[O25] **Can you really teach scientific inquiry online?**

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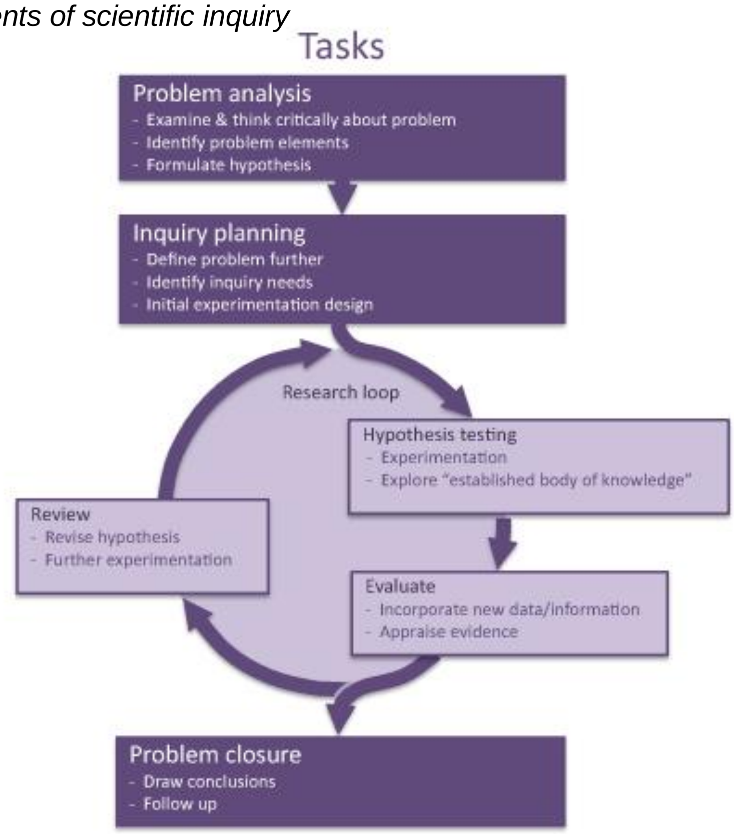
Developing scientific inquiry

Scientific inquiry is the cornerstone of scientific research and the training of new researchers. It is an identifiable approach to investigation which rests on the idea of a testable hypothesis and provides a framework for problem-solving in science. Figure 1 is a representation of the elements of the process of inquiry (Elliott *et al*, 2009). It was developed from descriptions of scientific inquiry by Chinn and Malhotra (2002), De Jong and Van Joolingen (1998) and Kim *et al*, (2007).

***Figure 1**: Elements of scientific inquiry*



The elements of scientific inquiry are a series of cognitive tasks that can be taught. Each element requires development of higher cognitive skills and a complete inquiry requires integration of the elements.

The first step in the process of scientific inquiry is to analyse the problem and **define the research question.** Identification of key and relevant information, and perhaps more importantly what is not known, is a crucial step in both inquiry learning and problem-based learning. Inquiry planning begins with the **formation of a scientific hypothesis,** which is a formal statement suggesting explanation of a phenomenon. A scientific hypothesis is only valid if it can be tested. A scientific hypothesis predicts outcomes that can be tested by **observation or experimentation.** Extending the hypothesis to imagine measurable outcomes is a high-level relational cognitive skill. Testing the hypothesis requires careful planning to ensure the data collected is valid and reliable and is a key skill in scientific research. Evaluating data requires a keen sense of error and an awareness of observational bias. Collected data is **evaluated** and the hypothesis is **reviewed** in the light of the conclusions drawn from the data by inference or deduction and the result is communicated to others. The steps in scientific inquiry are actually cyclic rather than linear as exploration of the problem leads to reiterative refinement of the question (figure 1).

Budding scientists learn the process of scientific inquiry through their own research projects. Students undertaking their first research project in the final year of their undergraduate degree are apprentices in the research laboratory. They usually work one-to-one with a more senior researcher and explore the process of scientific inquiry by trial and error. Research students have increasing autonomy as they progress through their project, with time to identify mistakes and repeat experiments. They become responsible for all aspects of the project: setting hypotheses, planning, performing experiments, analysis and thinking about the implications of their work. A small-scale study of student experiences in final year undergraduate projects at the University of Leeds showed that most of the students interviewed had a much more realistic view of scientific inquiry after completing their research project (Ryder, 2004). The experience of working alongside and observing professional scientists caused a profound shift in the understanding of evidence and scientific hypotheses.

The cognitive skills required for scientific inquiry fit closely to the widely accepted graduate capabilities of analysis, problem-solving, communication and creativity. Undergraduates need opportunities to practice analysis of problems, gathering and applying information and drawing conclusions. Since research problems provide authentic experience for trainee scientists, it is logical to use scientific inquiry as a model for problem-solving in undergraduate bioscience courses. Many university teachers have constructed scientific inquiry tasks for undergraduate laboratories (reviewed for bioscience disciplines in Adams, 2009) or other forms of inquiry such as case studies.

