Descriptive account

Strategies for enhancing the learning of ecological research methods and statistics by tertiary environmental science students

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Abstract
To undertake rigorous research in biology and ecology, students must be able to pose testable hypotheses, design decisive studies, and analyse results using suitable statistics. Yet, few biology students excel in topics involving statistics and most attempt to evade optional courses in research methods. Over the last few years, we have developed a tertiary-level unit to create a positive, inquiry-based, learning environment for teaching survey methods and statistics to environmental science students. This paper reports the success of incorporating a staged sequence of learning and assessment tasks into an ecological research methods unit. To gauge reactions to the strategies incorporated into the unit, all students completed a questionnaire and several students were interviewed while the lecturer involved was interviewed. Overall, students demonstrated acquisition of fundamental research skills, enhanced understanding of the subtleties of the scientific method, and improved confidence in their use of inferential statistical procedures. Further, they recognised the value of interactions with their colleagues and the need for flexibility in research design to compensate for variable environmental conditions. Skills in statistics and survey design appear best taught using learning and assessment tasks that are integrated into the teaching sequence so that they emulate the steps involved in conducting 'real-life' scientific research.

Key words: Staged assessment tasks, environmental science, ecological research methods, biostatistics

Introduction

Tertiary environmental science students need to be able to design research projects with testable hypotheses, adequate replication and randomisation, and appropriate statistics to support or refute their hypotheses (Elzingha *et al*., 2001). Later, as professionals, they need to be able to produce results that are sufficiently robust to withstand scientific and legal scrutiny, and they must understand the limitations of analytical methods and statistics applied to biological data that are frequently non-normal and highly variable (Wardlaw, 2000). This is a considerable challenge considering that most life-science students struggle with topics involving numeracy, partly because they have learnt statistics in a 'pure' sense, often within a limited context (Murtonen and

Lehtinen, 2003) and seldom with a chance to apply them to data collected by the students themselves. The result is a fragmentary grasp of statistical theory, confusion about basic concepts of probability, and a lack of confidence in their own ability to apply the correct inferential statistics to a research problem (Panizzon and Boulton, in press).

Overcoming these problems and fears requires educators to consider teaching strategies that engage students actively in the learning process. This is crucial given that learning is an interactive process and students construct their own meanings and understandings using their prior knowledge (Mintzes *et al*., 2001). With each new learning experience, constructions are developed, changed, or restructured by the student (Costa *et al*., 1998) so that learning becomes a life-long process. Understanding the scientific ideas brought to any teaching situation by the students is a crucial place to begin. This is particularly important in the sciences given that many of the conceptions held by students before the teaching actually begins are scientifically inaccurate (e.g. Pfundt and Duit, 1994).

If educators in biological research methods and biostatistics are to meet the needs of their students, learning opportunities that are contextually relevant and stimulate engagement in the process must be provided (Benson and Blackman, 2003). Complementing these teaching strategies is the need to implement assessment tasks that support learning and motivate the students (Willmott *et al*., 2003). They should be given the opportunity to demonstrate their scientific understanding and ability to apply their knowledge to new learning situations (Cooper *et al*., 2003). This requires a move away from assessment tasks that favour the memorisation and regurgitation of scientific facts. For example, most students will continue to learn statistics by rote and memorisation as long as they are confronted with lectures where statistical analyses are presented as recipes for data analysis of increasing complexity while assignments and examinations focus on recalling formulae (Neumann, 2001). Later in their career, when faced with 'real-life' scenarios where statistical analyses are needed for assessing results of a scientific investigation, these students may be destined for failure.

This paper evaluates the experiences of a lecturer of a biological research survey and statistics unit who altered teaching strategies and assignments to better meet the needs of students and explores the responses by the students as assessed by questionnaires and interviews. Traditional statistics lectures and practical sessions were replaced with an inquiry-based approach that integrated learning experiences and environmental field work with a sequence of assessment tasks emulating the fundamental steps involved in the research process.

Educational Context

Resource Survey and Habitat Evaluation (RSHE) is offered as an optional elective unit in the Bachelor of Science, Bachelor of Environmental Science, and Bachelor of Natural Resources degrees in an Australian university.

