

HOW WE CAN ALL LEARN TO THINK CRITICALLY ABOUT DATA

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“Critical thinking with data” aims to teach undergraduate students to review and evaluate critically statistical information and arguments, to convince them of the relevance of statistical literacy, and to imbue them with the disposition of an enquiring statistical consultant. We use diverse strategies for engagement and broad content. Our materials are relevant, accessible, rich, interesting and varied; many are taken from the general media and are media rich. Presentation of statistical content is enriched through the use of eminent guest lecturers, case studies, and many real world examples. We do not rely on mathematics but present multiple perspectives on ideas, concepts and principles. Our abstract building block concepts are first presented through appealing and concrete case studies. Once students grasped the ideas in one context, they generalise these concepts through repeated exposure to manageable open-ended interpretative tasks using on-line and standard assessment tools. We provide illustrations of our approach.

BACKGROUND

In the last decade or so, introductory statistical education has become more applied, with more emphasis on design and aspects of statistical thinking. In Australia, this has occurred at the same time as the tertiary sector has expanded considerably, and the amount of mathematical training of secondary students has decreased. The newer generation of texts, starting with Moore and McCabe (1999), are consistent with this trend. *Lies, damned lies and statistics*, a course taught at the University of Auckland, and Utts’ (1994) book *Seeing through statistics* reflect this approach; all are, in part, responding to the “demathematization” of society (Khait, 2005) and hence of education. Statisticians can see an opportunity here. Those of us who espouse a clear distinction between mathematics and statistics can relish the chance to prove that it is possible to teach important statistical ideas without a mathematical treatment, even if this is not mainstream statistics education.

In 2008 The University of Melbourne (UM) introduced a new model of undergraduate education: the “Melbourne Model”. Students must take one quarter of their degree as “breadth”, defined as subjects not part of their core degree. One way students can do this is by taking a “University Breadth Subject”. This new type of subject is broad in the sense of taking perspectives from many disciplines, involving teaching staff from different faculties and teaching students generic skills as well as subject specific content. These changes were bold and contentious on the part of a “sandstone” Australian university steeped in tradition. We decided that this context offered a correspondingly bold, even risky, statistical educational opportunity, and developed *Critical thinking with data* (CTWD) as one of these University Breadth Subjects. It aimed to teach first year students some fundamentals of statistical science.

UM Breadth Subjects like CTWD must be available to all students. At first year level there can be no pre-requisites, so that no mathematical background can be assumed. As a University Breadth Subject, the content of CTWD must be sufficiently different from any other first year subject. Additionally, staff across all areas of the university had to have input to CTWD; this requirement is intended to ensure an interdisciplinary flavour.

Utts (2003) outlined seven important topics that the statistically educated citizen of today should know. Best (2005) argued that although we have long recognised the need to improve statistical literacy, “no discipline stepped up and took responsibility for teaching critical thinking” (p.214), and claimed that “statisticians are likely to consider teaching courses in statistical literacy as beneath their talents.” We agree that this view is likely, but suggest that the opposite is the reality. For many academic statisticians, this educational task is impossible, without further training or more realistic statistical experience. The task is formidable, but offers exciting potential for effective innovation and creativity, and a fresh approach to content. The lack of mathematical treatment is a challenge, but it also frees up space in the curriculum to include new material, and conventional statistical topics can and must be treated differently in a statistical literacy subject.

OUR APPROACH

Statistical consultants, especially those in a University, are called upon to explain statistical ideas and thinking to clients, many of whom are not strongly disposed towards mathematics. Further, because of the range of applications in statistical consulting they typically have a very broad experience of statistical issues and applications. CTWD was mostly developed by the authors of this paper, who work in the Statistical Consulting Centre (SCC) at the UM. In this working environment, consulting is often partly, or even largely, educative, and consultants are exposed to the common misunderstandings and poor statistical practices. We suggest that is an ideal body of experience to have in developing a course like CTWD. Among other things, we simply see a large *amount* of research.

