Models in teaching Chemistry – the research evidence

This is NOT a comprehensive review of research related to models in science teaching, but highlights some important research findings which have implications for practice.

What are models ?
A model is a representation of an object, event or idea. This representation creates a vehicle through which the object, event or idea can be conceptualised and understood.

Models are important in science teaching, as major tools for teaching and learning. They are more than this, however. Models are one of the main products of science – the progress of science is normally marked by the production of a series of models, each associated with a distinctive theory. Modelling is a major element in scientific methodology (Gilbert, 1994).

Models can be of a number of different types (Gilbert, 1998):
Mental model – that we each of us visualise in our mind;
Expressed model – when we try to explain or present in another form our mental model;
Consensus model – an expressed model which has gained acceptance within the scientific community;
Historical model – a *consensus* model which has been superseded at the 'cutting edge' of science e.g. the 'plum pudding' model of an atom is an historical model superseded by 'orbiting electrons' model.
A *teaching* model is one specifically produced to teach a difficult *consensus* or *historical* model.

The last four models can be put forward in a number of different ways including as objects, symbolic or mathematical representations, diagrams, spoken explanations or a mixture of these.

Mayer (1989) defined a good model as one that fulfils the following criteria (the 6 Cs):

I. structurally *complete* in the relationship of its elements - ie has all the essential elements of the target idea;
II. *coherent* and appropriate in its level of detail;
III. *considerate* in its form – appropriate vocabulary and form of presentation;
IV. *concrete* in its representation – the relationship of all parts of the model are obvious;
V. provides clear *conceptual* explanation – the associated theory can be explained through the model;
VI. highlights the *correct* comparatives between the model and the target idea – the scope and limitations of the model are pointed out.

These '6Cs' can be used to evaluate the effectiveness of a model in exploring the target idea.

How can models be used effectively in chemistry teaching?

Some studies have sought to describe the actions of teachers in using models, others have attempted to evaluate the use of models in helping pupils' understanding.

Jarman (1996) explored the extent to which beginning teachers used analogies in their 'normal' science teaching. She asked a cohort of PGCE students to keep a record of the types of analogies they used in explaining ideas. She found that 58% of the models were devised by the student teachers, mostly spontaneously but sometimes planned. Some models were culled from experienced teachers (20%) or textbooks (15%) with just a few (4%) from the student teachers previous experience of science education. The most frequent use of models in chemistry teaching for these student teachers was in explaining particulate nature of matter and rates of reaction. People, animals and familiar activities, such as making cakes, were frequent sources for models.

The student teachers presented the following reasons for using analogies:

I. To help pupils visualise a structure or process;
II. To help less able pupils to remember a concept or idea;
III. To simplify a difficult concept or idea;
IV. Because the pupils failed to understand a concept or idea on an earlier occasion;
V. To help the pupils link an unfamiliar idea with a familiar idea, particularly in an imaginative way;
VI. To entertain or to provide a variety of approach;
VII. Because the pupils were encountering a concept or idea for the first time.

A similar study was conducted by Thiele and Treagust (1994) in which they examined the models used by four experienced chemistry teachers. Figure 1 shows the analogies used. They showed that these four teachers had some similar characteristics to the PGCE students in Jarman's study in using models:

A. Teachers used analogies when they considered that the students had not understood an initial explanation;
B. There was little evidence that teachers preplanned their analogies;
C. Teachers tended to draw on their own experience or own professional reading as a source of analogies;
D. Pictorial analogies were frequently used in lessons;
E. Two of the teachers provided clear statements of the limitations of the analogies.

Figure 1 Analogies used by four chemistry teachers across 43 lessons

ANALOG	TARGET
Energy effects	
Pole vaulter attempting a vault	Activation energy
Car precariously located at the top of a hill	High energy of the activated complex
Reaction rates	
Students hurdling hurdles of different heights	Rates of various reactions having different activation energies
The student dance	Increasing in molecular velocities causing an increasing number of collisions
Coconut shy	Effect of increasing concentration on the number of successful collisions
Climbing through a Swiss mountain pass	Effect of catalysts on reaction mechanism and rate
Pushing a car around a side road	Ease of catalysed reaction mechanism
Chipmunks storing food before winter	Exothermic and endothermic reactions
Chemical Equilibrium	
Breaking apart a pen and its cap	Energy required to break chemical bonds
Water flowing in and out of a sink	Constant dynamic properties in a steady state open system
Gravitational effects on a body Elastic band returning to its original size	Tendency of a chemical system to revert ot equilibrium
People moving in and out of a shop	Rates of forward and reverse reactions for equilibrium
Person walking up a down escalator	Competing forward and reverse rates of reaction

These studies suggest that, as science teachers, we spontaneously use analogies to help pupils understand. Similar observations were made by Treagust et al (1992). They showed that science teachers used analogies extensively but with little advance preparation or introducing after explaining the target idea. They recognised that opportunities for pupil understanding were limited as teachers often did not fully explain the analogy being used. A more systematic and planned use of models in teaching may provide significant help to pupils in grasping concepts.

Raghavan and Glaser (1995) showed that by making models a central feature of the learning process, pupils were able to show high levels of conceptual understanding. The project, called Model-based Analysis and Reasoning in Science (MARS) was an attempt to 'create an environment conducive to fostering conceptual understanding and reasoning about scientific phenomena'. This qualitative reasoning by use of models 'concretised' abstract ideas and gave pupils a greater cognitive understanding, not only of the idea, but also the processes and reasoning by which the concept was modelled. Importantly, they also noted that previous underachievers participated with greater positive contribution. More recent studies have confirmed the learning gains which can be achieved by making models, modelling and evaluation of models central to the learning process (e.g. Tregidgo & Ratcliffe, 2000; Erduran, 2000).

