

ROAD TEST

The Sharp EL-9600: learning with Technology

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A new graphics calculator is likely to attract some attention these days, since this form of technology is beginning to have a significant impact on both teaching and curriculum in Australian schools. No doubt, manufacturers and designers, whether based in Japan or the USA, pay close attention to each others' products and to the environments in which they might be used. In such a situation, it is reasonable to expect that new calculators might emulate the most attractive features of their competitors and might also attempt to secure some advantage by innovations of some sort. Ideally, calculator designers will also take their intended users into account. Together, these expectations go a long way towards understanding the new Sharp EL-9600 graphics calculator, just released into the Australian market.

Sharp are no strangers to the field of graphics calculators. Having released their first model in the USA in 1987, the company is entitled to regard itself as a pioneer in the field; the early calculator, which I used extensively at that time, was improved upon substantially to produce the fine pair, the EL-9200 and EL-9300, in the early 1990s. So the EL-9600 needs to be regarded as the company's third version, and it is reasonable to expect it be a refinement of its predecessors.

The EL-9600 manages to accomplish all of these expectations very well. Feature for feature, it matches its obvious competitors focussed on the senior secondary school. The calculator retains many of the nice features of its most recent predecessor, the EL-9300, while including a number of innovations, particularly designed to suit secondary school students learning mathematics. There is not space to describe all of these assessments in detail, even in an essay review such as this; rather, samples to illustrate the claims will be made.

$$\frac{2}{3} + \frac{3}{4} = 1 \frac{5}{12}$$

$$\sqrt{12^2 + 5^2} = 13$$

$$\frac{5}{3} = 243$$

$$\int_0^1 \sqrt{1-x^2} dx = .785388252$$

Ans*4 = 3.141553009

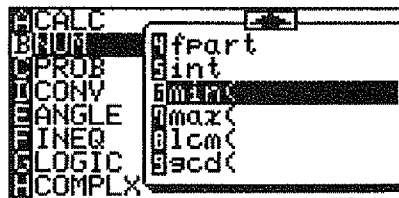
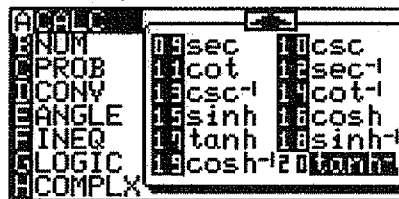
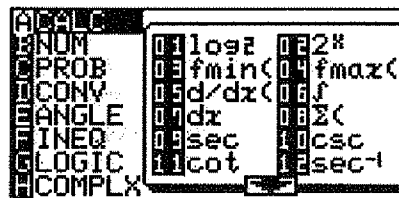
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The calculator uses natural mathematical syntax in an especially effective way, as the screens here show. Fractions are written with a horizontal vinculum, radicals are used correctly, exponents are shown raised and definite integrals are shown with both integral signs and limits in the proper places. Although some other calculators have something like this available after a command is entered, the Sharp EL-9600 uses these displays as the commands are entered, so that writing mathematical expressions on the calculator is rather like writing them on a page or a whiteboard.

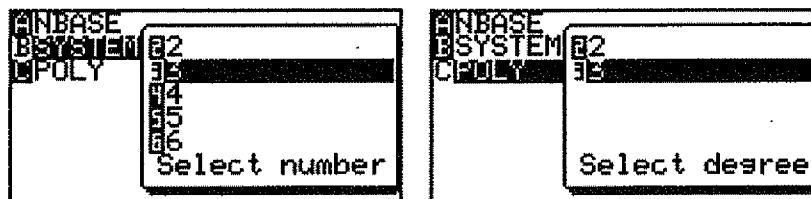
These features were all incorporated on the EL-9300 as well, and were regarded very highly by students and their teachers alike. For those who find the use of screen space in this way extravagant, or cumbersome, or a little slow, it is possible to turn off the feature (called, curiously, "Equation") in favour of the more common, "one line" display. Most users will find the use of conventional mathematical syntax like this attractive, however, I would think, despite the small costs attached to it.

