THE "PLUS" PROVIDED BY GRAPHICS CALCULATORS IN TEACHING UNDERGRADUATE STATISTICS

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ABSTRACT

It has long been accepted that the use of technology, in the form of computer packages, is beneficial in teaching undergraduate statistics. However, having recognised the potential of graphics calculators with inferential statistics capabilities, the relative roles of the different forms of technology were investigated. Initially, the focus was on calculators versus computers, evaluating the students' preferences. It soon became clear that it is technology as a whole that is important in a statistics course, rather than one particular form. Consequently, during 2001 the emphasis has been on providing access to learning with a whole range of technologies. Through surveys and interviews, the students have indicated that, whilst they recognise the need for computer packages in future work situations, their learning has been greatly enhanced by the use of graphics calculators. This seems to be due, in part, to their existing familiarity and confidence with the calculators as much as to the calculator's capabilities. Graphics calculators are required in the school leaving examinations in Western Australia and the majority of science students arrive at Murdoch University owning one that has statistical inference facilities. (Typically, about three-quarters of the students have a graphics calculator capable of statistical inference in their final examination.) The benefits to effective learning gained by incorporating, as an extra learning tool, facilities that the students already have at their fingertips have definitely outweighed any extra time required in developing appropriate learning activities.

KEY WORDS: Inferential statistics; technology; graphics calculators; computer packages

1. Introduction

The teaching of statistics has changed enormously over the last few decades with the development of calculators and computers. Their use has not only made the computations easier it has changed the way that people think and teach. The statistician David Moore puts this transition very clearly.

> While the impact of fast, easily accessible computing has had an impact on mathematics as a whole, it has revolutionised the practice of statistics. An obvious effect of the revolution is that more complex analyses on larger data sets are now easy. But the computing revolution has also brought about changes in the nature of statistical practice. In the past, statisticians conducted straightforward but computationally tedious analyses based on a specific mathematical model in order to draw conclusions from data. Instruction in statistics showed a corresponding emphasis on learning to carry out lengthy calculations. Now the paradigm statistical analysis is a dialogue between model and data. ... All [methods] are computationally intensive, and the most widely adopted make heavy use of graphic display. ... Statisticians ... have welcomed calculators and computers as a liberating force. Calculating sums of squares by hand does not increase understanding; it merely numbs the mind. In these circumstances, it is natural for a statistician to urge the use of calculators and computers in instruction at all levels. (Moore 1990, p99-100)

This comment seems to reflect the move towards using technology in the learning and teaching of statistics. Current work is looking at ways of developing appropriate technology tools to enhance student understanding (Chance, Garfield & delMas 2000) and it's importance is being recognised by joint initiatives such as the *Maths, Stats & OR Network* in the UK (Bishop & Davies 2000). The integration of technology into the teaching and learning of statistics brings with it the need to determine the appropriate roles of calculators and computers in various programs of study. This paper looks at the role of both calculators and computer packages in the teaching of introductory statistics courses at the undergraduate level and the merits of using a range of technologies for student learning.

2. Background

Since the mid 1980s it has been common practice in the teaching of statistics courses at the undergraduate level to include the use of a statistics computer package. By taking away the drudgery of tedious calculations more emphasis can be placed on the understanding of data types, methods of data collection, choice and interpretation of analyses and determination of conclusions. Initially, many packages were run on mainframe computers with complexities in access and coding similar to the complexities in the calculations that were being replaced. More recently the advent of desktop & laptop computers, combined with the continual upgrading of computer software has led to very simple access to menu driven packages that rapidly provide sophisticated output for even complex analyses of large amounts of data.

However, the latest "computers" that can perform inferential statistical processes are even smaller than laptops, being the hand held graphics calculators. Whilst the authors admit that these calculators would not be the first choice for performing major analyses, we feel that they can play an important role in a student's first learning experiences with inferential analyses. These calculators are familiar to an increasing number of students, they have the ability to perform

simple analyses with summary data as well as raw data (a facility that is often not available on larger packages) and they can provide students with an easily accessible experience of inferential statistics (Kemp, Kissane and Bradley 1998).

