Responding to alternative conceptions in the classroom

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Alternative conceptions often impede learning in science. This Royal Society of Chemistry project aimed to develop classroom materials to diagnose and challenge specific misconceptions.

Alternative conceptions and good practice

There is now a vast literature reporting learners' ideas about science topics. This canon of work demonstrates that in any class, in any science topic, at least some of the students are likely to come to lessons already holding their own 'alternative' notions about the topic (Driver *et al.*, 1994). Often these ideas are labelled *mis*conceptions, but they are also referred to as 'alternative conceptions' and 'alternative conceptual frameworks'. These conceptions are often not just different from, but may also *contradict*, the science to be learnt. Sometimes students' alternative conceptions can be very tenacious, and are not greatly changed by instruction. Students may interpret teaching through their alternative frameworks, leading to a very different understanding from that intended by the teacher. If these pre-existing ideas are not diagnosed and taken into account by the teacher, they may interfere with further learning.

ABSTRACT
Research shows that students come to science classes holding a wide range of alternative conceptions about curriculum topics, and that these ideas often interfere with classroom learning. The Royal Society of Chemistry established a Teacher Fellowship project entitled 'Challenging misconceptions in the classroom'. Classroom materials to diagnose and challenge specific alternative conceptions were developed. Key ideas from research into how learners construct knowledge when learning science were used to inform teachers about strategies to teach science more effectively. The main outcome of the project is a two-volume resource that has been distributed to schools.

It is now considered to be good practice for teachers to make sure they are aware of their students' alternative conceptions at the start of a topic. Trainee teachers are encouraged to elicit students' ideas before teaching the topic, and to take student thinking into account when planning their teaching. Indeed, in the UK, they are expected to demonstrate proficiency in this aspect of teaching (*inter alia*) before they can be awarded Qualified Teacher Status. The Government is also including this aspect of teachers' work as a focus for its Key Stage 3 Strategy for science. Teachers in all state schools with 11–14 year-old students are being provided with continuing professional development (in-service training) including information about eliciting learners' ideas through such approaches as concept maps and concept cartoons.

One of the largest, and best known, research programmes in science education, the Children's Learning in Science Project, made the elicitation and discussion of learners' ideas a key part of its model for approaching curriculum development in science (Driver and Oldham, 1986). Diagnostic assessment in science teaching is also a key theme of on-going research being funded by the UK's government-funded Teaching and Learning Research Programme (TLRP).

The Royal Society of Chemistry project

Each year the Royal Society of Chemistry (RSC) appoints a Teacher Fellow to work on a project related to science education. These projects usually produce materials to support teachers, which are distributed to schools as part of the Society's educational work. The Teacher Fellowship project for 2000–2001 was entitled 'Challenging misconceptions in the classroom'. The present author was privileged to be appointed as the Teacher Fellow.

During the 2000–2001 academic year classroom materials were drafted, sent to schools for piloting and comment, and then written-up for publication. Teachers from a large number of schools and colleges from throughout the UK (as well as some overseas) helped by testing out the materials and offering comments and suggestions. Although the specific foci of the project were topics from chemistry, the overall approach was more generally applicable to teaching science. Indeed, one outcome of the project was the establishment of an e-mail discussion list on science learning, the Learning-Science-Concepts list, which is open to all those with a particular interest in aspects of learning in science.

A free resource for schools

The main outcome of this project is a book, *Chemical misconceptions – prevention, diagnosis and cure*, published in two volumes by the RSC, and distributed to secondary schools and 16–19 colleges in the UK. Volume 1 develops the rationale for taking learners' ideas seriously in teaching. It presents a view of how research from both the psychology of learning and from science education can be used as the basis for a practical approach to teaching science. Some of the key ideas are discussed in this article, which gives a flavour of how they were applied in the project. Volume 2 contains revised versions of the classroom probes and exercises tested during the project. These materials may be freely copied within schools and colleges for educational use. The specific classroom materials relate to science topics, primarily chemical in nature, from various parts of the 11–19 science curriculum (see Table 1).

