[O31] Threshold concepts, misconceptions and common issues

K. Moss, C. Greenall, A. Rockcliffe, M. Crowley and **A. Mealing**
Centre for Effective Learning in Science (CELS), School of Biomedical and Natural Sciences, Nottingham Trent University
Karen.Moss@ntu.ac.uk

Keywords: threshold-concepts, knowledge gaps, student surveys, mathematics

Context

In every area of science there are some ideas that many students find difficult to grasp. Such difficult but key ideas has been recently termed *Threshold Concepts* by Meyer and Land, (Meyer and Land, 2006). They define a *Threshold Concept* as:

- Core to understanding the subject;
- *Seismic*: 'getting it' brings about a significant shift in perception of the subject;
- *Irreversible*: the change in perspective that comes with understanding;
- *Integrative*: understanding it exposes interrelatedness (previously hidden);
- *Bounded*: has distinct edges and affects other new concept areas;

Meyer and Land also describe the allied idea of *Troublesome Knowledge* areas which are major barriers to learning, where they are central to the subject and are often characterised by behaviours such as:

- *Ritual knowledge* – students are able to perform superficial tasks and techniques to get a result, but fail to understand the complexity that lies behind it.
- *Inert knowledge* – concepts are understood but not actively used or connected to the 'real world', a failure to see the 'big picture';
- *Conceptually difficult or Alien* – counter-intuitive, alien or incoherent e.g. mass, weight and gravity; i.e. the strangeness and complexity of scientists' views of the matter.
- *Troublesome language* – when are 'familiar' concepts are rendered strange and subsequently conceptually difficult?

Summing up Meyer and Land

> *'Failure to understand threshold concepts leaves the learner in a suspended state where understanding is mimicked or lacks authenticity.'*

In the sciences, there have been a small number of studies in area of university science – work by Taylor and Prosser (Taylor, 2006), but the majority of previous work in this area has focused at pre-university level e.g. work by Keith Taber (Taber, 2002) and Vanessa Barker, (Barker, 2005)). In her review '*Beyond Appearances: Students' misconceptions about basic chemical ideas*', Barker describes a number of chemical misconceptions. In one example, with 16+ students she identifies as a key factor the limits of the students' ability to wear 'molecular spectacles', when examining chemical concepts.

> *'When students cannot "see" particles they cannot really understand chemical reactions and so the fabric of chemistry is lost to them in a haze of impenetrable events completely at odds with their every day experiences of a "continuous" world.'* (Barker, 2005)

Taber considers several different concept types and the problems that arise when *natural* concepts (everyday life) appear inconsistent with *scientific (new)* concepts, as well as issues to do with language. For example, a student who has just learnt the idea of a covalent bond in a limited context does not share the same meaning of the term as their lecturer. The lecturer's meaning is very much more in-depth and sophisticated and is integrated into an extensive framework of chemical ideas, (so called *elaborated learning*). Taber identified both obstacles and impediments to a students learning. Some of these ideas resonate with initial findings from our studies.

Impediments can occur on two levels: firstly, *null learning impediments* where students fail to make sense of our teaching - either because they have prior knowledge gaps or because they fail to integrate their new information into their existing framework. Secondly, Taber describes *substantive learning impediments* where a student has alternate but wrong conceptions or is taught in an inappropriate way.

In her higher education study, Taylor recounts that troublesome concepts in biosciences can arise from problems with both *process* concepts and *abstract* concepts and situations where students develop 'islands of knowledge' that are not integrated into the bigger picture. (Taylor, 2006)

The Research

Building on the work of these workers and others, our plans were to firstly understand the nature of the problem:

- Discover what the common misconceptions are? (Staff and student perspective)
- Explore students' understanding with work in class or in focus groups
- Use questioning to explore understanding – diagnostic tests, questionnaires
- Identify knowledge gaps?
- Track which misconceptions persist from pre-university days?
- Examine which misconceptions are perceived to be maths related?

Having collected this data then the next step is to develop materials and approaches that help both with knowledge gaps and misconceptions, e.g. by considering the language used to teach and by setting things in context.

Qualitative Studies

Focus Groups
A number of students were interviewed and asked questions to find out:

- *What are the concepts students find difficult or troublesome?*
- *What concepts have transformed their understanding?*
- *What are the gaps they perceive in their knowledge?*
- *What are the concepts they are most keen to understand and why?*

Initial groups interviewed were Forensic Science students. On this interdisciplinary programme, students have to deal with concepts from biological sciences, chemistry, physics and forensic science itself. In addition they have mixed entry profiles of A2 and AS-levels in different subjects. This will affect their prior knowledge, and hence is likely to affect their ability to acquire both knowledge and understanding of concepts.

