Coherent and Purposeful Development in Statistics across the Educational Spectrum

Helen MacGillivray
Queensland University of Technology
Australia

Abstract

The development of statistical thinking and data sense needs steadily progressive and cohesive building of concepts and learning experiences. Meaningful discussion and analysis of curricular approaches to facilitate such development require a reference context. This paper uses a particularly relevant Australian context to combine a cross-sectional report on interaction with teachers in the development and implementation of school syllabi, with analysis of commonalities in cross-disciplinary tertiary student learning in introductory data analysis. These are used to demonstrate the need and potential for genuine and ongoing collaboration between statisticians, teachers and educationalists to develop strategies in constructing, supporting and implementing curriculum to achieve coherent progression in statistical literacy and thinking across educational levels. Such strategies must also include support for teachers.

The Contexts

A combination of circumstances has enabled simultaneous and detailed observation over almost a decade of a range of statistical issues in curricula across school levels in the Australian state of Queensland (population of approximately 4 million) and across many disciplines at the tertiary level. In Australia, schooling is a state matter, although there are national committees of State Education ministers, national minimum standards in numeracy and literacy at selected levels, and National Statements in some key areas like mathematics. The general division of schooling into primary, junior secondary and senior secondary is fairly similar across Australia, but details of syllabi, curricula, implementation, support, and assessment, are individual to each state and territory. Differences at the senior secondary school level tend to be more marked than at pre-senior levels.

The Senior School Context

Queensland has had no central syllabus-based examinations for approximately 25 years. The senior secondary (ages approximately 16-17 years) assessment system is school-based, externally-moderated, and is an innovative system that attracts international interest. The Queensland Studies Authority (QSA) develops and oversees all the syllabi, from primary (ages approximately 5-12 years) through to secondary (ages approximately 13-17 years). Fourteen Subject Advisory Committees are responsible for authority subject syllabi. The word "syllabus" is the term officially used in Australia, with the word "curriculum" used as a more vague and general term across subjects and educational levels. The maths syllabi describe rationale, aims, objectives, organisation, topics, focuses, learning experiences, criteria, assessment strategies and standard descriptors. Assessment at senior secondary level is criteria-referenced (not outcomes-based) with the standards for levels of achievement specified in each syllabus.

There are three authority senior mathematics subjects, with annual enrolments of approximately 18000 in each of two alternative subjects – one a core subject and the other a non-calculus, non-algebraic subject – and approximately 4000 in an extension mathematics subject which has the core subject as corequisite. The emphasis since 1995 has been holistic, problem-based, real-life, with "modelling" and investigations. The core subject involves algebra and introduces calculus. The statistics strand occupies approximately 1/8 of it, with emphasis on data. The non-algebraic, non-calculus subject has 1/3 "statistics" with an option of a further 1/10. The extension subject has an optional section focussing on introductory probability modelling.

Moderation is an ongoing process carried out by regional panels of teachers in each subject. Regional chairs report to State Panels which consist of very experienced teachers and a selected tertiary representative. The focus of the moderation against the criteria is on student work through school submissions consisting of assessment packages and representative student portfolios. State Panels are responsible for monitoring standards across the State, for providing guidance to regional panels and schools, and for resolving disputes. The production of tertiary entrance scores is also based on moderation of school results but is a different process using innovative core skills tests for moderation and is not discussed here.

Syllabi are devised and revised by the Subject Advisory Committees, with the detailed work done by sub-committees for large subjects such as mathematics. All teachers and schools are able to have input through surveys and feedback on drafts. Subject Advisory Committees are made up of teachers and selected representatives of parents, employers and the tertiary sector.

Following involvement in workshops for teachers during 1992-1995, the author has been a selected tertiary representative and the only statistician on the Senior Mathematics Committee since 1996, the Mathematics Subject Advisory Committee since 1997, the State Panel for the core Mathematics subject since 2000, and the chair of Senior Mathematics Committee, 2002-2005.

Some advantages and disadvantages of the senior school system

One of the most valuable effects of the system outlined above is the state-wide collaboration amongst teachers within subjects. This collaboration is across all types of schools, and helps to build a true community of practice. The work of the Senior Mathematics Committee and the regional and state panels is intensively and deeply collaborative. Such close collaboration, with emphasis on student work, facilitates insight into teacher and student needs at the senior school level, and at transition into, and from, senior secondary school.