It is selected in the final year level of the degrees, and requires at least first-year level statistics or mathematics, which are core units for all these degrees and are taught as lecture-based units without practical work. The RSHE unit comprises 26 one-hour lectures and 13 three-hour practical sessions over the course of a thirteen-week semester.

The unit commences by contrasting inductive and deductive methods in biology, and pointing out the complexities of the scientific method. During a group discussion in the first practical session, students are encouraged to identify previous experiences with the application of the scientific method, their grasp of statistics, and their perception of the relevance of the unit they are about to undertake. Virtually all of the students have negative experiences with statistics or mathematics and confess to severe apprehension about the impending RSHE unit (Panizzon and Boulton, in press). Significantly, they have only a sketchy understanding of *any* scientific method, few are able to phrase hypotheses or explain the concept of 'statistical proof', and for most research reports they have prepared, the data have either been collected or analysed for them already. Students admit that they follow a cook-book approach and that they do not fully understand what statistics are being used or why, strengthening the feeling of confusion and helplessness when faced with novel data analysis tasks.

The focus of RSHE is to introduce students to the 'real-life' steps of contemporary biological science including the professional activities of developing a research proposal (assignment 1), peer review of other students' proposals (formative assessment task conducted during practical sessions), conducting research in the field, presentation of findings in a seminar (assignment 2), and completion of a final scientific report (assignment 3). Each of these tasks generates immediate feedback thereby helping students improve the quality of their work, and ultimately, their major research report (similar to Willmott *et al.,* 2003). Consequently, research expertise is built using a staged sequence of assessment tasks. Not surprisingly, students react enthusiastically to these tasks because of their perceived relevance to future career goals and the immediate feedback they get on their progress.

The lectures link tightly with these tasks by introducing students to the theory and concepts underpinning environmental research including the necessity for the design of robust surveys, the importance of replication and randomisation, and the value of statistical methods as a critical tool in the research process. The main teaching strategy employed during the lectures each week is a question-and-answer approach with the lecturer building upon the understanding exhibited by the students. Theory is introduced interactively so that students are engaged in classroom dialogue, and most of the research examples used by the lecturer are contemporary environmental issues concerning Australia's natural resources. Towards the end of the unit after the students have been exposed to a wide range of field survey and statistical techniques, guest lecturers and researchers are invited to present their research to the students and respond to questions and comments. Although not formally interviewed, these guest lecturers commented favourably on the depth and perception of the students' questions.

Supporting the lectures, practical classes allow students to become familiar with a variety of design techniques, sampling equipment and statistical analyses before they need to settle on a research method for their individual project. An overview of the teaching focus and sequence is provided in Table 1.

Table 1 Overview of teaching program

Week	Teaching Focus	Assessment Task
1	Explain objectives of unit. Contrast inductive and deductive methods in biology. Identify prior experiences with statistics and scientific method	
2	Theory of survey design and a simple field practical class using quadrats to illustrate how to choose size and number of replicates	
3	Students nominate a research topic, individual discussion about design with lecturer	Draft research proposal prepared
4	A second field survey practical class demonstrating methods and a sampling design including replication and randomisation	
5	Peer review of research proposals using the same assessment proforma as that used by lecturer. Class discussion of findings and complexity of peer review	Submit modified proposal based on reflection and peer reviews (assignment 1)
Mid-semester break		Research project and sampling completed
6	Individual appointments with students regarding research data and analysis. Practical classes over next 4 weeks go through statistical packages and show students how to analyse their data	
7	Lectures on statistics and their limitations	
8	Univariate analysis methods	
9	Multivariate analysis methods	
10	Seminar presentation of initial research findings and overview – questions from peers and lecturers. Develop oral presentation skills, reflect on project results, obtain peer and lecturer feedback for final report	Student seminar (assignment 2)
11	As above	Student seminar
12	Lectures from guest lecturers and researchers. Students comment on design and analysis	Project report completed (assignment 3)
13	As above	

Methods

To gauge the students' perceptions of the teaching and assessment strategies employed in the unit, all students (n=28) completed a questionnaire in Week 6 of the semester. The focus of the questionnaire was on the research proposal and the peer review process of the proposals. It consisted of a series of open-response questions and Likert scale items.

