A Study of the Effects of Calculator Use in Schools and in the Certificate Examinations

Summary Report on Phase I

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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 the introduction 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 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 Junior Certificate mathematics examination). Phase I, which the current report describes, involved administering mathematics tests to a nationally-representative sample of Third-year students who had studied the pre-2000 Junior Certificate mathematics syllabus, and who would not have access to a calculator when attempting the Junior Certificate mathematics examination. Some students had access to a calculator during testing, while others did not. Phase II (which will be carried out in 2003) will involve a similar sample of students taking the same tests. However, these students will have studied the revised Junior Certificate mathematics syllabus, and will expect to have access to a calculator when sitting the Junior Certificate mathematics examination.

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Summary

This report documents the outcomes of Phase I of a two-phase study on 'The Effects of Calculator Use in Schools and in the Certificate Examinations'. The study arose in the context of the intended use of calculators in the revised Junior Certificate mathematics syllabus which was introduced in 2000 for first examination in 2003. The study is funded by the Department of Education and Science (DES).

The objectives of Phase I included the following:

- to summarise international research on the effects of calculator usage and the availability of calculators during testing;
- to examine the extent of calculator usage by teachers and their students in third-year mathematics classes;
- to examine the attitudes of both teachers and students towards calculator usage;
- to examine the effects of calculator availability during testing on student performance; and
- to examine variables that may be related to student performance on tests, where students may or may not have access to a calculator.

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

In preparation for implementing Phase I, three tests were developed:

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

The content of the tests covered aspects of the Junior Certificate mathematics syllabus that were deemed to be relevant for calculator use and also common to all three syllabus levels. These included Number Systems, Applied Arithmetic and Measure, and Statistics. In addition, some Algebra items were presented. While some items were context-free, others were set in practical contexts with 'realistic' data.

In addition to the cognitive tests, Teacher and Student Questionnaires were developed to generate background information. This could be used to interpret the performance of students on the tests.

The tests and the Student Questionnaire were administered to 1469 third-year students in 66 second-level schools in November, 2001, while the Teacher Questionnaire was administered to the students' mathematics teachers. The students were drawn from secondary, community/comprehensive and vocational schools. They represented the last cohort of Junior Cycle students to study the pre-2000 Junior Certificate mathematics syllabus, which did not refer to calculators and for which their use in the Junior Certificate examination was not allowed.

The Phase I study generated important baseline data against which the performance of students in a new representative sample of schools can be compared once implementation of the revised Junior Certificate syllabus has been consolidated. Examples of items at different levels of difficulty on the tests are provided in Appendix 1.

The principal results on each of the Calculator tests are as follows:

(1) *Calculator Inappropriate Test:*

- The mean score on the Calculator Inappropriate Test was 60%.

(2) *Calculator Optional Test:*

- Students with access to a calculator achieved a statistically significantly higher mean score (59%) on the Calculator Optional test than students who did not have access to a calculator (47%).
- The difference in the scores of high-ability students (those achieving at the 90th percentile) with and without access to a calculator was not statistically significant.
- The greatest difference (statistically significant) in performance between those with and without access to a calculator was observed in the area of Number Systems (notably items involving square roots and/or long division). Smaller differences (not statistically significant) were observed on items in Applied Arithmetic and Measure, and Statistics.

(3) *Calculator Appropriate Test:*

- The Calculator Appropriate test (mean score 33%) was more difficult for students than either the Calculator Optional (53%) or Calculator Inappropriate (60%) tests. The calculator appropriate test contained more items of the 'problem-solving' type than did the other two.
- The written responses to the Calculator Appropriate items revealed that many students did not record intermediate steps in their work, even when it might have been advantageous to do so.

(4) *Performance by Gender:*

- Male students outperformed female students on two of the three tests (Calculator Inappropriate, Calculator Optional), and female students outperformed male students on the third (Calculator Appropriate). However, differences between mean scores were not statistically significant, nor was the interaction between gender and calculator availability on the Calculator Optional test.

(5) *Performance by Junior Certificate Level:*

- Students who planned to take the Junior Certificate mathematics examination at Higher level in 2002 achieved a significantly higher mean score on the three tests than students who planned to sit the examination at Ordinary/Foundation levels.
- On the Calculator Optional test, the mean score of Ordinary/Foundation level students with access to calculators was statistically significantly lower than the mean score of Higher-level students without calculator access. However, the actual difference between scores was small.

(6) *Familiarity with Calculators and Performance:*

- Students who reported working with a calculator at school (regardless of subject area) enjoyed an advantage on the Calculator Appropriate test over those who did not. This suggests that, as students become more familiar with the use of calculators in mathematics, their performance on tests such as the Calculator Appropriate test may also improve.

(7) *Student Attitudes Towards Calculators:*

- Students were generally positively disposed towards calculators. While 71% 'agreed' or 'strongly agreed' with the view that calculators could help them to achieve better marks in school mathematics, just 47% showed similar levels of agreement with the view that calculators could help them to get better at mathematics.
- A minority of students (19%) 'disagreed' or 'strongly disagreed' with the view that they should be allowed use calculators in the Junior Certificate mathematics examination.

(8) *Teacher Attitudes Towards Calculators:*

- Just 14% were taught by teachers who allowed the use of calculators in mathematics classes by their current Third-year students.
- Over 70% of students were taught by teachers who believed that Junior Certificate students should be allowed to use calculators in mathematics class, while 73% were taught by teachers who believed that calculators should be used in the Junior Certificate mathematics examination.
- A small proportion of students (about 15%) were taught by teachers who were negatively disposed towards calculator usage either in mathematics classes or in the Junior Certificate examination.
- Teachers indicated that a calculator would be most suitable for use as a tool for teaching and learning mathematics in Trigonometry, Applied Arithmetic and Measure, Statistics, and Functions and Graphs.