Table 1 The published set of classroom materials.

Title of classroom resource	*Primarily useful for*
Changes	lower secondary (11–14)
Chemical comparisons	lower secondary (11–14)
Elements, compounds and mixtures	lower secondary (11–14)
Mass and dissolving	lower secondary (11–14)
Revising acids	lower secondary (11–14)
Word equations	lower secondary (11–14)
Chemical comparisons	upper secondary (14–16)
Ionic bonding	upper secondary (14–16)
Iron – a metal	upper secondary (14–16)
The melting temperature of carbon	upper secondary (14–16)
Precipitation	upper secondary (14–16)
Revising the periodic table	upper secondary (14–16)
Stability and reactivity	upper secondary (14–16)
Types of reaction	upper secondary (14–16)
Acid strength	sixth form (16–19)
An analogy for the atom	sixth form (16–19)
Chemical comparisons	sixth form (16–19)
Chemical stability	sixth form (16–19)
Definitions	sixth form (16–19)
Hydrogen fluoride	sixth form (16–19)
Interactions	sixth form (16–19)
Ionisation energy	sixth form (16–19)
Reaction mechanisms	sixth form (16–19)
Scaffolding explanations	sixth form (16–19)
Spot the bonding	sixth form (16–19)
Learning impediment diary	teachers

As well as covering a selection of topics, and being targeted at different ages within the 11–19 range, the individual classroom materials are written in a variety of styles. Some of the materials are designed to enable teachers to *elicit* common alternative conceptions. These probes may be used for diagnostic assessment before teaching a topic, in order to provide the classroom teacher with useful information to plan teaching. Some of these probes are equally suitable for use at the end of a topic, to check student understanding during revision, prior to a formal test.

Other materials were written to help teachers to *challenge* common alternative conceptions, or to model teaching approaches to develop the appropriate scientific understanding. Each of the classroom materials is accompanied by teachers' notes that explain the rationale and suggested use of the materials, and provide either a feedback sheet for students or suggested answers for teachers.

The first volume sets out to complement the classroom materials by explaining key ideas about how learners construct their scientific knowledge. Although alternative conceptions develop long before a topic is met in school science, there is also evidence that teaching can be the source of some tenacious misconceptions. A project with the brief of 'challenging misconceptions in the classroom' should not just be concerned with how to *respond* to alternative conceptions once they have appeared, but should also encourage teaching approaches that avoid some of the common misconceptions that are believed to derive from the way topics are taught. As the adage proclaims: 'prevention is better than cure'.

The project does not offer a revolutionary new way of teaching science: rather it attempts to bring together ideas on best practice based on research into science education and wider aspects of learning (Taber, 2000), and to show how they can be applied in the context of familiar science topics. In a one-year project there was limited scope for developing and testing novel teaching strategies, but it was possible to prepare a text about learning in science that could be made available to classroom practitioners for comment and appraisal. The draft text was circulated to interested teachers, and was then revised and developed into the first five chapters of the book (see Table 2). Chapters 6 to 9 apply the ideas in the context of key areas of chemistry, before the key ideas are reviewed in the final chapter.

Alternative conceptions and frameworks

The book begins with a discussion of the importance of learners' ideas in science. There is no attempt to provide a comprehensive survey of all the alternative conceptions that have been uncovered by research. A number of accessible books already deal with these issues, and the research into students' understanding of chemical topics has been reviewed for the RSC and is available via the Society's website (Barker, 2000). Rather, some examples of common misconceptions are discussed to illustrate the range and significance of such ideas, and how they may interfere with the teacher's job of explaining the scientific models. The reader is also introduced to the notion that, whilst some of the reported ideas may be seen as specific alternative conceptions, others may be integral components of more extensive (and tenacious) explanatory frameworks.

