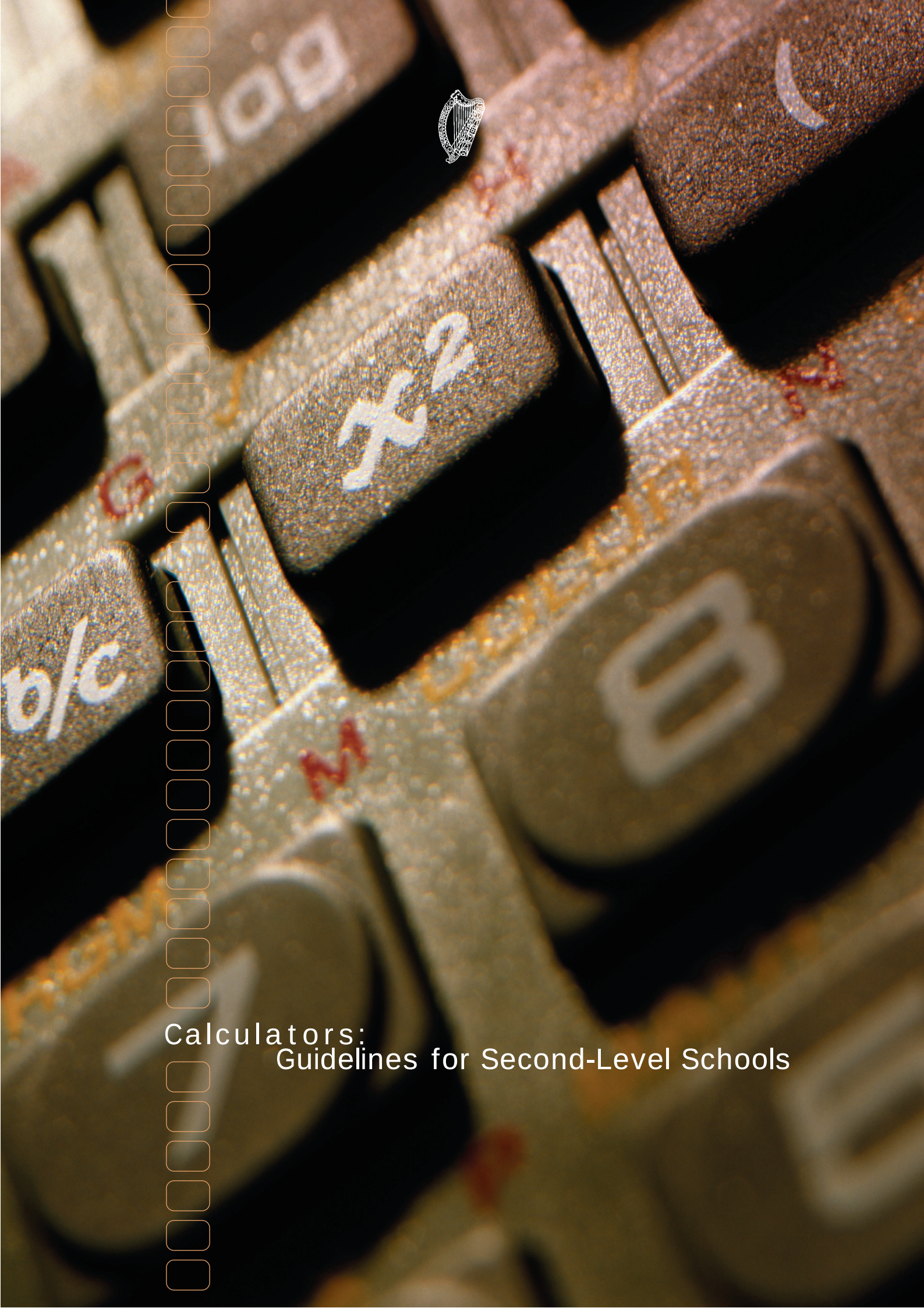

Calculators:
Guidelines for Second-Level Schools

Contents

1 Introduction and Rationale

Introduction

The use of calculators in second-level schools is becoming increasingly widespread. A place for the calculator is firmly established in senior cycle programmes; its use has been allowed in examinations at Leaving Certificate level for more than a decade. In the Junior Certificate Examination, use of calculators is currently permitted only in Business Studies. However, the revised syllabuses in Junior Certificate mathematics, introduced in September 2000 for first examination in 2003, formalise the use of the calculator as a teaching and learning tool at this level. With effect from 2003, use of appropriate calculators is allowed in all subjects in the Junior Certificate Examination.

