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Skills taxonomy driver for designing an independent learning course in environmental chemistry*

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Abstract: Most chemistry courses at secondary or tertiary level are still content-driven being delineated to a large extent by the answer to the question 'what does the student need to know?'. A different question is 'what should the student able to do?' and it is toward this outcome-orientation that we have designed a skills driven, environment focused, independent learning, course at an introductory tertiary level. We have developed a taxonomy of problem-centred skills and used this as the driver in the construction of a context departure point, multiple media course.

Inevitably the philosophy has led to a non-traditional structure. The most significant feature is a top down approach starting with the familiar, introducing ideas on a 'need to know basis' and developing concepts on a spiral curriculum. The result is that students with no, or very limited prior experience, can competently deal with, for example, problems relating to molecular architecture of drugs and receptor sites. The outcomes are defined in terms of behavioural objectives involving such skills as molecular representation and modelling, problem solving, team work, literature analysis and communication.

A vital (but oft neglected) feature of educational innovation is an evaluation of effectiveness. Our investigation covers a wide range (background, age, gender, social class) of students, a significant number of whom lack previous experience of chemistry. Data indicate that prior experience/knowledge does not map directly to exit behaviour and that skills acquisition may be hampered by content loading.

In common with educational systems the world over, higher education in the UK has been under great pressure during the last 10 years to become more competitive, more efficient and to widen its student intake. Funding for universities has traditionally been from government resources and this still provides a major slice of funding for teaching and learning. However, this funding is now directly linked to student numbers and the amount for each student decreases in real terms year on year in compensation for 'so called' efficiency gains. What this means for universities is that funding will decrease if efficiency does not improve (that is lower cost per student), funding will decrease if student numbers do not increase and even an increase student numbers does not guarantee an increase in funding. For many institutions, survival means more students without a proportionate increase in resources to provide for their education. For a discipline like chemistry, which has never been able to compete in terms of student numbers with the popular areas such as the arts or psychology, this regime is particularly severe. Indeed failure in the competition for students has been used as argument for the closure of some chemistry departments.

Out of this difficult and apparently adverse situation has come a real opportunity for revolutionary thinking. Even academics who, 10 years ago, would have given short shrift to any suggestion that their teaching programmes could be improved are now desperate to try new approaches. Minds are focused and

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ideas that would have seemed to be heretical are now given serious consideration. Adversity has created an attitude change, which coupled with an emphasis on the quality of the student learning environment, has given us a rare chance to embark on a rethinking of the curriculum, and even to question to what extent chemistry should be taught formally as a discipline within its own right.

For many academics the challenge comes down to how can we present the ideas of chemistry in such a way as to attract students *and* to retain students. Maybe the immediacy is now greater but this is not a new mission. Why have we not been spectacularly successful in the past? What is wrong with chemistry (or at least with the way chemistry is presented) that makes the subject so unattractive to so many? An answer to this question could well allow us to restructure our programmes in an informed way. However, there is little point confining our enquiry to those students who are studying chemistry: it is those students who have chosen not to do chemistry that need be addressed too.

The multiplicity of views and comments can be filed under three main heads: dynamism, difficulty and image with scores of low, high and low, respectively. Chemistry is not seen to be dynamic and alive. It is a collection of facts that have to be memorised, there is little room for opinion and interpretation and there is apparently little relationship between chemistry and human culture. Difficulty can mean many things from a student perspective and at one level, the huge discrepancy between the student contact hours for the literature fresher and the chemistry fresher, is a significant demotivator. Chemistry is inaccessible in terms of its jargon, symbolism and shorthand and it does seem that to be creative you need a huge background of knowledge. Finally the image of the chemist is somewhat ‘nerdy’ with laboratories being occupied with white-coated, bespectacled men (and relatively few women). The environmental image of chemistry tends to be based on the unappealing aspects of pollution and industry. In some ways this latter problem is partly of our own making in that many environmental chemistry courses focus on global issues with a negative connotation such as the ozone hole, global warming and pollution.

Could we successfully address at least some of these factors in the design of an introductory chemistry course within the context of our own somewhat unusual learning environment. The Open University in the UK was set up about 25 years ago to provide undergraduate education through distance and independent learning methods. The market was those potential students who had missed out (for financial, domestic or other reasons) on the opportunity to study at degree level when they left school. The system had to cater for students that were home based and had to create study patterns to accommodate their other commitments of employment and family. (In essence this boils down to a context of open access, mature students, multiple media and a modular system.)