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

1. Context of the Study

The purpose of this chapter is to outline the context in which the 'Study on the Effects of Calculators in Schools and in Certificate Examinations' took place. First, recent revisions to the primary school mathematics curriculum in Ireland are considered as they relate to calculator usage. Second, background information on the introduction of calculators into the second-level mathematics programme is produced. The third and fourth sections address the evolution of calculator usage in mathematics at Senior and Junior Cycles respectively.[1]

1.1 PRIMARY SCHOOL MATHEMATICS CURRICULUM

At the time of the introduction of the revised Junior Certificate Mathematics syllabus (September 2000), *Curaclam na Bunscoile* (Department of Education, 1971) was operating in primary schools, and had done so for almost three decades. Not surprisingly, *Curaclam na Bunscoile* makes no mention of calculators. However, in the revised *Primary School Mathematics Curriculum*, published in 1999, the calculator is introduced from Fourth class up. In the revised curriculum, objectives dealing with computation specify that 'students should be able to [perform the various operations/computations] without and with a calculator' (DES / NCCA, 1999, p. 88). The mathematics element of the revised curriculum was implemented in Autumn 2002. Thus, the first effects of the changes will be found for the cohort progressing to First Year in Autumn 2003 (having experienced the revised curriculum in Sixth Class), and taking the Junior Certificate examination in Summer 2006.

1.2 SECOND-LEVEL MATHEMATICS: PRE-CALCULATOR ERA

By contrast with the situation at primary level, mathematics syllabi at second level were revised a number of times in the past thirty years. Updates were made to what was then the Intermediate Certificate syllabus[2] in 1973 (for first examination in 1976), and the Leaving Certificate syllabus in 1976 (for first examination in 1978). In neither case was calculator use a matter of major discussion, and calculators were not mentioned in the syllabi. In the ensuing years, the issue came to the forefront. Arguments in favour of calculators typically emphasised their usefulness in removing the need for tedious computation when this was not the main focus of attention (for example, when dealing with percentage, area or volume) and in preparing students 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 latter 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 these examinations should test basic numeracy

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

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

skills. According to this argument, calculator use in examinations for other subjects at Junior Cycle level, and in Leaving Certificate examinations, was acceptable because basic numeracy was not an assessment objective in these cases.

The Intermediate Certificate syllabus was revised again during the 1980s – the revised version being introduced in 1987 for examination in 1990 – but calculators were not mentioned in the syllabus, and the ban on their use in the corresponding examinations remained in force. Utilisation 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 acted as a disincentive to their utilisation.

1.3 CALCULATORS IN THE SENIOR CYCLE

At Senior Cycle level, non-programmable electronic calculators were permitted in the mathematics 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, typically candidates were told to take π to equal $^{22}/_{7}$ and the radius of a circle would be a multiple of 7 to allow easy cancellation. In practice, however, use of a scientific calculator became the norm.

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

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

1.4 CALCULATORS IN THE JUNIOR CYCLE

By this time, the position at Junior Certificate level had become anomalous. Reviews of Junior Certificate mathematics in the early 1990s by the National Council for Curriculum and Assessment (NCCA) Mathematics Course Committee had identified the absence of calculators from the syllabus and examinations as one of the chief negative aspects. Arguments against calculator use on grounds of cost or social inequity were less powerful than previously because of the falling price of machines. The availability of reasonably-priced scientific calculators, in particular, obviated the need for very time-consuming (and arguably outdated) use of four-figure tables in dealing with trigonometry. Technical problems with calculators in the examinations in which they were permitted did not appear to be an issue. Moreover, it was becoming clear that calculators would be included in the revised *Primary School Mathematics Curriculum* as described above. 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 included in the assessment objectives. Also, as in the revised *Primary School Mathematics Curriculum*, increased emphasis was given to estimation in the syllabus, and it was intended that this too should be assessed. Benefits with regard to examinations include the fact that questions could now include more realistic data and – a minor but not insignificant point – a more accurate value of π could be specified.

1.5 NEW DIRECTIONS

In 2001, a booklet, *Calculators: Guidelines for Second-Level Schools* (DES / NCCA, 2001), was issued to schools. The booklet was designed to familiarise school personnel with the rationale underlying the introduction of calculators into the teaching-learning process in mathematics and in other subjects, to deal with issues relating to the development of a school policy on calculators, and to provide advice on calculator usage in state examinations. In relation to mathematics examinations, it was suggested that students should continue to provide detailed supporting work when solving problems.

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

2. Calculators in Mathematics – What the Research Says

The basic or four-function calculator is permitted at primary level in many countries. At second level, the scientific calculator is well established and increasingly, the graphics calculator is being used. This chapter looks at the availability and use of calculators in the teaching and learning of mathematics and at connections between calculator use and achievement.

2.1 CALCULATOR AVAILABILITY AND USAGE

Given the affordability of the simple hand-held calculator, it is hardly surprising that it is easily available in the workplace and at home. However, some controversy has surrounded its use in the classroom as teachers, parents and students have felt that calculator usage might cause a diminution of mathematics skills. The extent of the gap between acceptance of the calculator in society and its acceptance in the classroom varies among countries. Internationally, there is a reluctance to incorporate the device on a frequent basis in primary schools (Mullis, et. al., 1997). In Ireland, it has been found that, in primary schools (before the introduction of the revised curriculum), calculators tended to be used by lower-achieving rather than by higher-achieving students (Shiel & Kelly, 2001).

With regard to degree of calculator usage in Irish second-level schools, pertinent information is available in international surveys such as the Second International Assessment of Educational Progress (IAEP II), and the Third International Mathematics and Science Study (TIMSS). In the Irish national report on IAEP II, which took place in 1991, it was reported that the use of electronic calculators for mathematics was less common in Ireland than in most participating countries, with just over 25% of 13-year-old students reporting usage of a calculator (Martin, et. al., 1992). Data from TIMSS suggest substantial differences in reported usage of calculators between countries. In Ireland, just 24% of students were taught by teachers who reported calculator usage at least once a week. This contrasts sharply with countries like Australia, Canada, England, Iceland, Netherlands and Singapore where over 80% of students used calculators in mathematics classes 'almost every day' (Beaton, et. al., 1996).

2.2 CALCULATORS AND ACHIEVEMENT

As the calculator gains in acceptance in both primary and second-level schools in Ireland, what will its effects be on mathematical achievement? American and European research on the use of the basic calculator was conducted mainly in the 1980s and early 1990s, predominantly in primary schools. Interest then turned towards the microcomputer. More recently, the effects of graphics calculator usage at second-level has received some attention.

