Teaching with Examples and Statistical Literacy: Views from Teachers in Statistics Service Courses

Sue Gordon, Jackie Nicholas

Corresponding author: sue.gordon@sydney.edu.au
Mathematics Learning Centre, The University of Sydney, Sydney NSW 2006, Australia

Keywords: teaching statistics, service courses, statistical literacy, example use

Abstract

Statistical literacy is essential for science students as a tool in their professional lives as well as an essential competency for their citizenship in the contemporary world. Reforms in teaching statistics call for pedagogy that addresses the links between statistics as a topic of study and evaluating and communicating about data in the field. In this paper we present a model of statistical literacy (Gal, 2002) and relate it to university statistics teachers' reports about their pedagogy. One core practice is to use examples in instruction, yet teachers' goals for using examples tend not to be well articulated. We categorise how teachers use examples, drawing on data from an empirical investigation on teaching service statistics at university. Three overlapping categories are proposed: examples are developed and presented by educators in basic instruction, examples are generated by students, under teacher direction, and examples connect statistics with students' future professional work. We present excerpts from three statistics educators in the sciences to illustrate further how respondents promote statistical literacy in their teaching. We relate the ways teachers use examples to Gal's (2002) model to provide a framework for enhancing pedagogical development and to address challenges of engaging science students in learning statistics.

International Journal of Innovation in Science and Mathematics Education, 18 (1) 14-25, 2010

Introduction

I guess many students see statistics as a complete mystery. They think it's a game that we're playing with them, messing with their lives or something. They don't ask themselves the questions: What is the point, what are we doing this for? They don't recognise that statistics is based in reality and common sense and all of those words I think are to do with statistics.
Statistics Lecturer

Statistics is taught as a service course in a wide range of science courses, including psychology, biological sciences, medical sciences, computer science, physics, chemistry and agricultural sciences. A major challenge for teachers of statistics in these courses is to make the learning of statistics meaningful and relevant. Research has shown that undergraduate students in service courses have a range of conceptions of statistics, with some conceiving of statistics as decontextualised formulae and algorithms or as irrelevant information to be mastered and stored in the short term to meet the demands of assessments, while a few showed awareness of statistics as a tool for professional work and personal growth (Gordon, 2004; Petocz & Reid, 2005).

It is well documented that many students experience difficulty and anxiety learning statistics (Onwuegbuzie & Wilson, 2003). Negative affective reactions may be exacerbated in some cases by the size of statistics classes and the key role played by statistics in accreditation of professional courses such as psychology (Swingler & Bishop, 2008). Identified cognitive difficulties for students studying statistics in the context of medical studies include making the transition between qualitative and quantitative aspects of a problem or scientific concept and applying “pure” mathematics to less tidy problems in the field of study (LeBard, Thompson, Micolich & Quinnell, 2009). Other issues relating to statistics education in science courses include the lack of connection between the statistics curriculum and other areas of the mainstream discipline and the shortage of trained practitioners in the sciences with specialised knowledge of statistics. For students, a major dilemma concerns the gap in time and knowledge between their learning of statistics — often in the junior years of their undergraduate degrees — and the application of those skills and knowledge in their later work or research as scientists.

In response to challenges of teaching statistics as a service course, statisticians and university statistics educators have recommended approaches to teaching and learning that align with statistical practice and show the relevance of statistics to scientific fields or professions (Baldi & Moore, 2009; Moore & McCabe, 2003). All science students will require some level of statistical knowledge for their future professional work. Some students will go on to become “data producers” (Gal, 2002, p.3) where they will carry out empirical investigations, interpret their own data and results and report their findings and conclusions. Many more will become “data consumers” where they will need statistical literacy, portrayed by Gal (2002) as the ability to interpret, critically evaluate, and communicate about statistical information and messages. We discuss this model of statistical literacy below.

The use of examples has long been an integral component of statistics teachers’ instructional repertoires and indeed, examples have been described as the “core of teaching statistics” (MacGillivray, 2009, p. 20). In this paper we draw on empirical data from a research project investigating effective teaching of “service” statistics using email interviewing (Gordon, Petocz & Reid, 2009; Gordon, Reid & Petocz, 2007) to summarise participants’ use of examples. We then present more detailed excerpts from e-interviews with three participants who teach statistics to diverse science cohorts, to highlight the broader issue of engaging students in their learning of statistics. We relate findings to Gal’s (2002) model of statistical literacy and discuss the implications for statistics pedagogy.