Topics they identified as causing problems included:

In chemistry:
Electrochemistry; chromatography; bonding; functional groups; spectroscopy, radiochemistry; Arrhenius equation; chemical equations, analytical science; crystal field theory, formulas and equations, dilution factors, structural formulas; calibration of instruments

In biology:
Energy chains; electrophoresis of proteins and nucleic acid immunodetection; many types of chromatography (e.g. size exclusion);

In physics:
Microscopy; waves; photography and image processing; ballistics; complexities caused by different theories, equations and functions

In general:
Equation manipulation;

Some of their reflections on learning:

On the perils of oversimplification and its consequences
'. . . but they teach you one thing and then you get to the next level and they say forget everything you learned in GCSE, it's not like that, it's like this and it's the same when you get to the degree, they say forget everything you learned at 'A' level, this is how it is and you have to keep resorting back to what you learned in the first place and it just confuses you'.

On maths issues
'I agree with X about having the grasp of maths and rearranging equations, stuff like that, that would be good.'

On the value of contextualising

> *'. . . why do you need to know that? If you are using a microscope you don't need to know that the light is behaving as a particle, all you need to know is that you have to adjust the thing to get it into focus and that's the thing I would rather have learned, rather than looking how the light bends this way?'*

On the use of language

> *'I find a lot of the technical words are difficult to grasp . . . it's like anything that you are working with, if you use it all the time, they become part of your everyday language and you don't realise that people don't understand it. I worked with the police force for eight years and they use loads of acronyms etc.'*

Chemistry survey

The survey asked fifty first year students to rate their understanding of topics in a core chemistry module, which covers aspects of the three main branches of chemistry. The survey asked students to rate their understanding of each topic on a 5 point Lickert scale from None to All, for example 'Half: I understand some of the facts/theories and can relate them to/solve straightforward problems; to All: 'I understand all of the facts/theories and can relate them to new problems.'

Students who indicated their understanding as 'none' or 'little' for any topic were also asked to suggest reasons as to why they found it difficult. In addition, we asked for information on their types of entry qualification and the grades they had achieved.

Topics which had low understanding ratings included:

> *Markovnikoff's rule; MO theory; VSEPR theory; Arrhenius Equation; Inductive effects; Alkyl halides (SN1, SN2 reactions); pH; dissociation constants and SI units*

Where given, student reasons for their difficulties included comments on:

> *'A lack of prior knowledge of some topics'; 'difficulty in understanding'; 'uncertainty over meaning of terms'; 'books were 'confusing'; 'insufficient examples to demonstrate the purpose of required field of knowledge' i.e. a lack of context.*

There is an implication in these comments that a lack of familiarity brings a lack of confidence in how to solve problems in, or apply, 'new' areas of knowledge.

Staff Surveys

As learning involves both teacher and student, it was felt important to ask teaching staff for their perceptions of students' difficulties with scientific concepts. Two groups of staff have been surveyed so far: academic staff teaching science at Nottingham Trent University; and secondary science teachers. It was intended to help identify those areas of the post-16 curricula where conceptual difficulties are carried through into undergraduate study.

18 Academic staff from a range of sciences, who responded to our survey, listed the following as difficult/troublesome concepts for their students:

> *Genetics; differences between viruses, bacteria and fungi; biomechanics; statistics in final year projects; anything that involves a formula; biochemical*

pathways (e.g. Kreb's cycle); molecular biochemistry (DNA); moles, ionic and covalent bonding; cellular respiration; cloning; transgenics; rearranging equations.

We also asked for suggestions from staff as to why these concepts were troublesome. They suggested:

'Abstract concepts'; 'mathematical formulae phobia'; 'lack of prior knowledge'; 'difficult for them to conceptualise'; 'not well taught at school'.

18 Science Teachers stated the following issues for their students:

Biochemistry – structure of macromolecules; DNA and protein synthesis; quantitative chemistry; electron structure; bonding; qualitative chemistry; valency; writing formulae and equations; electrolysis; systematic nomenclature; polymers; fuels; catalytic converters; how chemistry relates to the real world; inter-molecular forces; balancing equations and stoichiometry; relating properties to structure; photoelectric effect; nuclear particle families; nuclear reactions; calculations.

Quantitative Studies

Diagnostic testing in Physics

Further factors for analysis were supplied by diagnostic testing with both first year physics and chemistry students. The physics test is part of a process begun in 1998, which has run every year for 8 years in the initial weeks of the programme, using the same test material. The test papers are in 5 sections, which cover: scientific notation, graphs and units; Motion; DC electricity; Atoms and radioactive decay; and Waves. Students are allowed up to 2 hours to complete the 23 questions, which are then peer assessed. The results are collected anonymously and the results tabulated by the member of staff. The students get their test paper back, common areas of weakness are identified and students then referred to appropriate units in the Open University Flexible Learning Approach to Physics (FLAP) materials. Students have persistently valued this approach highly. Results for these studies clearly show that the sections on *Waves* and *DC Electricity* persistently have poorer scores. A three year sample reveals that those getting 3 or more questions right in each section were usually 75-80% for sections on scientific notation, 60-76% on motion and 60-64% on radioactivity but only 13-21% on DC and 0-24% on waves. Further studies are therefore indicated to explore why these two topics are persistently difficult.

