

Scaffolding learning in chemistry

This chapter is concerned with the issue of how much help teachers should give learners ie the balance between 'spoon-feeding' and expecting students to cope without support. The notion of 'scaffolding' learning is discussed - that is providing support that is gradually reduced as the learner masters the material - and the technique of providing learners with scaffolding 'POLES' is introduced.

The problem of the optimal level of difficulty

Most teachers are familiar with the problem of deciding how difficult to make work that is set for learners. Some students always seem to want to be 'told the answers' (and some seem to think it is the teacher's job to simply provide information), but that is no good reason to acquiesce. Teachers set classes many varied tasks, not just to keep students busy, or to assess understanding (although that is useful), but because we tacitly know that learning is more likely to be achieved when learners are actively engaged.

Copying information from the board is often an 'activity' that implies that students are not actively learning, but this is not always the case. Good teachers can involve students in skilful expositions of a difficult concept area, with a certain amount of incidental copying (note-taking) along the way. However, it is generally recognised that most students do not actively process information when the task set is primarily of a copying nature. There are simple techniques to convert note-taking to a more active process (eg DARTS, which are discussed below).

Science, of course, is not just about learning facts (whether through copying or more active means), but involves learning how (and when) to apply the definitions, principles, models and theories that make up so much of what science is about. Useful learning involves developing the networks of meaning discussed in Chapter 3.

Worked examples may be given to get learners started, but students will only master the application of scientific ideas if they explore their use through the exercises set by the teacher. (At a higher level of understanding learners will be able to develop a mental 'toolkit' of concepts which they will use in solving problems where they have to select the appropriate tools and work their way to a solution.¹

Exercises, by contrast to problems, are used to practice the use of tools being acquired, and it will normally be clear to the learner which ideas he or she is expected to apply.) Teachers become skilled at writing exercises, and - indeed - sometimes it may be too easy for the teacher to produce a set of practice questions for students. Some learners find security in being able to answer large numbers of very similar exercises. Often these are students who do not reflect deeply on learning (or indeed on the point of being in the classroom at all!), and who value a column of Js, and a mark of '20/20', more than having mastered new ideas. Brighter learners may well lose interest after a few similar exercises, and see little point in spending time in what they recognise as a largely algorithmic and repetitive exercise. They need something more challenging.

However, I am sure most teachers will recognise that it also possible to underestimate the difficulty of tasks set for learners (see the comments about the Revising acids activity discussed in Chapter 3). Something that is set as a quick exercise to reinforce a new idea, can become a major challenge that takes most of the class much longer than intended. In a subject such as chemistry such a problem can readily arise. For one thing the teacher brings

to mind a wide range of pertinent and familiar background knowledge that learners may not recognise as relevant (see Chapter 4). The sheer subtlety and complexity of the subject - the wide range of models used for example (see Chapter 6) - can also overload learners.

Clearly part of the problem facing any teacher is that of differentiation as within any class the learners will have a wide range of skills and abilities, levels of confidence and knowledge, and preferred learning styles. No lesson, or lesson material, will be pitched at an optimum level for each learner. Even ignoring this, and thinking of a single learner, setting activities with the right degree of challenge is a significant undertaking.

A cartoon that always appealed to me showed a class at work at their desks, with one of the students with his arm aloft. The caption had the student asking to be excused, as his brain was now full. The humour that was intended derives from our familiarity with the fact that human brains seem to have an effectively infinite capacity to acquire more information. Our memories are not always accurate, and we do not always remember everything we might wish to, but they do not fill up! Yet, I suspect, the reason I found the cartoon funny was that - like most good jokes - I knew it contained more than a 'grain of truth'. I empathised with the cartoon student. Whilst our memories do not reach their potential capacity, we all know that sometimes we are overwhelmed by information. Our ability to think clearly about a topic can become overloaded. This can either be because the information is too complex, or because it is simply arriving too rapidly. Most of us are familiar with being mentally 'lost' and needing to step back, 'clear our minds', and start again. Some learners probably find much of their experience of studying science to be of that nature!