A model of statistical literacy

Gal (2002) argues that, for data consumers, statistical literacy is enabled by five inter-related knowledge bases: literacy, statistical, mathematical, context and critical, together with essential supporting dispositions and beliefs. While Gal’s focus is on statistical literacy for adults in everyday life contexts, his ideas extend to essential knowledge foundations for university students and graduates who are potential users of statistical information in their work.

Literacy skills, as the first component of the model, go beyond skills in reading, writing, listening and talking that are essential for comprehending and processing information and interpreting or discussing documents. Literacy skills for statistical literacy — essential to scientists — encompass an awareness of the meaning of basic statistical terms and an ability to make sense of graphical and tabular information, as well as a range of text and media messages.

Requirements for statistical knowledge, the second element of Gal's (2002) statistical literacy model, depend on the context and hence cannot be prescribed by a definitive list of topics. However, reviews of the literature indicate agreement on the importance of including basic notions such as variability, key terms and ideas relating to producing and describing data, some understanding of probability and some knowledge of how statistical conclusions are reached.

Mathematical knowledge, Gal's third component or knowledge base, appears to be more controversial (Gordon et al., 2009; Moore, 1997), with some statistics educators arguing for less emphasis on mathematical derivation and theory in introductory or service statistics courses, while others insist that at least basic quantitative skills and some formal mathematics are needed to appreciate statistical concepts or to understand statistical findings on more than a superficial basis.

The fourth knowledge base, an ability to place statistical information in context, is considered essential by Gal (2002). Context knowledge is the main determinant of sources for variation and error. Without this knowledge:
"it becomes more difficult to imagine why a difference between groups can occur, what alternative interpretations may exist for reported findings about an association detected between certain variables, or how a study could go wrong" (Gal, 2002, p. 15).

Finally all these knowledge bases support the fifth component of critical evaluation: students' abilities to interpret statistical information critically and make informed decisions and judgments on the basis of data. Utts (2003) argues that it is the responsibility of those of us teaching introductory statistics to ensure that our students can think critically and are not among the millions being misled through common misconceptions in statistics, such as confusing a conditional probability $P(A|B)$ with $P(B|A)$ or mistaking a probable coincidence for an omen.

Statistical literacy, in this model, is not a passive possession of skills and knowledge but includes the dispositions that enable a person to access and use the five knowledge bases. Gal (2002) uses the label "dispositions" (p. 18) to refer to related concepts about stance, beliefs and attitudes. Firstly, critical stance is required — that is, a willingness and confidence to question statistical messages. This stance needs to be accompanied by beliefs and attitudes that support statistically literate behaviours — so that learners will invest effort and engage critically with statistical tools and concepts. Madison and Steen (2009, p. 6) describe this as "liberating" literacy, encompassing not only the skills to enable performance of statistical tasks but the mind set necessary to critique statistical information, reflect on it and apply it to make decisions.

The Project

The investigation consisted of a three-phase series of e-mail interviews with statistics educators from around the world. Participation was invited through an electronic request to the membership list of the IASE (International Association for Statistics Education) and Australian bulletin boards. The 36 IASE members who participated were from many countries including Argentina, Australia, Belgium, Brazil, Israel, Italy, Netherlands, New Zealand, Slovenia, Spain, Uganda and the USA. In addition, e-interviews were conducted with 9 Australian educators who responded to invitations to participate in the research through departmental bulletin boards. The resulting interview transcripts of over 70 000 words formed the raw material of the study.

The participants taught statistics at universities in a range of contexts. They taught at various levels, from pre-degree and first year to postgraduate, using various teaching methods including large-group lecturing, tutorials and small research groups, problem-based learning and distance education; in some universities, statistics teachers pooled their strategies and resources to work as a team. All participants were teaching statistics as a service course, with the majority of them (31 participants) teaching cohorts in one or more areas of science. These included biology, psychology, medical science, agricultural or environmental sciences, physics, information technology and/or computer science. Many participants reported teaching service statistics to student groups in several disciplines.