One of the disadvantages of the system outlined above is the absence of centrally-produced or centrally-accredited resources. The absence of central subject examinations increases expectations of school-based resources and learning strategies. In subject areas of strong familiarity, there tend to be extensive teacher experience and resources, but in less familiar areas, there are substantial unmet needs in teacher support. Any texts that include less familiar topic areas also need to be very high quality – thorough, carefully-written and closely aligned with teacher needs. During the past decade, the most frequent requests from teachers to the above mathematics committees and QSA mathematics officers for further explanation or more substantial help, have been in statistics. This need for help with statistics has been repeatedly demonstrated through teacher surveys, during syllabus implementation, in accrediting school work programs and in moderating assessment packages.

The Primary and Junior Secondary Context

The Studies Authority appoints teams to develop and revise primary and junior secondary syllabi, for example in mathematics. These teams usually consist of seconded teachers from these levels. Unlike the senior committees, they do not have to produce standards or moderation processes, but they do produce elaborations and some resources for teachers.

Since 1990, all Australian states have had Chance and Data strands throughout their primary and junior secondary mathematics curriculum. The curricula in Chance and Data are similar across Australia, with the data strands built around collecting, exploring and graphing data, but with the chance strands still dominated by very old-fashioned emphases on games of chance, counting outcomes and other contexts isolated from the real, the everyday and all notions of modelling with probability and data. Like the senior levels, it is in the statistics that much assistance is being requested. Unfortunately the formats and wordings of primary and early secondary syllabus documents tend to be subject to considerable bureaucracy, which can make it difficult to express statistics components in terms that provide sufficient guidance for teachers.

The tertiary context

There are many tertiary statistical subjects and syllabi in introductory data analysis. Apart from pedagogical considerations, the nature and objectives of each subject or syllabus come from the specifications prescribed by the course or discipline being serviced; the size, diversity, background skills and attitudes of the student cohort; the time restrictions; and the resources available. The requirements from other disciplines often tend to be highly specified, and frequently (at least prior to negotiation by the tertiary statistician!) excessive in expectations within the time frame allocated, allowing for the background and diversity of the student cohort.

The similarities in listings of topics in such subjects are because the statistical tools needed to carry out, interpret or participate in introductory data analysis tend to be remarkably similar across disciplines, even though there may be differences in level of understanding and usage. The challenges of developing statistical thinking and understanding at the introductory level, plus the wide diversity of student cohorts, give rise to subtle differences amongst many tertiary introductory statistics subjects, even with similar pedagogies. Differences might appear minor to outside observers, but experienced tertiary teachers are well aware of the impact of very small differences in teaching and learning strategies in introductory statistics. On the other hand, the sharing and adaptation of resources and strategies across such subjects provide immense benefit to students and tertiary teachers. The cross-disciplinary and across-capabilities experience and expertise of tertiary statistical teachers are some of the most important factors in facilitating strong foundational statistical thinking and confidence for all student cohorts.

The list of tertiary courses in which the author has developed syllabi, resources and/or teaching strategies for introductory statistical data analysis, provides examples of the ranges of cohorts in which Australian tertiary statisticians can be involved in developing curriculum. In some Australian universities, some of the areas below may be replaced by economics and business, whereas statistics in psychology is often taught by psychology staff. Because the Australian statistical community has made significant progress in teaching introductory statistics over the last decade, disciplines not taught by statisticians can be isolated from the latest developments in statistical education. The list referred to above includes:

- electrical, computer, aeronautical, civil, mechanical, medical engineering
- surveying; urban and regional planning; property economics
- life, natural resource, chemical and physical sciences
- medical laboratory sciences; optometry
- computer science and data communications
- master of business administration (MBA)
- library studies

Typically the approach is a balance over EDA-focussed/inference focussed, software-intensive/pencil-and-paper, graphic/formulaic, with the delicacy of the balance dependent on the student cohort, but with emphasis on real data and real data investigations for all student cohorts. In all cases there is input from the serviced area. In the case of the MBA, students are usually required to be in a workplace relevant to business, or have prior business workplace experience. The workplace variety, and the similarities and contrasts between postgraduate and undergraduate needs, are a rich source for statistical education analysis (MacGillivray, 2003).

