06	8.06
B21	72	1.9	46	1.6	26	2.48	**21.04**	**30.96**
B22	37	0.4	39	0.4	-2	0.57	**-3.13**	**-0.87**
B23	77	0.8	62	2.6	15	2.72	**9.57**	**20.43**
B24	49	1.2	48	1.8	1	2.16	-3.32	5.32
B25	67	1.8	45	2.3	22	2.92	**16.17**	**27.83**
B26	61	3.5	35	3.7	26	5.09	**15.83**	**36.17**
B27	93	0.6	64	1.3	29	1.43	**26.14**	**31.86**
B28	47	2.3	7	1.8	40	2.92	**34.17**	**45.83**
B29	9	0.4	8	0.7	1	0.81	-0.61	2.61
B30	43	4.5	37	1.5	6	4.74	-3.47	15.47
B31	40	4.7	23	5.4	17	7.16	**2.70**	**31.30**
B32	22	4.2	17	6.4	5	7.66	-10.29	20.29
B33	50	0.9	27	5.7	23	5.77	**11.48**	**34.52**

*Diff = Difference; SED = Standard Error of the Difference; 95%CI = confidence intervals; significant differences in **bold**.*

Appendix Table A5.4 *Mean Percent Correct Scores on the Calculator Appropriate Test (2004)*

Booklet	Item Number	% correct	SE
C-1	C1	83	0.5
	C2	71	0.5
	C3	55	3.7
	C4	78	0.9
	C5	73	0.2
	C6	41	0.4
	C7a	64	2.2
	C7b	18	0.2
	C7c	48	1.5
	C8	51	3.8
	C9	36	0.5
	C10	13	2.6
	C11	5	1.2
	C12	44	2.9
	C13	19	1.0
C-2	CC1	91	0.5
	CC2	91	2.2
	CC3	37	3.9
	CC4	42	0.3
	CC5	62	3.2
	CC6	33	3.6
	CC7	59	2.4
	CC8	6.3	0.3
	CC9	1	0.9
	CC10	2	2.1
	CC11	56	3.8
	CC12	10	2.4
	CC13a	70	1.2
	CC13b	16	2.6
	CC13c	40	0.8

Appendix Table A5.5 *Item Difficulty and Number of Rough Work Incidents for the Calculator Inappropriate Test*

Calculator Inappropriate Test		
Item Number	**% Correct**	**Number r.w.**
A01	94	98
A02	87	24
A03	83	55
A04	72	77
A05	54	379
A06	51	681
A07	62	26
A08	77	112
A09	52	876
A10	43	89
A11	64	289
A12	42	269
A13	31	620
A14	81	83
A15	66	981
A16	53	779
A17	56	746
A18	77	449
A19	53	967
A20	56	638
A21	60	664
A22	50	806
A23	69	503
A24	29	672
A25	42	754

Appendix Table A5.6 *Item Difficulty and Number of Rough Work Incidents for the Calculator Optional Tests*

Item Number	No Access to Calculator % correct	No Access to Calculator Number r.w.	Access to Calculator % correct	Access to Calculator Number r.w.
B1	57	511	60	383
B2	34	370	58	90
B3	74	456	80	194
B4	69	405	83	243
B5	75	600	89	236
B6	85	543	97	208
B7	55	389	59	258
B8	54	582	61	384
B9	30	441	40	291
B10	55	453	64	244
B11	69	430	70	212
B12	43	429	64	192
B13	38	487	48	325
B14	79	587	92	76
B15	44	554	94	69
B16	75	557	88	158
B17	37	531	89	61
B18	30	480	94	58
B19	73	469	91	151
B20	67	302	69	171
B21	46	429	72	198
B22	39	465	37	267
B23	62	471	77	291
B24	48	492	49	357
B25	45	404	67	315
B26	35	397	61	364
B27	64	415	93	142
B28	7	201	47	257
B29	75	270	9	292
B30	37	391	43	390
B31	23	233	40	193
B32	17	242	22	183
B33	27	256	50	210

Appendix Table A5.7 *Item Difficulty and Number of Rough Work Incidents for the Calculator Appropriate Test (Form 1)*

Item Number	% correct	Number r.w.
C1	83	182
C2	71	162
C3	55	249
C4	78	61
C5	73	51
C6	41	311
C7a	64	160
C7b	18	193
C7c	48	180
C8	57	189
C9	36	191
C10	13	232
C11	5	253
C12	44	258
C13	19	221

Appendix Table A5.8 *Item Difficulty and Number of Rough Work Incidents for the Calculator Appropriate Test (Form 2)*

