® HELPING STUDENTS FIND THEIR STATISTICAL VOICES

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Communication in statistics is multifaceted, and is involved in all phases of statistical analysis and modelling: planning, collecting, handling, exploring and discussing data; articulation, synthesis and development of probabilistic/statistical models; understanding and applying concepts; and using, interpreting and reporting results of, formal statistical analyses in context. An important thread throughout, for students in their learning, and for statisticians in communicating, is connecting with everyday and "already-owned" concepts in probability and data. This paper discusses and analyses strategies that have been integrated throughout some introductory tertiary courses to help students develop their communication in, and of statistics - to themselves, with others, and in carrying out all aspects of statistical data investigations, analyses, interpreting and reporting.

INTRODUCTION

This paper focuses on some key communication aspects of introductory tertiary statistics courses, mostly introductory data analysis courses, but also introductory probability and distribution courses that include some statistical/stochastic modelling. Introductory data analysis courses have received much attention in the statistical education literature in the past decade, associated with the universality of data analysis across many disciplines. Topics have included issues of maths anxiety; emphasis on real contexts and data; effects of technology; and the increased inclusion of data across all school levels. For these reasons, plus the extent of the learning and teaching impact of the own-choice group project strategy in data analysis (MacGillivray, 1998; 2002a), this paper focuses particularly on the communication aspects of the introductory data analysis types of courses across a range of disciplines, including prospective statistics majors. However, emphasis on data should not prevent awareness of the importance of communication in probability and probability modelling.

The push to emphasise statistical thinking through the use of more data (for example, Moore, 1997), with fewer recipes and derivations, along with the automation of computations and graphics, is now the norm for many introductory tertiary data analysis courses. Issues that inform discussion of communication in, and of, statistics include analysis of statistical reasoning and statistical thinking (Watson & Callingham, 2003; Wild & Pfannkuch, 1999); assessment practices that assess what is valued and that help students to develop understanding of themselves as individual learners (Angelo, 1999; Chance, 2002); and student engagement (James, McInnis, & Devlin, 2002).

Also of relevance are the strength of intuitions students bring to statistics courses (Konold, 1995) including those linked with public perceptions (Watson, 2004); understanding of variation (for example, Reading & Shaugnessy, 2004); and the use of technology, particularly in graphing (for example, Konold, Pollatsek, & Well, 1997).

Here, communication in the linking of data, probability, random variables and everyday processes is briefly discussed. The paper then focuses on communication aspects of the semester-long, own-choice group project strategy (MacGillivray, 1998; 2002a), with qualitative and quantitative commentary on student projects over many topics and disciplines. Many of the communication strategies discussed here have been developed from helping and observing students throughout their projects, from initial ideas and planning, through all phases of collecting, exploring and analysing, to final report.

The term "courses" is used here for any self-contained unit, module or subject of study that is assessed and receives a grade that is recorded on a student's official tertiary academic record.

COMMUNICATION ASPECTS IN INTRODUCTORY PROBABILITY AND DISTRIBUTIONS

Whether introductions to probability and distributions are small components within a data analysis course, or in a course of their own, the traditional ways of learning and teaching in this area tend to have insufficient links with data, and with everyday processes and variables. The use of media to assist younger students in developing concepts of chance and data (for example, Watson, 2004) should also be extended by statisticians and senior school/tertiary teachers to develop probabilistic and distribution thinking closely linked with data and everyday experiences. Just three communication aspects are discussed briefly here – estimation of probabilities, communication with conditional probabilities, and the use of graphs for data collected by students from simple stochastic processes.

Estimating probabilities by relative frequencies is such a natural human activity that students are surprised and delighted to discover how much they already understand, particularly when the learning experiences emphasize estimation of conditional probabilities. Apart from simple examples such as the probabilities that females/males wear glasses, the probability that a person wearing glasses is male, and the proportions of redheads amongst males/females, estimates of probabilities for variables such as the number of cars per minute, the number of cars between successive trucks, intervals of heights or other continuous variables, are easy preliminaries to any theoretical considerations.

