

## Open-ended enquiry in undergraduate biology laboratories: moving to student-designed practicals.

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### Summary

Moving from set-piece (or ‘cook book’) laboratory exercises to ones that are more open-ended and enquiry-driven can be challenging in undergraduate practical classes, given the limitations of time and resources such classes face. Yet if undergraduate science classes do not move beyond set-piece practicals, students can miss entirely the process that underlies science: developing models, making predictions, testing the predictions and making judgements about the worth of the model. Moving to more open-ended laboratory investigations throws the responsibility for the scientific process back onto the students, engaging them more fully in it, and reintroducing some of the excitement and curiosity that working scientists experience. This contribution describes two experiments, one at first year level for a large biology class, and a second one at second year level for smaller ecology class. The first year exercise asks students to answer a question about the water uptake characteristics of a seed, and can be completed within 3 hours. The second year exercise asks students to design an experiment to test hypotheses about what stimulates germination of seeds from a fire-prone environment. This exercise requires an initial design and set-up practical, several weeks for germination to occur, and a final practical to score germination, graph and analyse results, and draw conclusions. The exercises align with a number of the principles about approaches that support effective learning from the *Guidelines on Learning that Inform Teaching*: #1 (active engagement of students); #2 (climate of enquiry, challenging students and linking to research; #3 (interesting and challenging activities); #7 (dialogue with teachers and amongst students); #14 (responsibility for own learning develops higher-order thinking skills).

### Introduction: overview and context

Science at its simplest is a way of finding out how the world works. Doing this generates a vast body of content as parameters are measured, systems are described, and their functioning elucidated. A problem for teaching in science is that it is easy to mistake the content for the process, and to view teaching mainly as the imparting the facts generated by Science. Of far more importance, for University graduates, is a good appreciation of the *process* of science in understanding how the world works. In particular, graduates must be able to use the process correctly themselves, and be able to judge whether the work of others has done so. They need to be able to recognise when the process has been used incorrectly, or when it suffers from limitations, for their professional work.

If science teaching concentrates solely on the content, it will concentrate more on lower-order cognitive processes: the unistructural and multistructural stages of the SOLO taxonomy (Biggs 2003), where skills such as identifying, enumerating, and describing are used. As teaching concentrates more on the process, the emphasis shifts to the higher-order cognitive skills of the relational and extended abstract levels: analysing, comparing, explaining, hypothesising and reflecting. Practising scientists use these higher-order skills

routinely; the challenge facing teachers of science is to induct undergraduate students into use of these skills.

Most Practical sessions in undergraduate science rely on students following instructions to complete a set experiment or investigation. While this approach can impart the lower-order cognitive skills, it can be less effective at imparting the higher-order skills of hypothesising, devising good tests of hypotheses, using data-handling techniques to assist interpretation, and drawing correct conclusions. This is because, in the set experiment approach, these kinds of skills have already been used by the designer of the Practical, rather than- by the student doing the Practical. Indeed, students can complete the entire set exercise, and still be ignorant of the reasoning behind the experiment.

An alternative is to use open-ended investigations at undergraduate level, in which students are given a question, materials with which to design and execute an experiment to test hypotheses they have derived themselves, and assistance with the handling and interpretation of the results. Practicals that do this are more authentic in the sense that this is how practicing scientists proceed. Biggs (2003) comments that such tasks are more likely to encourage deeper, higher-order learning: the students have to use more of the higher-order skills to complete the exercise, than in the set-experiment approach.

At First Year level in a large biology class, an open-ended experiment on the water uptake characteristics of *Grevillea* and *Acacia* seeds is used in this way. *Acacia* seeds do not take up water unless the seed coat is pierced or scarified first (called a 'hard' seed coat); students are asked whether *Grevillea* seeds share this mechanism, or not (*Grevillea* does not; the seed coat is very permeable to water). Students are given seeds of both types, and asked to devise an experiment to answer the question. While there is really only one experimental design that is appropriate to use, getting the students to devise it is hugely beneficial for learning.

At Second Year level in an ecology class, students conduct self-designed experiments on fire-related factors that stimulate germination of Australian native plants, obtain data which is summarised and analysed, draw conclusions on the basis of the data and analysis, and present these findings orally to their peers. Students are provided with the materials to conduct the experiments, but conduct the whole process, from framing their research question through to analysing the results, themselves. There is more scope for individualised experimental designs in this Practical, depending on what question(s) the students ask.

Using these experiments in other locations would probably mean using different species, and modifying the questions and experimental treatments accordingly. But the underlying principle of asking undergraduate students to use the scientific method to answer questions remains.

Full versions of both Practicals are available as pdf files.

### References cited

- Biggs J (2003) *Teaching for quality learning at university: What the student does*. 2<sup>nd</sup> Edition. Berkshire, UK. Society for Research into Higher Education and Open University Press.

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