2.2.1 Short-Term Studies

Early research into effects of calculator usage has boded well for the introduction of the calculator. Hembree and Dessart (1986) conducted a meta-analysis of 79 calculator research reports. The studies were concerned with students in the mainstream mathematics programme in Kindergarten to Twelfth-grade (Grades K-12 in the United States). In each of the studies that met the criteria for inclusion in their analysis, one group had access to a calculator during a treatment period and the other group covered similar material without access to a calculator. The length of treatment varied from one class period to a full school year. Their findings suggest that calculator usage does not lead to a deterioration in basic paper-and-pencil skills (except, perhaps, at grade 4) and, in fact, enhances these skills for students of average ability. However, availability of the calculator during the testing process appears to be a crucial factor in producing better results. The main effect of calculator usage on solution of word problems was avoidance of computational errors but it can also facilitate choice of correct operation (Szetela, 1982).

2.2.2 Long-Term Studies

Most long-term studies have focused on the use of the hand-held calculator at primary level. The CAN project was part of PRIME, a U.K. project which was established to examine the effect of integration of new technology, especially calculators, into the number curriculum (Shuard, 1992, p. 33). CAN commenced in September 1986 and initially involved twenty classes of 6-year-old children and their teachers. The teachers involved in the project were asked to allow the children to decide for themselves whether or not to use the calculator and they were encouraged not to teach the paper-and-pencil methods for the four number operations. Among the observations that arose as part of the qualitative evaluation of the project were that children were working on topics normally considered too difficult for their age, that they developed an interest in non-calculator methods of calculation, and that there was a growth in problem-solving and investigative work.

The Calculator as a Cognitive Tool project (CCT) was another U.K. research project. It looked at a cohort of primary children who commenced Year 1 at the start of the 1990/91 academic year and completed primary education at the end of 1995/96. Of the six schools involved, three had participated in the CAN project. On Key Stage 2 mathematics tests (administered at age 11), no significant differences were found between the results of the post-CAN and non-CAN schools, suggesting that participation in the project had neither advanced nor hindered the children's achievement in the long term. Such findings suggest that factors other than tools used for computation impact on the learning of mathematics (SCAA, 1997).

The Calculators in Primary Mathematics Project (CPM) was an Australian project based on a similar approach to CAN. It commenced with kindergarten and first grade in 1990 and involved approximately 1000 children and eighty teachers in six schools in Melbourne (Groves & Stacey, 1998). The project followed the children through the schools to fourth grade in 1993. Data compiled from interviews and written tests showed that project children performed better than non-project children on items involving negative numbers, place-value in large numbers and, in particular, decimal numbers. Furthermore, project children were more discerning in their choice of calculating device.

2.2.3 International Surveys

Data from international surveys give some indication, not only of the levels of calculator usage in different countries, but also of associations between usage and the mathematics achievement of 13-15 year olds. The results of the IAEP II survey showed that, in England, Scotland, France, Canada, Hungary and Taiwan, over two thirds of students reported using a calculator in school (Lapointe, Mead & Askew, 1992). In each of these countries the average score of the group of students that used a calculator in school was found to be significantly higher on a test for which calculators were not available than the average score of the group that did not. In Ireland, however, where just over 25% of 13 year old students reported use of a calculator in school, there was no difference between the average mathematics scores of those who did and did not use a calculator (Martin, et. al., 1992). As there are no data available on the characteristics of the Irish students who used a calculator at school, these results should be interpreted cautiously.

The TIMSS study, which was conducted in 1995, provides information on calculator usage among students in countries that participated in the study. High performing countries in this study include Singapore, Japan and Korea. However, the profiles of these countries in terms of calculator usage contrast sharply. Approximately three quarters of teachers in Japan and Korea report 'never or hardly ever' using the calculator at grades 7/8 while in Singapore over 80% of teachers report using the calculator almost every day. Another contrast is provided by France and Ireland. The mean achievement of students in these countries is broadly similar, yet extent of calculator usage is markedly different (Beaton, et. al., 1996). Again, this suggests that factors other than a calculating device bear influence on mathematical achievement.

In 2000, the first cycle of Programme for International Student Assessment (PISA), an international assessment involving 15-year old students in second-level schools, was conducted. Twenty-eight OECD countries, including Ireland, participated in the assessment. On the test of mathematical literacy, students were permitted to use calculators if their principal teachers had indicated that they normally used a calculator during mathematics lessons. Just over one quarter of Irish students for whom responses were available stated that they used the device in the assessment. The mean score of students with access to a calculator was significantly higher than that of students who said that they did not have access to a calculator (Shiel et. al., 2001) – although PISA items were designed to be calculator neutral and so would not be expected to confer an advantage on students with access to a calculator. Important caveats here are that no information is given on the characteristics of students with/without a calculator, and that information on usage of calculators during testing is not available for other countries in PISA.

2.3 CALCULATORS IN ASSESSMENT

The main rationale for the incorporation of the calculator in assessment is based on the premise that it promotes a shift in emphasis in what is tested and consequently what is taught, away from computation to problem-solving and mathematical reasoning. Calculator usage also means that more time can be spent on mental arithmetic and estimation. Therefore, issues around calculators in assessment include the development of items that test basic computation, estimation, and problem-solving skills (Greenes & Rigol, 1992). In the construction of items for the assessment of estimation, a multiple-choice format has been found to give accurate feedback on students' competencies in this area (Payne, 1992). Also, student familiarity with a calculator appears to be a key factor in performance on tests (Hopkins, 1992).

It might be safely concluded from the existing research literature that, while the calculator has not harmed acquisition of mathematical skills, it is one of several factors that should be considered in attempts to improve mathematical achievement.

3. Framework for the Study

This chapter describes the development of a framework for the tests used in the calculator study. It also outlines the design of the questionnaires.

3.1 CALCULATOR TESTS

The research requirements specified by the DES for the cognitive testing component of the project were:

- To assess present levels of students' skills and understanding in the areas of:
  - o mental and written arithmetic skills
  - o calculator skills
  - o understanding of number
  - o 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 over time 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 (hence, to a cohort which would not use calculators in the Junior Certificate mathematics examination), and the second when the new courses were established (hence, to a cohort that was being prepared to use calculators in the Junior Certificate examination). This report deals with the first phase of testing.

For the design of the cognitive tests, three types of issues needed to be answered: *calculator issues*, *curricular issues*, and *assessment issues*. Suitable items then had to be chosen or written and assembled into tests.