For example, it is common for learners to adopt a meaning for the term 'neutralisation' that implies a product which is necessarily neutral (Schmidt, 1991). It is easy to see how students may come to such a conclusion, taking their cue from the way the term 'neutralisation' derives from 'neutral'. As the

Table 2 The structure of the 'Theoretical background' volume.

Chapter	*Title*	*Notes*
1	Alternative conceptions in chemistry	Chapters 1–5 provide a general background to learning in science, and chemistry in particular, based upon research into learning and learners' conceptions
2	Concepts in chemistry	
3	The structure of chemical knowledge	
4	Overcoming learning impediments	
5	Scaffolding learning in chemistry	
6	Chemical axioms	Chapters 6–9 consider learning difficulties in key chemical topics, in terms of the ideas introduced in Chapters 1–5
7	Chemical structure	
8	Chemical bonding	
9	Chemical reactions	
10	Constructing chemical conceptions	Chapter 10 reviews the key themes

examples of neutralisation discussed in any detail in elementary chemistry often involve strong acids and strong alkalis which give neutral products, this assumption is readily reinforced – *unless* the teacher makes particular efforts to avoid students forming this conclusion.

This alternative conception does not match the scientific version, and could result in students becoming confused, and dropping examination marks later in their study of chemistry. However, it is a relatively discrete idea and when teachers are aware of the potential problem they may readily respond. For example, teachers may plan to include in their presentation of this topic specific examples where neutralisation does *not* result in a neutral product, to emphasise the way the term is used in chemistry.

Not all learners' ideas are so discrete. For example, the idea that reactions occur so that atoms can form full outer shells (or octets of electrons) is very common among students by the end of secondary schooling, and is widely used as a key explanatory principle by those starting college courses. One of the classroom probes used in the project demonstrated that A-level (i.e. post-16 college level) students will commonly 'explain' the reaction between molecular hydrogen and molecular chlorine in these terms, even though the explanation is evidently invalid. Yet challenging such an idea is made more difficult because it is part of a wider framework of ideas (Taber, 1999).

This alternative conceptual framework (the 'octet' framework) has an internal coherence, because it comprises a range of ideas that are mutually self-supporting. Like any well-established way of thinking, it is not easily overturned simply by demonstrating the inadequacy of some of its component ideas – especially before there is a convincing alternative available to the student. The reluctance of students to accept that cherished notions are inadequate has many precedents in the history of science!

Research has suggested that learners using the octet framework as the basis for thinking about their chemistry are likely to demonstrate a *wide range* of subordinate alternative conceptions (Taber, 1998), such as:

- in NaCl, each ion is only bonded to one other;
- a magnesium atom can only undergo two successive ionisations;
- an electron would not be attracted to a sodium Na^{+} cation;
- neon has a high ionisation energy *because* it has a full shell;
- the sodium Na^{7-} anion is more stable than the sodium atom;
- when bonds break, electrons necessarily return to their 'own' atom;
- hydrogen bonds are covalent bonds to hydrogen.

As such extensive frameworks of ideas are difficult to shake once established, it is important to attempt to understand why students should *develop* such a way of thinking, and to change the way we present topics to prevent such notions being acquired. In this particular case it is clear that the octet rule (a valid heuristic for determining stoichiometry in many compounds, and for identifying the charges on many common ions) has been promoted to the status of an explanatory principle, which has then been generalised far beyond its valid range of application. The teacher, then, needs to be concerned with finding effective ways to teach science that avoid 'misconceptions' forming, as well as with diagnosing and challenging such ideas once formed.

Student difficulties with conceptual learning

We must consider the nature of the concepts science teachers are charged with teaching, and the problems of communicating the meaning of some of the most central concepts in chemistry. Notions such as 'compound' or 'molecule' are fundamental to science, but cannot be clearly and unambiguously defined for students when they first meet them. Attempts at definitions tend to be either inaccurate, imprecise, or so wordy as to be unhelpful to learners. This was illustrated in the project by the lack of agreement between experienced teachers when asked to judge the accuracy and helpfulness of basic definitions. This may seem surprising, as definitions seem to be important in science – but in practice many scientific ideas cannot be explained easily through definitions. In many cases, the definition is only useful or meaningful to the student *after* the concept has been acquired. People tend to acquire concepts more by a process of trial-and-error than by applying definitions.

