



8 | THE SCIENTIFIC METHOD: TEACHING THE HOW OF SCIENCE AND NOT JUST THE WHAT

The scientific method, in its pared down form, follows the approximate order: an observation is made of a phenomenon; information is gathered; a hypothesis is put forward; an experimental strategy is devised and carried out; results are collected and analysed; a conclusion is drawn about the validity of the hypotheses, or whether more experiments are needed to make a determination.

In university science classes however, much of the lab work is of a cookbook variety, where the students are told exactly what to do, how to do it and – much of the time – they are even told the results they should get and the conclusions they should draw. While this way of teaching science is valuable, showing students the importance of precision in following protocols and illustrating facts from lectures, such an approach should be complemented by laboratory classes where the students are provided with a more realistic experience of the scientific process. In a recent survey we carried out in a first year biology class (Shearer and Smith, in preparation) students showed a desire to understand the scientific process itself and for freedom to explore different avenues:

“more explanation as to how the tutor came up with the given method for each experiment”

“more creative element would be great, to introduce a skill and then allow the students to go away and explore the use of the skill/technique in their own way/own experiment without the concern that if they make a mistake they will lose lots of marks”

However, a free-for-all is not a good educational tool either. To make sure that students do not simply go wildly off on the wrong path (nor cause damage to themselves, or to the labs!), one method we have found works well in a first year class of biologists (based on White, 1999) is for the students to be shown a simple biological observation and asked the question, ‘why?’. They are provided with a set of tools to approach the problem, and the class is split into small groups of

3 or 4 and left to develop hypotheses and experimental strategies. The class then reconvenes and the various hypotheses and strategies are shared and discussed, and in some cases, rejected. Each group then decides on their experiments, carries them out and observes the results. Another class discussion takes place (teaching the importance of interaction in the scientific arena), the students plan another round of experiments and so on. This approach more closely mirrors the process of science as carried out in research laboratories, underscores the dynamic nature of science (replete with all its contradictions and controversies) and creates a collaborative learning community, encouraging intellectual debate. But further, this strategy of active inquiry-based learning challenges and engages the students; two key factors necessary for effective learning.

Teaching the process of science – hypothesis formulation, problem solving, experimentation and data analysis (Handelsman, Houser and Kriegel, 2002) enhances the student experience on a number of levels and better trains future scientists. Providing such experience early in the first year allows students to bring the understanding of the scientific process to material they are taught throughout their degree. With such a perspective on the body of their scientific knowledge, they are well-prepared to continue into the realm of scientific research themselves. However, there is an additional and equally important benefit of such an approach.

Not all science undergraduates will eventually become research scientists, but will instead contribute to many other sectors of our society. Teaching the process of science in practical classes equips all students with the skills and understanding required to make them scientifically literate. And in today’s society scientific literacy is essential. The media and popular press inundate us daily with headlines, breakthroughs, findings and statistics and if our students are not practised in the understanding and analytical skills essential for delineating fact

from fiction (and are content rather to believe everything they hear or read without question) then we find ourselves in a precarious situation.

However, by experiencing first-hand the process of science – not just the what but the how – “students will see the allure of science and feel the thrill of discovery ... [T]he benefits will be an invigorated research enterprise fueled by a scientifically literate society.” (Handelsman *et al.*, 2004).

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STUDENT ESSAY WINNER

Congratulations to the winner of our third annual student essay competition, Aneeqa Meedin, a third year Biomedical Sciences student from the University of Sheffield, wins £250 for her essay “What advice would you give to students starting your course?”. Aneeqa’s essay, the runners-up and shortlisted essays, are available through the Centre for Bioscience website at:
<http://www.bioscience.heacademy.ac.uk/publications/essay07.htm>

2 | CAN WE SET FAIR QUESTIONS?