3.1.1 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 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-specific skills, as this would typically involve observing individual students as they worked. 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 $(3 \times 4) / 2$), and another section (for which calculators would be provided) should consist of items for which use of a calculator is deemed *appropriate* (for example $(3.12 \times 24.75) / 0.2052$). It remained to consider the placement of items for which the use of a calculator might be considered as *optional* (for example $(3.1 \times 25) / 2$: these could be tackled sensibly using either a calculator or pencil and paper). Inclusion of a section consisting of items of this type would allow a 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 2.1: SUMMARY OF TESTS DEVELOPED

Calculator Inappropriate Test –
No Calculator Available –
All Students

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

Calculator Appropriate Test –
Calculator Available –
All Students

3.1.2 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 as meaning use of a calculator for computation and problem-solving. Since one of the main arguments for encouraging calculator use in schools is to allow students to address problems containing 'realistic' data, 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, finding maximum and minimum values of areas and volumes. However, this type of work has not been emphasised in the Irish school mathematics curricula, and the revised syllabus (DES/NCCA, 2000) and *Guidelines for Teachers* (DES/NCCA, 2002) do not focus on change in this respect. Test questions on these areas, therefore, would test students' familiarity (or unfamiliarity) with the basic methodology of investigational approaches rather than their skill in using 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.

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

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

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

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

3.1.4 Compiling the Test

Items were located, or written when necessary, and were then assembled into tests using the principles devised above. Details of the number and type of items for each component of the main test are given in Chapter 4. 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 the greater complexity in some cases was due only to the use of 'realistic' (rather than conveniently rounded) numbers, whereas in other cases it was due to the amount of problem analysis required. The Calculator Appropriate test contained items predominantly of the 'applied' type (emphasising the use of the calculator with 'realistic' data), while a high proportion of those in the Calculator Inappropriate test were ‘pure’, emphasising basic numerical skills. Finally, 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.

3.2 QUESTIONNAIRES

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

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

4. Implementation of the Study

This chapter describes the implementation of the Calculators in Mathematics study in second-level schools. It describes the pilot and main studies, and refers to procedures used to analyse the data gathered during the main study.

4.1 THE PILOT STUDIES

Prior to implementing the main study in November 2001, 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. In addition to providing valuable information on the performance of a large number of items for the tests, the studies pointed to aspects of test administration that might be fine-tuned in the main study, including the allocation of time to different tests. Informal feedback on the quality of the Teacher and Student Questionnaires was obtained from teachers and students, respectively.

4.2 THE MAIN STUDY

Following the second pilot study, test booklets were prepared for the main study. The items for the Calculator Appropriate test were divided between two booklets, with half the sample taking one form of the test and half taking the other; this allowed a substantial number of items to be used in the comparatively short time frame allocated for the tests. Table 4.1 shows the distribution of items in the main study by mathematical content area. Table 4.2 gives the distribution of items by item type (multiple choice or short constructed-response). Examples of items similar to those on the tests are given in Appendix 1.

TABLE 4.1: NUMBERS OF ITEMS ON THE CALCULATOR INAPPROPRIATE, CALCULATOR OPTIONAL AND CALCULATOR APPROPRIATE TESTS, BY MATHEMATICS CONTENT AREA – MAIN STUDY

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

*Refers to both forms combined.

TABLE 4.2: NUMBERS OF MULTIPLE-CHOICE AND SHORT CONSTRUCTED-RESPONSE ITEMS ON THE CALCULATOR INAPPROPRIATE, CALCULATOR OPTIONAL AND CALCULATOR APPROPRIATE TESTS – MAIN STUDY

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 combined.

The main study was implemented in November 2001. Ninety schools were invited to participate. As indicated in Table 4.3, these included five school types – large Secondary, small Secondary, large Vocational, small Vocational, and Community/Comprehensive. Size was determined by the total number of students enrolled in the First to Third years (Junior

Cycle). Sixty-six schools (including four replacement schools) agreed to participate, yielding a response rate of 69% before replacement, and 73% after replacement. Within each selected school, one Third-year class was selected at random to participate, with one exception, where two classes were selected.

TABLE 4.3: POPULATION, SELECTED SAMPLE, AND ACHIEVED SAMPLE OF SCHOOLS, BY STRATUM – MAIN STUDY (NOVEMBER 2001)

	Population*			Achieved Sample		
Stratum	Schools	Students	p**	Schools	Students***	p**
Secondary – Large	265	86830	50.5	34	792	53.91
Secondary – Small	122	19031	11.07	7	132	8.99
Vocational – Large	85	26310	15.3	8	175	11.91
Vocational – Small	80	11482	6.68	3	60	4.08
Community/ Comprehensive	84	28306	16.46	14	310	21.10
Total	636	171959	100	66	1469	100.0

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

The three calculator tests were administered to students by their mathematics teacher, or by a senior mathematics teacher in their school. First, all students attempted the Calculator Inappropriate test, without access to calculators. Then, one half of students (half of each class) attempted the Calculator Optional Test with access to calculators, while one half attempted the test without access. Finally, all students attempted one of the two forms of the Calculator Appropriate test, and all had access to calculators. After taking the three tests, students completed the Student Questionnaire, while their mathematics teachers completed the Teacher Questionnaire.

In all, 1469 students completed the Calculator tests. Of these, 1418 students returned completed Student Questionnaires. Of the 67 teachers whose classes were tested, 64 returned completed Teacher Questionnaires. The responses of these teachers were mapped to the data for 1416 students taught by the responding teachers.

Items on the three tests were scored by third-level mathematics students. Items were scored on the basis of whether they were right or wrong, according to an answer key. No partial credit was given.

4.3 SCALING AND DATA ANALYSIS

The calculator test data were analysed using a number of procedures, including percentage correct methods and Item Response Theory (IRT). IRT scaling is particularly useful in a study such as this as a small number of items can be removed, and new ones added, when the tests are being prepared for Phase II. More detailed information on scaling and analysis may be found in Appendix 2.

Prior to analysis, achievement and questionnaire data were weighted to take into account the somewhat unequal representation of students from different school types in the sample. A weight was computed for each class. It took into account the probability of selecting the school and class, and the level of absence within the class. The resulting weight was then applied to each student in the class.

Several procedures were used to analyse the data. These included conducting tests of statistical significance to examine differences between mean achievement scores, computing correlation coefficients, and carrying out factor analyses and computing factor scores. These procedures are also described in Appendix 2.

5 Performance on the Calculator Study Tests

This chapter describes student performance on the three tests used in the study: the Calculator Inappropriate test, for which students did not have access to calculators; the Calculator Optional test, for which only one half of students had access to calculators; and the Calculator Appropriate test, for which all students had access. Performance is described in terms of percent correct scores on each test, and on the different mathematical content areas covered in the tests.