So the challenge was to design an introductory course in chemistry that would:

- assume no prior chemistry
- be accessible to a wide range of potential students
- attract, engage, interest and retain large numbers of students
- provide a departure point for students going on to other chemistry-based courses but would be complete as a terminal course.

It was felt to be essential that those students who did not go on to take further chemistry courses should end the module with a positive view of chemistry and of their experience. The student study time should be about 220 h (plus a 3-day residential component) which equates to 30 points of a 360 point basic bachelor degree.

The next stage is to move to outcomes: what should the student be able to *do* by the end of the course? Inevitably, there was always going to be the academic constituency that would see a starting point of a low knowledge base as necessarily resulting in a low level outcome. There was no shortage of suggestions of acceptable outcomes from this group of academics but the outcomes were, without exception, intrinsic and knowledge-based: be familiar with chemistry of the transition elements, know basic crystal types, be familiar with synthetic methods in organic chemistry and so on. The other outcome of this approach (that curiously was not mentioned) was that there would be very few students.

An alternative to this content-driven approach (much favoured by the ‘educators of yesteryear’) was to focus on behavioural outcomes and ask the sort of questions that students might realistically ask. What are these questions? It is very easy to find out simply by asking science and nonscience students. Admittedly some questions arose that could not be linked to chemistry by even the most tenuous of threads but there were many questions that gave us a starting point for our course.

- Why did the Bronze Age come before the Iron Age?
- Why do oil and water not mix except that they do in mayonnaise?
- Why do some dyes not take on certain fabrics?
- Why is the colour of hydrangeas dependent on where they are grown?
- How does 'Ventolin' (the bronchodilator salbutamol) work?

It might appear that to address even these few questions we would have to 'teach' a massive amount of chemistry. So does this not point to a need to think carefully of what is included in a course and most importantly why it is there? If inclusion cannot be justified (and 'a chemist should know this' is not a justification) then the material should not be included.

These outcome questions began to define areas in which the course should have its focus and they also brought in a guiding principle of the course. Necessarily a different approach to the teaching of chemistry was required. We had to start with the familiar (that is the familiar to non scientist), to use a top down approach (in contrast to the bottom up starting with atomic structure), to teach on a need-to-know basis as far as possible and to be prepared to accept a non content-driven structure.

Before tightening up on outcomes we need to look at two areas that also relate to the initial challenge of the course and these focus on the 'customer'. This is just the same approach that might be applied to the design of a new product. Figure 1 shows a summary of the student profile investigation. Out of this comes an indication of student interests, experience and aspirations that can help us to shape the course. Further there are indications of an unfamiliarity of the process of study. One also one needs to take into account that students from a wide range of backgrounds bring a huge amount of baggage with them. How you *learn* (as distinct from what you are taught) depends on what has been your earlier experience.

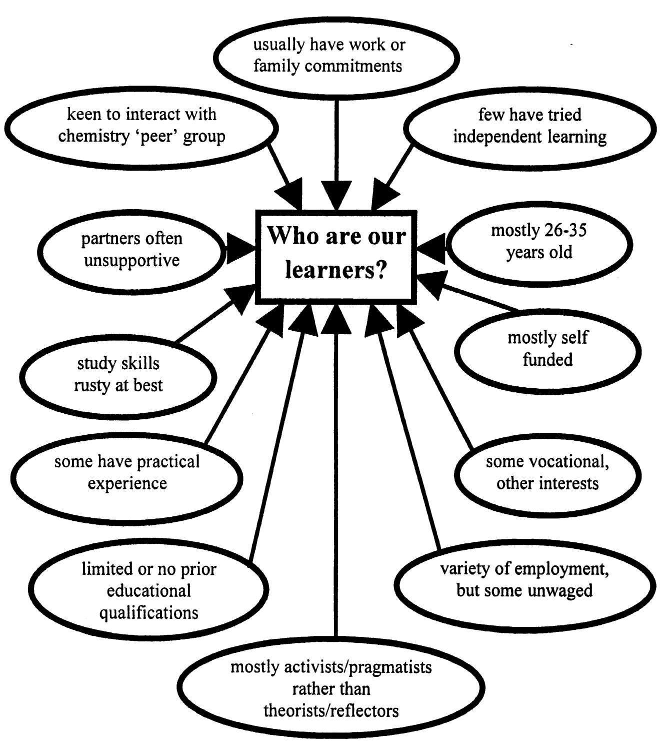

Fig. 1 Student profile.