At Murdoch University there are three introductory level statistics courses (equivalent to $1/8^{th}$ of a students first year of study). One is intended primarily for commerce and business students and the other two are for students who take the course as part of their studies for degrees mainly in the biological, biomedical, environmental, marine and veterinary sciences, in biotechnology, ecology and molecular biology. Each course consists of lectures and tutorials (of up to 20 students) with marked homework assignments, mid-semester test and final examination. Most of the students would have recently completed at least one mathematics course in the final year of secondary school leading to participation in the Western Australian school leaving Tertiary Entrance Examinations (TEE). Students have been required to use a graphics calculator in these examinations since 1998. Therefore, many students arrive at Murdoch University owning and, more importantly, being very familiar with a graphics calculator. The possible exceptions are interstate, overseas or mature age students.

This paper will focus on the use of technology in the two courses intended for science students. These courses are coordinated by the first author, with the second author providing support classes for the students experiencing difficulties in the courses. The use of computer packages has been fully incorporated into the courses for fifteen years (Bradley 1996). However the authors decided in 1999, after extensive experience with graphics calculators in non-statistics courses (Bradley, Kemp & Kissane 1994), to look more carefully into the roles of different technologies from a teaching and learning perspective. As an ongoing part of this analysis of the role of the graphics calculator as well as other technologies in the courses, the various facilities available on the technologies and relevant to the courses were collated and are given in **Table 1** (at end of paper). The three computer packages are those that have been used in the introductory courses at Murdoch University. The Casio, Texas Instruments, Sharp and Hewlett Packard calculators referred to here are those with descriptive and inferential statistics capabilities, the HP incorporating a specially written aplet. The table also indicates the ability of the technology to use raw data and summary data (such as means and standard deviations).

Until 1999 the computer package *MINITAB* was used in these courses but subsequently, due to financial cuts, a switch was made to using *Excel* and *SPSS* from 2000 onwards. The site licence for *MINITAB* became too expensive and it was assumed that many students would have access to *Excel* at home. The decision to change was rued by the authors as the *MINITAB* statistics package seems to be the most appropriate for this level of student.

As can be seen from the table, the graphics calculators provide more of the facilities used by students in the statistics course. Whilst the displays may not be as large as those produced on computer packages, the graphical displays themselves are often easier to produce and modify to see the effect of data changes. There is also the advantage that students will have been using some of these facilities on their calculators as part of their high school studies. The calculators have the advantage that students can use either summary or raw data for the simple analyses in the courses.

3. Early student responses

Since 1999 the coordinator of the courses has consistently incorporated both graphics calculators and computers into the teaching and learning of statistics. Lectures include demonstrations with graphics calculators and interpretation of computer output and students are

required to attend computer laboratory sessions to learn how to use the computer packages. In their initial work during 1999 and 2000 the authors research focus was on students' perceptions of the benefits of computers versus calculators. At that time not as many students owned graphics calculators with the inbuilt statistical inference facilities as they do now. All students had to learn how to use the computer packages, as their use was required for some marked assignment tasks and interpretation of outputs was expected in the final examination. Those students who had graphics calculators were encouraged to use them and, in addition, the authors made calculators available for use in tutorials and in the library; indeed some students decided to buy them during the semester.

In 1999 students were asked for their comments on the graphics calculator versus computer use. There were positive comments for both *MINITAB* and the graphics calculators, with some students being in favour of both technologies in various ways. Their responses included the following comments:

Firstly for ***MINITAB***:

- *MINITAB* output is good.
- Good diagrammatically, has everything written on it.
- Better for more complex tests.

Comments supporting the **calculators** included:

- You can see more.
- It is better value.
- You can take it wherever you are.
- You get a greater understanding of what the calculator tells you than *MINITAB*.
- Had to understand first by doing it by hand. The graphics calculator enhanced understanding.
- The relevance of the P-value was brought home by the graphics calculator.

On whether they would **recommend the calculators**

- Yes, even before books.
- Yes, because they are used in other subjects and there is a future for them.