Item Number	% correct	Number r.w.
CC1	91	294
CC2	92	62
CC3	37	98
CC4	42	288
CC5	62	73
CC6	32	181
CC7	59	138
CC8	6	309
CC9	1	230
CC10	2	273
CC11	56	351
CC12	10	275
CC13a	70	154
CC13b	16	183
CC13c	40	153

APPENDIX 6 – ADDITIONAL TABLES CHAPTER 6

Appendix Table A6.1 *Mean Scale Scores for each Calculator Test, by Frequency of Using Calculator in Mathematics Class*

Frequency	n	%	SE	Inappropriate %	Inappropriate SE	Optional %	Optional SE	Appropriate %	Appropriate SE
Never	8	0.56	0.156	228.58	38.06	217.54	16.54	221.02	19.87
Sometimes	263	18.25	1.961	240.39	10.40	244.70	12.14	255.32	7.95
Often	1169	81.00	2.031	243.87	3.07	251.14	3.10	265.68	1.37
N/A	3	0.19	0.087	259.13	26.14	251.42	31.40	245.61	13.75

Appendix Table A6.2 *Comparison of Scale Scores for Each Calculator Test, by Frequency of Calculator use in Mathematics Class*

	Inappropriate Diff	Inappropriate SED	Inappropriate 95% CI		Optional Diff	Optional SED	Optional 95% CI		Appropriate Diff	Appropriate SED	Appropriate 95% CI	
Often-Some	3.48	7.97	-30.8	37.8	6.43	9.50	-34.5	47.3	10.36	7.16	-20.4	41.2
Often-Never	15.29	35.74	-138.5	169.0	33.60	14.11	-27.1	94.3	44.66	19.18	-37.9	127.2
Some-Never	11.80	27.80	-107.8	131.4	27.16	4.84	6.4	47.9	34.30	12.07	-17.6	86.2
Often-N/A	-15.26	23.19	-115.1	84.5	-0.28	28.39	-122.4	121.9	20.06	12.60	-34.1	74.3

APPENDIX 7 – ADDITIONAL TABLES CHAPTER 7

Appendix Table A7.1 *Level of Usage of Selected Calculator Activities*

	Mean	SE	Sometimes	Seldom	Not at all	Missing
Countdown	1.37	0.17	13.27	6.67	69.83	10.23
Broken calculator	1.13	0.08	0.97	9.54	79.68	9.81
Five steps to zero	1.15	0.05	6.23	0.86	83.52	9.39
Squares & square roots	1.96	0.10	38.46	12.13	42.61	6.80
I have … you have	1.21	0.04	6.43	6.55	77.63	9.39
Guess and press	1.38	0.04	8.80	16.07	64.39	10.74
Wipeout	1.10	0.08	2.26	4.74	83.60	9.39
Cross-numbers	1.39	0.01	12.88	10.11	69.44	7.56
Beat the calculator	1.46	0.04	16.14	9.89	65.92	8.05
Choose and use	1.15	0.07	2.45	8.04	76.91	12.59
Estimate then check	2.20	0.05	52.16	12.61	32.53	2.69
Missing operators	1.37	0.02	10.02	13.29	67.30	9.39
Missing digits	1.29	0.03	6.77	13.11	70.73	9.39
Other	1.02	0.02	0.0	0.87	53.29	45.84

Appendix Table A7.2 *Percentage of Students Whose Teachers Feel Calculator Availability Has Affected Specific Content Areas*

Content Area	n	Yes (%)	If yes, state how:	%
Sets	1428	48.8	Check answer with calculator	49.7
			Aids teaching of multiplication & computation	50.3
Number Systems	1428	20.1	Teaching fractions	1.6
			Teaching weaker pupils	24.2
			Reinforces rules	11.9
			Check answers	49.2
			Must display all calculations	13.0
Applied Arithmetic & Measure	1428	46.3	More time for methods	24.6
			Decimal calculation of percentages	2.0
			Less computation	17.9
			Check answers	15.0
			Helps weaker students	9.2
			Log tables not needed	8.8
			Answers more accurate	10.6
			Less time spent on because calculators	12.0
Algebra	1428	13.9	Leaves more time for methods	23.5
			Check answer by substitution	9.4
			Check answer with calculators	26.0
			Helps weaker students	14.1
			Helps with signs	27.1
Statistics	1428	68.2	Check answers by substitution	32.8
			More difficult questions were attempted	18.8
			Give pupils confidence	9.3
			Calculating means	6.0
			Quicker addition	14.2
			Quicker calculation	14.1
			Makes calculations easier	4.7
Geometry	1428	6.9	Check answers using calculator	56.8
			Quicker computation	43.2
Trigonometry	1428	49.9	Don't use log tables	67.1
			Easier than maths tables	4.2
			Functions	7.5
			Quicker calculation times	7.8
			More trigonometry completed	5.0
			Lack of understanding	4.8
			Spend a long time explaining angles	3.6
Functions and Graphs	1428	25.0	Effective in graphs	20.2
			Has replaced tables	11.3
			Computing outputs	21.9
			Has replaced drawing standard box	4.1
			Substituting X & Y coordinates	11.8
			Check answers with calculator	13.8
			Calculation times quicker	10.6
			Calculation difficulties reduced	6.3