Some published tasks have shown that it is possible to use authentic scientific inquiry even in large undergraduate laboratory classes with truly open-ended experiments or real-world (and messy) problems (Adams, 2009). However, resources often significantly limit capacity to provide this experience for all science students. It is certainly simpler for the teacher to define an inquiry task through recipe-style experiments or using problems where there is only one right method and answer. Under these circumstances the student has limited or no autonomy and is less likely to take personal responsibility for the inquiry. In contrast, teaching modes that rely on genuine enquiry-based learning generally produce increased engagement and deeper learning in their students (reviewed in Eberlein *et al*, 2008).

A second feature of undergraduate classes which differentiates them from research training is the pace of the inquiry. Undergraduate students usually work to a timetable set by their institution whereas authentic research moves at the pace of the individual researcher. One possible solution to assist with the limitations imposed by resource issues is to move to a virtual learning environment where the student controls progress through the inquiry. Virtual classrooms and resources can replace or augment expensive face-to-face teaching. Online resources can also allow the student to proceed with the task at their own pace outside the constraints of the University timetable. However, students in a constructed virtual environment may be moving further from the traditional research laboratory and the apprenticeship model used successfully in advanced research training (Charlesworth *et al*, 1989). Can the online environment provide successful experience of scientific inquiry? What are the characteristics of a task which successfully develops scientific inquiry skills?

In order to explore these questions this project has examined a range of scientific inquiry tasks currently implemented in Australian Universities. The study provides a snapshot of current practice and in particular looks at the role of education technologies in teaching scientific inquiry. The final aim of the project is to construct a framework for evaluation of activities designed to develop scientific inquiry skills.

Teaching scientific inquiry in Australian universities

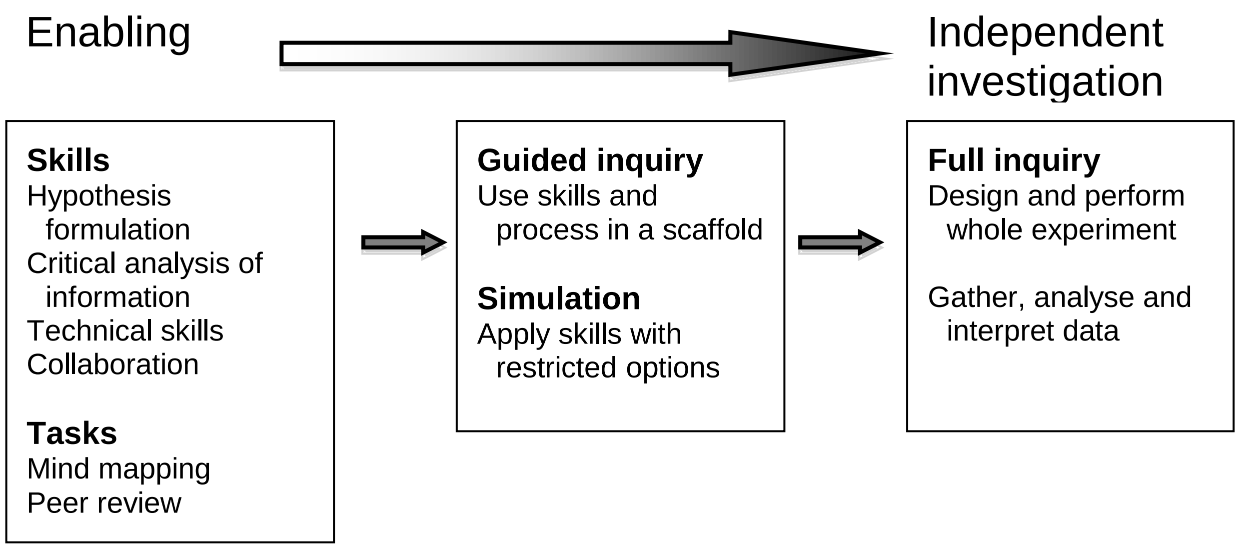
Examples of teaching scientific inquiry in current undergraduate programs were gathered by self-nomination and referral. Qualitative information about teaching activities was gathered through phone and face-to-face interviews with educators, on-site visits and review of teaching materials and publications. The final data set includes information from 20 case studies from 9 universities across five states and includes a broad range of biosciences: agricultural science, biology, biochemistry, immunology, microbiology, pharmacology, physiology, zoology. Specifically, information from each case was collected regarding the teaching approach, the use of educational technology, the skills taught and the evidence for learning outcomes in scientific inquiry.

The first striking feature of the data set was the diverse range of teaching approaches and methodology uncovered by the project. The student tasks reflect the learning objectives set by educators. Some educators wanted students to understand and practice particular elements of scientific inquiry such as critical appraisal of publications, formulation of a hypothesis, experimental design or selection of an appropriate analysis method. In contrast, other educators used activities to bring students to a conceptual understanding of the whole process of scientific inquiry.