Theme and objectives

Bartholomew (RSS presidential address, 1995) discusses types of statistical development to achieve a statistically-educated society with the necessary range of statistical numeracy. In discussing student development of statistical understanding in a particular context, Garfield (2002) defines five hierarchical levels of statistical reasoning. Although addressing different contexts, both authors are moving to identification of a continuum of statistical capabilities and understanding, whether in society or in an individual's development. For curriculum development to reflect this, collaboration across the educational spectrum is vital.

Many of the questions and requests from teachers (and students) at all levels of education, reflect the need for connectivity and coherence in teaching and learning in statistics. Questions from teachers and from those involved in writing and implementing syllabi, also demonstrate that, in statistics, there seems to be a need for the teacher to understand to a depth and level far beyond the level at which the teaching is occurring. As indicated by recent and current research, statistical thinking is complex and subtle to describe, so the extent of the challenge in its teaching and learning is to be expected. At any level, statistics requires at least some synthesis in both thinking and skills. At the workplace, user and professional levels, good data analysis practice and thinking require a balance of technical statistical skills, quantitative skills, judgement, the ability to comprehend and model (in the mathematical sense) in contexts that may be unfamiliar, and analysis and interpretation that include balance, synthesis and communication. Statistics is not the only discipline to require such synthesis and balance, and associated depth of teacher understanding, but a very rapid increase in the role and importance of statistics across the education spectrum has outstripped the available resourcing, support and training.

There has been much development and research in the past decade in statistical education. But the needs in all aspects have also been increasing, with many important questions and areas hardly touched as yet by research. In curriculum development, the need for greater involvement of the statistical community, greater collaboration across the full educational spectrum, and more resources and support for teachers, appears to be urgent. The objectives throughout this paper are to help identify and articulate the scope and some details of these needs, to illustrate the value of collaboration across the education spectrum, and, within the latter, to demonstrate some of the rich information available from the introductory tertiary level.

The following section of this paper considers some development and research over the past decade relevant to curriculum. The next section presents an analysis of questions, needs and problems that have arisen in the work of the various committees described above. The last sections discuss some commonalities in introductory statistics tertiary learning across disciplines and the potential for collaboration across the educational spectrum.

A Decade of Statistical Education Development and Associated Research

Since 1990, the increasing awareness of the importance of statistics in society, in the majority of disciplines and for progress in knowledge-based economies and a technological world, has led to increasing inclusion, often rapidly, of statistics in school education. It was of interest at ICOTS6 (Capetown, 2002) to observe the extent of awareness of the roles of statistical literacy in economic and social progress. During the same period of rapid growth in statistics components in school curricula, there has been increasing emphasis and research in the statistical and statistical education community on data-driven educational strategies; on the nature of statistical thinking and reasoning; and on the roles of technology in statistical education. The importance of statistics was already established across many disciplines in tertiary education. The focus in tertiary education during the last two decades has been on improving the accessibility of statistical thinking and data investigations across all disciplines, particularly at the introductory level and for those with little quantitative confidence.

Alongside calls for statistical educators to consider carefully and in depth the objectives, goals, contexts and content of introductory tertiary statistics courses (Hogg, 1991, Vere-Jones, 1995, Moore, 1997), there has been significant work on the meaning and accessing of statistical understanding, statistical literacy, statistical reasoning and statistical thinking, with emphasis on data (for example, Garfield and Gal, 1999, Snell, 1999, delMas, 2002, Rumsey, 2002, Garfield, 2002, Chance, 2002). A considerable portion of this work has been motivated by, and oriented to, introductory tertiary data analysis courses, particularly for non-quantitatively-inclined students (Garfield et al, 2002). Recently, some work has considered more closely the development of statistical understanding as children's overall reasoning develops (Watson and Moritz, 1999) and how statisticians think and acquire such thinking skills (Wild and Pfannkuch, 1999).

The richness, diversity, subtleties and importance of statistical thinking along with the rapid increase in inclusion of statistics in school curricula and in changes in statistical teaching at the tertiary level, have given the broad statistical community an extraordinary range and number of educational challenges, issues and research areas that can be, and in many cases need to be, investigated in a thorough and systematic way. As with all problem-solving, identification of problems, issues and the overall "picture" is required in an ongoing reflective and strategic manner involving the whole statistical and statistical education communities. Some such issues include ways of assessing attitudes to statistics (Gal et al, 1997), roles of technology (Cobb, 1999, Ben-Zvi, 2000), assessment practices (Chance, 2002), and measurement of statistical reasoning (Garfield, 2003). There is now a significant need to build on work such as Wild and Pfannkuch (1999), and Petocz and Reid (2001), to include investigation of statistical attitudes and learning by quantitatively-inclined students, and to link with work such as Watson and Moritz (1999) on children's development of statistical reasoning.