In light of these developments in curriculum and practice, it is important for schools to consider the approach that they should adopt in relation to calculators and their use. Organisational issues, as well as those to do with teaching and learning, need to be addressed. Schools need to be familiar with the rationale behind the introduction of calculators into various aspects of the teaching-learning process and with the range of possibilities in terms of choice, purchase, storage and utilisation of the machines. This document addresses these issues.

Section 1 of the document summarises reasons for introducing calculators and the benefits that are expected to accrue from their introduction. Section 2 addresses school issues that arise in relation to calculators and their use. Implications for the certificate examinations are addressed in section 3, while a list of resources is provided in section 4.

Rationale and expected benefits

There are many reasons for, and expected benefits from, introducing calculators. A selection is given here.

Calculators are part of everyday life, and in particular of the world of work

Students need to be prepared to use calculators appropriately—accurately and efficiently—in tasks for which they are suitable. Students also need to learn to judge when not to use them; that is, when other methods (such as mental computation) are more appropriate. The relevant skills should be formally taught and learnt in school.

Calculator use is included in the revised Primary School Curriculum

In particular, it forms part of the mathematics curriculum, alongside traditional paper-and-pencil methods, from Fourth Class upwards—that is, after children have learnt and used the basic number facts and skills. (The curriculum specifies that children should be enabled to carry out a variety of calculations "without and with a calculator".) Teaching in the junior cycle can build on the platform provided by the revised curriculum at primary level.

Research indicates that, with calculators, students gain in confidence and their attitude to mathematics improves, and that numerical skills can be maintained and developed

Students who have constantly failed at tasks involving, say, subtraction or long division can now experience success, and their self-esteem can be enhanced as a result. This facilitates further learning. Moreover, many studies suggest that paper-and-pencil skills do not deteriorate when calculators are introduced. The effect of long-term use needs (and is receiving) further monitoring. However, cross-national studies of mathematical achievement do not show any clear relationship between the extent of calculator usage in teaching and learning and scores on attainment tests. The benefits and/or disadvantages are likely to depend on the type of use. The development and maintenance of number sense and computational skills need to be addressed explicitly; teachers should decide the role that the calculator can play in this.

With calculators readily available, more time can be devoted to meaningful learning and problem-solving

Time formerly spent carrying out awkward calculations, and learning and practising techniques rarely used outside school, can be devoted to more useful topics and skills. Mathematics, in particular, can benefit greatly; more attention can be paid to developing concepts and to analysing and solving realistic problems.

The calculator is a teaching and learning laboratory, not merely a computational and reference tool

Calculators can provide great opportunities for enriching both teaching and learning in many subject areas. Even with very simple machines, number patterns can be investigated and number concepts explored. With more powerful calculators, especially those that can display graphs, statistical investigations can be carried out and high-level concepts

explored in many curricular areas. Problem-solving and logical reasoning can be addressed in new ways, and the skill of interpreting and evaluating results can be developed. If some additional equipment is available, the possibilities are particularly exciting; datalogging in science is a notable example.

With increased use of calculators, the development of estimation and checking strategies is given enhanced impetus

The importance of being able to estimate answers, and to judge whether solutions to problems of a mathematical nature are reasonable, has long been recognised. However, it has not always been reflected in teaching and assessment. At both primary and second levels, the wider use of calculators is being accompanied by increased emphasis on estimation.

