Inducing People to Think

PERSPECTIVES

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Listening to people describing their methods for and ideas about teaching and learning chemistry, and discussing these ideas into the small hours is almost always stimulating. I have been fortunate in the number of opportunities I have had to do this over the last few months. In presenting here my reflections on these discussions, I make no claim for originality. They are other people's ideas, and I hope to be forgiven for not giving the sources of all my quotations.

Why Teach Chemistry?

"It is the whole business of the university teacher to induce people to think".[1]

Of course, Haldane understood that thinking requires having something to think about, so that, as far as chemists are concerned the induction of thought involves creating opportunities to learn how to think about chemistry. We could paraphrase this by saying that our job as teachers of chemistry is to empower our students to think like scientists. This means a great deal more than knowing chemical facts.

Johnstone[2] has proposed that understanding chemistry involves recognising a triangle of components; at the apices of the triangle are the macroscopic (phenomena which are open to the senses), the sub-microscopic (the use of diagrams, pictures, etc. to represent phenomena at a molecular level), and the symbolic (the use of chemical and algebraic equations to represent or describe a phenomenon). Johnstone suggests that professional chemists move easily between the apices of the triangle, and even within the triangle, to select an appropriate way of dealing with a particular situation.

Many people apparently share a concern that traditional teaching deals primarily with the macroscopic and the symbolic aspects of chemistry. There is a view, backed by some supporting evidence, that understanding (and examination performance) can be improved when conscious attempts are used to introduce the sub-microscopic. The use of pictorial representations to aid visualisation at a molecular level does not help all individuals equally. However, using and creating models (visual or conceptual) is a key feature of 'thinking like a scientist', and many students have difficulty coming to terms with the idea that most of what we 'know' about chemistry is really a model which usefully represents reality.

Real scientists realise that most of our models are ephemeral:

"Half of what you have been taught is wrong - and furthermore we do not know which half."

"Everything we believe in now will be disproved in four years."

Even if these quotations exaggerate the uncertainty of 'knowledge', they illustrate that another key feature of thinking like a scientist is the ability to consistently review and adjust our models. It is a Piagetian idea of knowledge that we develop schemes and these lead us to have expectations. If our expectations are met there is no need to change our schemes; "*the proof of the pudding is in the eating*". Sometimes our expectations are not met; "*the exception proves the rule*". In both of these sayings 'proof' has the old fashioned meaning of 'testing' and the rule or scheme must be changed if it does not stand up to the test. So learning involves developing flexible and creative minds which allow students to respond to experience and to change their schemes of knowledge.

Students learn in different ways, and they start their university courses with different expectations. To take account of this, effective teaching involves using a variety of methods.

"A key feature of effective learning is to select the teaching methods which suit the needs of the student."

One need of all students is to overcome barriers to effective learning.

Barriers to Learning

There are many reasons for students finding chemistry difficult to learn. For example, when we teach we have to make assumptions about what our students know. We know (or ought to know) what these assumptions are, but we rarely analyse them in detail for ourselves, and we even more rarely make them explicitly clear to our students. Very often the assumptions we make (explicitly or implicitly) are wrong - for a whole variety of reasons: we may not know what students are supposed to have learned from their previous courses; we know that none of them have learned everything that was expected of them; students may think they know more than they do; and our students' 'knowledge' is often undermined by their misconceptions.

We can easily understand why we make wrong assumptions. For example, changes in the school curriculum are not always understood in detail by universities; in the UK how many university teachers can honestly say that they know what is in the A level or Scottish Higher courses? Even if we know the content which is covered by the syllabus, we know that no student scores 100% in any examination based on that syllabus (and the majority of our students get a substantially lower mark):

"The verb 'to cover' and the noun 'information' are responsible for much mischief."

Another common complaint is that students forget so much. The problem may be one of not learning rather than of learning and forgetting (Figure 1). So our students know less than we often expect or assume, and do not understand all that they know.

Unfortunately, it is not just lecturers who overlook the fact that students do not actually know everything that they have ‘covered’. Students themselves are likely to make the same mistake. Consequently they may mentally switch off when a topic is revisited and so lose the opportunity to develop their understanding. Probably a worse problem is that new information is incorporated into an unsound framework of existing knowledge: students (like the rest of us) understand incompletely, and frequently with misconceptions (Figure 2). Effective learning involves making connections between different pieces of information. This making of connections includes, but goes beyond, the process of ‘chunking’.[3] Students are bound to have difficulty (and to develop new misconceptions) when they are faced with trying to build new ideas into a faulty framework of knowledge, and when they and their teachers make different connections between parts of this framework. So we should think carefully about our assumptions, and those of our students. We would also do well to remember that many students, especially early in their course, see chemistry in the light of a dualist thinker (everything is right or wrong).[4] We need to steer them away from this, and not be afraid to have high expectations.