Semi-structured interviews were conducted with 14 students at the completion of the unit. These explored students' views about the applicability of the seminar presentations and the research project. The emphasis was on collecting detailed student responses that could be used to modify the unit for the following year. Consequently, both the questionnaire and the interviews focused on maximising the opportunity for students to provide detailed responses.

The lecturer involved in the unit was invited to reflect on the changes observed in student achievement, supporting his claims with aggregated data over five years. He was also questioned about his perception of the change in the students' confidence in research methods, their use of appropriate statistics, and their subsequent research experiences after completion of the unit.

Results: The Students' Perspective

Students' perceptions of the research proposals and peer review process

Q1: On a scale of 1 (very difficult) to 7 (very easy), please rate how difficult you found preparing this research proposal. Circle the most suitable number.

Very Difficult						Very Easy
1	2	3	4	5	6	7

In responding to this question, 14% of students selected '2', 22% preferred '3', 32% opted for '4', 25% selected '5' and 7% chose 6 indicating that the majority of students found the task of moderate to high difficulty. The reasons for this were explored in Question 2.

Q2: What aspects did you find difficult in preparing the research proposal? Please elaborate on your answers.

Student's responses provided interesting insights into their thinking. Sixty percent of the students claimed the hardest aspect was not being able to locate a literary reference that gave a single "right answer" or "right way of doing the research". Additionally, 35% of students found difficulty in writing their proposal so that it could be understood by someone with limited expertise in the field. In particular, they recognised the need for structuring their writing so that the aim, methods, and proposed data analysis for the research project fitted together logically. The real challenge for students was being concise (having a specified word limit) while giving enough detail to explain clearly the intention of the research project. For example, one student stated: "It was hard trying to explain the techniques and methods to be employed in a manner that was comprehensible to someone who might not be working on the same research topic".

In response to:

Q3. Would you approach preparing a research proposal differently based on your experiences over the last few weeks? YES or NO. If yes, explain in detail.

Approximately 84% of students indicated they would make major alterations to the way in which they tackled the task, in retrospect. The most common weakness, identified by 70%, of students was their underestimation of the amount of time required to conceptualise and develop their research design. Students acknowledged the need to start the process much sooner so as to review the relevant literature, think about trialing methods in a pilot study, and formulate projects that were feasible given that they had to be completed within a limited timeframe.

Students also highlighted the necessity to consider the type of analysis that would be suitable for the research design to ensure valid and reliable results. This recognition appeared to be a major breakthrough in thinking as students realised that there was little use in collecting data that could not be analysed correctly. Therefore, data analysis and collection had to be considered simultaneously in relation to the hypotheses being explored. This point had never been made explicit during lectures and discussions so it was gratifying to see the number of students who drew the association independently.

Finally, nearly all of the students stated that this was the first research proposal they had written. This is surprising given that the students were completing the final year of their science degrees and would have to undertake this task in a postgraduate research degree or for any grant application in future careers. Except for this unit, there is no other opportunity in the current curriculum for the students to complete an equivalent assessment task. In contrast, essays and examinations are virtually universal.

A closer investigation of various aspects of the research proposal was explored in Question 4.

Q4. On a scale of 1 to 7, please rate how important you considered the following aspects of a research proposal to be:

	Very Unimportant						Very Important
Clearly stated hypotheses/aims	1	2	3	4	5	6	7
Adequate replication	1	2	3	4	5	6	7
Adequate randomisation	1	2	3	4	5	6	7
Realistic budget	1	2	3	4	5	6	7

During the introductory lectures, basic concepts of survey design were discussed and explored. These included the need for adequate replication and randomisation (study design features) along with clearly stated hypotheses. Other aspects such as budgets were mentioned in relation to helping to identify the materials required for a field project and were considered by the lecturer to be of practical significance in outlining needs for a research proposal but not as critical as the first three criteria. Responses from students ranked the importance of the budget well below those of replication, randomisation, and clearly stated hypotheses (Figure 1). There was a significant association (Chi-squared, $P < 0.001$) between responses rating replication and randomisation equally. These two design features are crucial but are often overlooked in poorly designed research projects. Clearly, the emphasis placed upon these concepts during lectures was recognised by the students in their research proposals.