The interview protocol consisted of an initial series of six questions, reflecting the original research focus on educators' ideas about teaching and learning statistics in service courses. These questions were followed by up to two rounds of further questions which explored participants' responses in depth. The six initial interview questions were as follows:

- Q0) First, some background information please: What country do you work in? What type of institution do you teach in? What level of students do you teach statistics? What discipline areas do you teach statistics in?
- Q1) Tell us some more about the context in which you teach statistics.
- Q2) What do you consider to be the most important aspects of statistics for your teaching?
- Q3) What do you think makes a good statistics student?
- Q4) What are the attributes of a good statistics teacher at university?
- Q5) What approach or approaches would help you develop as a statistics teacher at university?

Questions 1 to 5 were posed in a deliberately open way to enable the participants to explore their own ideas rather than the researchers eliciting responses in a specified direction. After studying the initial reply, a second interview was sent with questions following up and probing each participant's responses. These follow-up questions explored the thread of thought that was prompted by the original question and so depended on the individual response. Finally, a third interview was sent with further questions to elicit clarification and in-depth explanations of the responses given. The third interview also included an open question (Is there anything else that you would like to tell us about any aspect of statistics teaching and learning, or your development as a statistics educator?) as well as a request to evaluate the e-mail interview method.

Hence, the interview process was a written version of the usual face-to-face interview, with the modification that at each point in the process the respondent had a record of all previous communication including their own responses, and both interviewers and respondents could continue the dialogue in their own time. A critique of this method of e-interviewing — with input from the participants — concluded that responses were well considered, leading to high quality data (Reid, Petocz & Gordon, 2008). Previous publications on this project have addressed different aspects of the data, such as what makes a "good" statistics teacher and "good" student (Gordon et al., 2009).

We did not specifically ask participants whether or how they included examples in their teaching, yet this was a spontaneous topic in about 60% of the transcripts. Analysis of data for this paper involved reading and re-reading participants' responses to all the e-interview questions. At the same time, we developed provisional categories or themes for respondents' reported goals for using examples in their teaching. These categories were discussed and refined by looking for both variation and commonality in the teachers' accounts.

Findings — Participants' Ways of Using Examples in Their Teaching

We classified participants' reports about using examples into three overlapping categories. In the first category, examples are developed and presented by educators for basic instruction in statistics. In the second category, students generate their own examples, under teacher direction, to aid learning. In the third category, educators present examples in order to connect statistics with students' future professional work.

The first category was expansive with educators suggesting diverse roles for examples in their instruction. These roles included engaging students (and oneself), illustrating ideas of lectures, grounding concepts, providing a template for students to follow and building conceptual complexity or developing critical thinking, as well as more unusual ideas, such as differentiating statistics from mathematics and personalising teaching. Expressions in the second category were sparse suggesting that statistics educators do not often engage students in this way. The third category provides evidence of the importance educators place on examples being relevant to and derived from practice in professional areas such as medical science. These categories are illustrated below with illustrative quotes from the e-interview transcripts. We use the notation // to denote non-contiguous statements in the transcripts. All pseudonyms were chosen by participants themselves and brief excerpts are reported under these self-chosen pseudonyms.

A. Examples as instructional devices used by educator

We illustrate some varied uses of examples in this category with quotes from participants' reports in Table 1.

B. Learner generated examples

There were few expressions fitting into this category.

Horace reported that if students could: *draw a picture, give the definition, state an example, and show they know when to use something, then that's a pretty good operational definition of understanding?! (If they can write the formula, that's a nice bonus!)*
Cara encouraged students: *to find examples of misuse (of statistics) on their own and present them in class.*

The few reports in this category indicated that student generation of examples helped students construct their own knowledge. As Janet Cole explained:
(The process) helps students put together/construct their own frameworks for learning. If a student can understand the process of constructing a confidence interval for a proportion (including checking conditions, mechanics, and presentation of results), then it should ideally be easier for that student to transfer this process to the construction of a confidence interval for any other situation. The student is not learning something entirely new, but is rather doing what I call a "variation on a theme."