“A pupil from whom nothing is demanded which he cannot do will not achieve all he can.”

Understanding Student Difficulties

Students are helped to overcome their problems with learning if they have a clear understanding of what is expected of them, what goals we set for them, and what goals they set for themselves. These may not be as clear as they are in some walks of life:

“in any sport both the rules and the scoring system are clearly defined; in universities our attempts to be all things to all people prevent us from defining either the rules of the game or the scoring system; this is a recipe for confusion.”

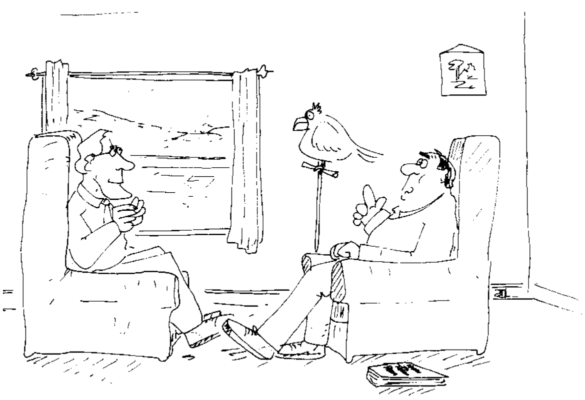
I have been offered many definitions of goals (including, of course, the quotation with which I began this paper). Here is a selection:

“Students need factual knowledge, technical skills, critical judgement, and a capacity for discovery.”

“We need to empower students to believe in themselves; if we do too much for them they become disempowered.”

“Chemists need to develop the skills of algorithmic reasoning, conceptual understanding, scientific thinking, and

Figure 1: I taught my parrot to talk



I can’t hear it saying anything

I said I taught it; I didn’t say it learned anything.

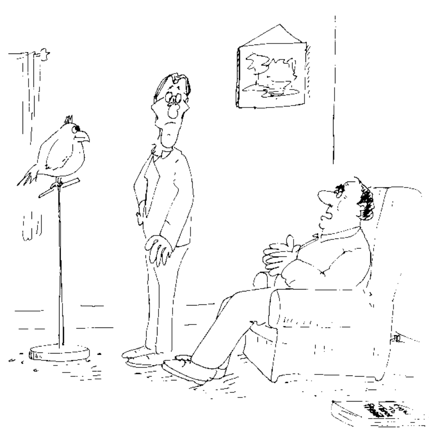


Figure 2:

a positive attitude to science."

"I want my students to know enough to know that they can learn more on their own; nobody poured knowledge into my head, and I don't expect to be able to pour it into someone else's."

"In order to replace their misconceptions, I need to know what those misconceptions are."

"Students need both instrumental understanding (knowing a rule and how to use it) and relational understanding (knowing what you want to do and why you want to do it)"

All of these suggest that our teaching objectives go far beyond that of content - though of course all of them include (explicitly or implicitly) the notion that content or knowledge is an essential component of learning chemistry. The key to achieving other objectives involves changing the mix of learning opportunities which our students experience in their programme of study. Planning an effective mix of learning opportunities means taking into account three factors.

First, we need to know what the student brings to his or her learning. An informal survey has shown that an overwhelming majority of academics want students with curiosity, a strong work ethic, competence in maths, and a willingness to learn for themselves. 'Knowing chemical facts', 'having lab skills', and 'knowing other sciences' all came way down the list. We don't always get what we would like, and it is worth considering what real (rather than ideal) students actually bring to their studies.

We probably know quite a lot about their level of knowledge (or ignorance), something about their misconceptions, and only a little about their aspirations. Ignorance and misconception are not quite the same; there are several different ways of saying *"getting the right answer shows that you know how to get the right answer, not that you understand why it is right."* Aspirations can greatly affect student learning. Surveys and tests are sometimes used in an attempt to assess conceptual knowledge and attitude in advance of a course (e.g.[5]); I wonder whether their increased use might lead to more carefully planned programmes of study.

