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Kissane, B. (1997) Graphics calculators and science. SCIOS: Journal of the Science Teachers' Association of Western Australia, 32 (1). pp. 16-19.

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Graphics calculators and science*

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In recent years, new kinds of calculators have begun to appear in secondary schools, especially in mathematics departments. These calculators are commonly called 'graphics' calculators (or some variation on the adjective), because they have a small graphics display screen rather than the one-line numerical display that we have been used to with hand-held calculators. The appearance of these devices in schools has been hastened considerably by the official approval of their use in the TEE from the 1998 examinations in all mathematics subjects and also in some science subjects. It would be a mistake, however, to make the inference that these devices are mainly useful for examinations. Rather, the official TEE sanction is an acknowledgment that examination prohibition hampers the use of appropriate technology in schools.

Although they are relatively new to WA, having first appeared in class-set quantities in schools about six or seven years ago, graphics calculators can hardly be described as a 'new' technology. For example, they have been on sale to the general public in USA since 1985, and have been in widespread use in high schools for a decade. Similarly, they have been available in schools and used in A-level examinations in the UK since the late 1980's. The machines on sale today are arguably the third generation of graphics calculators. There are four manufacturers at present, each a familiar multinational company. In alphabetical order, they are Casio, Hewlett Packard, Sharp and Texas Instruments.

The main uses of graphics calculators are for students learning and doing mathematics. However, in Western Australia, it is almost always the same students learning both science and mathematics. So, we can expect that almost all science students in upper school will have an increasing level of access to a graphics calculator in the near future, and that many students will own their own model. Even in the lower secondary school, the most likely scenario for the near future is that a graphics calculator will become standard equipment for most students, instead of the scientific calculator. Although many schools continue to ask students to purchase a scientific calculator early in secondary school, the decreasing price of graphics calculators (the least expensive now around \$60 tax exempt) are likely to encourage a rethink of this practice, to reduce the risk that students will need to purchase more than one calculator over their secondary schooling years.

This paper suggests some graphics calculator capabilities that may be of interest to science teachers, with the emphasis on student learning rather than assessment.

A better scientific calculator

A graphics calculator is, first of all, a calculator. That is, it can be used to calculate things for which students presently use a scientific calculator; in fact, it is a good substitute for a scientific calculator, rather than a device that one would use together with a scientific calculator. (Incidentally, I confess to being mystified as to the origins of the adjective 'scientific' used to qualify a calculator. There is nothing at all scientific about its operations, and it is no more likely to be used for science than it is for engineering, mathematics, accountancy, statistics, economics or architecture. I can only guess that it was a form of marketing ploy.)

The graphics calculator is a good substitute for a scientific calculator because it does the same kinds of things better and because it also does other things too. To illustrate these claims, consider the four screens below, electronically taken from a Casio cfx-9850G calculator.

Notice first that each screen shows that what is entered into the calculator stays on the screen, so that any punching errors can be detected. This allows students to check that they have calculated what they intended to calculate, rather than repeating the entire exercise to check. If errors *are* observed, previous lines may be recalled and edited to correct them, rather than retyping the entire command.

```

3(8.8)+5(7.1-0.14) 61.2
√(21²cos 72) 11.67375238
10log (10⁻⁴÷10⁻¹²) 80

```

The screen above also shows that the syntax of the calculator mimics that of conventional mathematical and scientific syntax. For example, operators like $\sqrt{\quad}$, log and cosine appear before the numbers concerned, while the squaring symbol appears after. How one enters an expression into a graphics calculator is generally the same as how one writes it down. Notice too that there is no multiplication symbol needed where one would not normally be written in text, such as outside a bracket.

A graphics calculator has the capability of repeating a particular set of command to quickly amass useful information. The next screen shows an example, with each successive press of an 'execute' key producing a result 3% smaller than previously, starting with a figure of 250. Such capabilities are especially useful in studying growth and decay models.

```

Ans×0.97 250.000
          242.500
          235.225
          228.168
          221.323
          214.684

```

The next screen shows that calculator memories can be used to store constants, permanently or temporarily. The constant values are used as if they were algebraic symbols.

```

10→M 10
15→V 15
1.2M V² 1125

```

Finally, graphics calculators tend to have inbuilt capabilities not usually available on scientific calculators. The screen below shows three examples for the Casio cfx-9850G, dealing with solving an equation in one variable (by finding roots of a function), integrating a function on an interval and evaluating a series.

```

Solve(2^X-7,2) 2.807354922
∫(X²,0,4) 21.33333333
Σ(X²,X,1,100,1) 338350

```

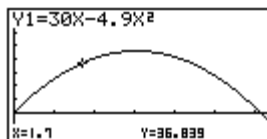
Although the results are approximate, the approximations tend to be very good, and provide ready access to results that may otherwise require more mathematical background. For example, solving the equation $2^x = 7$ would normally require students to use logarithms while finding the sum of the first 100 squares is well beyond all school curricula.