An example such as deciding how to estimate the probability that a male wears glasses compared with the probability that a person wearing glasses is male, is a valuable learning experience about conditional probability that links with percentages – clear identification of their reference group or given event. As with probabilities, the understanding of percentages that students bring to tertiary study is sufficient for them to solve initial problems involving the law of total probability and Bayes' theorem before any theoretical considerations are attempted. Assisting students to analyse their "intuitive" methods and articulate the generalisations, is a powerful way to help them self-analyse, to develop their understanding of implication and to build their ability to interpret and mathematically model a wordy contextual problem. Conditional probability examples abound in everyday situations seldom used in traditional probability courses. The following is the first part of one such example which continues to include Fred's younger brother, Pete, who is being trained as a 'sniffer' dog. Note that the change from %'s to a decimal probability is a calculated part of the learning.

Example: *Fred is a beagle 'sniffer' dog at an international airport. Fred is 95% reliable in detecting contraband substances when they are present, and is 99.5% reliable when contraband substances are not present. If Fred indicates that contraband substances are present in 1% of luggage pieces he inspects, show that the probability, that a piece of luggage contains contraband substances is 0.0053.*

The topics above lend themselves to relatively quick but non-trivial and highly stimulating student activities as preliminaries for analysis, generalisations and theory. In a first year course on probability, special distributions, and introductions to stochastic modelling, with students of diverse abilities and interests but united in dislike of "baby" exercises, the introduction of preliminary contextual and data-oriented activities such as the above contributed within one year to increasing overall student performance and satisfaction by approximately 20%.

The same first year course includes a small group project involving data collection from two possible Poisson processes of student choice, and checking the assumptions of Poisson processes. Apart from firsthand experiences of the nuances of sufficient or insufficient evidence against assumptions, there is great value in learning how to plan, carry out and describe data collection from real, everyday stochastic processes. It is of interest how much encouragement and guidance students need to use graphical methods to investigate the possibilities of trends or dependence over time of their data. As in Section 2 below, it is the combination of producing appropriate graphs, understanding their power and limitations, and judiciously integrating graphs within a report, that is significant in tertiary students' development of statistical communication skills.

LEARNING ABOUT GRAPHS: FIRST STEPS IN COMMUNICATION AND STATISTICAL INVESTIGATIONS

Graphs, plots and tables are forms of statistical communication in themselves, and the two obvious communication aspects in graphs, plots and tables are using them as means of communication, and reading and articulating key features of them. But learning about graphs, plots and tables can also be used to give students key skills for the data investigations of Sections 3 and 4 - from articulating ideas, to the planning, data collecting, handling, exploring, analysis, interpretation and report. This section emphasizes how learning about graphs can provide explicit foundations for the projects discussed in Sections 3 and 4. It is assumed here that students have ready access to a genuine statistical software package with easy use of the range of graphs, plots and tables used by statisticians. Minitab version 14 is ideal for learning and teaching in this area.

COMMUNICATION WITH GRAPHS

For students to gain understanding and confidence in *using* graphs, plots and tables, they need learning experiences within each of the three phases of exploration, presentation, analysis; with the learning experiences embedded within, or extracted from, larger whole contexts and data investigations that include analyses and reporting.

The starting points in using graphs are the same as those needed in planning a data investigation, whether experimental, observational or survey - identification of variables and their types. The key for students to plan and work with any confidence with their data is identifying and understanding the variables and the subjects in their data – the columns and rows of their spreadsheet of raw data. This is not necessarily natural even to quantitatively-inclined students, and requires initial specific learning experiences in identifying variables ("columns") and subjects ("rows"), and types of variables. Once quantitatively-inclined students have some initial learning experiences and see the value of this in data planning and procedures, it becomes a permanent part of their thinking; less numerate students often need ongoing assistance to develop this.