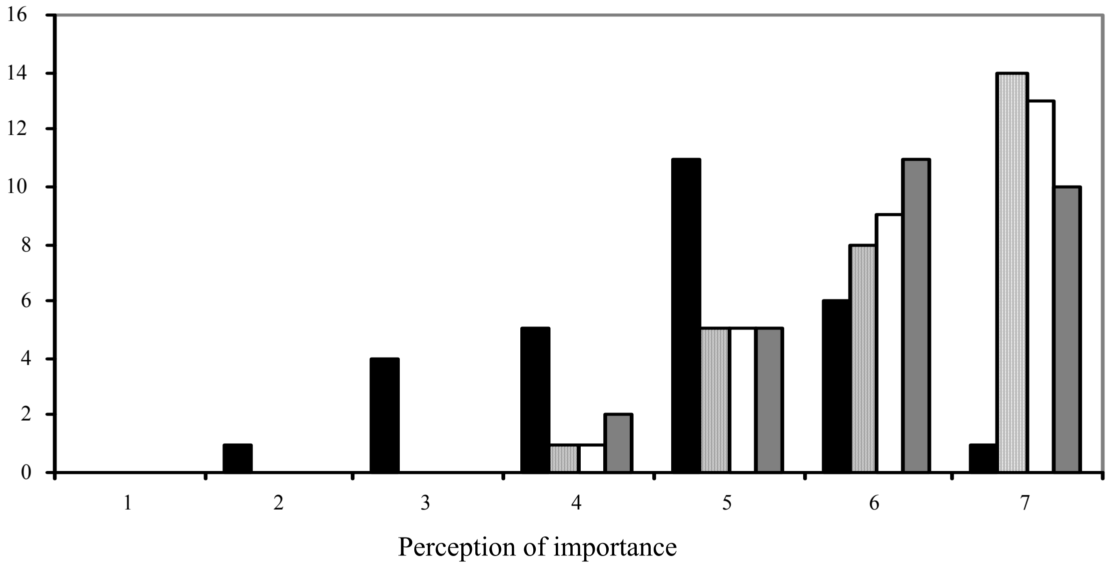

Figure 1 Frequency distribution of students' perceived importance of preparing the research proposal ranked from 1 (very unimportant) to 7 (very important). Categories of the proposal are represented by bars shaded as follows: black = adequacy of budget, stippled = clarity of hypotheses, white = adequacy of replication, dark grey = adequacy of randomisation.

Students were asked to comment on the peer review process of the research proposals. This activity seemed to really capture the essence of the research process for most students, partly because they realised that funding for research projects in the 'real world' usually hinges on a successful proposal judged by peers to be feasible and worthwhile. The students acknowledged the high degree of responsibility associated with the judgment of each other's work. In relation to:

Q5. Explain your initial feelings going into the peer review process. How valuable was your involvement in the peer review of research proposals?

All of the students admitted to initial apprehension given their lack of previous experience with a peer review process. However, with the experience behind them, the students considered that the task was rewarding. For 68% of the students, the most valuable outcome was being able to interact and talk to their colleagues about their research proposals. Implicit in their responses was the recognition that communication with others was an effective learning strategy. Not only did students receive constructive advice and comments from their peers, they benefited by being in a position to offer help to others. One comment during the follow-up interview was: “Being able to discuss ideas with people doing similar projects as me was terrific. We actually sat around, read one another’s proposals and gave a score according to criteria we have set in class. Everyone treated it really seriously and tried to provide helpful, constructive advice”.

Overall, students emerged from the learning experience with greater knowledge and understanding of survey methods and biostatistics. Encouragingly, other less obvious factors emerged such as the recognition by students of the value of working as a team and their markedly improved confidence (see Table 2). These are equally important attributes for all science students regardless of their future work place.