Diagnostic Testing in Chemistry

To compliment this physics data we began an investigation to obtain similar data about first year chemists. Fifty first year students were asked to complete a diagnostic test to check where there were conceptual difficulties.

The test involved 31 questions and question types included multiple choice, multiple completion and pairing. The questions were derived in part from an earlier diagnostic test (based on the RSC Question Bank). These were updated by the student running this investigation to reflect changes in syllabi at A-level on the advice of a highly experienced school teacher. The idea was to access levels of understanding with questions that started with A-level knowledge.

The poorest performances in the test were for questions on the following topics:

Trends in the Periodic Table; Electronegativity; Metal complexes; Isomerism; Electrophiles; Rates and Arrhenius

Conflicts of test and survey data

The first year group undertaking the test also did the survey. In some areas, students' test performances fitted their perception of their lack of understanding e.g. the Arrhenius equation. More interestingly, there were some discrepancies. The majority of students stated that they understood most aspects of *Trends in Periodic Table*, yet questions in this area produced the lowest scores of any in the test. This does raise some questions about how valid are students' perceptions of their own understanding and the relative outcomes of qualitative surveys versus quantitative testing. To what extent does self perception affect approaches to learning and perceptions of difficulty especially, for example, where mathematical ideas are concerned?

For all this work participants gave informed consent, data was anonymised and all research was conducted in accordance with British Educational Research Association guidelines (Furlong, 2004)

Conclusions and further work

From these initial studies, more detailed work is being carried out to explore why the concepts students and staff identified in our study are troublesome. Other subject groups are also being investigated e.g. sports science and bioscience and physics students.

Amongst our developing data, some common themes are beginning to emerge:

- Staff and students, at both school and university level, identify concepts involving the molecular but invisible, as causing problems: whether in biochemistry, molecular biology, or chemistry (e.g. DNA, structure and bonding)
- Mathematical issues, at all levels, from the manipulation of equations to statistics
- A perceived lack of teaching materials that relate scientific concepts to the real world
- Anything to do with the behaviour of electrons – from electrolysis, to DC to electrophoresis, is troublesome

Research, from Piaget onwards, indicates that it is not just about what is taught, but how it is taught that matters. Teaching needs to include activities and hand-on experiences, (McNally, 1973). It is about going beyond *Instruction to Intervention* where an experience maximises the learner's cognitive processing capability or development, (Adey and Shayer, 1994). As a result of these investigations, we are developing resources to support learning of some of these threshold concepts and troublesome knowledge – from VSEPR, and statistics, to protein purification and mole calculations, with a focus on the interactive, the visual and opportunities for repeated interventions. There's a lot more to do!

Acknowledgements

Ian Solomonides; Sophia Saleem; The students, teachers and lecturing staff who participated in surveys; Robin Turner; Glen Mchale and HEFCE for our CETL funding

References

Adey, P. and Shayer, M. (1994) *Really Raising Standards: Cognitive intervention and academic achievement*. London, UK: Routledge.

Barker, V. (2005) *Beyond Appearances: Students' misconceptions about basic chemical ideas*. A report, London, UK: Royal Society of Chemistry (Private communication, pdf accessible at **www.chemsoc.org/pdf/learnnet/rsc/misconceptions**; accessed 27th February 2007)

Furlong, J. (2004), *British Educational Research Association Revised Ethical Guidelines for Educational Research* (2004), available at **www.bera.ac.uk/publications/guides.php** (accessed 5 March 2007)

McNally, D. (1973) *Piaget, Education, and Teaching*. Sussex, UK: New Educational Press Ltd.

Meyer, J. H. F. and Land, R. (2003) Threshold concepts and troublesome knowledge in *Improving Student learning, Improving Student Learning Theory and Practice - Ten years on*, ed C Rust pp 412-424, Oxford, UK: OCSLD.

Meyer, J. H. F. and Land, R. (2006) *Overcoming Barriers to Student Understanding*. London, UK: Routledge.

Stapp, Yvonne (2003) Facilitating the acquisition of science concepts in L2, *TEFL Web Journal*, Volume **2** (1), 31 available at **www.teflweb-j.org/v2n1/v2n1/v2n1.htm** (Accessed 5 March 2007)

Taber, K. (2002) Chemical Misconceptions, vols 1 and 2, London, UK: Royal Society of Chemistry

Taylor, C. (2006) Do they fit the definition? In Meyer, J. H. F. and Land, R. (2006) *Overcoming Barriers to Student Understanding*, pp 87-99, London UK: Routledge.