The calculator screen has been changed in three significant ways from the earlier EL-9300 screen. Firstly, and most significantly, it is now a touch screen, so that some calculator commands can be carried out using a special plastic pen housed in the calculator body. The touch pen can be used to edit commands easily, to select menu items efficiently and to deal with some aspects of graphing. The second change is that the display has been made larger, with 8 lines of 22 characters each, or a graphical display area of 127 x 63 pixels. The wider screen means that more of a graphical display can be seen and that a vertically split screen still leaves enough space on each side for information to be presented. The third screen change, which may be a consequence of the other two, is that the screen seems a little less sharp than it was previously – although it must be said that the EL-9300 was clearly in front of its competitors in this respect. Although the screen is as readable as those of most other calculators, it is a little disappointing to see this particular trade-off made. In practice, users will have no difficulty adjusting to the screen, once they are familiar with it.

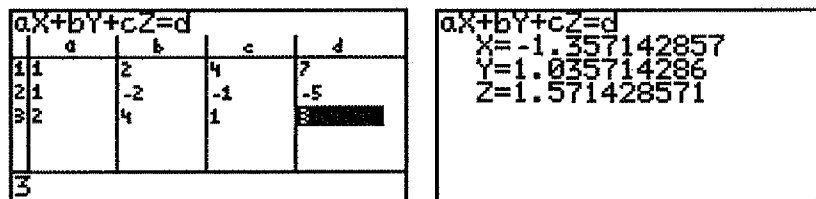
As a scientific calculator, the EL-9600 is both easy to use and very powerful. The pull-down hierarchical menu system works well, using either the relevant keys or the touch-pen. As illustrated below, the screen shows both the parent menu and the various submenus together. The suite of commands that is usually available on modern graphics calculators is available on the EL-9600 and there are even a few unusual inclusions (such as logarithms to base 2 and the reciprocal circular functions).



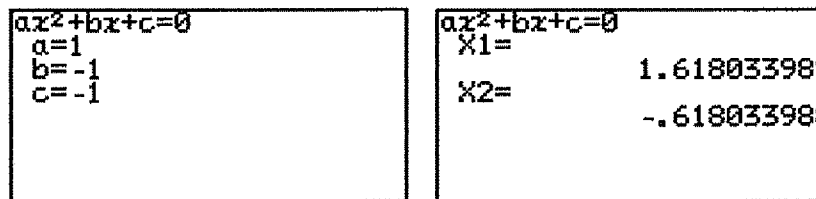
Access to such scientific calculator commands magnifies the impression that one of the powerful uses of a graphics calculator involves computation. Some of the things to be calculated would previously have required looking up tables (such as circular and exponential functions), while others require more sophisticated techniques (such as integration, differentiation and summation). In the same way, the EL-9600 provides ready access to the computations associated with solving equations in a "Tool" menu. As the screens below show, both systems of up to six simultaneous linear equations and polynomial equations of degree two or three are handled.



These all work quite intuitively, with the on-screen help provided removing any room for doubt. The screens below show that the simultaneous equations are entered (and edited) in the standard matrix format, with solutions easy to follow.



In the case of the polynomial equations, all solutions (including complex solutions) are given and are readily interpretable, as shown below.



Although modern graphics calculators, including the EL-9600, provide alternative ways of solving equations, it is convenient to have tools such as these built in to the command system. Matrix manipulations and graphical solutions to equations have some limitations. For example, the matrix manipulations are frequently a little cumbersome to use and interpret on graphics calculators, while graphical solutions to equations are generally restricted to real solutions. While there are some conceptual merits of dealing graphically with equations, at least for younger students, there is also a case for having ready access to equation solving commands as well.

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$$A^2 + B^2 = C^2$$

```
Solver: Newton
A=0
B=12
C=13
```

```
Newton solver
A=5
RIGHT=169
LEFT =169
L-R =0
```

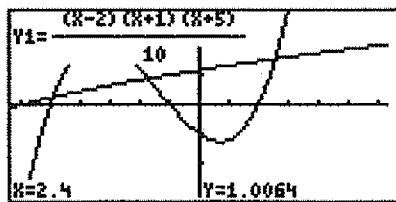
In the same vein, the calculator has retained the equation solver from the earlier model, allowing a general equation with several literal variables to be stored and solved for a single variable. The screens on the next page show the basic idea for the three variable Pythagorean relationship between the lengths of the sides of a right triangle. Once B and C are defined, the solver can be set to work to find a value for A that satisfies the equation.