Table 2 Specific positive outcomes of the peer review process for students ranked by student percentage responses

Positive outcomes	% of students
Helped clarify statistical understanding – both strengths and weaknesses	57
Facilitated ongoing related discussion outside of the classroom with peers	50
Emphasised the importance of being able to orally communicate ideas to others	32
Increased understanding of survey design	28
Increased confidence in knowledge and ability in the area	21
Highlighted the importance of working as a team	21

Students’ perceptions of the seminar presentations and research report

During interviews, students were asked: *Explain how your seminar presentation went?* The majority of students were pleased with their presentations and the way in which other members of the class responded. A number of students made comments similar to those in Table 2, stating that having to describe their research orally highlighted components that had not been adequately addressed. It also allowed students to identify aspects of their design and analysis requiring greater explanation. All of them agreed that it was a valuable assessment exercise to be obligated to speak about what they had achieved and how it was conducted although some students expressed typical apprehension about speaking in public.

Students were asked: *What are the key steps in doing scientific research that you have learnt from completing this unit?* Each of the students was able to specify a sequence of strategies and skills that had been developed by undertaking the unit. These included: identification of relevant dependent and independent variables; correct use of field methods and protocols that addressed the hypotheses and aims of the investigation; features related to the research design (e.g., adequate randomisation and replication); and, recognition of the types of data to be collected and appropriate ways in which to analyse these data. In addition to these aspects, students acknowledged the importance of interacting with other people and reviewing published literature as a means of not only clarifying ideas but also learning from what had already been done by other researchers.

Subsequently, students were asked: *Did you feel the research project was a worthwhile learning exercise*? The overwhelming response to this question was positive with students explaining that they had developed a greater sense of the actual mechanics of research in terms of aims, outputs, and data analysis. For many who had entered the unit with negative experiences from previous statistics units or with deep-seated fears of research methods and data analysis, this was a dramatic reversal of their opinions and mind-set. Best of all, some of the students were applying their new knowledge to problem-solving tasks in other units.

Finally, to gain a broader perspective of the students' views of the unit as a whole, they were asked: In hindsight, have the teaching and assessment strategies implemented in this unit helped to develop your understanding of survey methods and statistics? All the students identified that the unit was worthwhile and the approach beneficial. They agreed that the series of varied and integrated assessment tasks had improved the quality of the final research report. Students also recognised that they had gained awareness of the complexity of undertaking ecological research in the field. They realised that their initial views about conducting research had been over-simplistic and they now had a greater appreciation for the extent to which confounding factors could impact severely the quality of a research project. This seemed to be an important lesson for all the students, and their reflective comments revealed how often they had found the need to refine their methods and questions when faced with challenges of sampling design and environmental variability.

"When I had a look at my actual study again, it changed quite a bit from my initial proposal. There were all these additional variables that I couldn't overcome. I guess I found out that it is sort of hard to make a certain study and then stick to it – you have to continually change your methods to suit the environment which I really wasn't prepared for at the beginning".

Results: The Lecturer's Perspective

The lecturer has 12 years experience in teaching field survey and statistics, and adopted this staged sequence of tasks after disappointing results from co-teaching a similar unit at another university where the approach was more traditional (i.e. lectures and worked examples). Student grades are presented in support of the improvement in performance with adoption and refinement of the staged approach (Figure 2) but it is acknowledged that without adequate controls and given year-to-year variation in average student ability, these trends are only a weak indication. More insightful were the lecturer's reflections to a series of open-ended questions as summarised below.