In 2000 the students were using *Excel* and *SPSS*. The internal students undertaking the two courses for science students were surveyed about a quarter of the way through the course with about 63% responding. As can be seen from **Table 2** (end of paper) and **Figure 1** (below) although the majority of students had access to *Excel* at home, they still preferred to use their own calculators or tables books for normal probability calculations. This preference for using calculators over computers can also be seen in **Table 3** (end of paper) giving survey results for week 3 tutorial exercises in one of the courses. Students were given detailed instructions for calculating means and standard deviations using scientific and graphics calculators as well as computers and asked to indicate, with reasons, their preferred method.

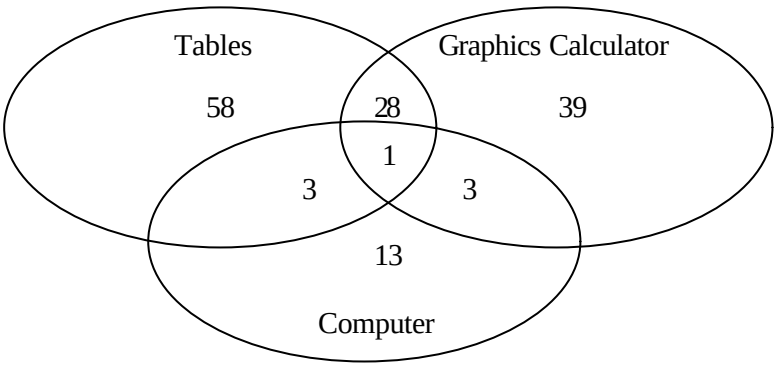

Figure 1: Methods used to calculate normal probabilities on assignment during week 4 - 2000

Throughout the semester the number of students using graphics calculators steadily increased (**Table 2**). This was in part due to the aplet provided about half way through the semester by Hewlett Packard for the HP 38G calculators providing automatic confidence interval and hypothesis test calculations. A number of students in both courses indicated that they were using the calculators in the Reserve section of the library (available for 2 hour or overnight loan). All students who wished to use a graphics calculator for the tests and final examination but did not own one were able to borrow them.

Apart from the survey results, it became evident during lectures and tutorials for both courses that the enthusiasm for graphics calculators with statistical inference increased over the semester. When students did not have access to computers, or when they were not required to use computers by the nature of assignments or tests, they were comfortable with using graphics calculators and became more so over the duration of the course. The students appreciated the extra support classes, provided by the Teaching and Learning Centre, which focused both on the content of the courses and the practicalities of using the calculators. (It is especially helpful for this kind of support to be provided when students come to class with a number of different makes and models of graphics calculators.)

4. Teaching strategies

After reflection on the students' comments and discussion with colleagues in Australia the course coordinator decided to take a slightly different approach with a view to improving student awareness of the power of the different packages and calculators. This new approach in 2001 incorporated all the previous uses of technology. However, this was combined with a strong emphasis on how each kind of technology could contribute to each stage in the development of statistical ideas. This included discussion of the advantages and disadvantages of the different aspects of the various technologies for both learning and performing statistical analyses. Bearing in mind that the major aim of the course is to teach students introductory statistics as well as the use of technology this has to be done quite carefully.

As part of the teaching process, students are given comprehensive technology guidelines and examples in three different ways. Firstly, course notes are prepared giving instructions for using *Excel* and examples of *Excel* output as well as details of the required statistical techniques. Secondly, during the lectures examples of *SPSS* and graphics calculator output are used. Finally, in tutorials students receive detailed written step by step instructions for both *Excel* and *SPSS* together with instructions for all different makes of calculators. Calculators are taken along to the tutorials for students who wish to borrow them and are available for use in the university library.

For assignments students are often given a choice of using *Excel*, *SPSS* or calculators but they need to be able to read *SPSS* output for the final examination.

