Challenging students to think critically: a science unit focussing on generic skills

Susan M. Jones
School of Zoology, University of Tasmania, Hobart, Australia
S.M.Jones@utas.edu.au

Leon Barmuta
School of Zoology, University of Tasmania, Hobart, Australia
Leon.Barmuta@utas.edu.au

Abstract: *Biggs (1999) stressed that education should be about "conceptual change, not just the acquisition of knowledge". Paradoxically, however, undergraduate science units often emphasize acquiring the knowledge content of the curriculum rather than the ability to think critically. There is evidence that science students in general appear to be less and less able to read critically, or to write with clarity and purpose (Birkerts 1994); yet these are key generic skills for all science professionals. We have developed a new level 2/3 unit, Evolution, Ecology and Society, that exposes students to contemporary theories and concepts in ecology and evolutionary biology, and examines how these ideas are used to inform both scientific progress and public debate. The unit focuses on developing the students' information literacy, their ability to assess scientific theory critically and analytically, and their communication skills. The teaching pattern is centred upon four learning modules dealing with topical issues in science. We visualise the basic module as a "learning spiral", beginning with student choice of topic, library research, and reporting to the group on their readings, working towards critical and comparative assessment of material through discussion, oral presentations and written assignments. Student response has been overwhelmingly positive. This paper elaborates on the learning strategies employed in this unit, which may easily be extrapolated to other discipline areas.*

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Many of today's "burning issues" in science are biological: controlling the SARS virus; pros and cons of genetically engineered organisms; consequences of clear-felling forests; the relevance of Darwinism to social policy. However media coverage of such issues is often limited and uncritical. How are our students, the biologists of tomorrow, to develop the ability to assess the scientific evidence and develop an opinion of their own on such weighty topics? School science fosters the view that science " results from single discoveries, is an individualistic process, that its social context is irrelevant, and that it is unproblematic in its application "(Jarman and McClune, 2001, p.73). However we want our graduates to have the confidence and the skills to enable them to gather evidence and make sound judgements based on scientific evidence, even when the debate is not in their area of specialised knowledge. As Biggs (1999) stressed, education should be about "conceptual change, not just the acquisition of knowledge". Yet many undergraduates have commented to us that they feel unable to argue or defend positions about important public issues that involve ecological or evolutionary topics: recent examples of such issues include the possibility of human cloning, various claims by creationists, arguments about the rate of biodiversity loss, threats posed by oestrogen-like synthetic chemicals in the environment, the pros and cons of biological control of pests and the many uses and abuses of 'Darwinism' in social policy debates (Thornhill's recent advocacy of the 'adaptiveness' of rape is a recent high profile example).

Most undergraduate science courses still focus on providing students' with an adequate knowledge base for further study. In a typically overcrowded undergraduate curriculum, there is usually little opportunity to examine current topics critically, nor to accommodate student-led exploration of such themes. Moreover, science students in general appear to be less and less able to read critically, or to write with clarity and purpose (Birkerts 1994). These scientists of the future may therefore be ill-equipped to make critical analyses of current scientific theory and its applications, or to contribute effectively to public debate in their professional capacity.

From this premise, and spurred by a necessary re-structuring of our second year zoology program, we have developed a new level 2/3 unit, *Evolution, Ecology and Society.* The focus is on generic, rather than subject-specific, content: indeed, all students do not cover the same subject matter. Instead, the emphasis is on improving skills in researching and collating published scientific evidence, understanding and evaluating competing arguments, and integrating and presenting scientific arguments in a professional manner. These skills are germane to becoming an effective scientist, and will have applicability beyond the study of Zoology.

This type of approach lends itself best to small-group teaching and independent learning activities, and to continuous assessment by assignment than by formal examination. Indeed, co-operative learning opportunities model the collaboration that is the hallmark of scientific professional work (Tanner, Chatman, and Allen, 2003). We used WebCT as a tool for communication between staff and students and within student groups. The overall teaching pattern is based around interchangeable 5-week modules, each led by one staff member, working with 15-20 students. We visualise the basic module as a "learning spiral", beginning with student choice of topic, library research and reporting to the group on their readings, working towards synthesis and critical assessment of their research material through group discussions, and, finally, oral presentations and written assignments.

