Embedding case studies into statistical teaching to enhance quantitative skills of biomedicine students

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Abstract

Students often find it difficult to appreciate the relevance of statistical analysis and the role of quantitative skills (QS) to their future profession in the health sciences. Recent studies have pointed to the use of interdisciplinary or context-based approaches to bring relevance to the role of statistics and mathematics in the life sciences. We speculated that the choice of case studies that cater to the interests of biology students undertaking introductory statistics subjects may improve the relevance of QS to them. This paper reports a strategy we used to teach statistical concepts and building QS of biomedicine students by linking the teaching of biology and statistics using interdisciplinary case studies. We asked, would the use of authentic case studies drawn from influential health science discoveries lead to an improved perception of the relevance of QS? Students' perceptions of the initiative were determined through the use of a questionnaire asking students to provide their opinions about the relevancy and importance of studying QS. We found pre and post survey students held negative views about mathematics and statistics, and although students' comments indicate the use of real-life case studies kept the lessons in statistics interesting, they did not think statistical analysis was important to them or their careers.

Introduction

An active global citizen within the science domain has the knowledge to engage with significant global issues such as biodiversity, health, food security, and the environment, including climate change and water. They also possess the skills to debate, make informed decisions, identify questions, investigate, and draw evidence-based conclusions about these issues (Goodrum, Hackling and Rennie, 2001). Although first year tertiary statistics subjects provide a foundation for the development of these analytical skills, which are essential for graduate competence and preparedness, many undergraduate students hold negative views of quantitative subjects and fail to appreciate that statistical analysis is critical to making decisions about the reliability of real-life information (MacGillivray, 2009; Brown, 2009). Furthermore, students often find it difficult to appreciate the relevance of statistical analysis to their future profession (Gal, Ginsburg and Schau, 1997).

Recent reports examining science, and more specifically biomedical and biology undergraduate education, stress the increasing role of statistics and mathematics and the need

for graduates to be prepared with sufficient quantitative skills (QS) (NRC, 2009; Labov, Reid and Yamamoto, 2010). QS have been identified as a skill set required for science graduates, with QS referring to the application of mathematical and statistical thinking and reasoning in a given context (Matthews, Adams and Goos, 2010).

Recent studies have pointed to the use of a context-based approach to teaching statistics and mathematics (Wood and Solomonides, 2008; Madison and Steen 2009; Matthews, Adams and Goos, 2009; Gordon and Nicholas, 2010). In the case of biomedicine students, the use of authentic statistical problems drawn directly from the health sciences research literature could therefore provide students with a clear understanding of the relevance of QS to their domain.

University of Melbourne: QS in Biomedicine

In the new generation Bachelor of Biomedicine degree at the University of Melbourne, approaches have been taken to improve the QS of students through the introduction of a compulsory core subject entitled *Experimental Design and Data Analysis* (EDDA). This subject aims to provide fundamental concepts of probability and statistics, allowing students to analyse and interpret standard data sets in order to make sound evidence-based conclusions. The specific learning objectives of the subject are to develop:

- Analytical skills – the ability to construct and express logical arguments and to work in abstract or general terms to increase the clarity and efficiency of analysis
- Problem-solving skills – the ability to engage with unfamiliar problems and identify relevant solution strategies

A preliminary survey of 146 first year Biomedicine students who had completed *EDDA* in semester two 2010 revealed that many students continue to hold misconceptions about the relevance of the subject to their future careers in the health sciences. For example, only 38% of respondents indicated that statistical analysis was important/very important to their future careers, with only 27% reporting it was important/very important for their future decision-making. The written comment, '*… for students who want to do research or stats it is important but not for those who want to do med'* highlighted the overall students' thinking. Furthermore, despite its importance in the development of QS, it is rare for biomedicine students to continue their study of statistics beyond first year.