In explorations of 'concept formation', subjects are assumed to have acquired a concept once they are able to correctly identify examples from non-examples (Kellogg, 1997). A related approach to

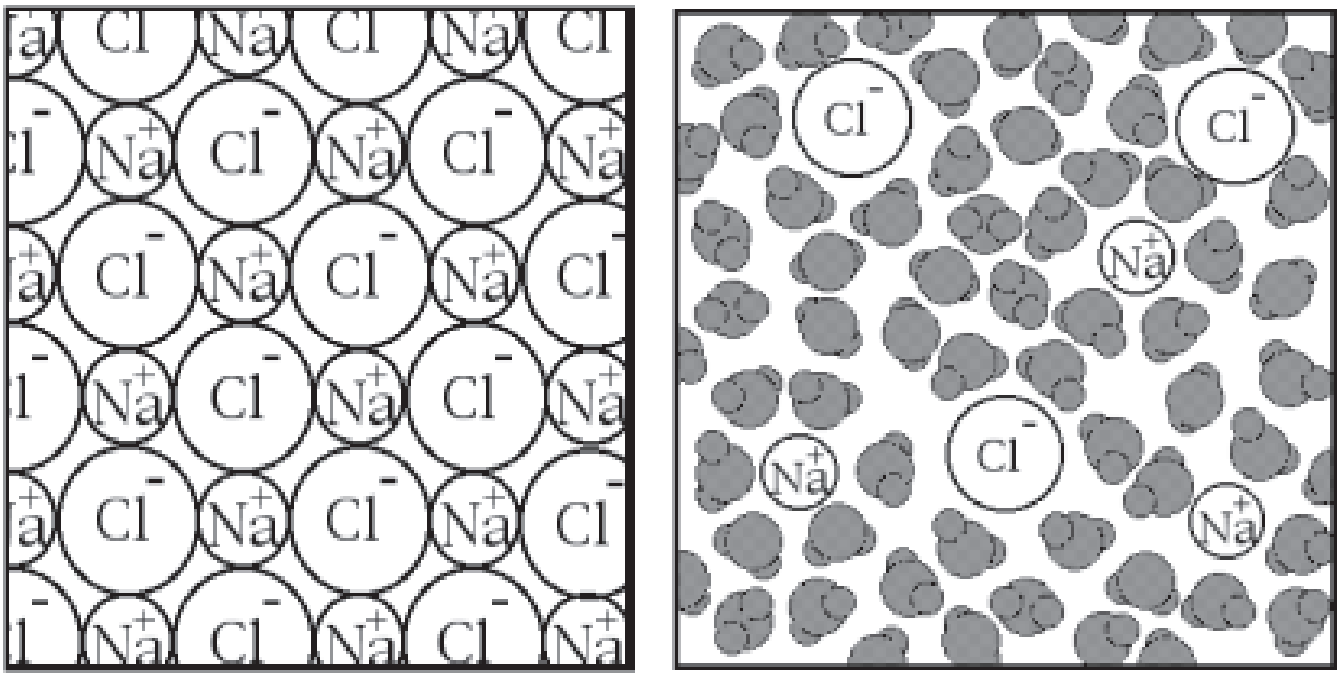

Figure 1 When asked to spot the differences between these two chemical systems, many students would suggest that both diagrams show mixtures, which would reveal a key area of misunderstanding.

exploring learners' ideas in science is to present pairs of diagrams of chemical species or systems to students and ask them to suggest similarities and differences. As a diagnostic tool this can be useful in helping teachers to spot alternative conceptions, as well as apparent 'gaps' in expected knowledge. Consider, for example, the similarities and differences that a 16-year-old might be expected to spot between the chemical systems represented in Figure 1. In this example many students would suggest that both diagrams show mixtures, which would reveal a key area of misunderstanding.