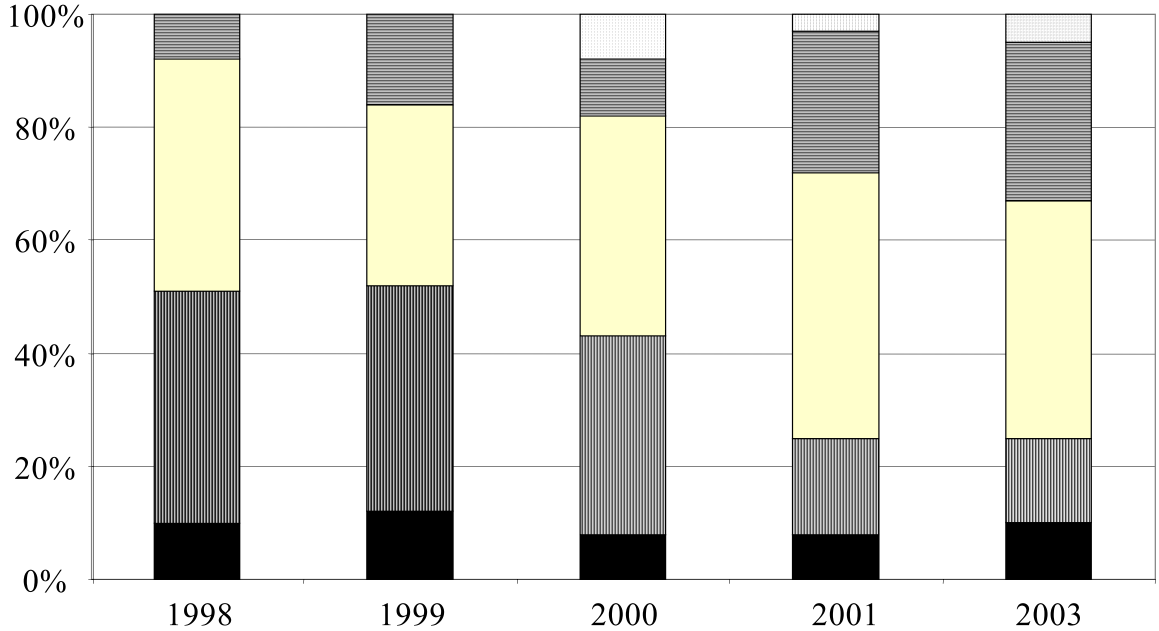

Figure 2. Changes in proportions of student grades over time since staged sequence introduced in 2000. Bars shaded as follows: failed grade = black, pass (50-64%) = vertical lines, credit (65-74%) = white, distinction (75-84% = horizontal lines, high distinction (>85%) = stippled. Class sizes were 31, 25, 33, 36, and 43 students respectively; the subject was not offered in 2002.

In response to a question about the most striking changes in students' learning as a result of this staged sequence, the lecturer identified enhanced confidence in the students' ability to design research studies, their greater critical ability in assessing research projects that were being undertaken as practical components in other units in the degree (this was also commented on by lecturers in those units), and the overall improvement in survey and experimental designs by Honours students undertaking research projects the following year. So marked was this response that many other lecturers now insist that their students do the RSHE unit before they are allowed to undertake research Honours projects. The lecturer also commented that students interacted more with each other after the peer review of proposals, even doing fieldwork together and critiquing each others' work in an informal way. Furthermore, students no longer came to him with data asking 'how shall I analyse these?' (a common occurrence) but now came and discussed approaches to data collection and analysis before the research work commenced, showing greater maturity in the choice of analytical approaches and techniques to ensure randomisation and replication.

The lecturer's response to the question: *How well do assessment tasks match learning outcomes*? was ambiguous. Although he clearly recognised the value of setting assessment tasks that emphasised to the students what aspects of the unit were considered important, his perception of specific learning outcomes was less clearly articulated and tended to focus on practical skills that he wanted the students to be able to achieve more than philosophical values or an appreciation of preconceptions that the students may be bringing to the unit. Nonetheless, he considered that the staged sequence of tasks and the students' ability to build on feedback from preceding assessments led to marked improvements in their grasp of the material and satisfaction of the practical skills of research project design, conduct, and analysis.

Finally, the lecturer expressed his satisfaction in teaching the unit using this new approach. Although he admitted that time input was greater because of increased face-to-face interactions with students in the development of their research projects and organisation of field equipment (usually only quadrats or pond-nets), he considered the results worthwhile. In his previous job, he had 'block-taught' the material in the unit in a 5-day intensive session and had been disappointed by the lack of student understanding evident a few months later. In his view, the strength of the current approach was the time allowed for the 'gestation' of ideas and understanding, while enhancing the retention of key principles of replication and randomisation as students physically designed and conducted their research projects. He was particularly struck by the strong sense of 'ownership' of the research results, evident from the students' oral presentations and the fact that some of them went on to develop their research project for an Honours degree.