Table 1: Ways that examples are used in instruction

Educators' use of examples	**Illustrative quote**
To engage students (and oneself)	Ron Fisher: *I am constantly updating my examples, and looking for new applications that will interest my students. Not only do I do this for the students' sake, it also makes the class much more interesting for me, since I am interested in the world around me.*
Illustrate ideas of lectures	Andrew: *The large methods courses have a one hour tutorial each week where examples are worked on that illustrate the lectures of the previous week.*
To ground concepts	Joyce: *[How do real world examples help students to learn statistics?] To use an educational psychology phrase, it gives them "an anchor".*
As a template for students to follow	Natalie: *By giving students worked examples they can use these as a "template" until they are comfortable creating their own non-technical explanations.*
Develop skills	Margaret: *To develop good case examples for students to work on so that they develop their skills in a step by step fashion. To learn how to guide students and keep their interest as they go from simplistic examples to the more complicated.*
Extra practice	Kay: *(Struggling) students get extra worksheets with examples.*
Differentiate from mathematics	Primavera: *Students believe that Statistics is a branch of Mathematics. They change their mind with the use of real examples.*
Way into theory	Baz: *Even the students who can handle theory can learn from illustrative examples, and students who can't have no other choice.*
Develop critical thinking	Jane Johnson: *I sometimes use examples of incorrect analyses – as a warning to those who do not think critically.*
Build conceptual complexity	Despina: *I try to structure the problems I use as examples and as tutorial work so that we begin with a basic problem and slowly add complexity.* Kay: *We go over a number of examples, spread throughout the course –distributed versus massed practice, "spiralling" to repeat earlier concepts.*
Demonstrate the statistical process	John: *We will use an example reported in the media to illustrate how we can identify the statistical investigative process and understand statistical aspects of the study as reported.*
Explain terminology in everyday words	Annette: … *I just use examples from (imaginary or real) situations and try to explain the meaning of concepts using only these words that we use in our everyday conversation. And I ask students to do the same — to interpret the statistical results using the words which people who have never learned statistics would also understand.*
Indicate variation	Daria: *(We show students that variation is present in everything we do) by means of many "real" examples in the course of the lecture, and tutorials.*
Personalise teaching	Natalie: *Even though (many of us) use the same master resources, we each adapt these materials — add in our own examples, tweak to our preferences.*

C. Examples presented to demonstrate applicability of statistics as a methodological tool in future professional work

In this category educators used examples to indicate the work of statisticians, or relate to students' disciplines and future professional work. We demonstrate this category with two quotes from statistics educators in the medical sciences.

Statsboy: *So, in teaching statistics to medical students you MUST use medical examples – show me how the authors have analysed their data and what it means. Don't write a regression model with alphas and betas without giving me a relevant example of how this works in real life.*

Henry VIII: *What I try to show medical students is that, even they don't ever intend to do any research, they still need some basic knowledge of stats in order to be able to fully understand the concepts of "statistical patterns" and "typical values", and the probabilistic nature of* *the decisions they have to make every moment during their practice. I try to do this by highlighting, through examples, the probabilistic nature of the patterns and decisions, and by trying to steer them away from the sort of deterministic thinking they are exposed to during most of the other courses they attend at college. // My most successful lecture on the Probability subject, for instance, is the one in which I discuss the interpretation of sensitivity, specificity and predictive value of diagnostic tests — these are very practical application of the rather abstract Bayes' theorem, and the students love it.*

The reports by participants indicate that the majority of them used examples, chosen by themselves, for a range of instructional goals. In particular, many educators used examples to indicate the utility of statistics in the student's own discipline. A few participants reported that they encouraged students to generate examples to assist students in constructing their own knowledge and develop their critical thinking. Our data suggest that this aspect of statistics pedagogy needs development.

Findings — Case Studies on Teaching Statistics in the Sciences

In many of the above excerpts we see educator's goals for using examples that fit with principles (Garfield and Ben Zvi, 2007) on how students learn statistics — including developing conceptual knowledge, practising skills, and confronting misconceptions. We develop this idea below starting with three case studies of participants teaching statistics in different areas of science.

We first consider the ideas of Andrew teaching a large, first year class of 1100 students on Biostatistics. Andrew explicitly outlines the ways that he draws on medical studies for examples that illustrate statistical concepts and knowledge.

We attempt to introduce study design principles gently early on but then have to go through the standard material on statistical methods usually involving standard textbook exercises to illustrate the methodology each week. This is a fairly traditional approach, which is enjoyed by half the students and less liked by the other half.