Access is all important in an introductory course and we were determined to ensure that our assumptions of entry skills were consistent with our anticipated audience. Workload is another factor that can influence student choice and can certainly influence student drop out. Educators in chemistry seem to be excellent at including new information from recent research in their courses. This is physically evidenced by the steady increase in the size of textbooks over the years. We are not good at removing information from a course and as a result we are asking the student to package greater and greater amounts of knowledge. Is it essential that the fresher is familiar with Rutherford, Bohr and Schrodinger models of the atom? Can we get by initially with a very simple idea of an atom and yet expose the student to some contextual chemistry?

It is not simply the total amount of information that is pertinent but the skills that the student develops to handle new information. There is a limit to the number of items that can be held and processed in the short term memory. This limit seems to vary little from person to person and is in the region of five to eight items. People who can apparently operate at higher levels have learnt the skill of chunking, the ability to collect pieces of information into sets or chunks so that they can operate with the limited number of chunks. This skill can be illustrated by considering a representation of the nitrobenzene molecule Fig. 2. The trained chemist sees this as comprising two components, phenyl group and a nitro group. The untrained person may see something more like the second diagram which comprises the same number of lines and symbols as does the nitrobenzene molecule.

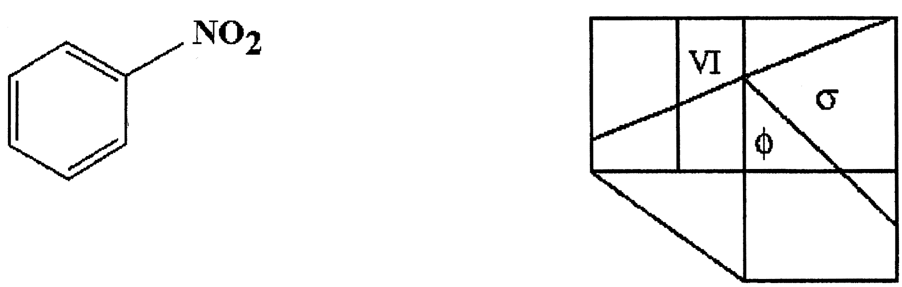

Fig. 2 Illustration of 'chunking'.

For our course (now with the title *Our chemical environment*), refinement of outcomes has led to the main areas of:

- materials (metals, ceramics, polymers)
- nutrition (food types, synthesis of foods, metabolism, emulsions)
- health (cleaning and detergents, mode of operation of drugs, drug screening and drug design)
- futures (nanotechnology, virus control, virtual modelling)

Note that the content is consistent with the notion of the environment immediate to the student. Our questionnaires indicated that there was a much better focus with potential students of the 'real' rather than the 'intangible'. We had to start from the familiar and develop from there. This implies the almost heretical approach in an introductory course of not starting with the atom and its structure.

We were now getting close to the construction of a concept map but first some work on skills was required. We categorised skills as chemical, transferable and environmental. Chemical skills would include the calculation of quantities from chemical equations, representations of three dimensional structures in two dimensions, prediction of chemical reactivity using a functional group approach, etc. Predicting the effect on the operation of a water treatment plant of an increase in the detergent loading of the input water, identifying the advantages and disadvantages of the colour green for plant leaves, rationalising the ability of flowers such as hydrangeas to change colour with soil pH are environmental skills. Transferable skills concern communication, presentation, argument construction, evaluation of evidence, etc.

All skills should have associated behaviour tests that help define and test them. In addition, skills can be put into a hierarchy which at its simplest would include categories of basic, middle and higher order.

An example of a transferable skill is the ability to construct and present an argument. The skill can be broken down into a number of components, each testable and which collectively generate the overall skill. The initial stage of acquiring information may be scanning and speed reading which are testable by requiring the student to produce a list of points from an article. The hierarchy of skills moves through defining the criteria against which to select information, selecting information relevant to the argument, developing steps in the argument, grouping the information to support the steps, constructing the argument, presenting the argument and evaluation. All of these steps can be tested often in ways that are not necessarily onerous on the student. Testing the presentation could be by asking students to write down an the argument but, more imaginatively, to make a presentation of a two minute lecture to their peer group. The peer group can also be involved in evaluation if this latter route is taken.