While such solvers do not provide more mathematical capability than a univariate equation solver, they can be convenient in contexts such as physics and engineering where equations often involve several variables and need to be solved often.

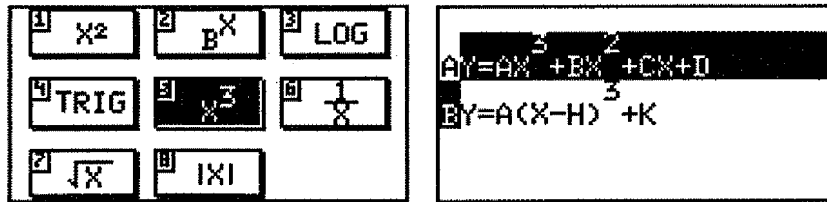
Overall, then, the EL-9600 is a powerful and flexible tool for student use, even if they do not make use of its graphing, tabulation and statistical capabilities, all of which are considerable.

In fact, the calculator has been well-designed to allow students to explore elementary functions either with graphs or tables or both. As generally accepted among manufacturers of calculators at this level, all four ways of thinking about functions are dealt with smoothly: rectangular coordinates, polar coordinates, parametric functions and recursive (sequence) functions. Functions are easy to define, edit and graph, and it is not difficult to change the window settings involved. As is normal these days, a range of automatic scales are available in the zoom menu, to suit various purposes, such as having equal scales on each axis, making every pixel step an integer, catering to circular functions and so on. The screens below show that the screen features of the calculator are also used to advantage in defining functions and (optionally) identifying functions when tracing.

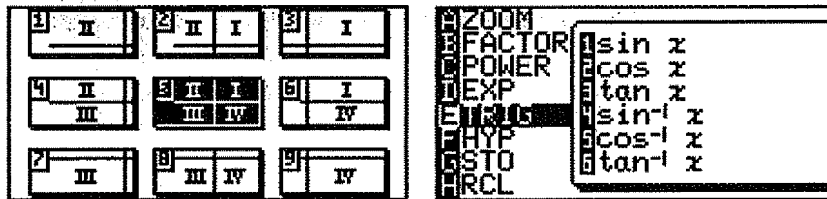
```
Y1= (X-2)(X+1)(X+5)
      10
Y2= X+10 -2
Y3=
Y4=
Y5=
```



The EL-9600 also incorporates a number of devices to make it easier for the user to define and graph functions. An EZ ("easy") key gives access to a suite of possible functions for defining, as shown below, when pressed at the function definition stage.



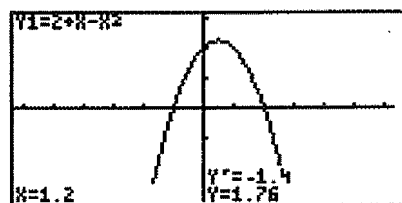
A choice of standard forms is provided for pasting into the function list. These can be altered if desired to give particular values for the coefficients, saving several keystrokes in many cases. In the same sort of way, the EZ key gives access to a range of suitable screens if pressed at the window stage of constructing a graph. These seem to be flexible tools which are in addition to the standard ways of defining functions, so that a user can decide for themselves whether they wish to use them. In addition to the use of the EZ key for defining windows, the zoom menu provides a large number of inbuilt screens to suit various purposes, as shown below for the case of circular functions.



The user is not obliged to use these pre-determined screens, of course, but they may well be handy for some kinds of graphic explorations, particularly when the user is past the introductory stage of studying a particular kind of function. All of the choices for defining functions and windows can be made either with the pen or by standard key stroke methods.