This set of classroom materials was designed to include examples appropriate for use with students at different stages of school and college chemistry. As well as acting as diagnostic tools for the teacher, it was felt that the exercises could also encourage students to form the mental habit of actively making comparisons between different scientific examples and systems, to help them refine their concepts. Such open-ended activities also provide scope for imaginative responses – giving a context for students to be creative. As such, the task is suitable for students at different levels of attainment, and – in particular – an opportunity for the most able to demonstrate divergent thinking.

Knowledge structures

So although definitions may be valuable summaries of knowledge, they do not reflect the 'natural way' we learn concepts, and are not usually an effective way of communicating scientific ideas to students. It may sometimes be sensible to introduce definitions at the start of a topic as 'advanced organisers', but our knowledge might be better represented as an evolving web of interrelated concepts.

The use of concept maps (which represent an area of knowledge graphically) can be particularly helpful here, both for teachers and students. Where some people may naturally tend to think about a topic in 'linear' terms, others find sequencing ideas, and finding logical precursors, much more difficult. Concept maps can be used to represent the formal structure of curriculum topics, for instance to help teachers in the initial stages of planning teaching. In the publication deriving from the RSC project (Taber, 2002) the example is given of a concept map for 'acid' based on the requirements of the English curriculum for 11–14 year olds.

Concept maps are also useful as a tool for eliciting student knowledge, *and* as an option for study and revision aids for students. Many (although not all) students find presenting information in such forms easier than writing revision notes and summaries. Concept mapping can also be a more open-ended (and on-going) task, which is suitable for generating useful formative feedback; it also encourages creative thinking and readily differentiates by outcome.

For teachers who are inexperienced in using concept mapping, or unsure how to introduce the technique to classes, the classroom materials included in the RSC publication include two revision activities based on concept mapping – for acids and bases at key stage 3 (11–14 year olds), and for the Periodic Table at key stage 4 (14–16 years). These may be used with students who have no prior experience of the techniques, and provide models for approaches that could be adopted. As with the other classroom materials, model answers are provided.

Being a learning doctor

The title of the publication, *Chemical misconceptions – prevention, diagnosis and cure*, alludes to the metaphor of the teacher as a learning doctor, who sometimes needs to 'debug' the students' scientific thinking. Such learning bugs, or learning impediments, are often found *even* among keen and able students who are ever-present and attentive during well-planned and well-executed lessons from skilled practitioners. Human learning is a complex process, and there is much to go wrong even when proficient teachers work with model students.

The vast literature on students' ideas and learning difficulties in science suggests a number of possible causes of failures to learn the intended scientific models (Taber 2001). These include:

- students not having the expected or necessary pre-requisite knowledge, and so failing to make sense of the teacher's presentation;
- students not recognising the relevance of the assumed prerequisite knowledge (for example, if the present teacher uses different terminology to a previous teacher);
- students coming to class already holding alternative ideas about a topic that are inconsistent with, and interfere with, the intended new learning.

Any of these situations can result in failures of teaching, but only by diagnosing the type of learning impediment operating in particular cases can the teacher take effective remedial action (the cure). Where alternative conceptions derive from prior teaching (rather than everyday experience or folk-science), there may be the possibility of changing teaching approaches to avoid problems in the future (the prevention). The project materials include a suggested approach to developing the learning doctor's diagnostic skills.

Seeing science at the learner's resolution

Teachers need to be able to 'step outside' their own expert subject knowledge to view the science at the 'resolution' that is available to the students. By 'resolution' I am referring to the way complex information is perceived. Where experts can recognise a familiar pattern (e.g. $CH_3.CH_2.COOH$) holistically, the novice does not have the prior experience to do this. The learner lacks the conceptual tools to code the information in this way, and sees the information at a 'finer grain size' (so it seems more complex).