Two weeks ago the lectures introduced issues of selection and information bias, confounding and external validity. This was followed up by a class exercise, which required the students to read a three page paper from the New Zealand Medical Journal on attitudes to sun exposure, tanning and melanoma among New Zealanders of all ages and ethnicity with a view to establishing opinions in the community. This study was part of a health dept funded research project. The study involved a phone survey with about 1200 respondents. It raised the question of the study size and non-response, which reinforced an earlier discussion of power from the lectures. // This study reinforced four lectures which we had taught earlier on contingency tables and of course also involved p-values which had been covered in our section on hypothesis testing. In two weeks a second appraisal exercise will be looking at some tables from a Canadian study on melanoma and the possibly protective effects of moderate sun exposure among farmers as opposed to office workers. This study involves a discussion of multiple regression and the way in which a confounder can be controlled.

Andrew proposes that by using "real" examples: "students who struggle with statistics, tell me that they suddenly realise the greater picture of statistics".

Such examples abound but they must be chosen very carefully. They must not be artificial class exercises in my view. //In statistics you can deal with real problems whether you are modelling data, searching for pattern in data using multivariate methods, controlling for different aspects of variability, designing and/or analysing survey data, estimating populations, looking at environmental or ecological issues.

Hence Andrew puts a strong emphasis on learning statistical concepts by relating these to relevant applications and contexts.

Our second case study is Johanna, who discusses the wider aspects of statistical literacy. Johanna works in a regional Australian university, teaching applied service statistics units to students mostly enrolled (internally and externally) in the Science Faculty in areas such as Rural Science, Natural Resources and Information Technology. Joanna's ideas about statistical literacy for these science students immediately encompass many aspects of Gal's (2002) model: the statistical knowledge base, the ability to understand and communicate about statistics (literacy) and a critical, reflective stance to analysis.

Statistical literacy is now a very broad concept, but from my perspective teaching first year science students it is about familiarising students with basic statistical concepts and terminology— the idea of the statistical model so that when they need to interpret or analyse some "real" data - ie involved in some type of research they a) can understand the approach, b) can identify fundamental flaws in data collection, design, analysis, presentation and interpretation of results, c) can communicate interpretation of their own results effectively, d) are aware of the limitations of their own knowledge and so they know when to seek professional advice, e) have sufficient knowledge to be able to communicate effectively with a statistical consultant.

Joanna proposes ways to promote critical thinking, to support the literacy knowledge base, and to highlight context.

So to achieve this, we discuss: poor/misleading presentation of results; we highlight the "limitations" of the unit (it is not a stand alone unit - it is the foundation unit preparing students for later units that allow them to analyse real data from more complex designs.); put a lot of emphasis on written communication (this includes minute papers in lectures - explaining their ideas in writing and interpretation and presentation of results in tutorial and assessment tasks).

Joanna acknowledges that connecting "service" statistics to the scientific discipline presents challenges.

We have ongoing discussions amongst the staff in the Science Faculty about how to reinforce the link between stats and the rest of their degree program. The reinforcement needs to come from both sides and unfortunately the staff who teach other units are not always willing or able to reinforce the concepts that we try to teach in our statistics units.

A different and problem-based approach to teaching statistics is described by Sjefke in the Netherlands. Sjefke outlines how his distance students are being taught how to do research in psychology by combining all the separate courses about statistics and methodology into practical research training courses.

For a lot of psychology students, statistical material and material regarding methodology is very abstract. In statistics courses students learn how to do sums. They are presented with problems (or better: sums) and they learn how to use a formula to get the answer to the problem. That the problem they got is actually derived from a research question is not taught. Therefore, students have no idea that there is a lot going on before you get the numbers you need to do the sums. They don't realize that the numbers are actually research data. They don't realize therefore that they are answering a research question when they do the sums. The same goes for methodological course material. Students have no idea that data gathering can be performed in a million ways. And that the way in which you gather your data has a consequence for what you can do with this data.

Sjefke emphasises that connecting statistics to psychology is crucial for students' engagement with the material.

My experience is that most psychology students choose psychology because they want to help people who have psychological problems and not because they want to find answers for research questions. They want to work with people, and not sit in a room and do sums. At the beginning of the study they have no idea that they have to know anything about statistics.

Sjefke describes what statistics could mean to psychology students.