Assessment problems can arise quite inadvertently when classes contain students from a variety of cultures with different experiences, attitudes and expectations of education. All students are different but the assessment for every student tends to be the same. It is difficult to devise assessments which are totally free from bias. Researchers have identified bias arising from cultural differences, gender difference, disability and other factors (see original paper for references). Here I give several examples of culturally loaded questions and suggest that all science and engineering assessments should be scrutinised from the cultural perspective.

I define a 'neutral' assessment item (e.g. exam question) as one that every student has an equal opportunity to demonstrate the extent to which they have met the intended learning outcome (ILO) being tested. In less pompous words, the question should be clearly understandable and relate to the appropriate curricular content. This is easier to specify than to achieve, particularly for classes which contain students for whom English is a second language or from different cultural backgrounds.

In higher education we expect to be assessing ILOs at all six levels of Bloom's taxonomy – simply expressed as knowledge, comprehension, application, analysis, synthesis, evaluation. Above level 2 (application, analysis, synthesis, evaluation) potential problems of bias abound. Words which might be used in assessment items could include analyse, compare, contrast, create, defend, discriminate, evaluate, interpret, justify, modify, predict, reconstruct, or relate. Each of these requires a sophisticated grasp of language as well as the required cognitive understanding. At levels 5 and 6 (synthesis and evaluation) a critical approach is essential and it would be impossible to demonstrate ILOs at these levels using words and phrases which had come from lecturer or book.

A clear question has two elements – vocabulary which is understandable and contextual examples which can

be interpreted based on the student's prior experience.

Subtle examples can be found when teaching management topics. A module on Project Management at Liverpool is given to a large class drawn from every engineering discipline, computer studies and pure sciences. To assess at level 3 (application of knowledge in a new situation) it is necessary to select a number of 'new situations' which are accessible to all the students. This rules out using project scenarios based on dam-building (familiar to the Civil Engineers but to no-one else), or software engineering, or banking or in fact almost anything! A level 3 question such as 'devise a work breakdown structure for (some familiar process)' is very difficult to write in a neutral manner. What process is familiar enough to all students? No industrial process, certainly. The unfortunate result is that the remaining scenarios are mundane and lack complexity – the key aspect which makes a project worth undertaking.

Similar issues arise from a question designed to allow students to be creative in the context of a SWOT analysis. An obvious question is 'Analyse the Strengths, Weaknesses, Opportunities and Threats of the following proposition, and then make a recommendation whether it should be adopted.' It is very difficult to identify a neutral proposition. I used the real proposition (reported in *The Times*) 'An advertising company should rent advertising space on students' foreheads.' This appears to be totally neutral: surely every student understands advertising and certainly everyone has a forehead. However, on reading 220 answers (some very imaginative) it became clear that a minority of students did not understand the word 'forehead'. Therefore we cannot assume that the vocabulary used in assessment items can be universally understood, even when questions are couched in 'ordinary' English. A further example comes from a study looking at the technical and non-technical vocabularies available to A-level physics students. It revealed 96% of the students surveyed claimed to understand the word 'transmitted' whereas only 30% could explain or define it.

My own experiences recently revealed first year students who did not understand 'opaque' or 'inflammable'. The vocabulary used in my last three years' exam papers included the following words which were not defined in classes:

Assembly, auditor, batch, blizzard, client, deadline, deliverable, finishing, functional, machining, morale, polishing, rapid prototyping, resource, revenue, review, sandwich, script, stamping, standards, stock.

It is not clear whether all of these were understood by all students, although their inclusion was intended to give appropriate contextual colour to otherwise dry questions.

In the UK, examination papers – but not always other assessment items – are usually checked both by the setter and by a moderator. If the assessment is not supposed to be a test of language skills, then it should be checked for technical accuracy, for alignment to the ILOs and for grammatical accuracy. This review indicates that moderators should also be asked to check for unintentional bias.

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AMENDMENT

Credit should also go to author V. Anne Smith for her contribution to the article *The scientific method: teaching the how of science and not just the what* which appeared in the Summer 2007 (No. 21) edition of the *Bulletin*.