Although good subject knowledge is essential for effective teaching, it can also present a barrier when teachers are trying to appreciate students' learning difficulties. Having spent years developing a coherent, well-integrated, broad and deep understanding of a subject, the teacher needs to become proficient at recognising how apparently straightforward ideas and clear logical explanations may often seem anything but simple and rational to students with limited, disjointed and inaccurate subject knowledge.

A key limitation to developing complex new knowledge is the learner's working memory. Working memory may be considered to be the 'mental scratch-pad' where information is processed when students are trying to understand new information or solve problems. It is known to have an extremely limited capacity, and may often act as the bottleneck in the student's cognitive apparatus. Teacher and student are likely to have similar limitations *in absolute terms* on how many items of information they can 'keep in mind', which might seem to suggest that most students should be able to 'keep up' with the teacher. However, this ignores the notion of the 'resolution' at which they experience the information. So, the formula $CH_3.CH_2.COOH$ can be perceived as a single datum by an expert with the knowledge to re-code (i.e. re-cognise) it as propanoic acid. However, the same information can seem complex to a relative novice, who has to try to keep both the component parts and their sequence (C; H; 3; •; C; H; 2; •; C; O; O; H) in mind at once.

Teachers' subject knowledge often allows incoming information to be eased into existing mental 'slots', but students will not have these conceptual templates available. (Consider the difference in trying to record the day's football results from the radio using a prepared coupon that already lists the fixtures in order, rather than starting with a blank piece of paper.) This is reflected in the difficulty that students often have in writing word equations.

One of the classroom probes asks students to complete word equations for examples of key reaction types discussed in school science. Some of the errors made by students show that although the questions may seem trivial (having answers which logically follow from the information provided) to the expert, nevertheless many students find the task beyond them.

As some key scientific ideas seem too complex when first met by many learners, teachers need strategies for helping learners develop their thinking, such as 'scaffolding' learning (Scott, 1998).

Learning as knowledge construction

The notion of scaffolding learning fits quite well with the idea of 'constructing knowledge' – something that can only be expected to be effective when there are 'solid foundations'. Although the term is much discussed, there seems less *practical* advice available on what 'scaffolding' *means* when teaching science.

Building-up knowledge is very different from building a house, but the notion of constructivism is more than just a metaphor. There is a very real sense in which students construct their own knowledge structures (which are inevitably somewhat at odds with the formal conceptual structure of the subject). Humans have no other choice than to build-up their conceptual frameworks piecemeal, because we do not have the conceptual apparatus to absorb whole areas of knowledge en masse: our brains just do not work that way (Miller, 1968).

Meaningful learning requires the student to relate what they are being taught to their existing knowledge, and so the notion of 'foundations' becomes germane. This is why it is important that teachers undertake conceptual analyses of topics to identify the necessary prior learning, and then audit the learners' knowledge to ensure there are no significant gaps or alternative conceptions.

However, even when the prerequisite knowledge is 'present and correct', learners may need help in identifying which aspects of prior knowledge need to be accessed. Even then, constructing scientific knowledge may be problematic in view of the limited capacity of the mental scratch-pad, and the complexity of the science as perceived from the learner's resolution. This is where scaffolding by the teacher is essential.

Developing scaffolding tools

The principle of scaffolding is that teaching should enable learners to achieve with support what they are not *yet* able to achieve unaided, and then to gradually reduce the support as they gain confidence and new skills. As the student learns to use the new ideas they become perceived as less complex, and can often be fitted into the new mental templates being developed. So the key to scaffolding is to find ways to reduce the apparent complexity of the material students are asked to focus on at any moment in time. In effect the teacher is trying to supplement the capacity of the learner's mental scratch-pad by organising a task so that a limited number of features need to be attended to at any moment.

Sometimes teachers do this very effectively through their development of explanations in the dialogues they hold in class. However, the RSC project attempted to consider what kind of paper-based classroom materials could provide similar support. There are two particular roles that such materials could take.