Dealing with graphs

One of the persistent misconceptions about graphics calculators is that they are mainly useful for drawing graphs. While there are many other ways in which graphics calculators can help someone think about or work with mathematics, drawing a graph is certainly one of them, however. Graphs of univariate functions are readily drawn, interrogated (by processes of tracing and zooming or by an automatic procedure) and interpreted. A number of graphs can be drawn simultaneously. The ease of drawing graphs may suggest some different ways of tackling situations in science.

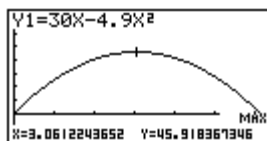
For example, assuming negligible air resistance, the height of an object propelled vertically from the Earth with an initial velocity of 30 ms^{-1} is given by $h = 30t - 4.9t^2$, where t represents the elapsed time in seconds. A graph showing the height at various times can be produced on a graphics calculator, and then studied to answer questions of interest. The calculator assumes that the independent variable is x and the

dependent variable y , as shown below.

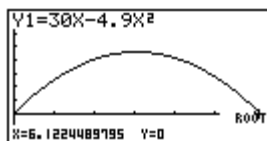


The graph has been traced to show that the object has attained a height of 36.84 m after 1.7 seconds.

As well as tracing, there are automatic methods available on many calculators to locate points of particular interest. In this case, the maximum of the function shows that the object attains its maximum height of 45.92 m after 3.06 seconds:



Similarly, the positive root of the function, shows that the object returns to the Earth after 6.12 seconds:

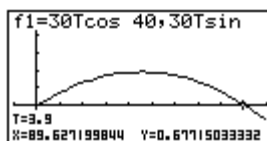


Each of the maximum and root of a function were located automatically by the Casio cfx-9850G, as the two screens show.

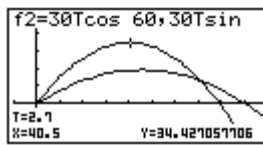
As well as graphs of functions, graphics calculators can often draw other kinds of graphs, such as those using polar coordinates and those defined parametrically. A parametric definition of a graph may allow new approaches to familiar problems. For example, consider a projectile with an initial velocity of 30 ms⁻¹ fired at an angle of 40° to the horizontal. So the vertical component of its velocity is initially 30 sin 40°, while the horizontal component is 30 cos 40°. Under the influence of gravity, and once again neglecting air resistance, its vertical height is given by $y = 30t \sin 40 - 4.9t^2$, while its horizontal movement is described by $x = 30t \cos 40$, where t refers to elapsed time in seconds. These components can be defined as functions of the parameter t , as shown in the next screen.



The resulting graph, defined parametrically with t as the independent variable shows the actual path of the object (Unlike the earlier graphs, in which the parabola does *not* show the path of the object). Tracing the graph suggests that the projectile will land about 90 m away after about 3.9 seconds:



Paths of objects under different conditions can be compared. The graph below shows a second projectile with the same initial velocity, but projected at an angle of 60°:



Tracing the graph suggests that the projectile reaches a maximum height of about 34.4 m, while the x-axis suggests a range of about 80 m. In the same way, students could investigate easily the effects of changing the initial velocity.

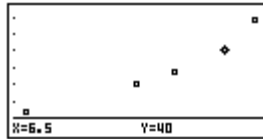
Dealing with data

The essence of much scientific work involves data, collected to test hypotheses or at least to verify scientific principles. A graphics calculator differs from scientific calculators in two important respects as far as data are concerned. Firstly, the data are stored in the calculator, as shown below, and so can be readily checked, edited, modified, transformed or even discarded (in the event that outliers are regarded as defective). The screen below shows an example, from a small data set ($n = 5$):

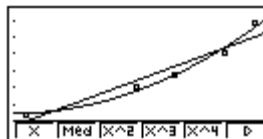
	List 1	List 2	List 3	List 4
1	1.8	4		
2	4.4	20		
3	5.3	27		
4	6.5	40		
5	7.2	59		

GRAPH CALC

The second important difference is that data analysis is not limited to the calculation of sample statistics, but can also include various graphical representations as well. For example, a common data analysis technique is to construct a scatterplot of two variables, with a view to deciding what kind of relationship, if any, is present.



If the scatter plot suggests that a linear relationship is involved, a line of best fit can be drawn on the graph. Alternatively, other regression models can be examined, should they appear to be more suitable. It is particularly useful to visually compare regression models on the calculator. In the present case, it seems that the points fit a quadratic curve better than a linear one, although caution is needed with so few data points:



As the screen above suggests, fitting a regression model on this calculator requires only the touching of a single key, and does not clutter the student's mind with lots of messy calculations, which generally provide little, if any, insight into the relationships involved.