2 School Issues

The formal introduction of the calculator into the classroom for the upper classes of primary level, and the extension of its use at second level, provide the potential for a significant change in teaching and learning in several areas of the curriculum. It is important, therefore, that schools put in place a carefully thought out approach to managing this resource for the benefit of students. A variety of issues will need to be addressed; some of these are organisational in nature, while others are pedagogical. This section of the document initially provides a summary of these issues and outlines other factors that may contribute to the decision-making with regard to the use of calculators. The issues are then explored in more depth. Calculator types and features are described, teaching strategies and approaches to skill development are considered, and further possibilities are suggested for the use of calculators to enhance teaching and learning across the curriculum.

All issues should be revisited from time to time and school policy should be updated accordingly.

Organisational Questions

The following questions may be useful in discussions aimed at developing school policy in relation to calculators.

- Should the school purchase calculators for classroom use? If so, how many sets should be bought? How will this resource be managed? How or when will the set(s) be upgraded or replaced? Where will the calculators be stored? How will they be distributed and collected from students in such a way as to avoid loss, theft or damage? When or how will lost/stolen/broken calculators be replaced?
- Should the school purchase a number of calculators designed for use on the overhead projector (so that keystrokes and/or results can be seen by the whole class)?
- What provision should be made in respect of students with special needs (physical disabilities and mild general learning disabilities)?
- How are associated resources such as lesson plans, handouts, tests, games and so forth best managed and shared among the teaching team for the benefit of all teachers and students?

- Should the students be required to purchase a calculator? If so, should this be a specified model? What about students who already have a different model?
- If the students bring their own calculators to school, how can the level of loss, theft or damage be minimised?
- Should the school make provision for candidates who forget to bring their calculators to the examinations?

Pedagogical Questions

- Should calculators be available to students at all times in class? Should they be available during all class tests and school examinations?
- How does one ensure that basic mental skills and, where appropriate, paper-and-pencil skills are maintained and developed?
- What is the most suitable model of calculator?
- When should various aspects of calculator use be taught?
- How is consistency across subject areas to be achieved (for example, in the techniques used for handling percentages, or in the approach taken to scientific notation)?
- How can lessons that either develop or depend on calculator use be evaluated in terms of their effectiveness?
- How will the learning requirements of students with special needs be met?

Arriving at a decision

The school's policy on calculator use should be developed inclusively, involving all teachers who may require students to use calculators in their subjects. A consistent approach to calculator use is required if the skills developed by students in one subject area are to be reinforced across the full range of subjects where such use may arise. It will be important, for instance, that due consideration be given to such issues as calculator type, logic type and specific features that may be desirable, as described later in this section. *Experience elsewhere has shown that the adoption of a common calculator type throughout the school avoids many of the problems that arise when individual classes or subject groups opt for different calculator models.*

Where links facilitating the discussion of pedagogical issues exist between a second-level school and feeder primary schools, teachers could take advantage of these to develop some measure of consistency between the two sectors. Obviously this applies to a much broader range of issues than calculator use alone.

Ownership / Purchase of Calculators

There are advantages and disadvantages both to a system in which schools have sets of calculators for classroom use and to one in which students have their own calculators.

Where a class or school set is used

- all students are working with the same model of calculator
- all students will have calculators when required
- calculators are available for lessons such as laboratory work in science
- opportunities arising at any time can be availed of for calculator practice
- the burden of acquiring, managing and updating the stock falls to the school.

Where students have their own calculators

- the calculator is available to them at home, so skills developed in the classroom can be reinforced by appropriate homework
- calculators are available for use in all subjects in a very natural way; students take them out and use them when they need to do so, just as in everyday use outside school
- students may be inclined to treat their own calculators with greater care than perhaps might be the case where class or school sets are being used
- difficulties may arise if students have different makes or models of calculator.

Where some or all students in a given class or year already have their own calculators, there may need to be a degree of flexibility with regard to specifying a particular model. A phased process of specification may need to be considered.

It should be noted that modified technology is available to assist students who are visually impaired, or who do not have the required motor skills to operate a standard calculator.

Calculator types and features

Variety of calculator types

Four main types of calculator are available at present, with features as described in the table below.