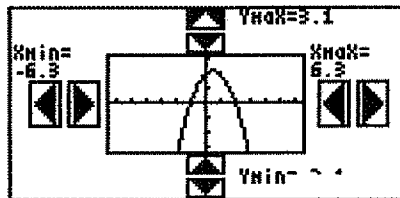
The calculator includes a style feature, allowing different graphs to be drawn using different styles (i.e. a solid line, a bold line, a dotted line, etc.), although I am not persuaded that this is always a useful thing to do on such a small screen. I think I would prefer students to have other ways of telling which graph is which than by using a different style to draw them.

As well as being easy to use for defining graphs, the EL-9600 is very well-designed for exploring the graphs. The standard tracing and zooming capabilities all work well, and an option to label graphs on-screen is available. There is also an option for a derivative trace, so that both the coordinates of each point on a graph and the derivative of the function at that point are displayed dynamically. As the graph below shows, the screen is wide enough and the font size small enough for these capabilities to be useful for exploring a function.

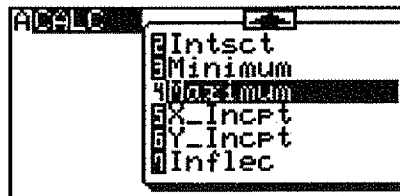


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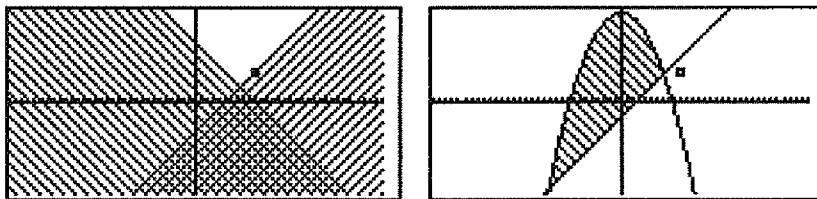
The EZ key can again be used to manipulate a graph after it is drawn, as the screen below shows. The key functions as a “rapid zoom” for adjusting the axis settings using the pen. I am not sure that I have yet mastered this apparently useful idea, since it seems a bit slower than the manual methods. However, it is a nice example of the way in which the calculator has been designed to take the needs of users into account, and may be especially useful for initial explorations of a situation.



A suite of automatic graphical interpretation commands is available, allowing intercepts, points of intersection and relative extrema to be located to the available accuracy on request. Interestingly, a point of inflection command is also included in the suite, as shown below. The omission of a definite integral command from this menu is also curious, even though the calculator has capabilities for defining areas of the screen to be shaded (for example, to explore inequalities). Integrals can be calculated, as noted above, in the home screen of the calculator.

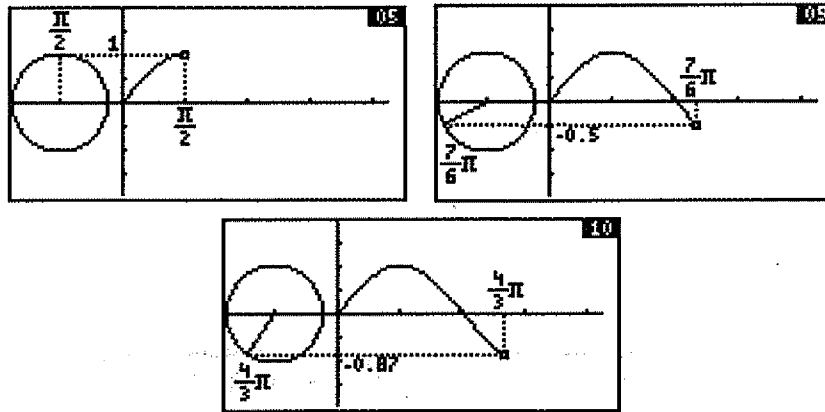


Relations expressed as inequalities can be represented on the calculator by using the draw facilities to shade appropriately. The screens below show that compound inequalities can be represented by judicious use of the shading facility, although there are some limitations.