Although "it is nonetheless true that statistics makes heavy and essential use of mathematics" (Moore, 1997) and "because statistical models of reality are mathematical ones, they can be fully understood only in terms of mathematical formulae and symbols" (Salsburg, 2002), the links, interrelationships and contrasts with mathematical thinking, backgrounds, education and abilities have received very little attention (Gnaldi, 2003). There is also a growing need to extend the research and thinking to include more on the development of understanding the probability and distributional concepts needed in statistical modelling. Inspection of current electronic resources, introductory statistical textbooks, and school syllabi, indicates a considerable gap between resources for the more abstract notions of chance, and for those probability concepts needed in the statistical modelling of variation and the statistical data analysis of real world problems. The strategies associated with media reports (Watson, 1997, Pfannkuch et al, 2003) could help to bridge these gaps. However, as with the progression from data displays to the concepts and interpretation of statistical variation, probability *for statistics* is a challenging component for statistical educators in designing curricula, resources and teacher support.

School Syllabi, Teachers' Questions, and Implications for Resources

Syllabus formats and their effects

As mentioned above, the word "syllabus" refers here to all the documentation and information provided by the educational authority to schools and teachers for the teaching of a subject. The word "curriculum" (www.qsa.qld.edu.au) appears to be used only in a collective sense across all subjects, and only for primary and junior secondary.

Many of the questions from teachers can be placed under the headings of "Why?" and "What should we do at this stage, and how do we build/connect to the next?" These questions reflect teachers' understanding of the importance of connectivity, coherence and progression. For every question that arises, well-chosen and varied examples are needed to satisfy the questioner. Although no statistical educator would be surprised by this, it is worth considering the effects of restrictive formats for syllabi.

The tendency to express objectives, focuses, subject matter and learning experiences in school syllabi in bullet point form, assumes sufficient knowledge about “spaces” between bullet points to build sound, systematic and coherent development of student understanding and skills around those bullet points. This also tends to be accompanied by an assumption that a sufficient and full range of resources will be available for teachers and schools who will be comfortable in judging the *quality* of available resources and selecting from them.

In the senior secondary context described here, the syllabus topics are written in bullet point form for focus, subject matter, and a range of suggested learning experiences. Suggested learning experiences are an excellent way to give indications of examples, provided there are sufficient resources or knowledge to fully support their implementation. In the context described here, neither the syllabus writers nor the Authority are permitted to write, accredit or commission texts and other resources. The principle behind this is to try to avoid slavish following of a single textbook, but from the practical point of view, sufficient support for teachers and successful implementation of the syllabus are therefore not assured.

In the primary and junior secondary context described here, the syllabi are written in a hierarchical form, moving from a single sentence defining a core outcome, to a few bullet point phrases of core content, to “students know” and “students do”. This rather semaphoric style is not conducive to seeing how the components fit into a connected and coherent progression, particularly once a level is reached where the challenge is to start to move beyond simple observing, recording and graphing. There is little emphasis on developing skills in handling contexts that gradually increase in challenge as students mature. Resources in the form of some examples are written to illustrate the core content, but there is no provision of statistical assistance or expertise for the syllabus team – if they want it, they have to find it for themselves.

In the Chance and Data strands of the National Statement for Mathematics (Curriculum Corporation, 1990), the bullet points tend to represent “bits” of statistics, with little evidence of progression. Little consideration appears to have been given to a question such as: “What can/should be learnt progressively through school across the student spectrum, and into post-school, and how should these be structured?” In addition, the Data strand tends to over-emphasize drawing and reading from graphs, and “making decisions” based on graphs. This emphasis on data as being absolute rather than representative, tends to inhibit development of understanding of variation, and, later, of inference. As mentioned above, the Chance strand scarcely moves beyond contexts such as coins, dice and cards, and needs fundamental changes.

A recently completed resource paper written for the Data strand (MacGillivray, 2005) is built around real and relevant data examples and their practicalities, with explicit description of the gradual development of data sense and statistical thinking, particularly through senior primary into junior secondary (ages approximately 11-15 years). The paper incorporates wide-ranging requests and feedback from teachers at these levels, and is described by teachers as just what they want, but it is merely a start.