5.1 STUDENT PERFORMANCE BY TYPE OF TEST

This section describes the performance of students on the three Calculator tests.

5.1.1 The Calculator Inappropriate Test

The purpose of the Calculator Inappropriate test was to obtain insights into the performance of students without access to a calculator on a set of items that could (and perhaps should) be performed mentally or with minimal use of pen and paper. The items were mainly in the area of Number Systems and Applied Arithmetic and Measure. The overall percent correct score of students on this test was 60% (SE = 2.1%). The items on which students did best were all in the Number Systems area, and included:

- Identify the (decimal) number corresponding to a fraction (87%) (see Appendix 1, example A1)
- Divide a positive integer by a negative integer (83%).

Some of the most difficult items were in the area of Applied Arithmetic and Measure, and included:

- Calculate the percentage profit, given the cost price and selling price of a CD (expressed as single-digit amounts) (45%) (see Appendix 1, example A2)
- Calculate the volume of a cylinder, given the diameter and height (28%).

5.1.2 The Calculator Optional Test

Items on the Calculator Optional 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. Items for this test were distributed over four content areas: Number Systems, Applied Arithmetic and Measure, Algebra, and Statistics. The mean score of students who completed the Calculator Optional test with access to a calculator was 59% (SE = 2.9), while the mean score of those who attempted the test without access was 47% (SE = 2.09). The difference was statistically significant.

Items on which students with and without calculators achieved similar scores, and items on which they differed are given here:

Items with small differences (i.e., the differences are not statistically significant)

- Number Systems: Find the sum of three numbers expressed as fractions (57% with calculator; 58% without calculator)

- Applied Arithmetic and Measure: Given an illustration of a rectangular picture pasted to white paper, and the length and breadth of the paper and the picture, find the area of the paper not covered by the picture (59% with calculator; 56% without calculator).

Items with large differences (i.e., the differences are statistically significant)

- Applied Arithmetic and Measure: Given the thickness of a stack of 120 cards, find the thickness of one card (65% with calculator; 40% without calculator) (see Appendix 1, example B1)
- Number Systems: Find the product of two decimal numbers (94% with calculator; 64% without calculator) (see Appendix 1, example B2).

Students without access to calculators had a higher percent correct score than their counterparts with calculators on just one item on the Calculator Optional test, though the difference between their scores was not statistically significant:

- Applied Arithmetic and Measure: Given the time each of five songs takes to play on a CD (expressed in minutes and seconds), find the total time required to play all 5 songs (34% with calculator; 45% without calculator) (see Appendix 1, example B3).

5.1.3 The Calculator Appropriate Test

The Calculator Appropriate test consisted of items for which it was judged that a calculator would facilitate computation and allow for a focus on problem-solving. Three content areas were assessed: Number Systems, Applied Arithmetic and Measure, and Statistics. The average percent correct score was 33% (SE = 1.61) indicating that students found the test to be quite difficult. In addition to getting items which they attempted wrong, a large number of students omitted to do certain items at different points on the test. The following examples illustrate the range of items on the test:

- Applied Arithmetic and Measure: Given the cost of one can of lemonade, find how many can be bought for €5 (68%)
- Number Systems: Find the square root of a three-digit number to two decimal places (54%)
- Applied Arithmetic and Measure: Given the formula for calculating the area of a circle, find the area of the shaded region in a rectangle in which the circle is embedded (answer to two decimal places) (2%) (see Appendix 1, example C4)
- Applied Arithmetic and Measure: Given a bar chart, find the mean score (50%) (see Appendix 1, example C2).

5.2 STUDENT PERFORMANCE BY MATHEMATICAL CONTENT AREA

This section describes the performance of students on the mathematical content areas assessed by each of the Calculator tests.

5.2.1 Performance on Content Areas on the Calculator Inappropriate Test

Average percent correct scores on subsets of items on the Calculator Inappropriate test ranged from 68% (Statistics) to 53% (Applied Arithmetic and Measures) (Table 5.1). It should be noted, however, that there was just one item each in Algebra and Statistics, so, for these areas, the data represent item statistics.

TABLE 5.1: PERCENT CORRECT SCORES ON MATHEMATICS CONTENT AREAS – CALCULATOR INAPPROPRIATE TEST

Content Area	N of Items	N of Students	Mean Percent Correct*	Std. Dev.	Std. Error
Number Systems	13	1456	64.5	23.81	2.09
Applied Arithmetic and Measure	10	1456	53.1	25.87	2.14
Algebra	1	1456	63.7	48.11	3.10
Statistics	1	1456	67.6	46.82	4.80
Total	25	1456	60.0	24.02	2.10

*Weighted.

5.2.2 Performance on Content Areas on the Calculator Optional Test

Tables 5.2 and 5.3 summarise the performance of students in each content area on the Calculator Optional test, in relation to whether or not they had access to a calculator during testing.

TABLE 5.2: PERCENT CORRECT SCORES ON MATHEMATICS CONTENT AREAS ON THE CALCULATOR OPTIONAL TEST – CALCULATORS AVAILABLE

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

*Weighted.

TABLE 5.3: PERCENT CORRECT SCORES ON MATHEMATICS CONTENT AREAS IN THE CALCULATOR OPTIONAL TEST – CALCULATORS NOT AVAILABLE

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

*Weighted.

The largest, and only statistically significant, difference between the two groups is found in the area of Number Systems. The mean score for the calculator group was 74%, whereas the mean score for the non-calculator group was 53%.

5.2.3 Performance on Content Areas on the Calculator Appropriate Test

Table 5.4 provides the mean scores of students on the Calculator Appropriate test. In computing these percentages, the scores of students taking the two forms of the test were combined. Mean scores ranged from 37% (Statistics) to 31% (Number Systems).

TABLE 5.4: PERCENT CORRECT SCORES ON MATHEMATICS CONTENT AREAS – CALCULATOR APPROPRIATE TEST

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

*Weighted

5.3 PERFORMANCE AT KEY PERCENTILE RANKS

The scores of students at the 10th, 25th, 50th, 75th and 90th percentile ranks on the Calculator Optional Test were compared across the calculator access/no access conditions. It was found that while the difference in performance between students at the 90th percentile was in favour of those with access to a calculator, it was not statistically significant. In contrast, significant differences were observed between those with and without access to calculators at the 10th, 25th, 50th and 75th percentiles. It appears that higher-achieving students (those scoring at the 90th percentile) did not benefit from access to a calculator when attempting the Calculator Optional items to the same extent as students with lower levels of performance, though the difference that was observed at the 90th percentile was in favour of students with access to a calculator.