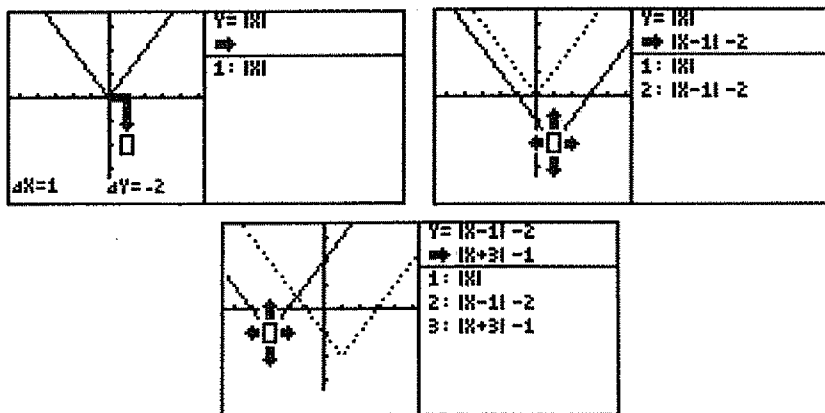
Overall, the calculator handles graphing very well. But the most interesting innovations in the calculator are the inclusion of some educationally useful features associated with graphing. Although many aspects of the calculator are clearly designed with the needs of students (rather than professionals) in mind, the most explicitly educational features are those for exploring (and defining) slide shows, the shift/change facility for exploring transformations of functions and the substitution facility for exploring the effects of coefficients on graphs. There is space to describe these only briefly.

The slide show feature allows students to explore a succession of previously saved screens by successive presses of the "Enter" key. The built-in slide shows cover a range of functions. The examples below show screens from the sine function slide show, illustrating nicely the relationship between the unit circle and the graph.



The facility to define slide shows might be attractive to teachers, especially when coupled with an overhead projection facility. The calculator also contains the software and port to allow transfer of information from calculator to calculator, so that an effective slide show might be transferred to individual student calculators. As yet, I have not been able to evaluate either of these facilities for communication at first hand, although the technology is pretty standard these days and worked well on the previous calculator, so I would be surprised if it doesn't work well. (The same port allows for transfer of screens to a computer, as this review testifies.)

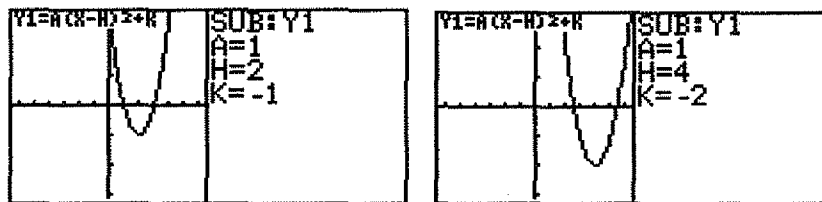
The shift/change facility is intended to allow students to explore the relationship between translations (shifts) or scale changes (changes) of graphs and the associated defining rules for the functions. Any graphics calculator can allow students to see what happens to a graph if you change the definition; the innovation in this calculator is to do the reverse: move the graph and see the resultant changes to the definition. The screens below show this in action for the particular example of the absolute value function.



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The user moves the graphs (on the left of the screen), using either cursors or the pen, and the result is shown on the right of the screen. A succession of results can be stored and then easily replayed to match rules with graphs. Although the shifts are restricted to integers, the graphs close to the origin and the functions restricted to eight kinds, these are not serious limitations if one keeps in mind the main idea: to help students experience and hence understand the connections. The scale changes work similarly, stretching or shrinking vertically. It is not possible to apply *both* a scale change and a translation at the same time. Nonetheless, this is a nice idea, even if it will lapse in significance once a student knows how the transformations involved work.

The third educational feature designed into the calculator is the substitution capability, in which graphs of functions are explored by altering the values of the coefficients. The examples below show the standard completion of the square form of a parabola, after defining the quadratic function $Y1 = A(X - H)^2 + K$ in the usual way. The calculator recognises that the function has three coefficients and the substitution graph facility allows the user to give these values and to see the effects on the graph.



Once again, this is a nice facility that I can imagine being quite useful for many learners. Unlike the shift/change facility, the calculator is not restricted to a standard set of functions (or window settings), so that the facility can be used for a range of situations to good effect.