Further, as we developed CTWD, we came to see that one of our aims was to develop something of the *disposition* of a statistical consultant in the CTWD students, with emphases on asking fundamental and broad questions about research, questioning sensibly arguments based on data, and learning to communicate statistical ideas orally and in writing.

CTWD had to have breadth in content and applications. This could not be achieved by taking a standard introductory statistics subject and “subtracting” the mathematics. We decided to approach the task from first principles, by consciously adopting a blank sheet and attempting to develop a coherent content sequence *ab initio*. We consulted widely with stakeholders in the subject. We invited three eminent researchers with strong statistical orientations, from epidemiology, finance and environmental science, to give two lectures on an application in their area. For the year or so before the commencement of the subject, and subsequently, we became alert to data-based investigations that received some media attention, sharing the view of Watson (1997) that media exposure is strongly motivating. We especially sought examples whose media representation was “rich”, with video clips, images and substantial information on the web, and we preferred examples from contexts that connected with the students’ interests.

We debated whether to create a problem-based approach to the structure of the subject, but opted for a topic-based approach; we felt that this would be less unsettling for first years. The structure of CTWD was informed by our own views on statistical thinking and by liberal arts approaches to statistics. Wild and Pfannkuch (1998) outlined a set of “worry questions”, such as “where do the data come from?” These are the sorts of questions that are essential to address in good statistical consulting. The same idea is present in the seven critical components described by Utts (2004).

CTWD will be taught for the fourth time in 2010. The course has evolved with this experience; we describe CTWD as it was run in 2008, but provide examples from all years. The subject covered four “themes”, and 15 topics, as shown in Table 1. Thinking about these issues from first principles is illustrated by the issue of *types* of research. How is data-based research carried out? What are the distinctive approaches? Different disciplines tend to create their own taxonomies. Is it possible to describe a broad taxonomy that applies to all areas? We came up with four basic types of research: experiments, surveys, observational data and meta-analysis. This classification may be contentious; it is included here merely to show the sort of educational issue that must be faced in a statistical literacy subject that aims to be broad.

LEARNING OPPORTUNITIES AND ASSESSMENT

We illustrate the structure of our educational approach by considering the nature and content of the learning opportunities for one of the topics: Variation. The important points for this topic were:

- Variation is pervasive in most quantitative research.
- An understanding of variation in a given context is vital to the correct interpretation of the data.
- The idea of ‘background’ or ‘unexplained’ variation: it captures the variation not accounted for by identifiable sources.
- Distributions reflect variation in a number of ways.
- Variation plays a major role in modelling data.

Table 1. Themes and topics, *Critical thinking with data*

Topic	Theme 1: Finding data as evidence	
1	Data quality	Anecdotes, intuition or evidence
2	Context	Data – a number with social value
3	Variation	Embracing the way we vary
4	Sampling	Sampling matters
5	Designed experiments	Evidence – by design
Theme 2: Examining evidence in data		
6	Graphics	Good pictures paint a thousand words
7	Summaries	Understanding relationships
8	Observational data	Relationships can be deceptive
9	Statistical models	Bell curves & other interesting models
Theme 3: Understanding uncertainty in data		
10	Probability	Probability – objective and subjective
11	Risk	Understanding risk
12	Psychological influences on probability	Psychology and probability
Theme 4: Drawing conclusions from evidence in data		
13	Confidence intervals	How certain can we be?
14	P-values	How significant is our evidence?
15	Meta-analysis	Resolving inconsistencies and accumulating knowledge

These are quite abstract and deep ideas. In the lectures, a number of examples were used to illustrate the points. The Antarctic ice-core data (Etheridge et al., 1998, Barnola et al., 2003) illustrated the second point, by using a sequence of time series graphs that gradually expanded the time interval considered; see Figure 1.