Erduran's study highlights the abilities of 11-13 year old pupils in discussing important aspects of chemical models which are not present in teachers' explanations about the models.

For example pupils could discuss the boundaries of a model – its applicability to a new chemical concept – a feature lacking in some teachers' explanations.
The importance, then, of illustrating the strengths and limitations of models cannot be underestimated.

Grosslight et al (1991) show that learners' and experts' views of models differ (table 1).

Table 1 Learners' and experts' views of models

Learners' Views	Experts' views
Models are physical or visual in nature	There are both physical and abstract models
They show or help communicate about real things	Models help us to understand or think about phenomena
	The validity of a model can be tested by comparing its implications to observations and measurements in the real world
Different models of the same thing show literally different aspects of real things	Different models of the same phenomenon can be built to accommodate different purposes
Scientific models can change if they are made wrong or new information is found	Scientific models can be replaced by better ones

From this they suggest that we should provide pupils with a range of activities to take their understanding from 'level 1' to level 3':
Level 1: Models are simply copies of reality
Level 2: There is a specific, explicit purpose which affects the way a model is constructed. It no longer must exactly correspond with the real world object or event.
Level 3: Models are constructed for developing and testing ideas. The modeller takes an active role in construction. Models are manipulated and subject to tests.

Grosslight et al (1991) suggest some activities which might help pupils develop their understanding of models and of the target concepts. This includes providing learners with experience of using models to solve problems. The model can then become a tool of enquiry and not a package of facts. Another strategy is to provide multiple models of the same phenomenon. This can be helpful as concepts, such as atoms and molecules, are refined with increasing experience of their use.

Harrison and Treagust (1996) highlight what happens when models are not used carefully in explaining chemical phenomena. In studying pupils' mental models of atoms and molecules, they found such misconceptions as: atoms grow and reproduce and atomic nuclei divide; electron shells are visualised as shells that enclose and protect atoms, while electron clouds are structures in which electrons are embedded. They attribute some of these misconceptions to inadequate explanation and exploration of the models presented by the teacher. They argue that analogical models are an intrinsic part of chemical understanding and suggest that student understanding may break down when models are used 'because the students often do not recognise that the explanation or process they are using is a model and, consequently,

they mistake the model for reality'. They make two recommendations from this detailed study:
Students should be given time to develop modelling skills, including using models to explain ideas and recognising the strengths and limitations of particular models;
Whenever an analogy or model is used, 'teachers should consciously ensure that the analogy is familiar and that they make the effort to identify both the shared and unshared attributes with the students'.

Recommendations for practice

Taken together, the research evidence discussed suggests the following as being effective in helping pupils understand chemical concepts and models as an important aspect of developing and explaining ideas:

I. Use models at the beginning of a topic (Sizmur & Ashby, 1997) or integrated fully into the teaching of key ideas.

II. Where analogies are used, check pupils' understanding of the analogy itself before using it to explain the key idea.

III. Show the similarities and differences of the model to the target idea – i.e. highlight the strengths and limitations of the model.

IV. Give pupils practice in developing their own models and use them to explain ideas. Highlight the strengths and limitations of their models

V. Encourage pupils to explore the use of (their) models in explaining related ideas – does the model still hold?

VI. When using concrete models (e.g. drawings/ 3D models of atoms, bonding etc), 3D models seem to lead to greater understanding and retention of key ideas compared to 2D.

VII. Enjoy using models – they provide an interesting, visual and stimulating way of understanding chemical ideas! Models can really help and motivate low achieving pupils.

References:

Erduran S (2000) Designing learning environments to nurture growth of chemical knowledge through modelling *Paper presented at Modelling in Chemical Education Conference University of Reading, March 2000*

Gilbert J K (ed) (1994) *Models and modelling in science education*. Hatfield ASE

Gilbert J K (1998) Explaining with models In Ratcliffe, M (ed) *ASE Guide to Secondary Science Education.* Cheltenham, Stanley Thornes pp159-166

Grosslight L., Unger, C., Jay, E., and Smith, C. (1991) Understanding models and their use in science conceptions of middle and high school students and experts. *Journal of Research in Science Teaching* 28, 9, 799-822

Jarman R (1996) Student teachers' use of analogies in science instruction *International Journal of Science Education* 18, 7, 869-880

Harrison, A.G. & Treagust, D. (1996) Secondary students' mental models of atoms and molecules: Implications for teaching chemistry *Science Education* 80, 5, 509-534

Mayer, R E (1989) Models for understanding. *Review of Educational Research* 59, 1, 43-64

Sizmur, S & Ashby, J (1997) *Introducing scientific concepts to children – research summary* Slough: NFER

Thiele, R B & Treagust D F (1994) An interpretive examination of high school chemistry teachers' analogical explanations *Journal of Research in Science Teaching* 31, 3, 227-242

Treagust, D., Duit, R., Joslin, P., & Lindauer, I (1992) Science teachers' use of analogies: observations from classroom practice *International Journal of Science Education* 14, 4, 413-422

Tregidgo D & Ratcliffe M (2000) The use of modelling for improving pupils' learning about cells *School Science Review* 81, 296, 53-59

Publication Team:

Jane Smith
Head of Science Oaklands School Southampton
Dave Tregidgo
Head of Science Woodlands School Southampton
Jenny Wells
Team Leader in Chemistry Taunton's College Southampton
Mike Evans
Formerly Science Inspector Southampton LEA
Mary Ratcliffe
Senior Lecturer Southampton University
Su Eaton
Illustrator

With thanks:
for financial support,
Royal Society of Chemistry
Southampton L.E.A..

for comments on draft materials,
Royal Society of Chemistry
Caro Garrett Taunton's College Southampton
Science ITT trainees at Southampton University

Summer 2001