Type	Features
Four-function	add, subtract, multiply and divide
Scientific	as above plus trigonometric functions, power and root keys, log and exponential keys, and simple statistical operations
Graphics*	all the preceding keys and functions; greatly expanded (usually programmable) memory; function definition; drop-down menus; tabulation and graphing facilities; max/min capability; split screen or full screen selection; editing capability; zoom, window, trace keys; matrix manipulation and numerical solutions of various types of equation; full statistics menu
Computer algebra system (CAS)*	as for graphics calculators, plus additional features for dealing with algebra and differential and integral calculus. CAS machines allow for varied simultaneous approaches, for example in solving equations and finding roots

* These types of calculator are not allowed in the public examinations. (For details, see inside the back cover of this document.)

Graphics calculators and CASs

The fact that the use of graphics and/or programmable calculators and CAS machines is not at present allowed in the Junior Certificate or Leaving Certificate Examinations does not preclude their use as a powerful teaching and learning resource in school. Use of graphics calculators for purposes of real-time datalogging in science subjects is becoming more common; they also have many advantages for teaching and learning several topics in mathematics. *Schools might give serious consideration to the purchase of a class set of graphics calculators for use in teaching and learning across a number of subjects.* A full class set of graphics calculators, along with a connecting OHP display panel, can be purchased for the cost of one or two personal computers.

Important issues relating to calculator type

Two particular issues arise in respect of different calculator types. It is important that these are brought to the attention of students, especially if they are required or encouraged to purchase their own personal calculators.

Arithmetic v algebraic logic

Consider the following sequence keyed into a calculator:

If the calculator executes operations in the order in which they were keyed in, the answer displayed will be 14—which is incorrect. If the calculator follows the conventional order of precedence for arithmetic operations, it will display the correct answer, 11. The first type of calculator is referred to as an arithmetic logic calculator. Many four-function and desktop business-style calculators are of this type. Virtually all scientific calculators, on the other hand, are of the second type. These are called algebraic logic calculators, and they apply the conventional rules of precedence to any sequence of arithmetic operations. ***Scientific calculators with algebraic logic are recommended for second-level students.***

Key sequencing

Most manufacturers have been moving towards producing calculators into which mathematical expressions can be keyed, keeping the same order in which they appear in writing. For example, when evaluating sin40°, it was necessary to use the key sequence [40][sin]. On modern models it is more common to enter [sin][40][=]. Such keying logic allows users to evaluate expressions by entering them in a very natural way. ***Calculators with this type of keying logic are the most appropriate for school use.***

With regard to rules of precedence for arithmetic operations, the mnemonic BOMDAS—also known as BEMDAS or PEMDAS—commonly used in schools will be familiar to many students. It is important that students understand all such rules of precedence and that they are aware of errors which may arise where the order of operations is not managed carefully. Such issues—together with their implications in respect of examinations—are addressed in more detail in section 3.

Other Features to Consider

The following features may be present in some calculators and not in others. Consideration should be given to the desirability of such features when prescribing a particular calculator model for student or school purchase.

- Recall last answer
- Recall last key sequence
- Dual line display
- Range of function keys:
  - nCr (combinations) and nPr (permutations)
  - fractions
  - degrees / radians
  - degrees, minutes, seconds (DMS)
  - negation function (as distinct from the operation of subtraction)
- Statistical facilities
- Complex numbers
- Numerical solution to common types of equations
- Matrix manipulation
- Integer arithmetic

This list is not intended to be exhaustive. *In all cases, it is important that students become familiar with a type of calculator that is suitable for use in the Certificate Examinations.* (See inside the back cover for details.)

Teaching strategies

Planning for calculator use

The use of calculators as tools in teaching and learning is new for many teachers. Use of calculators on a broader scale at primary and second levels offers the opportunity for teachers to consider how they as a team can develop, evaluate and refine a range of teaching resources. A number of questions arise in this regard.

- Will one subject area or teacher be the focus for skills development or will these skills be developed across a variety of subjects, by a variety of teachers?
- Is it expected that the student will use the calculator at all times in the various areas of the curriculum where its use is appropriate?

- What skills in the use of the calculator are required across the range of subjects; what skills or operations are specific to some subjects?
- For mathematics in particular, what approach will be taken to ensure the parallel development of mental and written computational skills on the part of students?