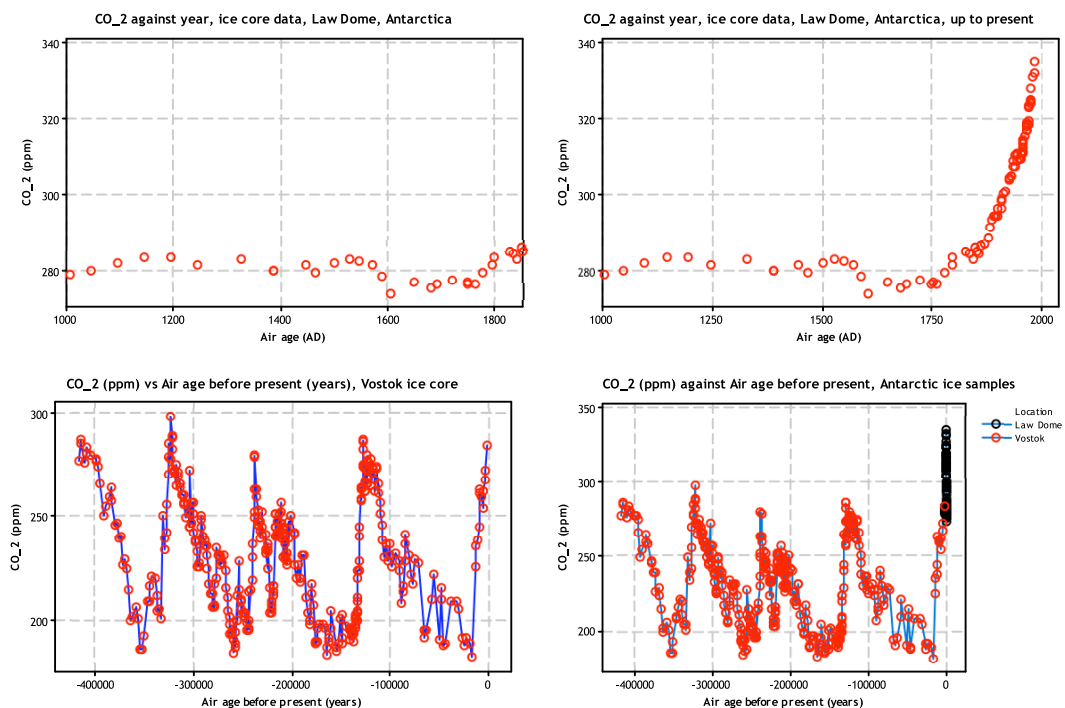


Figure 1. Sequence of graphs from Antarctic ice core data

Stanley Coren’s data on dogs’ apparent reaction to an earthquake (Coren, 2006) was used to demonstrate that outliers rely on background variation, or a model, for their identification. We

used numbers of overseas tourists to Australia over time (Australian Bureau of Statistics) to suggest that over-reaction to variation can be a common problem. The concept of a distribution is vital in statistical thinking, but subtle to communicate, as pointed out by Wild (2006). We used an example from the SCC's experience to illustrate how the absence of expected variation can be revealing.

The tutorial on variation used the death rates from the Titanic disaster (Dawson, 1995), with age, gender and class and eye colour as explanatory variables (the last of these was a deliberately fictional addition). Students were provided with a table of data, and were asked to plot the data in various ways to attempt to identify the event. This tutorial introduced the dotplot as a natural representation of data for the purposes of exploration. Students, in groups, needed to assess differences against background variation to get to the bottom of this riddle. They plotted both main effects plots and interactions in order to make conjectures about the historical event from which the data arose. Teamwork and discussion was integral to this tutorial and the element of a genuine puzzle engaged the students, sometimes intensely. While there were detailed instructions on how to construct the dotplots, the simple substantive question was "From what event did these data come?" The directness and immediacy of this question challenged the students to learn that graphical exploration with critical thinking can lead to understanding and knowledge. Student groups typically come up with a number of different incorrect events before settling on the answer. After identifying the event, students were asked the much more abstract question: "What makes you conclude there was or was not an effect of any of the variables?" This question is being addressed here in a manner that is foreign to conventional statistical education, and not reliant at all on mathematical formulae or formal testing.