However, it is also common experience, that the same information may overload one person and not another, even when we judge them to be of similar ability. (And when the information content is different, the roles may be reversed.)² There are, then, two aspects of this phenomena that need to be explained; the experience of being 'overloaded', and its apparent variation between both individuals and context.

A limited register

Research shows that when people are asked to process nonsense information, they can only handle a very limited amount at a time.³ Indeed, it has been suggested that our working memories can only handle 7 ± 2 discrete items at once.⁴ Most people could not hold a random 10 string of symbols (eg f67H32mdOw) in mind unless they are able to find a way to chunk the information. Of course it is much easier to remember a meaningful string. (Even I could probably hold on to 0123456789 or keithtaber .)

The 7 ± 2 rule (ie from 5 to 9 depending upon the individual) appears to be general, and to be a limitation of our cognitive apparatus, ie of the fixed structure of human brains. This provides a significant 'bottleneck' to our ability to process information: this working space can be considered to provide the channel between the enormous amount of sensory information available to each of us at any time, and the practically infinite store of memories.

In many cases this feature of the human brain will provide the 'rate determining step' in learning activities. The learner can only cope with material that can be processed in terms of a very small number of units at once. However, we are able to 'chunk' material so that what has seemed to be several different items may be counted as less. The extent to which we can do this is largely determined by experience. The email address keith.taber@physics.org consists of a string of 23 symbols (more than 7 ± 2), but a reader with the right prior experiences (who was familiar with the general structure of email addresses, and the

common domain endings {such as .com and .org}, and who already knew the name of the author), would be able to process the information as though it was comprised of many fewer than 23 units. Thus the same information that will overload an individual who is not familiar with a topic, may seem perfectly sensible to another who is. This is true whether the topic is a football team, a boy band, Star Trek or aromatic chemistry.

If two learners of similar ability (and similar motivation to learn), are presented with the same information, but differ in background knowledge, they will cope differently. The same learner will make more of an explanation about a familiar topic than of another explanation of similar inherent complexity and logical structure about a less familiar topic.

Teachers, by definition, have much greater familiarity with the subject matter they teach than their students, and consequently it is very easy for teachers to underestimate the complexity of a learning task set for students.

Seeing chemistry at a different resolution

Elsewhere (see Chapter 4), I have discussed the problem of learners not having available in their minds the prior learning the teacher expects. This is an important problem, that may be approached to some extent by a conceptual analysis of the topic being taught (see Chapter 3). The teacher can specify the concepts upon which the new learning depends, and ensure learners have these ideas available before proceeding.

This is important, but may not be sufficient to ensure learners follow the teaching. It is not enough to check the right background is available, the teacher also has to ensure that the exposition provided, and tasks set, do not overload the learners' working space. This means that the teacher has to learn to perceive the conceptual structure at the resolution available to the learners. As most research into the learning of science has not (yet) focused on these issues, there is little specific advice to help teachers with particular topics. But with sensitivity and practice teachers can learn to see the complexity that the subject matter had, before years of thinking about chemistry resulted in much of it being neatly integrated into manageable chunks. The aim is to help learners move towards a similar level of conceptual integration, but this requires a major (mental) building programme.

Building needs foundations and scaffolding

Although the notion of 'constructing' knowledge may seem to be just a metaphor (see Chapter 10), the analogy between constructing a building and building an understanding of a subject, such as chemistry, is a useful one, just as a building needs firm foundations, so does learning. When the necessary pre-requisite knowledge is missing the structure cannot be built (a null learning block), or at least does not match the architect's plans (a substantial learning block).