Statistics is a way of looking at data and giving meaning to data. Statistics gives you the tools to give a description of your data (mean, variance etc). It gives you tools to compare data of several groups and to look for relations between variables. But most importantly, I think that statistics provides students with an instrument, a technique, to describe a psychological theory in its most elementary form, and directs students to the most relevant aspects of the theory (modelling). By using statistics, students can see that a theoretical construct is more or less applicable to an individual. The diversity in the applicability of a construct is revealed in the variation in scores, which a group of people get on the construct.

Like Joanna, Sjefke emphasises integrating statistical knowledge with the discipline content in order to engage them.

Therefore, a good statistics teacher has to bridge the gap between the psychological content and the statistical concise summary of that psychological content. Statistics is a way of describing psychology in another language; it is not performing calculations at all! //Show the students that all the statements in their psychology lessons are based on or need empirical evidence and that they have to bridge the epistemological gap between the analytical level of abstract psychological concepts and the empirical level of data by using the top-down operationalization of those concepts and relations between them. Show the pitfalls, the misconceptions.

On the other hand, we - the statistics teachers - have to convince the psychological professors/teachers that they cannot "skip" the empirical foundations of their theories and their statements about reality. It is a well-known fact that many (psychological) theorists skip the "results-section" in scientific articles when they discuss these articles.

Our three case studies on teaching in the sciences illustrate various aspects of Gal's (2002) model such as supporting the literacy knowledge base and promoting critical thinking, as well as connecting statistics to science. We consider the implications of all the findings below.

Discussion: Enabling Statistical Literacy

We first discuss how respondents' reported ways of using examples in teaching relate to Gal's (2002) five inter-related knowledge bases and accompanying dispositions.

Many respondents reported that using examples helped students to build up skills and understand basic statistical concepts and processes — to develop the statistical knowledge base. Our participants' reports illustrate many aspects of this, such as Kay's "spiralling" examples to develop concepts, John's illustration of the statistical investigative process and Margaret's guidance of students' skill development.

Annette's insistence that students explain statistical terminology in plain English is one of many ways examples can be used to develop students' literacy knowledge base. A timely alert by Coutis (2007) reminds us that statistical concepts, particularly those defined in a probabilistic sense, present challenges in meaning to most students, but challenges are even more daunting to students from non-English speaking backgrounds.

We do not have evidence in these data of how, or whether, teachers used examples to promote the mathematical knowledge basis. However, Henry VIII arguably spoke for many participants in reporting that little mathematics was needed for the statistics courses he taught as "they are not courses on mathematical statistics" and: "we usually avoid doing mathematical demos of theorems". On the other hand Horace cautioned that some students do want to discuss the more mathematical aspects. "So I need to be careful not to put down them or their formal approach, indeed to encourage them to see how that body of theory is essential for the software and all I'm doing, and that they therefore have a privileged insight, even though my main aim is to present in ways accessible to as wide a range of students as possible".

Perhaps foremost of the five knowledge bases, our data show that examples provide context for statistical information. This is most evident in the responses that link examples to students' future professional work as exemplified by Statsboy, who considered it essential to use medical examples when teaching statistics to medical students, so that students have relevant examples of how statistics "works in real life".

There is also evidence that educators are alert to developing students' critical thinking skills. Jane Johnson's "warning" examples of incorrect analyses and Henry VIII's goal of highlighting "the probabilistic nature of the decisions they have to make every moment during their practice" are two examples of this. The findings show that teachers seek to develop both literacy and critical thinking through discussing and critiquing examples from the media or research. Finally, and perhaps most importantly, using examples in teaching can enhance the affective components of learning statistics, which, Gal (2002) stresses, support the knowledge bases of statistical literacy.

Motivating and Engaging Science Undergraduates in Learning Statistics

By drawing on examples from their own practices, such as psychology, biology or medical science, educators can demonstrate the relevance of statistical information to science disciplines, and enable students to see the "greater picture of statistics" (Andrew). At heart, our case studies on teaching in the sciences (Joanna, Andrew and Sjefke) are about making statistics personally meaningful to students; showing the relevance of statistics to their chosen fields of study. Enabling science students to appreciate and understand statistics in this way is essential for their professional development as scientists.