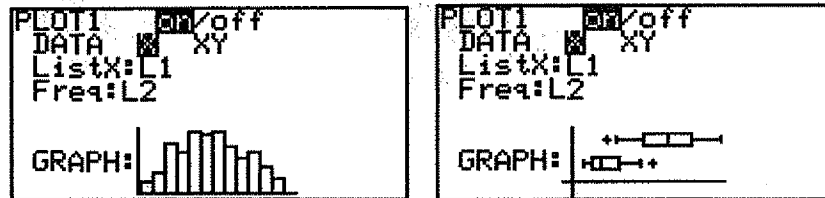
A significant omission on the EL-9300 was a table facility (first used on a later graphics calculator, Texas Instruments' TI-82), so it is no surprise to see this added to the EL-9600. As the screen below suggests, tabulation is well handled, helped by the wide screen which allows three functions to be seen at once. Only rarely would it be useful to see more than this, I would expect. The table commands work smoothly to alter the starting point and increment, so that tables are a useful complement to graphs of functions.

| H | Y1 | Y2 | Y3 |
|-----|------|------|-----|
| 0 | 3 | 2 | 1 |
| .1 | 2.99 | 1.99 | .99 |
| .2 | 2.96 | 1.96 | .96 |
| .3 | 2.91 | 1.91 | .91 |
| .4 | 2.84 | 1.84 | .84 |
| .5 | 2.75 | 1.75 | .75 |
| X=0 | | | |

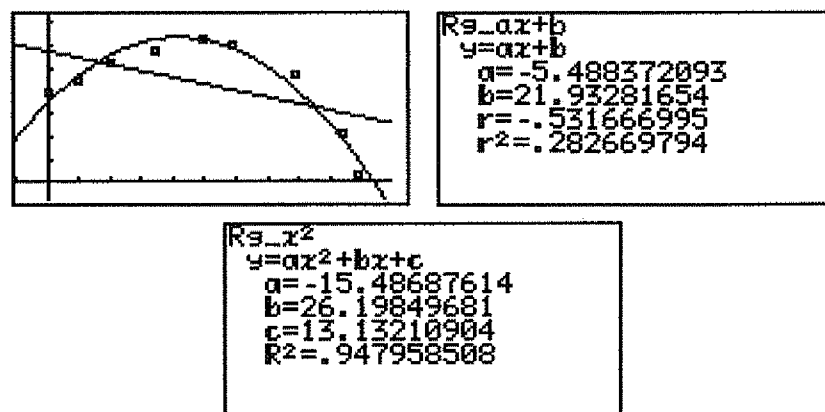
It is possible to see a graph and a table on the screen simultaneously, and the width of the screen renders each interpretable. However, the split screens are not independent; for example, the table produced consists of points traced on the graph rather than on table settings independent of the graph.

Apart from dealing with functions, a major use of graphics calculators is for data analysis. This calculator has been very well designed to deal with most aspects of data analysis of relevance to the secondary school and the early undergraduate years. Data are entered and displayed conveniently in lists and are readily analysed, both numerically and graphically. In line with recent trends in the USA, most notably the decision to permit graphics calculators to be used in the Advanced Placement Examinations for Statistics, the calculator also contains a suite of inferential capabilities, both for performing elementary hypothesis tests and for evaluating probability distributions. Together, these various capabilities render the EL-9600 as a powerful and flexible hand-held statistics device.

As for rival graphics calculators, three different statistical plots are available, and are user-defined from a large collection of possibilities. These include histograms, line graphs, normal probability plots, box plots (and modified box plots, in which outliers are evident) and scatter plots. The user-friendly feel of the calculator evident elsewhere also extends into the task of defining the statistics plots, as the two screens below indicate.



Numerical summaries of data are comprehensive for both the univariate and bivariate cases. A complete suite of possible regression functions is included for the bivariate case. Senior secondary students will find that the calculator meets almost all of their data analysis needs and is easy to use. As a brief example, the screens below show a scatter plot of some bivariate data. The calculator can fit a quadratic curve and a least squares regression line to the data, showing clearly the superiority of the quadratic model for the data. Numerical analysis is also readily available.