The main classification of variables for choices of data presentations (and introductory analysis) is into categorical and continuous, with guidance for count variables with few values, such as number of accidents at an intersection, and count variables with many values, such as traffic or attendance at sporting matches, which can often be treated as pseudo-continuous, or as flows or rates.

The emphasis in exploration is to explore within the ranges of presentations that are appropriate for the variable types. The emphasis in presentation is judicious choice from the exploration phase. The emphasis within analysis is that graphs and plots assist, support and illustrate formal statistical procedures. They do not substitute for formal statistical procedures, but are essential components of some, such as regression and ANOVA, and provide invaluable support for many. It is a non-trivial step in student learning to bring these three phases together in an integrated way within an overall data investigation, and needs confidence within the three phases plus learning experiences involving whole data investigations, whether own-choice or not.

COMMUNICATION ABOUT GRAPHS

Learning to communicate *about* graphs, plots and tables can be challenging, as it is a highly interdependent process combining confidence and awareness of (i) the scope and limitations of the various representations, (ii) discerning key features midst variation, and (iii) synopsis and efficient use of language. Although (i) is assisted by identifying types of data/variables, and (ii) can be assisted by guidance on a mental checklist such as "location, spread, shape and unusual features; relationships; effect of time" (MacGillivray, 2005, pp25-34), moving rapidly into learning experiences that combine all three in a "try it" approach can be daunting for both students and tutors. This became particularly apparent in an MBA (Master of Business Administration) course (MacGillivray, 2003) in which business and other non-quantitative graduates tended towards excessive detail with a confusion of appropriate and non-appropriate statements and very little attempt at synopsis. The learning experiences devised to help these students have since been incorporated in introductory data analysis courses across a range of student cohorts. They include providing a set of comments that refer to a given context and graphs, and asking students to choose which are appropriate and which not (MacGillivray,

2005, pp 40-46). Comments might be correct or incorrect; they can be unsupported by the given graphs (for example, there may be no information about averages or variances or relationships); or they can even be correct but inappropriate.

Such exercises not only provide initial learning experiences in communicating *about* graphs, plots and tables, but can also be used in exams to complement the assessment of choice, production, use and discussion of graphs, plots and tables in practical assignments and projects.

QUALITATIVE COMMUNICATION ASPECTS OF OWN-CHOICE GROUP PROJECT IN INTRODUCTORY DATA ANALYSIS

The original objectives of the strategy were to provide hands-on data investigations for mathematics/statistics majors, in contexts of their choice, from the conception, planning, collecting to exploring phases, and to integrate development of communication skills within mathematics/statistics degrees from the moment the students started tertiary study. There was also increasing interest in Australia in training "for consulting", and in cooperative honours and postgraduate student projects with industry (Diamond & Hallett, 1998).

The idea worked so well that it was trialled in 1994 with the engineering statistics course of approximately 400 students, with the aim of helping them to connect with statistics through ownership of their data. These students were not satisfied with leaving "their" data at the exploration stage, wanting to use data analysis techniques as, or even before, they met them. In expanding to include analysis, other unforeseen benefits began to emerge, and the own-choice projects strategy evolved and was adopted by other staff. University and national grants supported the development of resources (MacGillivray & Hayes, 1997), and ongoing observation and assistance of students has continually fed back into the courses, which are now structured around the carrying out of a complete statistical investigation, with learning experiences making use of excellent datasets from past student projects (MacGillivray, 2005).

The principles are that students suggest and staff respond. Staff help students to articulate their ideas, to identify their variables and subjects of observation, to obtain a dataset that is suitable for their timeframe and level, and as the semester progresses, to choose, use and interpret formal statistical analyses. Students form their own groups with assistance as needed, particularly in a large first year science course (approximately 500 students per year) in which the projects were changed in 2004 from optional to compulsory, at the suggestion of the students.