Hence across all schooling levels, even when the curricular emphasis is on a data-driven approach to developing statistical thinking, the needs are clear – statistical input, collaboration and substantial resources and professional development support that meet quality standards in both statistics and education.

Textbooks and Statistics

Writing textbooks is a highly complex and challenging process for any subject. The combination of universality and synthesis of skills in statistics creates even more challenges, particularly at school and introductory tertiary levels. The many roles of statistics throughout society and a diversity of disciplines, mean that fundamental statistical concepts are repeatedly used in contexts varying from everyday to specific. This repeated usage combined with the gradual maturing in statistical thinking necessary as students progress, make it essential that textbooks are not only statistically correct, but also frame discussion at the current level in such a way to help avoid problems later as the student’s learning and thinking mature. This is not trivial and can be achieved only through collaboration between appropriate writers, teachers, educators with statistical expertise, and statisticians with education expertise.

An example of the type of fundamental and serious mistakes that can cause almost lifelong confusion is the following, (O'Brien and Purcell, 1998). The example referred to consists of 30 tosses of a 6-sided die, with frequencies ranging from 3 (for a 1) to 7 (for a 6):

> The arithmetic mean is a method for locating the centre of distribution. It is found by finding the total number of frequency responses and dividing it by the set of numbers or items that have been graphed. For example, the mean for the graph on the previous page is 30 frequency responses divided by the 6 die faces. Therefore the mean equals 5.
>
> The range is the spread of distribution of scores. It ranges from the lowest frequency to the highest frequency. For example, the range for the graph on the previous page is 3 to 7.

Confusing values with their frequencies or probabilities is a difficulty that tertiary teachers know to look out for at the introductory level. It is usually, but not always, a temporary, easily-mended confusion that can accompany a student's coming to grips with some more sophisticated step in their statistical development. It is possible that the rather excessive sophistication of the language in the above could help to hide the very serious mistake from both teachers and children, contributing to potential lifelong problems for some students.

Framing discussion at one level to help students' subsequent development at further levels is an area needing collaborative research and development across a variety of levels from early primary through to secondary and post-school. Some examples relevant to current secondary school textbooks include the following:

- Extending the concept of a mode from discrete to continuous data needs discussion of matters such as estimation, effects of bin choices in histograms, and, ultimately, the concept of probability density functions. It may be advisable to avoid any mention of modes for continuous data until the educational level at which histograms as estimates of probability density functions can be tackled.
- Defining the theoretical mean only through the mean of a very small population can cause a student considerable conceptual difficulties. Consider, for example, the long term damaging effects of a statement such as "Now consider that the set of 20 scores is a population. In this case our mean is called the population mean."
- Defining "The Multiplication Law of Probability" as applying to independent events but without any discussion of independence or dependence has little benefit, particularly when tree diagrams are used to illustrate this "Law".
- The belief that data situations with possible binomial variables cannot be considered without first proving every theoretical detail of binomial probabilities can tend to contribute to confusion between data and models.

Combined effects of syllabus formats and non-commissioned, non-accredited texts

Many enterprising teachers are discovering or creating interesting contexts but need help in making the most of them. For example, an assignment item involved data about the times to emergence of an insect pest and the efficacy of an insecticide, with the question of interest being when is the best time to spray. The only solution given was to obtain, without comment, a confidence interval for the mean time to emergence, and to spray at the lower endpoint of that interval. Confidence intervals were not even part of the relevant syllabus, but a popular textbook included them as if they were, and many teachers thought they therefore had to include them.

For reference, the bullet points of just the subject matter for the statistics in the current core senior secondary mathematics subject are given below.

- Identification of variables and types of variables and data (continuous and discrete); practical aspects of collection and entry of data into spreadsheets or similar
- Choice and use in context of appropriate graphical and tabular displays for different data types including pie charts, barcharts, tables, histograms, stem-and-leaf and box plots
- Use of summary statistics including mean, median, standard deviation and interquartile distance as appropriate descriptors of features of data in context
- Use of graphical displays and summary statistics in describing key features of data, particularly in comparing datasets and exploring possible relationships
- Use of relative frequencies to estimate probabilities; the notion of probabilities of individual values for discrete variables and intervals for continuous variables
- Identification of the binomial situation and use of tables or technology for binomial probabilities (no formula use)
- Introduction of the concept of hypothesis testing through assessing whether data are consistent with a stated value of a proportion in life-related problems, using binomial probabilities (obtained from tables or technology). [Note: the introduction to hypothesis testing does not require any treatment of critical regions, levels, confidence intervals, type 1 and 2 errors.]
- concept of a probability distribution for a continuous random variable; notion of expected value and median for a continuous variable
- probability distribution and expected value for a discrete variable
- the normal model (for life-related situations) and use of standard normal tables