However all students come together for the first two weeks of the semester. Our teaching approach is very different to anything the students have yet experienced: thus those first two weeks are vital, first, for establishing ground rules, particularly for group work, and explaining our expectations. Second, the Science librarian runs specially designed and compulsory workshops on information skills. A survey of first year students (Krause, 2001)found that "finding relevant references by searching library computer databases" was rated as the most difficult task in academic writing. We needed to ensure that our students had revised and improved their information literacy skills before beginning the major learning activites. To practise using these skills, and to begin developing their ability to read critically, the students' first assessment task is a "reading report".

Reading reports were used effectively by Etkina and Ehrenfeld (2000) to develop their students' ability to appreciate and concisely summarise the main points of an article, and by reading critically, to discover its strengths and weaknesses. They suggest that the technique empowers the students through giving them a generally applicable method of extracting meaning from any reading material, as well as improving their written communication skills.

Etkina and Ehrenfeld (2000) used continuous formative assessment of weekly "reading reports" as a route to developing a critical approach to scientific literature. We use reading reports as assessment tasks only during the initial two weeks, which are focused on enhancing information literacy. We assign two reading reports. Working from a supplied popular article (eg from Nature Australia or New Scientist), students trace the original scientific paper that generated the news story. They then summarise and critique the abstract (Reading Report 1) or the paper itself (Reading Report 2). The first report, though compulsory, does not contribute to summative assessment ,but copious feedback (and a grade) is given, first by the lecturers and then through a peer marking exercise; the second is marked formally. Scores generally improve over the two exercises and both staff and students agree that the reports are valuable tools for consolidating information searching skills, practising evaluating a scientific article, and writing concisely and precisely. One student commented:

> *The progression from RR2 to Module 1…… provided a reasonably solid platform from which to jump into the plethora of literature out there for the Module 1 topic.*

In week three, we begin the first of two 5-week modules. Each module is a substantial topic in one of three potential 'streams': evolutionary biology, ecology, or structural and functional zoology. We suggest that the best way to maintain student interest is to pick current, usually controversial topics that interest the teaching staff involved, and broadly inform their research. The challenge of course, is to move beyond the students' (and our) initial preconceptions, and to read and evaluate the material in terms of its scientific content. A particular challenge is to get students to appreciate the continuing nature of the scientific research process.

We distribute the students first between topics(two topics run concurrently), and then between groups (maximum size of 10), taking care to balances numbers of second and third years, Study Abroad students, females and males, where ever possible. The first four weeks of each module is taken up with group work on the topic which is moderated or facilitated by the teaching staff involved. The modules involve no didactic teaching: we use formal lecture times only when we wish to bring all students together, for example, to discuss assessment requirements, for feedback sessions, or writing workshops. Students are largely expected to work independently, given the flexibility offered by the lack of formal classes.

Before the first group meeting, students are expected to have read the introductory outline of the topic, provided by the lecturer (via WebCT) and done some preliminary library research based on suggested readings. At the first meeting, the lecturer leads a discussion aimed at drawing out some major sub-topics, and students choose an area that interest them for detailed research. Within the group, specific tasks are allocated to pairs of students. Over the ensuing week, they carry out library research and then report back to the group on the content of their readings at the next meeting. The group (facilitated by the lecturer) considers the topic as a whole and research directions may be refined or altered. We find that students quickly take ownership of "their" area of research. We endeavour to ensure that students: realise the importance of their individual participation and contributions to the group; come to terms with the necessity of planning, time-tabling and sharing tasks amongst sub-groups of 2 – 3 students within the group; and understand *why* assessment tasks have been set (i.e. students need to identify what they will learn by doing each task, and what our expectations are).

The major assessment tasks for the unit are two written reports, termed "module reports", presented individually by each student. These are a novel format of communication, so we devote a "lecture" to explaining the module reports and their accompanying assessment template, which is provided to the students at the start. Each module report contains:

- a *general introduction* to the overall topic, identifying the broad issues, and showing how the group divided up the topic into related sub-topics;
- a *report on their personal research focus*, providing a clear overview of the topic, demonstrating an ability to integrate and critically evaluate material from a range of sources, and highlighting current key issues;
- a *synthesis of the group's research*, bringing together material from the whole group, and showing particularly where there are gaps in current knowledge.
- *reflective comments on the group process* (compulsory but not assessed).