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Undergraduate students may also find the calculator a useful data analysis tool. The statistical tests accessible on the EL-9600 include chi-squared tests, t -tests, z -tests and (one-way) analysis of variance and the calculator will also produce confidence intervals for the mean associated with both t -tests and z -tests. Together, these encompass the bulk of the needs for introductory tertiary courses in applied statistics. The next set of screens below shows that it is easy to set up an appropriate test and to interpret the resulting output, not all of which is displayed below.

```

EDIT
MODE
CALC
REG
TEST
DISTR
  01  $\chi^2$  test
  02 Ftest2samp
  03 Ttest1samp
  04 Ttest2samp
  05 TtestLinres
  06 Tint1samp
Ttest2samp
 $\mu_1 = \mu_2$   $\mu_1 < \mu_2$   $\mu_1 > \mu_2$ 
Pooled: No Yes
List1: L1 Freq1:
List2: L2 Freq2:

Ttest2samp
 $\mu_1 = \mu_2$ 
t = -2.791597653
P = .011264353
df = 20
 $\bar{x}_1 = 6.454545455$ 
 $\bar{x}_2 = 8.727272727$ 
 $s_{x1} = 1.507556723$ 

```

An obvious limitation of this technology, when compared with larger computer packages, is the memory size. Although the calculator memory is comfortably large with around 20K of useable space, it would clearly not be the best choice for analysing large data sets. However, very many of the data sets typically used in introductory courses consist of small samples, well within the sensible limitations for a hand-held device like this. The very considerable advantages of portability, accessibility, personal ownership and cost suggest that a careful consideration of the needs of early undergraduates in the light of this sort of technology may already be overdue. (The calculator costs less than typical computer software packages, which require ownership of a computer to operate — a very expensive addition to the software cost.)

The distribution functions allow for easy evaluation of standard probability distributions, including the normal, student's- t , chi-squared, binomial, Poisson, geometric and F distributions. For example, the screens below show Prob ($60 < x < 70$) for $x \sim N(50, 10)$ and the probability that there will be at most three heads when twelve fair coins are tossed.

```

EDIT
MODE
CALC
REG
TEST
DISTR
  01 Pdfnorm(
  02 cdfnorm(
  03 InvNorm(
  04 PdfT(
  05 PdfZ(
  06 cdfZ(
cdfnorm(60,70,50,10)
.135905121
cdfbin(12, 1/2, 3)
.072998046

```

The calculator handles lists well, with six separate lists available, each of which can hold up to several hundred values, subject to overall memory limitations. Various useful list operations are available, particularly those to do with univariate data, as the main uses of lists are for data storage and analysis purposes. A useful innovation is the option to store lists data, so that the entire set of six lists can be stored for later use. Up to ten sets of six lists can be stored, so that, theoretically, data for sixty variables could be retained in the calculator. However, overall memory constraints may militate against using all sixty, and an analysis that used more than one stored list data set at a time would be awkward. Nonetheless, this feature means that it is not necessary to discard all of one's data in order to conduct a fresh analysis of new data, and I suspect that this will be seen as an advantage. The EL-9600 also has facilities for communication between calculators, allowing stored data sets to be transferred from one calculator to another.

One particular kind of data that has aroused some interest recently is physical data collected by a data logger, and it seems that the EL-9600 is equipped to collect and retrieve data in this way as well. This feature is of interest both to the teaching of mathematics and to the sciences. As yet, I have not seen the details of the Sharp configuration, but gather that it makes use of some third party equipment (probes and data logger). No doubt, science teachers especially will be interested in the details on these matters when they are available.

Matrices are well handled also, with standard matrix operations available and easy to use. An innovation is the possibility of converting between lists and matrices: rows or columns of matrices can be stored as separate lists, and lists can be combined to become matrices. Thus, for example, a data matrix may be entered (and stored) as a matrix, and then individual variables extracted as columns of the matrix for statistical analysis. The calculator also includes commands to transform coefficient matrices into echelon form, allowing non-singular systems of equations to be tackled or systems of more than six linear equations to be solved.