This list is accompanied by appropriate, correct and well-expressed suggested learning experiences, also in bullet point form, but with no further assistance in how to put together a coherent and rich progression in student learning based on the above. The insecticide example demonstrates commendable but misguided attempts to find or devise real and rich examples. Other school-devised assessment items emphasize the damage caused by insufficient professional development and inadequate textbooks. For example, one item required students to carry out the test of the hypothesis that the theoretical proportion, p, was equal to the observed value of the sample proportion. Further evidence of the extent of dependence on textbooks in an area such as statistics is provided by noting that the normal distribution occurs in this syllabus only in the last bullet point above, but because a popular textbook included the normal distribution *only* in order to test hypotheses, it has become clear that there are no resources to support teaching the use of the normal as a model in itself for "life-related problems".

Resources teachers would like

Questions of the "Why?" and "How?" type are mentioned above. Other common questions have been of the "What?" and "What is right?" variety. For example, "What is the difference between a barchart and a column chart, and which is right?" "What is the right definition of a quartile, and how do we explain it?" "Which is the right form of a boxplot?" "How can I teach anything in statistics without first doing events and Venn diagrams?" "Isn't a histogram just a barchart with the boxes joined?"

Textbooks are for use with students and within classrooms, and many of the teachers' questions need a medium for answering other than in syllabus documents or textbooks, no matter how good these are. Based on the questions, inputs and feedback from teachers to the various committees, panels and teams described previously, a suggested summary of what teachers across all levels of schooling would like from curriculum development in statistics is:

- syllabi written in a form that demonstrates coherence and progression, both within and across levels
- rich and extensive resources of examples
- textbooks approved by those responsible for the syllabus and with statistical expertise
- support for teachers appropriate for teaching an important, but demanding and challenging area like statistics. This support could come via handbooks for teachers or short courses or both. Such support

should be specifically oriented to the statistics curriculum across the educational spectrum, and, as with textbooks, approved by those responsible for the syllabi and with statistical expertise.

Cross-Disciplinary Introductory Tertiary Subjects as a Rich Source of Educational Information

Many different disciplines require their students to do some introductory data analysis, and the specifications for most tertiary introductory data analysis subjects come from the user course, workplace or professional requirements of other disciplines. Hence analysis of such subjects is a rich, mostly untapped source of information for collaborative statistical curriculum development across the educational spectrum.

The similarities in statistical skills required across disciplines demonstrate commonalities in the types of data investigations that a wide range of other disciplines would like their students to be capable of carrying out at the introductory level. These commonalities, and the synthesis of data investigation skills needed, are represented within the free-choice parallel group project that has been a core component of many courses at the Queensland University of Technology since 1995 (MacGillivray, 1998, 2002b). As well as improving student learning and engagement beyond initial expectations, and providing an extraordinarily extensive and rich source of teaching and learning resources, the strategy has also proved invaluable in informing curricula, instructional structure, resources and teaching strategies within and beyond the subjects themselves (MacGillivray, 2002a, 2002b). An instructional structure built on, and oriented to, the development of learning in a data investigation from planning through to analysis and reporting, can be seen in MacGillivray (2004).

These student free-choice projects have also already provided the types of examples most valued by teachers at all levels. Some key common learning ingredients needed for these practical and holistic data investigations are used here to demonstrate some possible collaborative strategies in the coherent and progressive development of statistical literacy and thinking.

The Parallel Own-Choice Project Strategy in Introductory Data Analysis across Disciplines

The strategy was trialled in a first year science statistics subject in 1993 and then in 1994 in the engineering statistics subject with between 300 and 400 students annually. The original motivation was that no matter how real the data and contexts used in presented examples, students could experience the practicalities of setting up a problem and obtaining data only second-hand. Hence the initial emphasis of the strategy was on the practical challenges of data planning, collection, observation and exploration. A key concept is that the group choose their own context, identifying what is of interest to them, what data is accessible, and how to collect it. Positive student feedback through surveys and focus groups, together with improved overall subject results, led to inclusion of analysis, interpretation and reporting (MacGillivray and Hayes, 1997). It is now an established whole semester parallel activity for approximately 1000 students per annum across many courses, and derived or similar strategies are also used in other introductory statistics and probability subjects, again involving students across a range of courses.