Students are introduced to the value of using computers to easily handle a large data set. During the first lecture of both courses students fill out a questionnaire giving details such as their gender, height, eye colour, dominant hand and eye, number of brothers and sisters, method and time to travel to the campus each day. Other details relate to their studies, recycling habits and number of pets. The information is anonymous and, whilst the students can identify themselves by birth date (not including year) plus other details such as degree program etc, other members of the courses (including the coordinator) would find it very difficult. Altogether 17 fields are recorded for each student giving data sets each with well over 100 records. These are then used in lectures, in tutorials, for assignments and even examination questions. Over the eight years that the first author has been collecting and using the information, the students have indicated that they really find it motivating to be using a large data set that actually relates to themselves. Performing analyses on assignments and discovering whether, for instance, environmental science students are more likely to recycle than vet students seems more relevant than some standard text book questions. It also helps in talking about the difference between populations and samples and whether the samples are random. As well as being used for analyses the files (created in *Excel* but readily readable by *SPSS*) are useful for practice in manipulations such as sorting, converting text to number and vice versa, combining information (such as brothers + sisters = siblings), splitting files, combining data from two files and so on.

Students come to appreciate that a graphics calculator is a very powerful, portable tool for learning statistics. The more recent calculators can perform all the operations required in an introductory course. The visual representation of the P-value in hypothesis testing produced by graphics calculators helps the students better understand concepts (see **Figures 2 & 3** below). As students become more proficient they become more impressed by the facilities of the calculator and more likely to use them confidently.

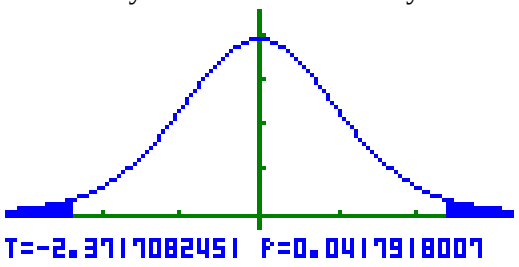

Figure 2

P-value for two tailed t-test - Reject H_0

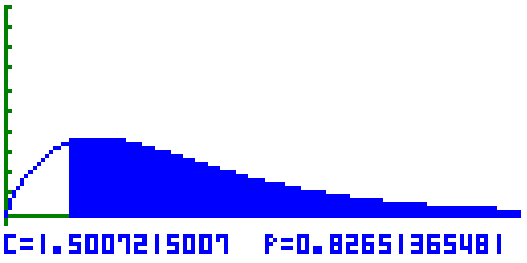

Figure 3

P-value c^2 test for association - Do not reject H_0

In 2001 students could complete the courses without using a graphics calculator but not without using either *Excel* or *SPSS*. More students than in previous years entered the two courses owning a graphics calculator with statistical inference capabilities and 75% of them chose to have one in the final examination. On marked assignments students were asked to indicate which technology they had used for those questions where there was an option. More often than not they had used the graphics calculators. When they had to use a package they seemed to prefer *SPSS* to *Excel* even though they all had to learn how to use *Excel* for some of the file manipulations.

The authors strongly believe in the total integration of technology, including graphics calculators, into all aspects of a course, including assessment (Kissane, Bradley & Kemp 1994;

Kemp, Kissane & Bradley 1996; Kissane, Kemp & Bradley 2000). Whilst this has been achieved for graphics calculators in some pre-calculus and calculus courses that are taught at Murdoch University, it has been more difficult to do so with the statistics courses. If the use of graphics calculators were required then every student would need access to a calculator and, unfortunately, the large numbers of students means that the resources are not available to ensure this. The calculators are still considered too expensive to require students to own one for a statistics course. Consequently there are no questions on marked assignments, tests or final examinations that require students to use a graphics calculator. Although access to computer laboratories is available to all students at allocated times this by no means implies that they have access whenever they wish. In recent years the move has been away from complex computations towards interpreting given output, especially in examinations. The only calculations that students are expected to complete in timed tests are those for basic hypothesis testing and confidence intervals. However if students have access to graphics calculators they may choose to use them for the actual calculations. A few, even those with calculators, prefer to do it all by hand, others prefer the calculator and many say that to start with they do it by hand then check using the calculator but, once they feel proficient and have limited time, will rely on the calculator.

5. Student Responses

From interviews with students in both 1999 and 2000 it was clear that all forms of technology had important roles to play in the courses. Students indicated that they found different aspects of the different technologies useful and could not place one clearly above another. In the early stages of the courses the calculators had definite advantages in that the simple tests and confidence interval calculations were not readily available on the computer packages. Familiarity with the technology, ease of access and 24 hour access were often cited as **pluses** for the calculators. Towards the latter end of the courses the computer packages had definite advantages for the more complex analyses - not so much in the performing of them - but in the printing of results. Not only is the print out easier to obtain, but it is also more comprehensive.