Note: Percentages in the final column are expressed as a percentage of those who indicated a 'Yes' response to the question

Appendix Table A7.3 *Percentage of Students Whose Teachers Identified Additional Benefits of Calculator Availability*

	n	%
Greater confidence for weaker pupils	179	10.4
Trigonometry & statistics made easier	415	24.2
Faster than using log tables	232	13.5
Makes work less tedious	11	0.7
Unfamiliarity with tables doesn't hinder concepts	119	6.9
Complicated division & multiplication made easier	48	2.8
Improves time management	154	8.9
No need to teach log tables	111	6.5
Can cover more topics	117	6.8
Fractions & decimals easier to teach	93	5.4
More accurate results	49	2.9
Gives greater independence	130	7.6
Good for checking hand written work	17	1.0
Negative numbers easier to teach	19	1.1
Total	**1718**	**100**

Appendix Table A7.4 *Percentage of Students Whose Teachers Identified the Following as the Greatest Drawbacks of Calculator Availability*

	n	%
Mental arithmetic suffers	154	11.1
Pupils believe what appears on screen	91	6.5
Check multiplication tables on calculators	0	0.0
Don't estimate answers	67	4.8
Often leave calculators at home	405	29.0
Use calculators when they're not needed	126	9.1
Don't understand concepts	21	1.5
Don't have a calculator for homework	7	0.5
Difficult to get used to diff calculator brands	310	22.2
Problem understanding features of the calculators	8	0.6
Difficult to spot errors when working isn't recorded	31	2.3
Not familiar with tables	12	0.9
Fall behind if forget calculators	42	3.0
May lose the skills they need	32	2.3
Having calculators in the wrong mode	58	4.2
Calculators get broken in school bags	27	1.9
Total	**1393**	**100.0**

APPENDIX 8 – ADDITIONAL TABLES CHAPTER 8

Appendix Table A8.1 *Comparison of Mean Scores on the Calculator Optional Tests, by Calculator Availability*

Mean Score	Level	Diff (Available – Not Available)	SED	95%CI	
Scale Scores	Higher	49.70	5.58	**38.57**	**60.83**
	Ordinary	40.61	3.87	**32.88**	**48.34**
	Foundation	33.14	10.23	**12.72**	**53.57**
% Correct (B)	Higher	21.96	2.16	**17.65**	**26.27**
	Ordinary	18.19	1.78	**14.63**	**21.75**
	Foundation	13.21	4.38	**4.46**	**21.96**
OMPS	Higher	-0.03	0.06	-0.15	0.09
	Ordinary	-0.08	0.15	-0.37	0.21
	Foundation	0.15	0.15	-0.16	0.46

Diff = Difference; SED = Standard Error of the Difference; 95%CI = confidence intervals; significant differences in ***bold****.*

Appendix Table A8. 2 *Performance on the Foundation Level Junior Certificate Mathematics Examination, by Year*

Year	Grade A-C	D	E-NG
2001	73.2	18.7	8.1
2002	73.5	19.4	7.1
2003	82.8	13.6	3.6
2004	85.9	12.0	2.1
2005	77.0	17.7	5.4

Appendix Table A8.3 *Performance on the Ordinary Level Junior Certificate Mathematics Examination, by Year*

Year	Grade A-C	D	E-NG
2001	68.4	20.2	11.4
2002	67.5	23.2	9.3
2003	71.5	20.8	7.7
2004	75.1	17.7	7.2
2005	73.0	18.8	8.2

Appendix Table A8.4 *Performance on the Higher Level Junior Certificate Mathematics Examination, by Year*

Year	Grade A-C	Grade D	Grade E-NG
2001	77.1	17.9	5.0
2002	74.1	19.8	6.2
2003	79.4	17.0	3.6
2004	73.3	20.3	6.4
2005	75.6	20.0	4.4

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