Evidence of success of the strategy includes increased student participation and performance as well as their qualitative feedback, and adoption of the strategy by statistical colleagues. The free-choice principle gives an amazing variety of contexts, a sense of ownership with no hidden agendas, and experience in real data problems from the first ideas and planning through to analysing and reporting. The project is a parallel activity to structured, well-signposted courses with many examples extracted from past projects.

The guidelines for students are written around the criteria for achievement which are organised into three sections:

- identifying and describing a context and issues of interest; identification of variables; planning and collecting of relevant data; quality of data and discussion of context/problems;
- handling and processing data; summarising, exploring and commenting on features of the data; statistical modelling;
- using statistical tools introduced in the subject for statistical analysis and interpretation of the data in the context/issues; reporting and discussion.

Staff help students to articulate their ideas, with suggestions and assistance about statistical and practical aspects; to identify their variables and observational or experimental units on which observations are made; to obtain a dataset that is suitable for their timeframe and level, but has enough in it to explore and, as a key objective, to demonstrate judgement in choosing, using and interpreting appropriate statistical techniques from their basic armoury.

These free-choice data investigations across so many courses and disciplines are a rich potential research source, from the types of choices through to reporting, including researching links between quantitative background and project capabilities and choices. The emphasis here is on some selected aspects of student learning that are fundamental to such real data investigations, and that can inform curriculum development in statistics at any level.

Identification of variables and observational subjects in multiple variable contexts

Identification of variables and observational/experimental subjects is a big step for students at both planning and analysis stages. This contributes significantly to the planning of data investigations as well as data handling, with spreadsheet/worksheet considerations providing a simple focus for students through "what will your columns be; what will each row correspond to". The next important step is identifying each variable type – categorical, continuous, small count, large count. Such identification provides the foundation for learning choice of procedure, as well as understanding key landmarks in the statistical structure.

In the amount of effort required to persuade students to identify variables, observational subjects and types of variables, and in the extent that it opens so many statistical doors for them, these are regarded by staff as some of the most significant learning steps. The theme of "identify variables, observational subjects and types of variables" has substantially contributed to the structure and examples in the variety of introductory statistics subjects, no matter what the cohort or its level (MacGillivray, 2003).

The free-choice projects are investigations of datasets with numbers of variables that can range from 5-10, depending on the mix of continuous and categorical. Essential components of the learning are the choice, use, interpretation and synthesis of statistical procedures. As mentioned, many of the examples used to introduce and demonstrate new concepts and procedures during the semester are extracts from past project datasets, reinforcing the multistep nature of real data investigations. This facilitates learning within more complex scenarios as advocated by Ridgeway, McCusker and Nicholson (2005), and experiential learning of the effects of confounding, masking, hidden or associated variables, as advocated by Schield (2005).

Estimating probabilities; proportions and testing proportions

Choosing to carry out surveys is popular with many students at the introductory tertiary level, particularly for those with less quantitative background. Apart from the challenge of design of questions, surveys deal mostly with categorical data. Early focus on categorical data at the introductory tertiary level has proved of considerable benefit to students who have difficulty with topics requiring concepts of sampling distributions of statistics such as means and variances.

People estimate probabilities in simple everyday situations using frequencies without a second thought. But it is a significant step for many to acquire sufficient confidence in the process to be able to handle proportions and estimates of probabilities in more complex situations involving a number of categorical variables typical of surveys. Understanding, combining and comparing proportions of different groups is important in handling information, and gradual development of awareness of the processes involved in directly estimating probabilities using relative frequencies would benefit all students.

Introducing the concepts and processes of hypothesis testing early in any introductory tertiary data analysis subject through the uses of the chi-square test with both one and two categorical variables builds on the above and has proved of great benefit to all students (MacGillivray 2002a, 2003). The form of the test statistic is simple to understand intuitively. The test is straightforward to carry out, and using statistical software emphasises the raw form of survey data with responses per subject, rather than the tables derived from the survey data. The test focuses on the essential concepts of hypothesis testing without the confusions and complications of sampling distributions, and enables rapid access to interesting investigations in many real contexts.