5.4 INVESTIGATION OF STUDENTS' WORKING

On each page of the tests a 'work column' was provided so that students had a place in which to record calculations if they wished to do so. The items on the Calculator Inappropriate test were intended to be done mentally or with only a small amount of written work. By contrast, most of the items in the Calculator Optional and Calculator Appropriate tests were unlikely to be done by mental methods alone. A study was undertaken to examine this written work using a small selection of the scripts.

For the Calculator Inappropriate test, approximately half of the answers were accompanied by some form of pen-and-paper calculation. Only one question did not produce any written calculation by any of the selected students. For the Calculator Optional test the main interest was the extent to which the two groups – those with calculator access and those without – used the 'work column'. For those with calculator access, about quarter of the answers were accompanied by written work. For those without access, over 70% of answers were accompanied by written work. For the Calculator Appropriate test, a mere 2% showed written work. However the high rate of omitted questions must be taken into account here.

6 Student and Teacher Variables Associated with Performance on the Calculator Tests

This chapter describes student- and teacher-level variables associated with performance on the calculator tests. The data are based on responses of students and teachers to questions on the Student and Teacher questionnaires, respectively.

6.1 STUDENT VARIABLES

In this section, associations between performance on the Calculator tests and a range of student variables are considered. The variables include gender, intended Junior Certificate examination level, socio-economic status, frequency of use of calculators at home and at school, attitude towards mathematics in general, and attitudes towards calculators in mathematics.

6.1.1 Gender

Small differences in favour of male students were observed on the Calculator Inappropriate and Calculator Optional tests, and a difference in favour of females was found on the more difficult Calculator Appropriate test. However, none of the differences was statistically significant. No significant interactions were found between gender, calculator availability and performance on the Calculator Optional test.

6.1.2 Junior Certificate Examination Level

About one half of students indicated that they intended to take the Higher level Junior Certificate mathematics examination in June 2002 (some 7 months after the study); the others indicated an intention to sit the examination at Ordinary or Foundation levels. Intending Higher-level students achieved significantly higher mean scores on the three Calculator tests than students intending to take the examination at Ordinary or Foundation levels. Mean score differences were large – about one half of a standard deviation on each test.

In a follow-up comparison of the performance on the Calculator Optional test between Higher-level students without access to a calculator, and Ordinary and Foundation-level students with access, the mean score difference (in favour of the former group) only just reached statistical significance. This outcome suggests that, on the items assessed by the Calculator Optional test, access to a calculator allows students intending to take the Ordinary/Foundation level mathematics examination to approach the mean score of students without a calculator intending to take the Higher level examination.

6.1.3 Socio-Economic Status (SES)

An item on the Student Questionnaire asked students to indicate their parents' main occupations. Responses were coded using the International Socio-economic Index of Occupational Status (ISEI), which places occupations along a continuous scale (see Ganzeboom et al., 1992; Ganzeboom & Treiman, 1996). Using parents' combined occupations, the mean scores of students in the high SES group (those in the top third of the SES distribution) were significantly higher on the three Calculator tests than the mean scores of students in the low SES group (those in the bottom third of the SES distribution). No significant interaction was found between calculator availability, SES and performance on the Calculator Optional test. Correlations between SES and performance on the Calculator Inappropriate (.22), Calculator Appropriate (.20) and Calculator Optional (.17) tests are in the upper end of the weak to moderate range.

6.1.4 Calculators at Home

Nine in ten students indicated that they had access to a calculator at home. However, just 3% indicated that they 'often' used a calculator for homework in Mathematics, 35% that they used one 'sometimes' and 53% that they 'never' used one. Students who 'often' used calculators performed significantly less well on the Calculator Appropriate test than those who 'sometimes' or 'never' did so. The opposite pattern occurred for Business Studies, where students who 'often' used calculators for homework in that subject did significantly better on the Calculator Appropriate test than those who 'sometimes' or 'never' used them.

Students with access to a calculator at home reported having access to basic and scientific calculators in equal proportions. Access to graphics calculators was very limited in both home and school settings.

6.1.5 Student Attitudes Towards Mathematics

Students were supportive of the view that 'mathematics is a useful subject for everyday life', with 78% either 'agreeing' or 'strongly agreeing'. Four in five students indicated that they liked doing sums when they knew the method, while just two in five 'agreed' or 'strongly agreed' that they liked tackling problems. In addition, only two in five reported liking everyday mathematics problems. This suggests a preference for routine procedural work over problem-solving activities of the kind encountered in school. Sixty percent of students either agreed or strongly agreed with the view that they liked mathematics.

A factor analysis indicated that items designed to measure attitude towards mathematics tapped three factors:

- A general positive attitude or disposition to mathematics
- A belief that mathematics is useful in the real world
- A belief in one's own mathematical ability (mathematics self-concept).

The correlations between student factor scores on mathematics self-concept (the third factor) and performance on the Calculator tests were moderate to strong, ranging from 0.38 (Calculator Optional and Calculator Appropriate tests) to 0.43 (Calculator Inappropriate test). Correlations between disposition towards mathematics and performance on the calculator tests were marginally weaker, while those between the usefulness factor scores and test performance were weak and not statistically significant.

6.1.6 Student Attitudes Towards Calculators

Students were generally positively disposed towards calculator usage. For example, 71% 'strongly agreed' or 'agreed' with the view that calculators could help them to achieve better marks in school mathematics. However, just 47% showed similar levels of agreement with the view that calculators could help them to get better at mathematics.

Factor analysis identified three factors tapped by the items designed to assess attitude towards calculators:

- A general positive disposition towards calculator usage in mathematics,

- A positive disposition towards calculators in areas of the curriculum other than mathematics
- A belief that calculator usage is associated with laziness or poor achievement.

Correlations between factor scores on disposition towards calculators and performance on the calculator tests were modest and negative. For example, the correlation between disposition towards calculators and performance on the Calculator Appropriate measure was -0.13. This indicates that lower-achieving students tended to be more positive about calculator usage than their higher-achieving counterparts, where the criterion measure was a test that required use of a calculator.