Groups are required to submit a simple description of their proposed data and its collection as soon as they wish, but by mid-semester. Students require considerable encouragement to identify their proposed variables and subjects, and to describe the practicalities of their planned investigation simply, without speculation or unnecessary jargon. The proposal description is for feedback only, but is an excellent learning experience in formalising ideas and in communication about statistical investigations.

The range of ideas and interests is enormous. In the past decade almost 1500 of these projects have been done by students across all engineering, and more recently by a wide diversity of students across science or mathematics majors or comajors. MacGillivray (1998; 2002a; 2002b) include details about projects and their impact in learning and teaching. In recent years, a more systematic approach to recording and storing projects has facilitated student access to past student projects as well as the model project resources of MacGillivray and Hayes (1997).

Staff in other disciplines may react to students' choices with "but what has this to do with the students' course?" The answer is "everything" if the students choose their own context for the learning they then transfer into their own discipline. Some of the most incorrigible topics have been thought up by some of the best students. The topics may be incorrigible but the work and the learning are excellent, and the feedback is that they feel that the statistical understanding they take into their own areas from doing a project they "invented" and owned, is better than one from a given list or from "serious" topics. Just a few examples of titles across years and courses include *Murphy's Law and its ramifications for Toast; Newton's Fourth Law - Do Singles Seek Comfort Through Trees? Get Popped; The Very Irresponsible William Tell; Do Bimbos Exist? To press or not to press; Chicks in red cars; Joy with Jelly; Flow rate of beer; Crash test stubbies; The egg crush experiment; Gogogo! Human Curiosity; What age should you stop catching rulers? Frangin' in the refectory; Death by statistics; Holding breath; Dissolving times of soluble*

aspirin; Free loop service; The science of publishing research; Study of different balls; The big news about breakfast.

The components of the project, and the criteria for grading, are (i) identifying and describing a context and issues of interest; planning and collecting of relevant data; quality of data and discussion of context/problems; (ii) handling and processing data; summarising, exploring and commenting on features of the data; statistical modelling and preparation for formal analysis; (iii) using statistical tools for statistical analysis and interpretation of the data within the context/issues. Thus communication of, in, and about statistics is integral throughout the project. Particular emphasis is placed on thinking of one's reader, and ensuring that a reader knows exactly the circumstances and assumptions, so that the study/investigation can be repeated or extended or re-interpreted.

Because the project includes assessment of choice of procedures, the production of graphs and analyses using statistical software, and the synthesis of issues, results and discussions, other assessment tasks can focus on the separate phases – the tools and building blocks of concepts, procedures, and their use. Such tasks still include communication skills, but in bite-size pieces. The approach is consistent with Gal and Garfield (1998), and it is essential that the complete learning and assessment package balances formative and summative assessments that support steady student development in all components, including communication aspects.

SOME QUANTITATIVE ANALYSIS OF THE EFFECTS OF OWN-CHOICE PROJECTS

As stated above, the project was originally introduced for mathematics majors, but has been a component of engineering statistics at Queensland University of Technology since 1994. Since 1997, a single introductory data analysis course has catered for all science and mathematics majors, with an optional and/or adapted version of the project. In 2003, the full version of the project with written report was optional, as was an essay on "How statistics revolutionised science in the 20th century" (Salsburg, 2002), but as a result of student feedback, the full project was changed to a compulsory component of the course in 2004.

Table 1 below gives a classification of project topics for a class of 200 second year electrical engineering students in 2002 and a class of 450 first year science-linked students in 2004. Although there are interesting differences in topic choices between the cohorts, it can be seen that students choose topics of everyday and personal interest.