Analysis of the teaching approach in each case revealed a spectrum of practice ranging from quite tasks with a low degree of enquiry and highly guided by the teacher to authentic scientific research. The teaching activities could be divided into enabling tasks that concentrate on developing individual elements of scientific inquiry through to a full inquiry which requires students to bring a series of tasks together. Two cases taught scientific inquiry as a process. The emphasis here was to help students to recognise inquiry as a skill which could be acquired and used in a specific context, for example, in the diagnosis of plant disease in an authentic case study.

Full inquiries used three main approaches depending on the data source. In seven tasks students used published information (such as gene sequences) or generated their own data from laboratory class experiments. Four tasks used problem-based learning through real-world or constructed scenarios. Two cases had students working in an active research lab. These latter tasks are similar to the research projects often offered to final-year students as a capstone experience or as summer research studentships (reference for final-year projects). The variation in teaching tasks forms a spectrum of practice (figure 2) which can also be regarded as a developmental process. Students can move between levels of activity as they become more independent. The spectrum provides a framework for educators to sequence tasks and for students to recognize the shift in their skills.

Figure 2: *Observed spectrum of practice in tasks for teaching scientific inquiry in bioscience in Australian universities.*



The difference in the complexity of the designed task is strongly influenced by the educator's opinion of the previous experience of the students. For example, this educator describes a scaffold for the inquiry process with enabling skills and plans open enquiry to follow.

> '*What they actually do in it isn't planned. It is the direction the students move in. What they do. The first 3 lessons have a lot of structure around it because they are first year students and if they are going to be successful and address their own questions, then they need to have a few skills in completing lab books, being able to look at what data they gather and make decisions based on that data …* '

Educational technologies in teaching scientific inquiry

The use of educational technologies varied considerably between cases. Despite literature reports of many custom-built online learning environments (Harper and Hedberg, 1997) incidences of this approach were limited. Educators primarily reported use of a range of existing technologies (Table 1).

Table 1: *Use of educational technologies in teaching scientific inquiry. Fourteen of the 20 case studies used educational technologies to support student activities. Technologies were classified by their use.*

Type of educational technology	Number of cases	Example of use
Communication	6	Student peer review Blogging Discussion group
Data analysis tools	5	Mind-mapping Bioinformatics Specific data analysis software (e.g. statistics packages)
Simulation	2	Laboratory/fieldwork simulation Present results from tests/experiments
Flexible workspace	1	Wiki

Educators reported that educational technologies were selected because of availability, previous experience of the education with the tool or necessity. One of the educators was faced with the loss of access to wet laboratories and replaced laboratory classes with an extensive simulation. Many educators use freely available software for elements of the teaching task. Software was used to provide customised information or give access to publicly available information such as the large National Centre for Bioinformatics databases. Software is also used for data analysis and data organization to allow students to interpret data and draw conclusions. Standard software is widely used for communication for example using discussion boards or blogs.

In two of the cases educators had constructed a purpose built learning environments. These integrated environments provided context for the study, information and data and resources for analysis. In both cases the learning environment was constructed to allow extra case studies to be added to the framework. This software simulates a research environment with students allowed to pursue dead ends and side issues to some extent. However, just as teaching laboratories are limited by logistics and resources, the scope of the simulation is limited by what the educator decides to include.

A new approach to teaching science

The diversity in teaching approach and use of tools that was observed in this study may have arisen because teaching scientific inquiry in large classes is a relatively new idea. Although there are a number of reported examples, explicit teaching of scientific inquiry is not a mainstream activity in most undergraduate science classes. Students from undergraduate science classes in the United Kingdom (Collis *et al*, 2008) and in Australia (Rice *et al*, 2009) report dissatisfaction with science practical classes which they find irrelevant and boring. Most of these classes are built on recipe-style practicals, which would be described as highly guided inquiry at best. Classes which include inquiry with consequential increase in student autonomy can produce increased student engagement and satisfaction (da Silva *et al*, 2008).

Educational technologies have an enabling role in delivering new teaching approaches and have been essential in delivering many of the activities identified in the study. Educational technologies have been used to allow off-campus students flexible access to resources and learning environments that otherwise would be out-of-reach. The initial question of whether or not scientific inquiry can be taught online has become a commentary on the role of educational technologies. The cases observed in this project show that educational technologies are very useful tools for teaching scientific inquiry but that there is not a preferred teaching mode or teaching tool which characterises a successful task.

In conclusion, the educators interviewed for this study are innovators. They have responded to a perceived deficit in student learning by constructing teaching activities to draw students into considering scientific inquiry. In many cases the tasks are constructed to reflect professional activity or authentic scientific research. Educators have used the teaching tools at hand and many are in the process of formally evaluating the outcome.

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