6.2 TEACHER VARIABLES

Using data from the Teacher Questionnaire, this section examines several issues associated with calculator usage in mathematics, and performance on the Calculator tests. Aspects include current use of calculators in mathematics classes, teacher attitudes towards calculator usage by students in home and school contexts, and teachers' philosophies about teaching mathematics.

6.2.1 Use of Calculators at Home and at School

Seventy-seven percent of students were taught by teachers who did not allow the use of a calculator during mathematics classes. No significant differences in performance were observed on any of the calculator tests for students whose teachers allowed/did not allow a calculator to be used in class. Teachers who did allow the use of a calculator in class indicated that the areas in which they were being used by at least some students were Applied Arithmetic and Measure (13% of all students), Trigonometry (11%), Statistics (9%) and Functions and Graphs (5%).

Teachers were largely positive about whether students *should* be allowed to use calculators for mathematics homework, and for the Junior Certificate Mathematics examination, though there was a tendency to approve of the use of calculators in other subjects to a greater extent than in mathematics (Table 6.1). Almost three-quarters of students were taught by teachers who approved of the use of calculators in the Junior Certificate examination.

Seventy-three percent (or almost three-quarters) of students were taught by teachers who felt that a calculator could be used as a tool for teaching and learning mathematics (i.e., not simply for computational work). The main areas in which teachers thought that a calculator might be used as a teaching and learning tool were Applied Arithmetic and Measure, Statistics, Trigonometry and Functions and Graphs. The areas of Algebra, Geometry, Number Systems and Sets were viewed as providing fewer possibilities. In this phase of the study, teachers were not asked how calculators might be used to facilitate teaching and learning.

TABLE 6.1: TEACHER VIEWS ON CALCULATOR USAGE BY JUNIOR CYCLE STUDENTS IN A RANGE OF HOME AND SCHOOL CONTEXTS – PERCENTAGES OF STUDENTS

	Do you think Junior Cycle students *should* be allowed to use a calculator (where a calculator is relevant to the task at hand)?		
	Yes	No	Missing
Mathematics Homework	74.1	16.3	9.7
Mathematics Class	69.9	18.8	11.3
Homework in Other Subjects	84.5	3.5	12.0
Classwork in Other Subjects	81.8	5.2	13.0
Junior Cert. Maths Examination	72.5	15.9	11.7

6.2.2 Teachers' Perspectives on the Teaching and Learning of Mathematics

Over four-fifths of students were taught by teachers who placed 'a lot' of emphasis on basic mathematical procedures, while 53% were taught by teachers who placed a similar level of emphasis on developing mathematical understanding. Neither developing mathematical applications (e.g., routine problems) nor developing mathematical problem-solving (e.g., non-routine problems, mathematical investigations) received the same level of emphasis. The areas of mathematics which teachers identified as posing most difficulty for students were Trigonometry (the most difficult), Algebra, Geometry, Functions and Graphs and Applied Arithmetic and Measure. Statistics was perceived as being least likely to cause difficulties. The areas that teachers enjoyed teaching most were Statistics (the most enjoyable), Algebra and Trigonometry.

6.2.3 Teachers' Philosophies about Teaching Mathematics

Teachers were asked to position themselves along five continua developed by Becker and Anderson (1998) that sought to ascertain beliefs about the teaching of mathematics. The exercise also allowed insights into whether teachers could be described as 'traditional' or 'progressive'. Teachers in the current study could be described as 'traditional' to the extent that more of them viewed their role as that of 'explaining and showing students how to do mathematics and assigning suitable practice materials' than 'enabling students to discover or construct concepts for themselves'. Teachers adopted a more progressive stance on continua dealing with the need to develop interest and motivation in doing mathematics, and the encouragement of mathematical thinking. Overall, however, teachers tended to be located at the centre of the continua, mid-way between traditional and progressive.

6.2.4 Teachers' Comments on Calculator Usage

Almost all teachers offered at least one comment in a section set aside for comments on the Teacher Questionnaire. An analysis of comments allowed teachers to be grouped as follows (examples of teacher comments in brackets):

- Those who see the calculator as having some positive role or roles (e.g., *'Many students can master methods and concepts, but, because of constant calculation errors their confidence is undermined; hence, they feel "I can't do maths" – the calculator greatly reduces this'*);
- Those who see the calculator as having some negative role or roles (e.g., *'I feel students overuse calculators at the expense of mental arithmetic'*);
- Those who see the need for special emphasis to be given to the development of computational proficiency in the light of calculator availability (e.g., *'I feel that there should be some element of the exam relating to computational ability without the calculator'*);

- Those whose view of calculator usage is related to the context in which calculators are made available, where contexts included curriculum, assessment, and the abilities of students (e.g., *'I believe in the use of the calculator for statistics by very good maths students who fully understand the concepts without calculators – this rarely applies to Third-year students'*);
- Those who expressed concerns about the time available for teaching the Junior Certificate mathematics syllabus (particularly at Higher level) (e.g., *'The course is long and revision time is important – do not want to use class time on developing mathematical problem-solving if it is not examined in the Junior Cert.'*).

The overall impression emerging from these comments is that most teachers would allow or encourage students to use calculators in mathematics work provided they were also allowed on the Junior Certificate examination, but that many teachers placed conditions on this. A small number of teachers believe that the calculator is detrimental to students' mathematical development in any circumstances.

7 Conclusions

The main research goal of Phase I of the study was to assess Junior Certificate students' mathematical knowledge in areas of the school mathematics curriculum where arithmetic or scientific calculators can have a bearing – Number Systems, Applied Arithmetic and Measure, and Statistics. These data can then be used as baseline data in Phase II of the study in 2003 to identify any changes that might occur in such knowledge when students will have experienced substantial calculator use in the context of a revised Junior Cycle syllabus in mathematics, introduced in First-year in schools in September 2000. In Phase I, a nationally-representative sample of Third-year post-primary students was given three mathematics tests and a questionnaire. The students' mathematics teachers were also given a questionnaire. Some qualitative data were collected in the form of teachers' written comments on calculator-related issues in the Teacher Questionnaires, and from students' rough work columns on the mathematics tests.

7.1 PERFORMANCE ON THE TESTS

7.1.1 The Calculator Inappropriate Test

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

7.1.2 The Calculator Optional Test

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

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

7.1.3 The Calculator Appropriate Test

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

7.1.4 Variation in Achievement

Students in the high-ability range of mathematical achievement (those achieving at the 90th percentile) did not appear to benefit as much from calculator access on the Calculator Optional test as their lower-achieving peers. This can be attributed either to more efficient computation strategies of higher performers, or to a ceiling effect on the Calculator Optional Test.