The representation of molecules in the two dimensions on the printed page is very much a chemical skill. This can begin with the idea of 'Lego', the infant building block game. A child soon realises that there is a limited number of blocks. Each block fits with another in a limited number of ways but there is a huge range of different structures that can be made from relatively few block types. Maybe the structural ideas of organic chemistry are not too far from this so why not take it as a starting point. The representation starts with the ball and stick, develop to the symbol and stick, then the contraction such as $CH_3CH_2CO_2H$ for propanoic acid for example. Further development takes the student to skeletal representations followed the introduction of the third dimension with techniques such as the flying wedge and projections. The secret here is to try to develop these skills covertly. Introduce a new representation gradually alongside the original one which can be phased out when the new representation is established. These skills can be developed in stages over the course and be tested with assignments that become increasingly sophisticated as the course progresses.

The final task before writing of a course starts is to construct a concept map which not only shows the interrelationships of the concepts but indicates how, when, to what extent and through what material the concepts are to be developed. The completed concept map may show up gaps in the range of concepts that many people would regard as essential in an introductory course. Be strong, you have *designed* the course. The concepts are matched to the outcomes that have arisen through a careful process of iteration. If colleagues indicate that they need a particular concept for a following course, let them introduce it at the time when it is needed. What we have to do is to try to teach on a need-to-know basis as far as possible and we have to be prepared to revisit concepts. Concepts should only be developed to the extent that they are needed and developed further only when the need arises.

The third stage in our course development (Fig. 3) is the achievement of outcomes. Here there are several areas that will affect the appearance of the course but not its educational ethos. Resources are vital and come under a number of categories: human, financial, material, facility and time. It is worth mentioning here the resource of a team working on the project rather than an individual. The careful putting together of a team and its leadership can have an enormous effect on the quality of a course. Every member of the team does not have to be skilled at every task but the matching of team members strengths to the tasks in hand can add greatly to the smooth running and efficiency of working.

Choice of media and delivery of the course are entwined. Media available will vary from one institution to another but a list for the distance learner (or independent learner) could include text, video/audio cassette, broadcast television, experiment kits, residential schools/field trips, computing and multimedia. The choice of media from this (or any other list) depends not only on the concept or idea being developed but on student study time, teacher development time, cost, availability and convenience. It might be that a two dimensional moving image is the best way of representing a three dimensional aspect of a molecule. However, to produce pages of text on a screen is not a good or convenient use of the medium.

Practical work merits special mention if only because it is frequently ritualistic rather than a learning experience. So often, it is time in the laboratory that is specified as some kind of measure of quality of experience rather than an assessment of skills. Time spent in laboratories is not always well used with many practical programmes including an unnecessary repetition of techniques. Another problem relates to active participation in experiment design. How often does the material supplied to students read like a

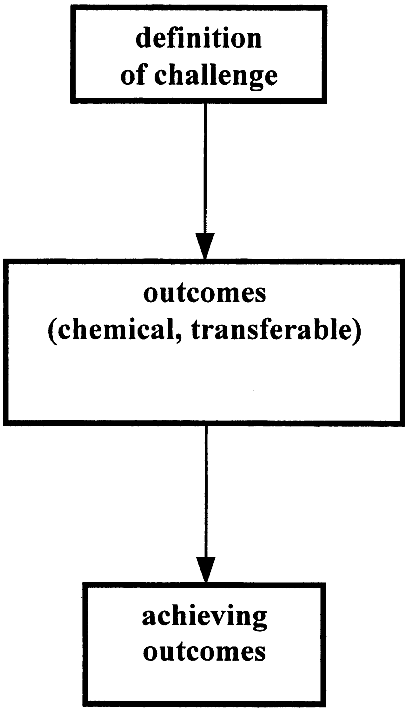

Fig. 3 Stages in course development.

recipe and how often is treated like a recipe by the student? The questions to ask are 'what skills should be developed in students, which of these skills are traditionally developed in the laboratory and can any of these be developed outside the expensive laboratory environment?'. It is impossible to home in on a unique list of skills but the major skills that are ideally developed in a practical programme would probably include:

- manipulation
- observation
- data collection
- processing of data
- analysis of data and observations
- interpretation
- problem solving
- team work
- experiment design
- communication and presentation
- laboratory ambience

A major problem is in the progressive development of these skills as the student moves through an undergraduate course. Each laboratory experience may be valuable and worthy in its own right. However, the next session (or even the next semester) in the laboratory may not take into account the extent of skills developed in the earlier session. Indeed, even today, it is not the norm to find laboratory programmes analysed, let alone designed, in a skills development context. We have extended our work on skills discussed earlier to include practical work and have developed a taxonomy set here too. To move in the direction of a skills driven programme is not only central to quality student progress but will result in a more efficient use of the laboratory resource.