This situation compelled us to pursue an interdisciplinary solution to teaching statistical analysis to biomedicine students. We proposed that by embedding authentic statistical case studies directly into biology and EDDA instruction, students would see the application of QS in biomedicine, and therefore better comprehend the relevance and importance of statistical analysis skills to the health sciences and be equipped with the analytical skills necessary to make sound evidence-based decisions. Research in this area has demonstrated that the inclusion of case studies was a factor in increasing biology students' perceptions of the importance and relevance of QS (Matthews, Adams and Goos, 2010). Given the recent AAMC (2009) report on requirements for entry into medicine in the USA, which highlights the importance of QS as a key requirement for doctors, it is critical that biomedicine students who aspire to enroll in post-graduate vocational courses including medicine understand the need for training in QS.

Purpose of the study
This paper reports on student's perceptions of a newly implemented context-specific approach to teaching statistical concepts in order to provide more relevance to students, than teaching biology and statistics in isolation from each other, as is the current practice at the University of Melbourne and many Australian universities. The central question guiding our study is:

> Would the use of authentic case studies drawn from influential health science discoveries lead to an improved perception of the relevance of QS?

Methodology

To capture student's perceptions, a survey design was adapted with a pre-post methodology to offer insight into the change of perceptions.

Institutional context
The University of Melbourne (UM) is a large, research-intensive university in Melbourne, Australia, with approximately 50,000 undergraduate and post-graduate students. The Bachelor of Biomedicine provides a tailored program containing 12 core subjects. In recent years, approximately 450 students enroll annually and the course attracts students from the top 2% of applicants based on entry scores. Students can choose from a variety of majors and the course sits within the Faculty of Medicine, Dentistry and Health Sciences.

Ethics
This project was approved by the UM Human Ethics Committee (Approval number: 1137022.1)

Participants
In semester one 2011, there were 203 Biomedicine students enrolled in the first year EDDA. The subject includes three (one hour) lectures, one practice class, and one computer laboratory class for a weekly total of five contact hours in the 12 week semester. This undergraduate subject has no prerequisites. Although 450 students are enrolled in any one year in Biomedicine, EDDA is offered in both semesters of first year study in order to accommodate timetabling elective subject options, and a maximum of 250 students can enrol in either semester.

Selection of Case Studies
A series of case studies with their original data sets (8), based on real experiments that have led to major breakthroughs and development of important concepts in biology *(e.g the discovery of antibodies)*, were selected by the lecturers of both Biomolecules and Cells (BIOL10002) & EDDA, and presented in parallel in lectures to students taking both subjects.

The first selection criterion for case studies was that the study addressed an important concept in the current Biomolecules and Cells curriculum. The second selection criterion was to find case studies that incorporated particular statistical concepts (e.g. diagnostic testing, odds ratio, p-values, randomization and standard errors, comparison of populations) that are taught in the current EDDA subject. The case studies were taken from the prescribed textbook for the subject Biomolecules and Cells, 'Life: the science of biology**,** Sadava, Hillis, Heller and Berenbaum, (2011), 9th Edition. In this textbook, each chapter includes a section called 'Investigating Life' in which the experimental details are presented in a simple diagram and the reference to the original journal article that included the complete data set is also

provided. The two lecturers involved in these subjects exploited these resources for each important concept.

Data from eight journal articles for example from van Bebring E. and Kitasato S. (1890) The mechanism of immunity in animals to diphtheria and tetanus. *Deutscbe Medizhiscbe Wocbenschift,* 16: 1113-1114, were used in both biology and EDDA lectures.

Appendix 1 contains a list of the references for the eight case studies from which the data was extracted and shown to biology students to illustrate how a biology concept was derived, and in EDDA to illustrate how a statistical concept used to support the conclusions in the papers and hence led to the development of the biological concept.

The experimental design, data and conclusions of each original journal article satisfying both criteria were presented during relevant lectures. During the biology lecture, an emphasis was placed on why the study was important and the value and importance of the statistical analysis that allowed scientists to be confident of the results and conclusions. During lectures for the EDDA subject, the same experimental design, data and conclusions were presented with an emphasis on the application and interpretation of statistical concepts used in the study.