Table 1
Percentage Classification of Topic Choices for Two Cohorts

First year science topics of choice, semester 1, 2004	%	Second year electrical engineer topics of choice, 2002	%
Food/drink	20	Media	20
Observational studies (mostly people)	15	Transport	20
Transport	15	Company/technical/PT work	12
Experiments	14	Food/drink	10
Surveys	9	Observational	8
Media	7	Sport/physical	7
Sport/physical	6	Experimental	6
Retail	5	Money	5
Company/technical/PT work	4	Surveys	4
Environment	3	Retail	4
Gambling	1	Environment	2
		Gambling	1

For both the above cohorts, the project was compulsory and the final exam covered the whole course with a mixture of single and short comment responses using computer output and real data contexts. In regressing the exam mark on the three component marks of the project, the analysis component was significant (p=0.000) for the first years, but for the engineering cohort, the exploring component was the significant predictor (p=0.000), reflecting observation that once

engineering students understand the data types and handling aspects, their project analysis mark is a function of their commitment. In both cases, the model was adequate with no interactions, but the R-sq of 7% for the first years and 17% for the engineering students, reinforce the observation above that the exam and the project are complementary rather than overlapping in their assessment criteria.

Because the project was optional for the first years in 2003, and counted only if it improved a student's result, the practical lab work in 2003 contributed to summative assessment. In 2003 the practical mark was, as intended, a significant predictor (p=0.002) of the project mark, but the R-sq of 13% again demonstrates the variability inherent in first year classes. The practical mark, whether the project option was chosen, and the project mark, were all significant predictors (p=0.000 for each) of the final exam mark, illustrating the strong links between understanding, using, interpreting and communicating statistical analyses. Again, there were no problems with the model and no interaction/higher order terms needed, with R-sq = 45%.

In 2004, with a compulsory project, the practical lab work was formative with short fortnightly quizzes contributing to summative assessment. Both the quiz mark (p=0.000) and the project mark (p=0.002) were strongly significant in predicting the exam mark, with R-sq = 31%, and the project mark was significantly correlated with the quiz mark.

The boxplots below show the overall and the exam marks in 2003 for those who did and did not choose the project option. The exam marks tended to be slightly higher and less skew to the right for those who chose to do the project in 2003. The overall mark in 2003, includes the project mark if it helped; Figure 1a shows the main effects for those choosing to do the project, were not only a better chance of a greater overall mark, but a decrease in spread and a shortening of the tails. The contribution of the doing of the project to reducing large variation in overall marks is also clearly demonstrated in comparisons between the 2003 and the 2004 data.
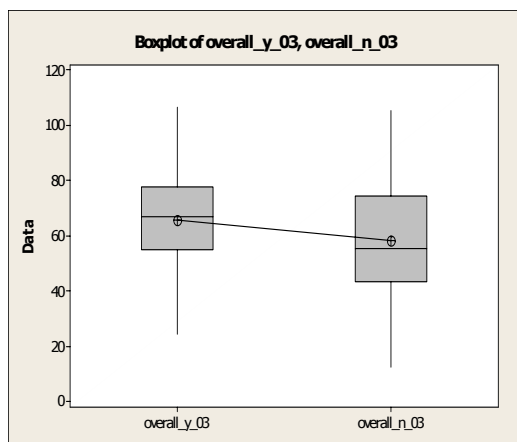

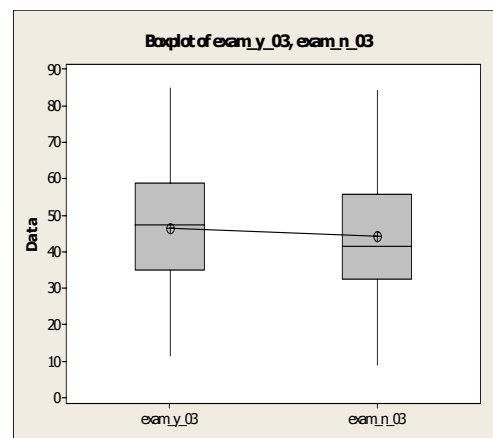*Figure 1a.* Overall mark by choice of project option.

Figure 1b. Exam only mark by choice of project option.

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