The compulsory readings that related to "variation" included an excerpt from Leon Kamin's 1974 book, *The Science and Politics of IQ*. Kamin's work initiated claims (and debate) about fraudulent data produced by Cyril Burt who argued that hereditary was more important than the environment in the development of intelligence. Kamin noticed the lack of variation in correlations reported by Burt as he accumulated twin pairs in his study. We also asked students to read accessible background material such as Bland and Altman's *British Medical Journal Statistics Notes*. Their note on variables and parameters was useful here (Altman and Bland, 1999).

Short assignments of 200 words or less aimed to teach the skill of capturing the essence of a well-argued response succinctly. A short assignment that partly covered variation used data on Melbourne's water supply. Students inspected the website of Melbourne Water, where a graph in the form of Figure 2 was found.

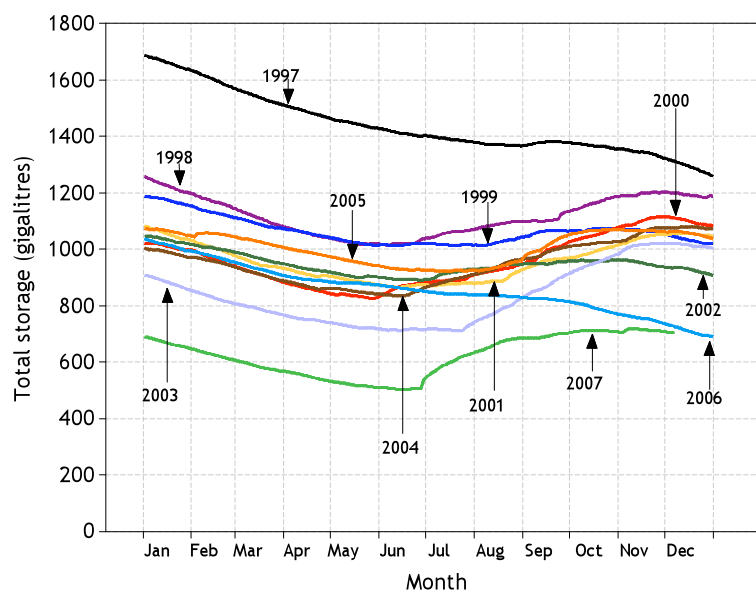


Figure 2. Melbourne's water storage, 1997 to 2007

Students in CTWD learn graphical principles, emphasizing the interpretation of graphical material, rather than graph construction. In this assignment they were provided with 12 alternative representations of the Figure 2 data. They were asked to choose a representation that best supported assessment of particular sources of variability in the data (e.g. seasonal factors, changes over time). They were asked to indicate their preferred option and explain the reasons for their choice.

Weekly online quizzes allowed a variety of different types of questions to be asked including multiple choice, multiple answers, exact numerical, matching, ordering, fill-in-the-blank and ‘hot spot’; all types were used in CTWD. A ‘hot spot’ question gives a visual representation, and students need to click on the area of the representation that gives the answer to the question. The use of visual representations was one approach used to present and assess concepts and principles traditionally given a formal mathematical treatment. An example of a question on variation showed four pairs of histograms, and asked the student to nominate which pair showed the clearest evidence of a systematic difference between the groups represented, in the context of the background variation; see Figure 3. This question illustrates the communication of an important modelling idea in a non-traditional manner, without formal mathematical treatment. It also connects naturally with the structure of hypothesis testing, again without treating it formally.