At the beginning of the intervention, the first case study was introduced by the two lecturers in both subjects. The lecturers chose to share a lecture to highlight two points: that discoveries in biology rely on statistics and an understanding of statistics is important for scientists. The concept chosen was the biological process involved in long term memory. The experimental design that underlies this concept is presented in Investigating Life: Figure 45.17 (Sadava *et al.,* 2011) and based on the work of Malinow, Schulman and Tsien (1989)**.** In the first half of the lecture, the biology lecturer (MF) described the experimental design shown in Figure 45.17, and why it offers an explanation of how long term memory is formed. In the second half of the lecture, the EDDA lecturer (RW) clarified further experimental details, then presented and used the data (see Figure 1, Malinow, Schulman and Tsien, 1989) to explain the statistical terms, standard error of the mean (SEM) and 95% confidence intervals for the true mean (the population mean).

Study Design

The time points during the 12 weeks of semester 1, 2011 when pre and post surveys were conducted, as well when the shared lecture occurred and case-studies in Biology and EDDA were embedded into the curriculum are shown in Table 1.

Data Collection

Pre and post paper-based surveys were administered in order to determine whether there had been an attitude shift in student perception pre and post the intervention (the embedding of case studies). Students' perceptions of the initiative were determined through the use of a questionnaire asking them to give their opinions about the relevancy and importance of studying QS, and the use of case-studies. The questionnaire was based on a refined version of one used in the pilot survey in 2010 and contained more specific items to check the consistency of an individual's response (Elliott, Boin, Irving, Johnson, & Galea, 2010). The response rates were: 72% Pre-survey (147 students) and 41% Post-survey (83 students).

Table 1: Time points for data collection, shared lecture and embedding case studies into the Biology and EDDA subjects in semester 1, 2011.

Time	Activity
Week 2	Data collection: pre-survey conducted at end of a one hour EDDA lecture.
Week 3	Shared lecture: the biology lecturer (MF) and the EDDA lecturer (RW) present a one hour lecture together in the Biomolecules and Cells subject.
Week 3-6	Case-studies presented in Biomolecules and Cells scheduled lectures by the biology lecturer (MF).
Week 3-10	Case-studies presented in EDDA when appropriate concepts were being introduced by the EDDA lecturer (RW).
Week 11	Data collection: post-survey conducted at end of an EDDA lecture.

The Survey
The survey instrument for this project was developed by the authors.

Part A. Students were asked about how relevant their first year core subjects in Biomedicine, Using a five-point Likert scale (1=not at all relevant to 5 = very relevant). The specific question was:

Q1. For the following subjects – typical for a 1st Yr Biomedicine Degree – indicate how relevant to you is each subject.

Subjects typical of first year biomedicine students were: biology, chemistry, mathematics, physics and statistics. Provision was made for students to address each subject separately.

Part B. Importance of Statistical Analysis
Using a five-point Likert scale, students were asked to respond to a series of questions.
(i) Importance of statistical analysis (1 = not at all important to 5 = very important)

Q2. How important is statistical analysis in helping you make decisions about the reliability of information?
Q3. How important do you think it is for Biomedicine students in general to have an understanding of statistical analysis?
Q4. How important do you think statistical analysis will be in your future decision-making?
Q5. How important do you think it is for a Biomedicine student to learn about statistical analysis using real-life bioscience or medical cases?

(ii) For each question above (Q2-5), students were also asked for their comments allowing for more in-depth data on perceptions to be gathered. Specifically we asked:

If you think question number … above is important or unimportant, please comment on why.

Data Analysis
The data were analysed with descriptive statistics, namely frequencies and percentages. The relevance of compulsory subjects is shown in Table 2. The importance of statistical analysis is presented in Table 3. Table 4 presents the data for open-ended comments on the importance of statistical analysis to biomedicine students, which have been categorised into major themes emerging from the comments.

Results

Pre and post survey data show that between 87% and 96% of respondents selected both chemistry and biology as relevant, whereas for statistics only 52% selected this subject as relevant pre survey with a small increase to 55% post-survey (see Table 2). Neither physics nor mathematics fared any better. For mathematics in fact there is a decrease of 12% compared to 54% post and pre survey respectively, while physics increased post-survey by 5%.