Clearly, to ensure a consistency of approach, teachers need to plan together. The planning stage can provide an opportunity for ensuring that issues such as different calculator models, key sequencing, and logic type are given full consideration.

Development of skills

Effective use of the calculator includes the development of skills in operating and using its various features. However, it also extends to the interpretation and evaluation of results produced, as well as the ability to judge when its use is appropriate. In developing strategies for the use of calculators in learning situations, calculations to be undertaken without the use of the calculator should be included. *Teachers should continually monitor how the students are using the calculator and indicate when its use is inappropriate.* It will be important to strike a balance between the tendency to over-emphasise mental computation on the part of the student and the neglect of this essential skill.

Teachers should plan student exercises in which estimation and checking strategies are taught explicitly. Such exercises can also be used to monitor the effectiveness of the student's use of the calculator. Indeed, the calculator itself may be used in the process of checking a result if different approaches are undertaken in solving the same problem. As part of an ongoing assessment of student progress, classroom tests can be prepared that are specifically designed to evaluate student expertise and accuracy in using the calculator. Such tests can also highlight the importance of recording intermediate results—something which might not form part of the routine when calculators are used in the course of daily classwork.

Exploring further possibilities

While ensuring that students are aware of the logic type that applies to the calculators they use, it can be informative to compare the results of mathematical operations when calculators of different logic type are used. Discussion of these results, and of the reasons why they arise, can lead to a clearer understanding of the conventional rules of precedence that apply to arithmetic operations. This can increase students' awareness of the need to be vigilant when using a calculator to carry out arithmetic operations.

The increasing availability of graphics calculators means that the study of functions and the processing, analysis, and presentation of statistical data can be managed more easily. This can be of benefit across a range of subjects, improving students' graphing skills and enabling them to understand and interpret the patterns and relationships involved. When graphics calculators are combined with devices that facilitate the collection of data, especially in science subjects, students can gain a better insight into the processes being monitored.

3 Implications for Junior Certificate and Leaving Certificate Examinations

The use of appropriate calculators has many advantages in the context of certificate examinations. However, candidates should be made aware that use of the calculator carries with it some risk of loss of marks. The risk is particularly high in cases where the candidate makes an error and then carries the result through into further operations, but fails to write down the intermediate work that would allow the source of the error to be identified. *To minimise the marks lost because of the initial error, candidates are advised to show all steps of a solution.* Since there is the possibility of creating an error every time a number is keyed in, appropriate use of the memory, recall, constant, and other available keys on the calculator should be encouraged. Partial answers should be retained in the calculator and re-used. The ability to estimate and/or check the outcome of a calculation may help the candidate to identify incorrect answers and hence rectify errors.

In Junior Certificate mathematics examinations, specific questions will be set that require candidates to estimate a solution. Additionally, the following should be noted.

- Some errors may arise due to an inability to interpret the calculator display during, or at the end of, a sequence of operations.
- Very large and very small numbers are particularly susceptible to error since they are displayed in scientific notation.
- Errors which lead to answers that are unreasonable in the context of the question may be penalised more heavily than those which result in incorrect but reasonable answers.
- Incorrect answers without supporting work are generally treated as having no merit.
- Candidates have in the past shown a strong tendency to offer insufficient supporting work for their answers. The use of a calculator may exacerbate this problem, unless students are well prepared for this aspect of the presentation of their work and record intermediate stages of their solutions as indicated above.

By way of illustrating some of these points, an example is given opposite of a typical question for which the focus is percentage calculation—a topic that could arise in a number of subjects. Some typical solutions that might be submitted by candidates are presented. Further examples, particularly relevant to mathematics, may be found in *Junior Certificate Mathematics: Guidelines for Teachers.*

Example

A concert ticket costs €33 excluding VAT. Find the cost of the ticket including VAT at 15%.

Solution 1

$33 \times 15 \div 100 = 4{\cdot}95$
total cost:
$€33 + €4{\cdot}95 = €37{\cdot}95$

OR

$€33 \times 1{\cdot}15 = €37{\cdot}95$

In each case, the candidate has shown the method used in arriving at the correct solution.