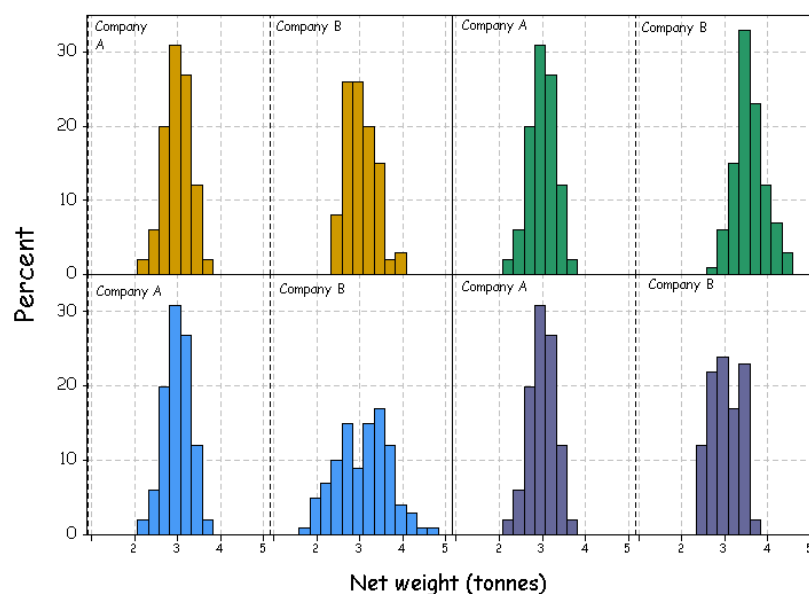


Figure 3. Question on “inference” using a visual representation

The examinations in CTWD reflect the nature of the subject in their construction, and therefore often include articles, diagrams and images from the media. Questions are modelled on the quick quizzes, short assignments and major assignment. The major assignment in CTWD required students to make a detailed review of a single research study. Students worked on one of a small number of case studies; each of which had a newspaper report and a published article. In one part of this assignment, groups were formed within tutorials to prepare for a (tutorial) poster display and presentation session, modelled on a conference poster session. We chose studies with relatively straightforward design, but varying complexity in their statistical analysis. In the second, individual part of the major project, students needed to provide a 1200 word critique of the reporting of the study in the news item and in the published article, covering both description and explanation of the strengths and weaknesses of the study. By the time students complete this final assignment, their knowledge is built on a foundation of understanding how variability might be measured, controlled and modelled. They need not understand the methods of statistical analysis *per se*, but need to think critically about the control and modelling of variability in the case study.

STUDENT FEEDBACK

The responses from students to this subject in 2008 reflected some of the challenges the subject faces. In open-ended questions, we encountered comments from “I expected some mathematical approaches” to “There’s too much maths”, and everything in between. The first time the subject was taught, in particular, students were somewhat uncertain about what would be expected of them in assessment, especially the exam, due to the difference between the style of the education in the subject, and their recent secondary school education. Students reported high percentages of agreement with propositions reflecting the aims of the subject: 78% reported that they “felt confident about critically evaluating media reports of quantitative data”, and 81% agreed that they had “developed their capacity to think about quantitative information”.

CONCLUSION

Critical thinking with data has formidable educational and political challenges. It is mainly “owned” by the Department of Mathematics and Statistics, which obviously has a mathematical culture; it is delivered to many students from a humanities background, with markedly different expectations about assessment, load and educational approach. This is one cause of tension. The subject is required to have contributions from staff from several disciplines. Hence there is a need to find suitable staff who share the vision and can present material that can relevantly dovetail with the core content. The need to produce examples and case studies for assessment purposes is ongoing and time-consuming, especially “rich media” content. Even finding suitable tutors is not straightforward; people with experience in mainstream statistics subjects do not necessarily have the right skills and experience; a willingness to deal with a non-mathematical approach is vital. In spite of all these challenges, teaching statistical literacy in a subject such as this is an exciting opportunity needing creative and committed input from academic statisticians with wide practical experience.

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