Variation and understanding estimation

Although most students quickly become comfortable at the tertiary level with commenting on variation in a descriptive way, they often miss the practical implications of variation comparisons. For example, in an experiment on the strength of egg shells, the comparison of the variation amongst different types of eggs was as important as average strengths, and in a quality control investigation into a style of sweet, the comparison of variation in packet weight with totals of individual sweets, provided valuable insight into the manufacturing process.

In many ways, statistics is the science of variation – modelling, allowing for, accounting for, interpreting, analysing and understanding variation. Inherent to statistical modelling is the concept of estimating parameters – a more complex concept than estimation of probabilities by relative frequencies. Although the concept of parameter is mathematical and subtle, the idea of "what is being estimated by this quantity we've calculated from data" in the case of averages, proportions and medians, can help students in understanding a range of statistical concepts that depend on understanding sampling variation and variation of sample statistics. It also helps with "what can we take this dataset as being a sample of", rather than abstract mathematical formalisations of sampling. Understanding that an interval estimate for a parameter is not an interval for individual values is another significant step in statistical understanding.

Estimation is natural in much of everyday life and human logic, but awareness of estimation is not. A gradual building of awareness of variation and of estimation across educational levels would be invaluable for all students no matter what their post-school destinations.

Problems associated with decision-making and formal notions of scientific method

The general emphasis on the importance of statistics in decision-making appears to have an unfortunate side-effect of over-emphasis on answering questions rather than posing them, and making decisions based only on data displays. This plus the increasing abundance of data and data displays can tend to stifle development of statistical thinking with respect to interpreting variation and the representative nature of data. The emphasis on problem-solving in syllabi and "generic" skills might be more beneficially changed to "problem-tackling" – posing and investigating problems rather than providing definite decisions to single questions.

Associated with answering questions and possibly with the notion of scientific method, is the impediment of the single hypothesis to real data investigations. The importance of planning, and accurately and fully reporting the how, when, where and any difficulties in obtaining data, was one of the original motivators of the free-choice project strategy. Encouraging students to focus on investigating a situation rather than answering a single formal question is now emphasized within project assistance.

Concepts that come from scientific experiments in which there is implicitly a "correct" model and in which error is only "measurement" error can get in the way of statistical thinking. Focus on correlation and black-box "fitting" to data without statistical considerations can also impede understanding for deterministically-inclined students. It is curious that in some contexts we have to curb tendencies to make decisions based just on graphs ("We can see from the histograms that A is definitely better than B"), but in investigating relationships, correlation dominates ("R-sq of more than, say, 68 percent signifies a good model, and less than 68 percent a bad model"). It takes considerable effort to persuade students to look at the many plots that play valuable roles in statistical analysis of relationships. We found during teaching in the Master of Business Administration, that many business people were familiar with time series plots but had very little idea of plotting one variable against another ("Why is there only one symbol on the graph? How do I read the axes?")

Quality and quantity; double-dipping and selection

Reporting skills and judicious selection of procedures at the tertiary level may be at a higher level in the educational spectrum in statistics, but emphasis on quality not quantity throughout education is of long term benefit to all students. Standard tips for the own-choice projects across all student cohorts include:

- Do not throw every possible graph or technique at the data in case something sticks – explore and choose judiciously.
- Do not manufacture questions to fit techniques. Consider the contexts and types of variables and choose appropriately from the toolbox available to you.
- Be careful not to double-dip with techniques. If a powerful technique provides you with answers to three questions at once, that's fine. Succinct reporting that provides a quality summary is better than a lengthy disconnected report.

Conclusion

Statistics is integral to an extensive range of functions of society and many disciplines. To achieve a statistically-educated society with the necessary range of statistical numeracy (Bartholomew, 1995) requires coherent and purposeful development of statistical literacy across the educational spectrum of ages and abilities. Involvement of the statistical community is needed across this complete spectrum. Such involvement can include:

- helping to identify and define the key structure of statistics - the concepts, the signposts, the science, the skills, the understanding
- helping to identify and develop the educational progression within this structure
- helping to develop and implement syllabi, elaborations, resources
- contributing to developing and delivering good resources for ongoing teacher professional development and for the classroom

The challenges for the statistical community in the coherent and purposeful development of statistics across the educational spectrum are significant, but collaboration and championing the value of statistics and mathematics and teachers' needs provide both the keys and the rewards.

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