The second factor affecting the effectiveness of a programme relates to the context in which information is presented. Good responses from students (both in enthusiasm and in learning) are claimed by those who have tried 'topic-based learning' or 'thematic teaching' (you can find a lot of chemistry in topics such as 'what can we do about global warming?' or 'is it economically and environmentally profitable to produce ethanol from biomass?').

The third factor to be considered in planning a learning programme is the style of learning offered. The fashionable words are 'problem-based learning', 'student-centred learning' and 'active learning':

"Knowledge is not passively received, but actively built up."

A Student-centred Approach to Active Learning

There are several perceived advantages and disadvantages of shifting the balance of a traditional lecture-based chemistry course to a more student-centred approach which encourages active learning. One disadvantage is that it takes longer to deliver the same amount of factual content in this way. The counter-argument, for which there is some supporting evidence, is that students have a better understanding of (and therefore remember better) a greater proportion of the smaller amount covered. From this it is easy to argue that 'less means more' - less material is covered, but more (not just a greater proportion) is retained and applied. This is only part of the advantage, since one of the aims of a student-centred approach to teaching is to help them to develop other skills - and especially the skills of learning to learn independently.

Another significant problem for academics (which ought not to be seen as a disadvantage) is that student-centred learning involves shifting the tutor's role from that of 'authority' towards that of 'facilitator' or 'manager of learning'. The loss of control which this implies can be difficult to adapt to. The positive side is that it allows the tutor to pay more attention to the higher levels of competence. Table 1 shows six levels of competence based on Bloom's taxonomy of cognitive levels.[6]

Table 1: Levels of Competence (Based on Bloom's Taxonomy)

Knowledge:	able to identify and define the concept.
Comprehension:	able to apply the concept when instructed.
Application:	able to apply the concept appropriately without instruction.
aNalysis:	able to dissect a problem and apply the appropriate concepts.
Synthesis	able to combine concepts in new and appropriate ways to give new/useful knowledge.
Evaluation	able to analyse a problem in multiple ways and to identify the relative strengths and weaknesses of each approach.

One way of moving towards student-centred learning is to adopt a problem-based approach 'Problem' is an ill-defined word and its meaning in this context needs to be carefully thought through. I like this definition:

"Problem solving is what you do when you don't know what do, otherwise it is not a problem".[7]

Table 2: Characteristics of Good Problems

- engage interest
- Require decision and judgement
- Need full group participation
- Open-ended or controversial
- Connected to prior knowledge
- Incorporate content objectives

Some characteristics of a good problem, based on a paper by Duch[8] are given in Table 2. Such problems may be extensive, such as those based on a historical sequence of published papers,[9,10] or may be quite short. Here is an excellent example of a short, thought provoking, question:

'Consider two beakers of pure water at different temperatures. How do their pH values compare? Which is more acidic? More basic? Explain.'[11]

Other questions might be based on the interpretation of a graph or figure, the creation of a pictorial representation of a piece of symbolism (such as an equation), the need to define what information is needed to answer a question.

A key feature of good problems is that they encourage students to talk to each other, and to stimulate each other to reflect on their answers. Both verbalisation and reflection are valuable aspects of the learning process. The former is an excellent way of exposing and clarifying concepts; peer-group discussions can be extremely effective, providing that there is sufficient tutor-interaction to ensure that the entire peer group is not led down a blind alley. Reflection is an important step in making connections between different topics and in assimilating new knowledge into an existing framework.

There is a strong case for giving students more careful preparation for and feedback from different learning experiences. In the laboratory context this means well-designed pre-labs and post-labs. At their best these are quite different from an instruction to 'read your lab manual' or the marking of a report. Pre-labs and post-labs have (or can have) parallels in any other style of teaching - lectures, classes, seminars, workshops, tutorials, or anything else.

A cautionary conclusion

Edmund Burke is reputed to have said

"to innovate is not to reform."

Do we want innovation, or do we want reform? We should be trying to introduce something better, and not all innovation does this. We need clear objectives. 'Inducing people to think' is a useful start. By inducing our students to think we would expect that they would make better connections between aspects of their chemical knowledge, and this would lead to better understanding, and to better ability to use knowledge to make judgements and to solve open-ended problems. Thinking students would also develop the personal skills needed to work effectively with others. It would be good to dispel the image of an extrovert chemist as being

*"someone who looks at **your** shoes when talking to you."*

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