Different kinds of data require different kinds of analysis, of course. Modern graphics calculators are able to deal with univariate data as well as bivariate data, and can draw histograms, box and whisker plots and line graphs as well as scatter plots. In each case, various numerical results are easily extracted, such as means, variances, regression coefficients, and so on.

The graphics calculator provides the science student with a hand-held statistics package of surprising power, and offers the opportunity for the focus to be returned to the meaning and interpretation of data, rather than the mechanics of manipulating or representing them.

Data logging

Of special interest to science teachers are the possibilities of *data logging* collecting data automatically and electronically transferring it to a calculator for analysis. Three of the four calculator manufacturers (Casio, Hewlett Packard and Texas Instruments) also produce a data logger suitable for their equipment. Data loggers are available as optional extras, and are not interchangeable between calculator brands.

Each data logger consists of a box about the same size as a calculator, a collection of *probes* that can be connected to the device and a means of communicating with the appropriate calculator. Each probe measures a different physical attribute, and data loggers are generally sold complete with a basic set of probes to measure temperature, light intensity and electrical measures (voltage, current and resistance). Other probes can be purchased separately, with a motion detector (using a sonic pulse) being the most popular choice. Many others are available, although they tend to be rather expensive, and much useful work can be done with a basic set.

The main advantage of a data logger over more usual methods of collecting data is that more data can be collected and recorded more reliably than is usually possible manually. Once the data are collected, they are readily analysed, since it is unnecessary to key punch each of them into a calculator a time-consuming and error-prone task that rarely offers students much insight into the phenomenon in question.

An example of data logger use is given in Kissane (1997). A temperature probe was heated in a cup of hot coffee and then withdrawn and allowed to cool. The data logger was instructed to collect a temperature reading every second for 100 seconds. The first few data points are shown below, with the first column containing times and the second column temperatures (in Celsius):

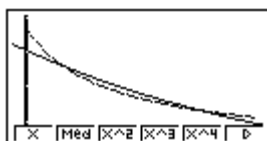
List 1	List 2	List 3	List 4
1	3.2E-3	78.125	
2	1.00271	76.563	
3	2.00541	74.722	
4	3.00811	73.333	
5	4.01081	71.944	

2.0021

SRTA SRTB DEL CLR IINS D

It would not be possible for students to collect this much data at this level of precision. The interval between data points is not precisely one second, although it is very close to it.

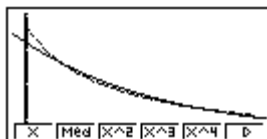
A graph of the data, together with Newton's Law of Cooling, suggest that an exponential curve should fit the data well, but the best-fitting model is not as good as might be expected:



After transforming the data (and analysing *differences* between temperatures and the ambient temperature), a better fitting exponential model is found, as shown in the next pair of calculator screens:

ExpReg
a=44.4354108
b=-0.0162715
r=-0.9922882
y=a·e ^{bx}

COPY DRAW



Data collected on a data logger can be shared among a group of students, so that different students can analyse the same data. Alternatively, students can collect their own data afresh, and the robustness of the

group's conclusions can be examined. Each data logger can collect data as a stand-alone device (outdoors, for example) for later transfer to the calculator for analysis; however, each operates a little differently from the others.

The Texas Instruments data logger (CBL, Calculator Based Laboratory) can be operated by sending commands direct from the TI-82 only via a calculator program written for the purpose; this runs a risk that the device will be seen by students as something of a black box, depending on their familiarity with the calculator program and the program itself. The TI-83 can also communicate directly by sending commands to the data logger, which allows the option of students setting up their own experiments.

The Hewlett Packard data logger (PLDL-100) is not yet available here, but will communicate with the HP-38G calculator via infrared signals and an applet (small application).

The Casio data logger (EA-100 Data Analysis Unit) allows students to set up many kinds of data collection *directly* on the device, independent of the calculator, as well as permitting the sending of commands and programmed operation as for the CBL. Detailed information is provided in Kissane (1997).

There are other differences among the data loggers that are worth attending to. There are differences in memory capacities of the data logger/calculator combinations, for example.

Conclusion

Graphics calculators are here to stay, since they are the first devices to offer access to personal technology for science and mathematics for all students. After mathematics, science is the most likely curriculum domain in which they will prove to be useful companions for students as well as their teachers.

Reference

Kissane, Barry 1997. [More mathematics with a graphics calculator: Casio cfx-9850G](#). Perth, The Mathematical Association of Western Australia.

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