Solution 2

$33 \times 15 = 495$
$33 + 495 = 528$
answer: €528

OR

$33 \times 15 + 33 = 528$
answer: €528

Here the candidate has ignored, or failed to understand the significance of, the percentage symbol.

Solution 3

$33 + 15\% = 48$
answer: 48

Here the candidate has shown no understanding of percentage calculation. Alternatively, where a calculator has been used, the solution presented could indicate a possibly correct* key sequence that may have been incorrectly executed by failing to press the [%] key properly.

* The correctness of a solution may be dependent on the calculator that is being used. On some calculators, the keyed-in sequence [33] [+] [15] [%] [=] will give 37.95, the correct answer to the question at hand. On other calculators, the same keyed-in sequence will give 33.15. Some calculators will not accept this sequence of keystrokes at all.

Note the serious consequences of a keystroke error in cases such as Solution 3. This highlights the importance of estimation and checking strategies, which would likewise have helped to detect the error in the case of Solution 2.

4 Resources

Teachers may obtain useful information from the following sources. More extensive support materials specifically addressing the use of the calculator in teaching and learning will be developed. Information relating to these will be circulated to teachers in due course.

Junior Certificate Mathematics: Guidelines for Teachers

Calculators can help with some of the "lesson ideas" presented in the guidelines. With regard to assessment, use of the calculator is evident in some of the sample solutions that are provided to indicate important aspects required in order to obtain full marks (see section 5.6 of the *Guidelines*).

Appendix 3 of the *Guidelines* lists a broad range of resources.

Scoilnet (http://www.scoilnet.ie)

This is an online support service that acts as a resource for schools, with information on a range of educational issues related to ICTs.

The Scoilnet website contains a number of useful links. The site also provides access to discussion fora, one of which is concerned with mathematics.

Irish Mathematics Teachers Association (http://www.imta.ie)

The association has many branches throughout the country and holds regular meetings and workshops/seminars to support mathematics teachers.

Irish Science Teachers Association (http://www.ista.ie)

This association provides wide-ranging support for science teachers. Some recent workshops focused on the use of graphics calculators for datalogging in science.

National Council of Teachers of Mathematics (NCTM) (http://www.nctm.org)

This (United States) association has regular issues of journals and news bulletins and other materials that contain interesting and useful resources for teaching mathematics.

Manufacturers of calculators

All the main manufacturers of calculators produce useful brochures/bulletins as an aid to students and teachers. A web search will quickly locate a range of sites. Some sites contain free downloadable material.

Use of Calculators in Certificate Examinations

Regulations regarding the use of calculators in the state examinations are included in the Rules and Programme for Secondary Schools (under Rule 74). The relevant extract from the rules, as they apply in the 2003 examinations and thereafter, is as follows:

The use of calculators is allowed in all examinations, subject to the following:

(a) The Department will not supply calculators to candidates and examination centres will not be responsible for the provision of calculators or batteries.

(b) The proper working condition of the calculator is the responsibility of the candidate. No allowance will be made for battery or other calculator failure during the examination.

(c) Calculators must be silent and must not require the use of an external power supply.

(d) Calculators may not be borrowed from other candidates during the examination.

(e) Programmable calculators are not allowed. The term "programmable" includes any calculator that is capable of storing a sequence of keystrokes for later retrieval and execution. It also includes calculators into which a formula or other such expression can be entered by the user. However, the facility to store numbers in one or more memory locations, or to execute procedures that cannot be modified by the user, does not render a calculator programmable.

(f) Graphics calculators are not allowed.

(g) Calculators with any of the following facilities are not allowed:
- data banks
- dictionaries
- language translators
- text retrieval
- capability of remote communication.

(h) Candidates must indicate on their answerbooks the make and model of any calculator(s) used in the examination.

(i) Candidates are not allowed to take an instruction manual into the examination hall. This includes instructions printed on the cover of the calculator.

This rule does not allow a candidate to bring into the examination centre any device that would be otherwise prohibited. In particular, mobile phones, electronic organisers or similar devices are not permitted under any circumstances. (See rule 65.)