The first of these is concerned with helping the learner to *organise* their prior knowledge in the most suitable way for developing the particular new ideas. It is sometimes necessary not only to identify which concepts are relevant, but also to juxtapose them in a manner that will encourage particularly fruitful associations. Such 'advance organisers' were labelled as PLAtforms for New Knowledge. These scaffolding PLANKs provide the basis for developing novel scientific ideas.

The second type of scaffolding tool goes beyond existing knowledge and presents a framework for developing the new ideas. It provides sufficient cues and structure to allow the learner to take responsibility for completing the construction process. Such tools would be like DARTs (Directed Activities Related to Text) type worksheets, but whereas DARTs often review or reinforce existing knowledge, the scaffolding tool provides an outline for extending understanding. This type of resource was labelled as a Provided Outline LEnding Support, as the intention is that once the construction of new knowledge is complete the learner will then be able to discuss and apply the new ideas even though the scaffolding POLES have been removed.

Some examples of how PLANKs and POLES could be used in teaching scientific ideas (hydrogen bonding, mole calculations) are explored in the first volume of the project materials. Certain of the classroom materials also apply some of these principles: for example a resource to help students develop their skills in building up scientific explanations.

Writing such materials is time-consuming, but may repay the investment. There are probably many examples of teacher-written worksheets that act as effective scaffolding PLANKs and POLES already being used in schools and colleges, but for those teachers who feel they wish to develop more effective classroom materials, the RSC project will provide ‘food for thought’, and some examples to try out.

Making the connection

Learning is about understanding new ideas, and so teaching can be characterised as ‘making the unfamiliar familiar’. Meaningful learning depends upon understanding something new in terms of what is already known. (This is why failures to learn scientific ideas often come about when the learner does not recognise the relevance of prior learning.)

One of the most creative aspects of science teaching is finding ways to relate new ideas (especially the more abstract ones) to what the student already knows – to ‘anchor’ novel ideas to the ‘bedrock’ of well-established prior knowledge. Common ways of making the unfamiliar familiar include using models, analogies and metaphors. Science itself uses such approaches a great deal, so science teachers are often very imaginative in developing such learning aids. However, teachers need to remember that learners are often very naive in their use of such devices, and may take them too literally, or transfer inappropriate features from analogues.

One example that was used to illustrate this was the metaphor of the atom as a tiny solar system. It is known that learning about the particle model of matter used in science is a source of many alternative conceptions. Atoms are highly abstract, and if students are familiar with the solar system then – in principle – it could act as a useful model to introduce atomic structure.

In practice it was found that upper secondary students often had alternative conceptions of the forces at work in both the atom and the solar system, so that for many students it would be difficult to use either system as a suitable analogue to introduce ideas about the other. (A classroom resource based on this example is included in the project materials.)

When simplification becomes counter-productive

One of the most difficult tasks facing science teachers is ‘finding the optimum level of simplification’. Effective learning requires teachers to break ideas down into ‘learner-sized chunks’ and avoid details and complications that would confuse the issue. And yet some alternative conceptions in chemistry clearly derive from teaching that has attempted to avoid or ignore the more abstract aspects of the subject. A number of examples of this are discussed in the project materials. Simplification without *over*-simplification requires fine professional judgement. It is hoped that the project materials will help teachers gain deeper insights into achieving the balance between intelligibility and scientific validity.

Evaluating the project

Despite the generosity of the RSC in funding the present project it was naturally limited by the amount that could be achieved by one person in one year. Three key issues that informed the project were:

- the need for differentiation to meet the needs of all learners in a class;
- developing students’ metacognitive skills to help them become more aware and self-directed learners; and
- meeting the needs of students’ different preferred thinking and learning styles.

However, these important themes were necessarily subservient to the central consideration of challenging misconceptions. Each would be a worthy focus of a substantive project in its own right.