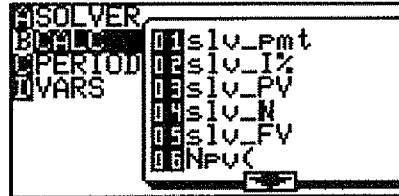
As did its predecessor, the EL-9600 handles complex number arithmetic smoothly, including complex powers, as shown below.

| | | | |
|------------------------------|--------------|-----------------------|-----------------|
| $\sqrt{12-48}$ $(3-i)(2i+8)$ | $6i$ $26-2i$ | $e^{i\pi}$ $(3+5i)^3$ | -1 $-198+10i$ |
|------------------------------|--------------|-----------------------|-----------------|

However, it is necessary to set the answers of the calculator to expect complex results or an error will be displayed. While this is generally not a problem, it is a little frustrating that the choice of complex number display means that the fractional capabilities are disabled, so that the results of fraction calculations are given as decimals. In practice, it is unlikely that this will cause much headache, I suspect, as generally users will not want both of these available at once.

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For reasons probably related to the US business mathematics curricula, the calculator also contains the standard suite of financial functions, some of which are shown below.



These allow various kinds of financial projections to be made, consisting in the main of various inbuilt formulas. They are of less interest in Australian mathematics curricula, although they would be of some use to students of such matters, I suspect.

The calculator manual is adequate, but will require some perseverance on the part of readers to decipher in places. Astonishingly, it has no index, so one must rely on the table of contents to find things out. While certainly an improvement on previous Sharp manuals, there is still room for better use of English and a more careful attention to the likely needs of beginners. While an experienced person such as myself could eventually find most things I looked for, I suspect that less experienced people may become frustrated more readily.

As for all graphics calculators these days, the EL-9600 is programmable and has enough memory to store programs for various purposes. I am a little surprised that the programming language seems a bit less sophisticated and a bit less structured than it was on the EL-9300. For example, it is now no longer possible to use words for variables, and all variables are global. (Previously, lower case letters could be used to construct variables that were local and which had names longer than one letter.) Rather than leading the field in this respect, the calculator seems to have reverted to the field. However, the language is manageable and programs fairly easy to write, so that it should serve its purpose of allowing the user to customise their calculator to an extent.

At the same time as the EL-9600 was released, Sharp also released a smaller calculator, the EL-9400, which is very similar in many respects. It will be an easy matter for students to graduate from the smaller calculator to the larger one, since it is essentially a subset of the larger one in all relevant respects. For those interested in students possibly starting out with a less sophisticated calculator early in secondary school, and then moving up to a more sophisticated model to suit their needs later, this is good design and makes a great deal of practical sense. (A detailed review of the EL-9400 is published in the companion issue of *The Australian Mathematics Teacher*.)

The most interesting innovations presented by the Sharp EL-9600 graphics calculator are the pen-touch facilities and the educational software. While all of these seem to work quite well, the best evaluation of these clearly will come about in practice. I am mildly uneasy about the robustness of a pen-touch calculator that is to be used mainly by adolescents, all too likely to tempt fate by touching the screen with unintended objects that may damage it. The screen seems to respond well to even finger touching, so I suspect that it may frequently have to deal with other, less benign, objects as well. Only time will tell whether such fears are

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groundless or not, and I am mindful that Sharp have produced many similar kinds of products and understand such matters well. In the same way, the educational features built into the calculator look very promising, but only time will tell whether they fulfil their promise in real classrooms with real students.

Overall, this is a very nice calculator, easy to use and with very few causes for concern. Since it is loaded with all the features expected at this level, and priced sensibly to compete in the rather fierce market in Australia these days, it is certainly worth a close look by those interested in mathematics at the senior secondary and lower undergraduate levels. The patient users of the previous Sharp calculators who have waited for the updated model will not be disappointed.

The Sharp EL-9600 costs \$120, tax exempt.

The review model was provided by

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