We have already addressed assessment and the importance of it being linked to clearly defined outcomes. Evaluation of student performance not only provides information about the student body but careful analysis can reveal shortcomings in the assignment strategies or even in the course itself. This leads to the general notion of constant re-evaluation and quality control, It is essential to build in a system that not only identifies the shortcomings (and the strengths) but provides a mechanism for informed change to take place.

So how successful was our course? Did the package of colour texts, broadcast television, video and audio, residential school, experiment kit, assessment package (continuous and examination) and multimedia using a top down approach work? If we use the criteria imposed on us by the funding masters then success is there. The course attracts 700 students each year (more than any other of our chemistry-based courses) and has a low drop out rate. Students who come to the course with no scientific (let alone chemical) background perform in assignments and the examination no worse than do students coming in through the Open University science foundation course. There have been many students who have come to the course from a programme in the arts or social sciences to 'see what chemistry is like'. The course has not encouraged many of these people to shift camps but comments such as 'I can see how things work' and 'It has completely changed my view of chemistry and it was fun' provide ample testimony to success.

I cannot claim that this approach gets it 'right' but it has represented change in the way introductory chemistry can be taught to a wide audience. The strategy is really little different from that taken by manufacturing industry which operates with the checklist of market, resources, product design, product manufacture, product quality, delivery and evaluation and performance. And there is advertising, something that we really are not very good at with chemistry. The links are illustrated in Fig. 4.

As a final thought, try to 'sit where the student is'. The perception of a course from this position is often very different from that of the teacher.

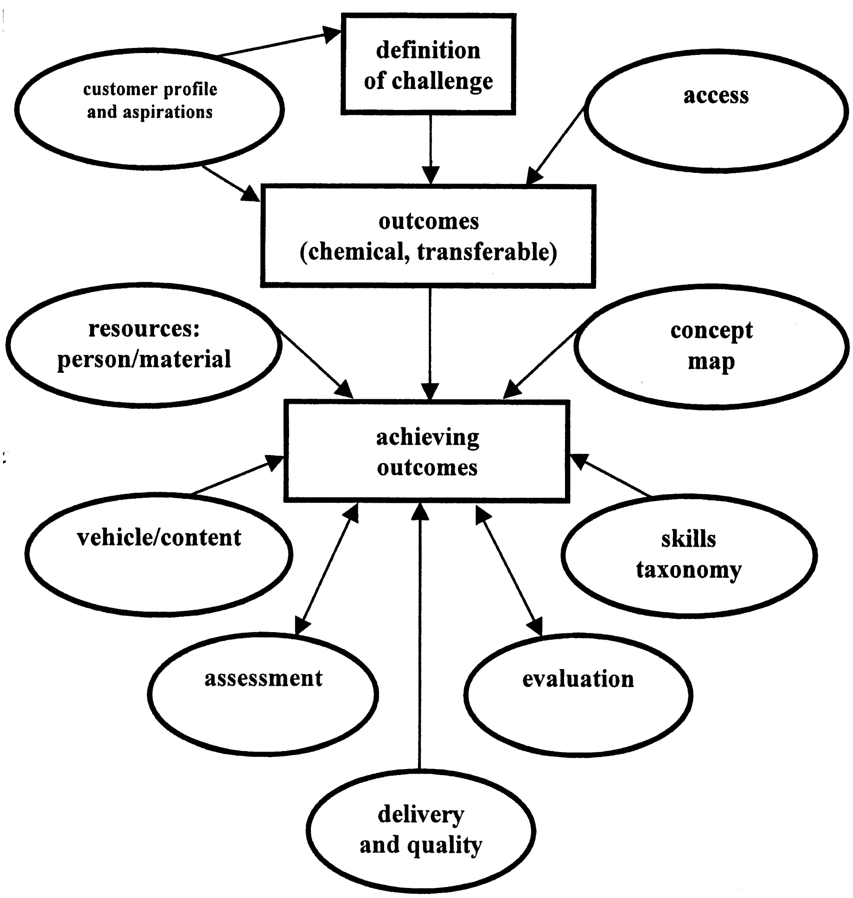

Fig. 4 Inputs into course design.