Table 2: Percentages of students reporting *very relevant* and *relevant* of relevance of compulsory subjects in 1st Year Bachelor of Biomedicine both pre and post the intervention with the difference calculated.

Subject	Pre	Post	Difference
Biology	92%	96%	4%
Chemistry	88%	87%	-1%
Mathematics	54%	42%	-12%
Physics	48%	53%	5%
Statistics	52%	55%	3%

Our pre and post survey data of the importance of statistical analysis to first year biomedicine students is shown in Table 3. Only 48% and 59% of students entering this course (pre-survey data) indicated that statistical analysis was important for making decisions about the reliability of information (Q2) or for biomedicine students (Q3) respectively. Post survey, there was a slight positive increase (+9) for the former question but effectively no change for the latter question. There was a small positive increase (+7) in the percentage of students who thought statistical analysis would be important to their future decision making (Q4) post intervention. At entry level 70% of students thought learning about statistical analysis using real-life bioscience of medical cases were important (Q5) and this remained unchanged post survey.

Table 3: Percentage of students responding important or very important in response to questions about the importance of statistical analysis and the difference between pre and post surveys also displayed.

Question	Pre	Post	Difference
Q2. How important is statistical analysis in helping you make decisions about the reliability of information?	48%	57%	9%
Q3. How important is it for Biomedicine students in general to have an understanding of statistical analysis?	59%	58%	-1%
Q4. How important do you think statistical analysis will be in your future decision-making?	34%	41%	7%
Q5. How important do you think it is for a Biomedicine student to learn about statistical analysis using real-life bioscience or medical cases?	70%	70%	0

The open-ended responses to questions 2 to 5 were coded and quantified, see Table 4.
Post-survey, when students were asked to comment on the use of statistical analysis in helping to make decisions about the reliability of information (Q2), responses fell into 3 main groups. The majority of responses (60%) were about the usefulness of statistical analysis for validating data.
Specific comments were:

> *"stats = assessment of reliability of info. Need to know reliability to know whether to use it"*
> *"reliability of information is important in any study and in decision making"*
> *"one can measure the reliability of data rather than guess"*

There was a reduction of 16% in the number of comments about the unimportance of statistical analysis between pre and post survey. Comments such as:

> *"Don't see myself validating information realistically any time soon"*
> *"I don't make use of this in my life"*
> *"because it confuses me"*

For Q3, students commented on the importance or unimportance of biomedicine students having a general understanding of statistical analysis. Post survey 58% of students selected important or very important in response to this survey question, but only 41 % of comments provided by students were supportive of this notion and there was a decrease of 6% in this category of comment compared to pre survey (54%). Supportive comments for example were:

> *"if one goes into research it's very important and if one goes into medicine it is helpful in understanding current research"*
> *"understand journal studies, relevance of information"*
> *"I think it's very important as biomed students ought to be able to read and write a medical paper"*

Table 4: Students' written comments on Pre and Post surveys in response to open-ended questions seeking information about why they selected important or unimportant in response

to survey questions Q1-4 (data shown in Table 3, and reproduced in table below). The specific question asked to elicit comments is shown below each survey question.

Comments	Pre	Post
Q2. *How important is statistical analysis in helping you make decisions about the reliability of information?* ***If you think 2 above is important or unimportant, please comment on why…***		
Important for validating data	47	60
Important for medical research	2	3
Important for data analysis and quantification	31	33
Other	20	4
Q3. *How important is it for Biomedicine students in general to have an understanding of statistical analysis?* ***If you think 3 above is important or unimportant, please comment on why…***		
Important for research but not medicine	20	28
Important for basic interpretation of results medical or research	54	41
Not important	5	11
No obvious application	19	6
Other	2	14
Q4. *How important do you think statistical analysis will be in your future decision-making?* ***If you think 4 above is important or unimportant, please comment on why***		
Important for career	20	39
Important for research not for medicine	16	4
Important for data analysis	23	15
Not important	16	19
Other	25	23
Q5. *How important do you think it is for a Biomedicine student to learn about statistical analysis using real-life bioscience or medical cases?* ***If you think 5 above is important or unimportant, please comment on why***		
Keeps lessons interesting	13	31
How it applies to medicine or research	43	54
Important knowledge for the future	21	11
Important for research only	6	4
Other	17	0