The Australian Bureau of Statistics (2009, p.4) emphasises that statistical and scientific literacy are "inevitably and thoroughly connected" — with an improvement in investigative skills requiring a concomitant improvement in students' statistical skills. This calls into question the common practice of introducing students to statistics in the junior years of their undergraduate degrees often in a decontextualised form with only minimal connection to their science discipline. By contrast, the three case studies we presented indicate that a priority in teaching introductory statistics to science students is enabling this connection — to bridge "the epistemological gap" (Sjefke) between statistical analysis of empirical data and the more abstract, conceptual foundations of the scientific discipline. Perhaps an important responsibility in improving the statistical literacy of science students could be to support the improvement in statistical literacy of science educators.

Relating our findings to Gal's (2002) model of statistical literacy provides statistics educators with a useful framework to guide their teaching and inform their pedagogical development. Science educators, too, can support and enhance statistical literacy by linking their discipline knowledge to its empirical foundations so that more science students find statistical knowledge liberating (Madison & Steen, 2009) rather than a "game that we're playing with them".

References

Australian Bureau of Statistics (2009). Statistical Literacy and Scientific Investigation. Retrieved May 14, 2010 from http://www.abs.gov.au/websitedbs/cashome.NSF/4a256353001af3ed4b2562bb00121564/00c7c7941b4c641dca2572fe001e58b2!OpenDocument

Baldi, B. & Moore, D. (2009). *The practice of statistics in the life sciences*. New York: W.H. Freeman and Co.

Coutis, P. F. (2007). Responsive curriculum design in a statistics service unit. *International Journal of Mathematical Education in Science and Technology*, 38(4), 501–515.

Gal, I. (2002). Adults' statistical literacy: Meanings, components, responsibilities. *International Statistical Review*, 70(1), 1-25.

Garfield, J. & Ben-Zvi, D. (2007). How students learn statistics revisited: A current review of research on teaching and learning statistics. *International Statistical Review*, 75(3), 372-396.

Gordon, S. (2004). Understanding students' experiences of statistics in a service course. *Statistics Education Research Journal*, 3(1), 40-59.

Gordon, S., Reid, A. & Petocz, P. (2007). Teachers' conceptions of teaching service statistics courses. *International Journal for the Scholarship of Teaching & Learning*, 1(1). Retrieved May 14, 2010 from http://academics.georgiasouthern.edu/ijsotl/2007_v1n1.htm

Gordon, S., Petocz, P. & Reid, A. (2009). What makes a "good" statistics student and a "good" statistics teacher in service courses? *The Montana Mathematics Enthusiast*, 6(1, 2), 25-39.

LeBard, R., Thompson, R., Micolich, A. & Quinnell, R. (2009). Identifying common thresholds in learning for students working in the "hard" discipline of Science. In A. Hugman *Uniserve Science - Motivating Science Undergraduates: Ideas and interventions* (pp. 72–77). The University of Sydney, 1-2 October.

MacGillivray, H. (2009). The teaching and assessment of statistical thinking within and across disciplines. *Australian Learning and Teaching Council Senior Fellowship Report.* Retrieved May 14, 2010 from http://www.altc.edu.au/resource-teaching-assessment-statistical-thinking-qut-2009

Madison, B. & Steen, L. (2009). Confronting challenges, overcoming obstacles: A conversation about quantitative literacy. *Numeracy*, 2(1), 1-25.

Moore, D. S. (1997). New pedagogy and new content: The case of statistics. *International Statistical Review*, 65(2), 123-165.

Moore, D. & McCabe, G. (2003). *Introduction to the practice of statistics*. New York: W.H. Freeman and Co.

Onwuegbuzie, A., & Wilson, V. (2003). Statistics anxiety: nature, etiology, antecedents, effects and treatments–a comprehensive review of the literature. *Teaching in Higher Education*, 8(2), 195-209.

Petocz, P. & Reid, A. (2005). Something strange and useless: service students' conceptions of statistics, learning statistics and using statistics in their future profession. *International Journal of Mathematical Education in Science and Technology*, 36(7), 789–800.

Reid, A., Petocz, P. & Gordon, S. (2008) Research interviews in cyberspace. *Qualitative Research Journal*, 8(1), 47-61.

Swingler, M. & Bishop, P. (2008). Enhancing self efficacy in experimental design and statistics using e-learning technologies: an interactive approach. *Practice and Evidence of Scholarship of Teaching and Learning in Higher Education*, 3(2), 164-180.

Utts, J. (2003). What educated citizens should know about statistics and probability. *The American Statistician*, 57(2), 74-79.