7.2 STUDENTS AND CALCULATORS

The study looked at a number of relevant student variables and their relationship to achievement on the tests.

7.2.1 Gender

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

7.2.2 Junior Certificate Level

Another interesting finding in the area of student variables was that the mean score on the Calculator Optional Test of students planning to do the Ordinary or Foundation level Junior Certificate examination who had access to a calculator was close to (albeit significantly lower than) the mean score of students who were planning to do the Higher-level examination, and who did not have access. This finding emphasises the value of introducing calculators into the Junior Cycle Mathematics syllabus. Calculators can help improve the confidence and performance of lower-achieving students and improve the image of mathematics.

7.2.3 Socio-Economic Status

Predictably, there were positive correlations, albeit weak to moderate, between student SES and mathematics achievement on the three tests. This is in accord with correlations obtained in other mathematics surveys including the recent PISA study (Shiel et al., 2001).

7.2.4 Calculator Use

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

7.2.5 Student Attitude to Mathematics

The three principal factors emerging from the factor analysis of the data obtained with the attitude to mathematics questionnaire – perceived usefulness of mathematics, like/dislike of mathematics, and self-concept in mathematics – are similar to the factors obtained in earlier studies of attitude to mathematics.

7.2.6 Student Attitude to Calculators

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

7.3 TEACHERS AND CALCULATORS

7.3.1 Use of Calculators in Home and School

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

7.3.2 Teaching and Learning Mathematics

Predictably, most teachers said they put a lot of emphasis on teaching basic mathematical procedures and some or very little emphasis on developing applications and problem-solving skills. This probably reflects the balance of emphasis on these processes in the Junior Certificate syllabus and examinations, the tendency of teachers to teach to the examinations, and also teachers' perceptions of school mathematics. The questionnaire data suggested that teachers found Trigonometry and Algebra to be the most difficult areas to teach, while they enjoyed teaching Statistics and Algebra the most.

7.3.3 Teachers Philosophies about Mathematics Teaching

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

7.3.4 Teachers' Comments on Calculator Usage

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

7.4 LOOKING TOWARDS PHASE II

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

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

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Appendix 1: Sample Parallel Items

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

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

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

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

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

Answer______________

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

Answer_______________

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

Answer______________

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

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

Answer_____________

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

Calculator Appropriate Items (C)

C1 Evaluate:

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

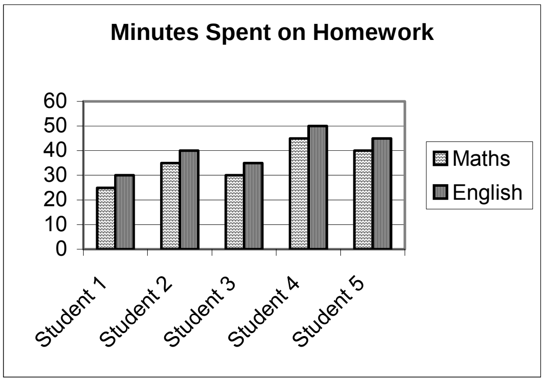
Answer______________

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

C3 How many 700 millilitre bottles of port can be filled from a 350 litre barrel?

Answer______________

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

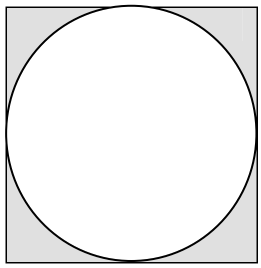


C2 Bar chart shows time (in minutes) spent on homework in Maths and English by a group of 5 students. What is the mean number of minutes spent on maths homework by the 5 students?

Answer______________

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

C4 A circle is inscribed in a square as shown in the diagram. The length of the diameter of the circle is 8cm. The area of a circle is πr^2.



Calculate the area of the shaded region (outside circle but inside the square). Use π on your calculator or take $\pi = 3.14159$. Give your answer correct to two decimal places.

Answer_______________________

Content Area: Applied Arithmetic and Measure
Difficulty Level: Difficult (2%)

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

Appendix 2: Scaling and Analysis Procedures

Scaling the Calculator Tests

Students' responses to the three calculator tests were scaled separately using Item Response Theory (IRT) models. These models involve mathematical expressions that provide the probability of a correct response to an item as a function of the ability of the examinee, allowing items and examinees to be placed along the same underlying scale. A modified three-parameter model was used for the Calculator Inappropriate test, while two-parameter models were used for the other tests. In the case of the Calculator Optional test, item parameter estimates were based on the responses of those who took the test without access to a calculator. These item estimates were then used to estimate all examinee abilities on the test. The mean and standard deviation of the score distribution on each of the calculator tests were set at 250 and 50 respectively. In this report, however, the performance of students on the calculator tests is reported in terms of percent correct scores.

Analysing Mean Score Differences

The standard error provides 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. Standard errors are used in testing hypothesis regarding whether differences between mean scores are statistically significant. A specialised statistical package, WesVar (Westat, 2000), was used to compute standard errors.

In assessing the significance of differences between mean scores, Bonferoni's procedure (Dunn, 1961) was used to adjust the alpha levels for multiple comparisons. This involved dividing alpha (set at .05 in this study) by the number of comparisons to be made. The critical value (t) associated with the adjusted alpha was then identified in a statistical table of such values, using 33 degrees of freedom (the number of variance strata associated with the balanced repeated replicate (BRR) method of variance estimation employed by WesVar).

Computing Correlation Coefficients

Pearson Correlation coefficients (r) were obtained using the square roots of the coefficient of determination (R^2) associated with the linear regression between an explanatory variable (e.g., socio-economic status) and test score performance. In determining statistical significance, the t statistic of the parameter estimate of the explanatory variable was referred to. Values of the correlations can range from -1 to +1. A value of 0 indicates no association between two variables. In this report, the magnitudes of correlations are assigned qualitative labels to assist in interpretation: (weak [<± .1], weak to moderate [± .1-.25], moderate [± .25-.4], moderate to strong [± .4 to.55], and strong [± .55 or greater].

Conducting Factor Analysis

Factor Analysis was used to construct scales summarising the responses to students to attitude towards mathematics and attitude towards calculators items on the Student Questionnaire. First, an exploratory principal components analysis was conducted with each dataset to identify an initial factor solution. Then varimax rotation 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 scores were used in subsequent analyses.