The importance of statistical analysis to biomedicine students for their future decision making (Q4) were generally very favourable in both pre and post survey with less than 20% of comments about the unimportance of statistical analysis. Students indicated that statistical analysis was important for their careers, research and data analysis. Examples of comments retrieved post-survey were:

"it is important for experimental situations"
"statistical analysis is important as a basis for scientifically testing the effect of a new drug. i.e. deciding if it is beneficial"
"being in a stats course has made me realise the power of analysis
"if researcher needs to know results of work significant or not. If doctor need to understand sig. of research"
"whether in research or as a medical professional it is important to verify the reliability of research and question consequential conclusions"

Examples of comments from students who indicated that statistical analysis was not important for their future decision making are:

"only relevant for people interested in research which is a minority"
"statistical analysis will only be very important if I end up a researcher/statistician. As a doctor for example, statistical analysis will hardly be used in practice"
"my career interest are in the science field and not in the stats field"

Comments returned post survey for Q5 (the use of real life case-studies) appeared to suggest the students found the use of real-life cases studies in parallel in the two subjects, particularly beneficial as the following comments show:

'It explained how stats can be related to biology real life example'
'makes me feel more confident of using statistic on biomed study'
"good to be able to see the use of statistics in real life"
'seeing stats in action is quite useful in building an interest for it'
'allows us to connect biology and statistical importance'

31% of comments related to keeping the lessons interesting and 54% of comments indicate students could see the relevance to medicine and research.

Discussion

This study describes our attempt to embed real-life case studies in parallel into two subjects, biology and statistics. The focus of the case-studies was basic science that describes important discoveries that have informed our understanding of cellular mechanisms in biology. It is worth noting that surveys were administered in the EDDA lecture time-frame and space, and not during biology lectures, as this may also become relevant when we try to make sense of our data.

In this study the use of authentic case studies drawn from influential health science discoveries lead to an improved perception of the relevance of QS in a small number of students". However, this study confirms that students' attitudes and beliefs play an important role in students' learning (Garfield, Hogg, Schau and Whittinghill, 2002; Matthews, Adams and Goos, 2010) and particularly with respect to their perception of the relevance of statistics. Around half our entry level biomedicine students indicated that mathematics and statistics were not relevant to them. This is in stark contrast to data reported by Matthews and colleagues (2010) that science students at the University of Queensland reported high levels of agreement with respect to the importance for mathematics than compared to biomedicine students at the University of Melbourne. A key difference exists, we were attempting to influence perceptions about statistical analysis as opposed to QS in general, and it is well

recognised that student beliefs about statistics are often negative, and it is common for students to report dissatisfaction with introductory statistics courses (Garfield *et al.*, 2002).

In addition, when examining comments provided by students, it seems that for the most part students do not see the relevance of statistics to medicine, and as most students in this course aspire to study medicine, they do not see the relevance of statistics to their career choice. From where does this dissociation between medical research and the practice of medicine come?

The recent study commissioned by the Office of the Chief Scientist to determine first year Students' attitudes in part to science and mathematics, 'STEM and non-STEM First Year Students' (2012) found that students had a poor understanding of career opportunities, and a gender imbalance with less females choosing science and if they did choose science focusing on vocational training. Perhaps a lack of understanding by our students about careers in general, and career paths in medicine in particular, may be a contributing factor to the lack of importance of statistical analysis perceived by biomedicine students.

Our intervention was research-focused and conducted on a small scale, and perhaps a larger intervention with medically-focused cases studies is needed to really link QS to biomedicine in a meaningful way. While our students indicated that the case-studies kept lessons interesting and allowed them to see how it was applicable to medical research, they also clearly indicated their belief that statistical analysis was important for research but not for medicine, and we are aware that many of these students aspire to become medical practitioners. We chose case-studies that were about basic research, most unaligned to their view of medicine or medical research – that is, none of our case studies were for example about the testing of new interventions for curing a disease or testing the efficacy of a new drug. Did we unwittingly then perhaps entrench their view of statistical analysis being important for research and thus not relevant to their interests by our choice of case studies?