The time restraint was especially significant, in that it was not possible for most materials to be developed through several cycles of classroom testing. However, teachers' feedback on the classroom materials was generally positive (and sometimes very much so), and those features of draft materials that were criticised were amended wherever possible. The responses of students to the draft classroom materials are used as examples to illustrate the volume of theoretical background. An electronic news-list ('*Challenging chemical misconceptions*') was set up for those interested in the project, and more detailed analyses are posted on the list website. It is intended to add more reports in due course when further analysis of the data has been undertaken.

Early drafts of the texts that developed into Chapters 1–5 were made available to interested teachers. The feedback received was mostly very encouraging, suggesting that teachers found the ideas resonated with their own teaching experiences. Teachers seemed to find the 'theory' accessible and sensible, and relevant to their classroom practice.

The RSC committed considerable resources to the project, and the real test for whether the Society gets 'value for money' is the extent to which these materials are used in schools and colleges. I hope that any readers who work in UK schools or colleges and who have not yet seen the materials will seek them out, spend a little time evaluating them, and try out some of the materials and ideas in their teaching. The publication includes a form for teachers' comments and feedback will be very welcome. I found the year working on the project to be very satisfying, and I very much hope that the 'product' will prove to be a useful resource for science departments.

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Further information

Chemical misconceptions: prevention, diagnosis and cure has been distributed to UK secondary schools and colleges. Further information may be obtained at: http://www.chemsoc.org/networks/learnnet/miscon2.htm

Electronic versions of the classroom materials are now available at LearnNet: http://www.chemsoc.org/networks/learnnet/miscon2.htm

An electronic *news-list* for the project is available at: http://uk.groups.yahoo.com/group/challenging-chemical-misconceptions

An electronic *discussion* list on learning in science is available at: http://uk.groups.yahoo.com/group/learning-science-concepts

For the TLRP-funded research into diagnostic assessment in science teaching see: http://www.york.ac.uk/depts/educ/projs/EPSE-Project1.

References

Barker, V. (2000) *Beyond appearances: students' misconceptions about basic chemical ideas: a report prepared for the Royal Society of Chemistry*. London: Education Division, Royal Society of Chemistry. Available on LearnNet at: www.chemsoc.org/networks/learnnet/miscon.htm

Driver, R. and Oldham, V. (1986) A constructivist approach to curriculum development in science. *Studies in Science Education*, **13**, 105–122.

Driver, R., Squires, A., Rushworth, P. and Wood-Robinson, V. (1994) *Making sense of secondary science: research into children's ideas*. London: Routledge.

Kellogg, R. T. (1997) *Cognitive psychology*. London: Sage.

Miller, G. A. (1968) The magical number seven, plus or minus two: some limits on our capacity for processing information. In *The psychology of communication: seven essays*. Miller, G. A. pp. 21–50. Harmondsworth: Penguin.

Scott, P. (1998) Teacher talk and meaning making in science classrooms: a review of studies from a Vygotskian perspective. *Studies in Science Education*, **32**, 45–80.

Schmidt, H-J. (1991) A label as a hidden persuader: chemists' neutralization concept. *International Journal of Science Education*, **13**(4), 459–471.

Taber, K. S. (1998) An alternative conceptual framework from chemistry education. *International Journal of Science Education*, **20**(5), 597–608.

Taber, K. S. (1999) Alternative conceptual frameworks in chemistry. *Education in Chemistry*, **36**(5), 135–137.

Taber, K. S. (2000) Chemistry lessons for universities?: a review of constructivist ideas. *University Chemistry Education*, **4**(2), 26–35, available on the web at http://www.rsc.org/uchemed/uchemed.htm

Taber, K. S. (2001) The mismatch between assumed prior knowledge and the learner's conceptions: a typology of learning impediments. *Educational Studies*, **27**(2), 159–171.

Taber, K. S. (2002) *Chemical misconceptions – prevention, diagnosis and cure, Volume 1: theoretical background*. London: Royal Society of Chemistry.

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