Discussion

All of the students claimed that their understandings of research design, methods and analysis had improved greatly due to their learning experiences. They identified ways in which the staged development of the research process matched with the sequential and integrated assessment tasks had helped them to understand and become actively engaged in the research process in a manner that was 'realistic' and relevant. The sequence of steps in conducting pilot studies to ascertain sample sizes and refine field methods, completing a proposal and receiving feedback from peers, and reworking their research proposals before undertaking the main project all demonstrated the importance of the reflective process on learning. This is a clear example of learning being an active and engaging process for students (Hannan and Silver, 2000) and supports a similar finding by Willmott *et al.* (2003).

Part of the success of the approach is the crucial link between pedagogy, content and assessment. Biggs (1996) refers to this as "constructive alignment" (p. 360) whereby frequent assessment allows students to appraise and evaluate their own performance in relation to individual learning goals. For example, sequential integration of the lectures, practical sessions, and assessment in the unit immersed students into the research process from the outset. There was little time to be wasted given that the research proposal was required for peer review in Week 6 of the thirteen-week unit. Immediate feedback from peers during the practical session was provided allowing students to improve their research designs. On final submission of the first assignment, the lecturer returned marked proposals to students within a week.

This assessment preceded a mid-semester break (3 weeks) when most of the students did their field-work. The result was that the quality of the research conducted in the field improved along with the analysis and subsequently, the final report. In this manner the assessment tasks were integrated or 'embedded' into the learning process allowing students to monitor their own progress in an ongoing manner (Biggs, 1996; Willmott et al., 2003).

Another aspect of the learning exercise that appeared to enhance the quality of the research experience for students was communication with their colleagues. Throughout the unit, students were encouraged to spend informal (discussions during practical sessions) and formal time (e.g., peer review of proposals) sharing their ideas with their peers. Although students may have been working on different research topics, they gained much from each other by discussing design, sampling methods, and likely statistical analyses. This is a valuable lesson to learn, particularly for environmental scientists where emphasis lies on integrating biological, chemical, and physical sciences in an interdisciplinary way. We contend that the sequential series of related assessment tasks provided tacit encouragement to share and refine ideas, mirroring the true process of research. Reflective practice typically generates enriched insights (Toohey, 1999) but few environmental science curricula explicitly cultivate this skill.

However, the ultimate success of the teaching and assessment strategies described here was demonstrated by the heartening positive change in attitude towards statistics displayed by many students. Initially, the unit appeared daunting to students but by the end of the course, they expressed increased confidence, particularly in their ability to plan successful research projects and in the application of statistics as a tool for analysis. This is a major advance because quantitative methods courses often worry students (Murtonen and Lehtinen, 2003) and the loss of confidence impairs their learning ability severely (Toohey, 1999). Part of the success of the strategies in boosting students' confidence was because they learned to think about statistics in a particular research context that was relevant and 'owned' by the student. It was their data, their project, and they were keen to know what the data were inferring, hence they could see the immediate value of statistics. Such positive attitudes to research methods can result from successful adoption of active learning methods (Benson and Blackman, 2003).

While doing their individual projects, students experienced all the typical problems associated with conducting ecological field research – floods and heavy rain, errant study animals, massive inherent variability and unexpected instrument failure. Students learnt to consider these eventualities early in the research planning and to make contingency plans. Those students who did not do pilot studies or consider alternative methods were frequently caught out. By carrying out the full sequence of steps in the scientific process, students were better equipped to cope with these environmental exigencies. Additionally, students realised that field-work invariably was more time-consuming than expected. As a consequence, they became flexible and adaptable, recognising the importance of being able to 'think quickly on their feet'. These are key attributes for researchers working in the environmental sciences and again, are almost impossible to learn from traditional lectures, tutorials and practical sessions.

In conclusion, we feel these strategies of staged assessment tasks cued into the sequence of steps in the scientific method, the active learning and 'ownership' of a small research project by students, the peer interaction and varied assessment tasks, and the cumulative feedback all combined to provide an engaging learning environment for this challenging unit. Student reactions to these various strategies were positive and the changes in attitude and confidence exemplify the success of this approach. Efforts are now underway to extend this strategy to other units in the biological sciences.

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