Conclusion

Given the recent AAMC (2009) report on requirements for entry into medicine in the USA highlights the importance of QS as a key requirement for doctors, it is critically important that biomedicine students who aspire to enroll in post-graduate medical courses understand the need for training in QS.

One way to improve student's perception of statistics is to use appropriate data-sets in these subjects. In addition, both MacGilivray (2009) and Gordon and Nicholas (2010) have pointed out that in the last ten years or so, academics are continually seeking appropriate datasets to include in statistic subjects which are taught as service subjects in a broad range of courses for science, medical and business students.

Another improvement is to use context-based approaches that have been advocated and are essential for teaching statistics and mathematics (Wood & Solomonides, 2008; Matthews, Adams and Goos, 2009). However, our data indicates that while beliefs about the importance of statistical analysis for biomedicine students are difficult to change, perhaps the use of more medically orientated case-studies in future interventions may help this particular group of students to appreciate the importance and relevance of statistical analysis for their careers.

It would seem from the data in this study, that positively shifting students' perceptions of the importance of statistical analysis is difficult. However, approaches that provide a comprehensive interdisciplinary subject can be effective. SCIE1000 brought together academics from mathematics, the biological sciences, and education to create a truly interdisciplinary quantitative course for first-year students (Matthews, Adams and Goos, 2010). These authors reported positive effects, including gains in positive appreciation of the importance for mathematics in the biological sciences by using real-world examples. However another approach reported by Carnell (2008) was the effect on attitudes to statistical analysis when students were directly involved in generating their own data collections. However, the inclusion of a project of this type into an introductory statistics course did not significantly impact students attitudes towards statistics.

The main issues for students appear to be that statistics is seen as difficult and irrelevant to their lives (Carnell, 2008; Gordon and Nicholas, 2020). We have speculated about when and how this perception develops and whether it may be due to a lack of students' understanding about career paths (STEM and non-STEM First Year Students, 2012). Perhaps it is due to a lack of understanding about how scientific knowledge is created and verified, and the vital role of statistical analysis in this process. Future studies may need to address these issues before any positive shifts in the importance Biomedicine students in particular attach to statistical analysis can be made.

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Appendix 1: Case Studies

Case Study 1
van Bebring E, Kitasato S. (1890). The mechanism of immunity in animals to diphtheria and tetanus. *Deutscbe Medizhiscbe Wocbenschift,* 16:1113-1114.

Case Study 2
Kuffler SW. (1953). Discharge patterns and functional organization of mammalian retina. *Journal of Neurophysiology,* 16:37-68

Case Study 3
Rall TW, Sutherland EW, Berthet J. (1957). The relationship of epinephrine and glucagon to liver phosphorylase. IV. Effect of epinephrine and glucagon on the reactivation of phosphorylase in liver homogenates. *Journal of Biological Chemistry, 224*, 463-75

Case Study 4
Hubel DH, Wiesel TH (1962). Receptive fields, binocular interaction and functional architecture in the cat's visual cortex. *Journal of Physiology, 160*, 106-154

Case Study 5
Coleman DL, Hummel KP. (1969). Effects of parabiosis of normal with genetically diabetic mice.American Journal of Physiology, *217*, 1298-1304.

Case Study 6
Heller HC, Colliver GW. (1974). CNS regulation of body temperature during hibernation. *American Journal of Physiology, 227*, 583-589

Case Study 7
Baylor DA, Lamb TD, Yau KW. (1979). The membrane current of single rod outer segments. *Journal of Physiology, 288*, 589-611.

Case Study 8
Malinow R, Schulman H, Tsien RW. (1989). Inhibition of Postsynaptic PKC or CaMKII Blocks Induction but not Expression of LTP. *Science, 245*, 862-866