When marking these, we provide ratings and constructive comments against each assessment criterion, and run a feedback workshop after returning the first module report (which is marked somewhat less stringently than the second). Students particularly appreciate the transparent assessment procedures: 91% agreed that assessment requirements were clearly spelt out, 95 % agreed that feedback on written work was useful and that it was an advantage to have the assessment criteria before submitting the report (SETL unit evaluation 2002). As one section of the assessment template is devoted to skills in written communication, we offer a workshop on academic writing. (In 2003, this will be based around "Scribble", the newly developed web-based tool for learning science communication skills - see Trivett, Jones, and Karsch in these conference proceedings).

Through the 5 week module, students report orally on their findings, and to share and swap information, ideas and references at weekly group meetings The lecturer needs to ensure that they are moving towards a holistic appreciation of the topic, and an appreciation of how their personal focus is connected with those of others. WebCT is used as an accessory communication device, being particularly useful towards the end of each module, when each student is required to provide a synopsis of their research for the rest of the group: 86% of students agreed that WebCT was an effective way of communication in this unit (SETL unit evaluation 2002).

The final week of each module includes oral presentations by each group to the class, as well as sharing of written summaries. Each group member speaks for 5 min on her/his topic, with the group responsible for organising the order of speakers, and providing an overall introduction and conclusion. While these oral presentations are not assessed, we provide written constructive critiques for all students who wish to receive them. Somewhat surprisingly, most avail themselves of this opportunity and again, they have commented on the usefulness of obtaining such formative feedback.

So does this approach achieve its aims and objectives? We can assess this first through our own evaluations of our students' work and second through their evaluations of the unit. We have been enormously impressed by the high quality of the module reports prepared by many of the students (to the extent that our overall grade profile was queried at faculty level for having "too many" high marks). This may partly reflect the positive impact of co-operative learning upon student achievement (eg. Springer, Stanne, and Donovan, 1999). Their performance against specific assessment criteria show them to have developed skills in information literacy, an ability to synthesis, critique and evaluate scientific literature, and to appreciate where new research is needed. These are high level skills that are generally transferable both within and across disciplines. This point was appreciated by the students themselves, 95% agreeing that they saw the importance of this unit …for other areas of study (SETL unit evaluation 2002). Sample comments include:

> *This unit was probably the most valuable one I did this year. The skills I gained will be indispensable in completing honours and later in my academic career.*
>
> *I really felt I learned to critique and evaluate science writing.*

On the other hand, only 55% agreed that they "prefer the structure of this unit to the standard lecture/tutorial format", despite 91 % agreeing that "the flexible nature of this unit really helped me develop my independent learning skills" (SETL unit evaluation 2002). We are not sure how best to interpret these results. Perhaps some students still prefer the "safety" of a didactic teaching environment even while appreciating the benefits of a more student-entered approach. Conversely, one student reflected that:

> *It's a big learning curve but thoroughly worthwhile and, unlike some other courses, I feel very motivated by what I have personally achieved.*

While we wholeheartedly endorse the value of cooperative learning strategies, one area we find problematic is the question of how, or, indeed, whether, to assess group process. This issue also concerns some students:

> *Never again try to assess group work. It does not work! Not everyone has the same interest.*

Our strategy has been to require, first, a compulsory but non-assessable, reflective commentary on the group process as part of the module report. We find these very useful in gauging the dynamics of each group, and reflecting on how we can better facilitate group work. Second, each student completes a form for "Assessment of Group Process" on which they score each group member (including themselves) against 4 criteria. This was based on a similar form used by Stefani and Tariq (1996). We remove the highest and lowest scores, and the student's final mark is the mean of the rest., contributing 10% to the mark for each module. We stress that we expect most people to gain almost full marks for this, and indeed most of them do: the process is effective at .penalising the very few who do not contribute well. We are not yet convinced that this is the best strategy, but feel assessing group process in some way will demonstrate to the students the importance we place upon developing skills in working cooperatively. We also point out that the module report has been designed to requires the group accountability (Tanner et al., 2003) that encourages real and effective collaboration.

In conclusion, we suggest that the teaching strategies and the assessment tasks developed for *Evolution, Ecology and Society* are effective in developing key generic skills in science undergraduates as well as stimulating students' interest in science through discussion of issues of major current significance. The overall outcome is an increase in the students' metacognitive skills: the unit helps them "understand how they know what they know" (Etkina and Ehrenfeld, 2000, p.607), to extract meaning from readings, and empowers them to evaluate and critique published literature. This fills an important gap left in many undergraduate science curricula.

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