During 2001, interviews with the students indicated student views consistent with previous years. One change was the fact that more students were coming to university accustomed to using graphics calculators. The familiarity the students had with the technology of their graphics calculators helped overcome their fears and dislikes of studying statistics. (About 99% of these students are doing the course because it is required not because they want to.) Learning about extra features was just seen as a natural extension of their previous use. Many students expressed delight that the calculators continued to have a role in their studies. Some who had passed their calculators on to younger siblings soon got them back or purchased new ones. Being able to check hand calculations and use of tables on the calculators increased their confidence and they particularly liked the visual representation of the P-value on the calculators, which enhanced their understanding of interpreting hypothesis tests.

6. Conclusion

There are advantages to using and making explicit the appropriateness of the different technologies at different times in the courses. Students see the importance of having access to computer packages that are likely to be used in their own research or future careers. Using data that directly relates to the students gives extra relevance to the course as well as producing some

interesting information and discussions along the way. On the other hand students also value the graphics calculators as portables aids to learning; the 24-hour access to the calculators through ownership or borrowing through the library is seen as a definite **plus**. Students who have mastered their use in one of these courses continue to use them in later courses.

Lastly, but not least, and possibly as a reflection of the technological age we live in, more students are deciding to do further statistics courses in their second and third years. The increasing relevance of the introductory courses helps students to enjoy and value these courses. These students can then add a statistics minor to their life sciences major and in so doing make themselves far more employable.

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Table 1

Descriptive and inferential statistics facilities

Test/CI	MINITAB	Excel	SPSS	HP	Casio/TI/Sharp
Histogram	R	R	R	R	R
Box and whisker	R	R	R	R	R
pie chart	R	R	R		
Scatter diagram	R	R	R	R	R
CI mean (*z*)	R			R S	R S
z-test mean	R			R S	R S
CI mean (*t*)	R		R	R S	R S
t-test mean	R	(R)	R	R S	R S
CI proportion	R S			(R) S	(R) S
z-test proportion	R S			(R) S	(R) S
CI 2 dep means (t)				(R) (S)	(R) (S)
paired t-test		R		(R) (S)	(R) (S)
CI 2 means (*z*)	R			R S	R S
z-test 2 means	R	R	(R)	R S	R S
CI 2 means (*t*)	R		R	R S	R S
t-test 2 means	R	R	R	R S	R S
CI 2 proportions (*z*)	R S			S	S
z-test 2 proportions	R S			S	S
c^2 association	T		T		T
ANOVA 1 way	R	R	R		R
Regression	R	R	R		R

Key: CI - confidence interval;

R - raw data; S - summary data; T - data in tabular or matrix format

(R) indicates that raw data can be used but only after some manipulation eg sorting for proportions and calculating differences for paired *t*-test;

(S) indicates that summary data for the calculated differences can be used.

Table 2

Survey results - 2000

Week 4 of Semester	
Access to Excel at home	112 (77%)
No	34 (23%)
Own graphics calculator with inference	41 (28%)
Own graphics calculator but without inference	73 (50%)
No	32 (22%)
Used only GC for normal probabilities - own	29
Used only GC for normal probabilities - borrowed	10
Final Examination	
Used graphics calculator with inference	113 (50%)
Used graphics calculator without inference	36 (16%)
Did not use a graphics calculator	75 (33%)

Table 3

Calculation of means and standard deviations during week 3 tutorial - 2000

(instructions for all forms of technology given) (one course only)

Preferred method		**Typical comments**
scientific calculator {also owned GC}	8 (9.9%) {0}	"not good with computers" "computer packages awkward to use"
graphics calculator {owned GC}	48 (59.2%) {44}	"faster, more familiar with" "more used to it and it will be available in exams" "don't have to log on" "less steps to take & simpler (even though I am unfamiliar with it)" {student did not own GC}
computer {also owned GC}	25 (30.9%) {13}	"data entry was easier" "the screen is bigger and easier to read"