Perhaps for some buildings, solid foundations are sufficient. I imagine building a pyramid might be like this: each layer can act as the foundation, and access route, for the next. Most buildings are more tricky; although the final configuration should be stable, one has to pass through some unstable intermediate states before that arrangement can be attained. A partly erected building often lacks the structural integrity to hold together unless it has external support. Without such support the building programme becomes non-viable; floors cannot be put in until there are walls to cantilever them, and walls cannot be reached because there is no floor to support the builder. In practice scaffolding is erected as a temporary source of support, until the building can progress to the stage where the scaffolding is no longer needed.

Knowledge construction can be seen to be closely analogous. Although one might imagine that a subject should be logically structured so that it can be built up brick by brick, many subjects cannot be learnt in such a straightforward way (see the discussion of the nature of chemical concepts in Chapter 2). Perhaps mathematics might aspire to be a 'pyramid' subject, with each theorem absolutely standing on others, down to the foundations of initial axioms. Science, however, is not quite like this. Scientific concepts evolve, and become better elaborated. Chemistry is a subject built upon models (see Chapter 6) - which are often mutually supporting. Chemists invent conceptual entities to help make sense of their data, and each new concept (acid, element, oxidation, orbital, hybridisation) opens up new investigations which allow a finer grade understanding of the behaviour of chemical substances - and allow us to refine and redefine the theoretical entities themselves.

For the learner, chemistry has much of the same nature; the more that is understood about one set of ideas (eg oxidation in terms of electron transfer), the better one might appreciate another concept area (perhaps, acids as electron acceptors). As discussed in Chapter 3, chemical concepts need to be seen as part of a network of inter-related ideas. Both the development of chemistry, and the development of student understanding, may be seen as iterative processes, proceeding through spirals of increasing sophistication. However, even if this was not the case, and chemistry could be reordered so that it could be taught as an entirely logical sequence of ideas, there would still be the problem of the learner's working space being limited to 7 ± 2 items. Even though the learner may know which group of the period table chlorine is in, and what is meant by electronegativity, and what bond enthalpy is ... a given exercise calling upon this knowledge may seem to require too many different pieces of information to be mentally juggled at once.

It may be pertinent here to note the change in question styles over the years as the perceived purpose of the public examinations shifted from being a way of selecting a few, to a benchmark to be achieved by as many as possible. Although it is argued that there has been no significant drop in the level and amount of chemical knowledge required, only a few questions now require candidates to select and organise information into lengthy answer.⁵ It is recognised that such questions are not very good at teasing out what most candidates actually know!

Scaffolding learning (1): trust me I'm a teacher

It seems then that teaching a complex subject such as chemistry requires the teacher to do more than just present the material clearly and in a logical order. The teacher must also help the learner by supporting them when the working space is insufficient to hold all the relevant factors in mind at once. In explaining a new idea to the class the teacher will refer back to the relevant prior knowledge, but not just to show how it supports the present topic. The teacher's role is almost that of a confidence trickster, persuading the learner that certain points have been accounted for (as is indicated by the appropriate jottings on the board) and can be ignored - or just taken as given - for the moment.

The teacher is taking responsibility for certain parts of the logical support of a new idea, and asking the learner to focus on others. (This is a bit like a parent telling a child it is safe to try and swim, because the child is being supported and cannot sink. In both cases, some children require more convincing than others.)

Scaffolding learning (2): being in the zone

Ideas about teachers 'scaffolding' learning derive from the work of a Russian polymath called Lev Vygotsky.⁶ Vygotsky wrote about learning (among many other things), and

introduced the notion of the zone of proximal development. However, as (a) he did some great work, and (b) he had the misfortune to die young, and (c) it probably does not sound quite as clumsy in the original Russian, we should perhaps forgive his terminology. Even those who write about Vygotsky's ideas tend not to use the full term - it is quaintly known as the ZPD.

Vygotsky was very interested in the social side of the learning process (writing at a time when the Soviet system was still seen as a revolutionary idea), and realised that a learner is often able to achieve a great deal more when supported by an adult or more expert peer. This may sound obvious, but Vygotsky did not mean that the adult sometimes actually did the work for the learner.

Vygotsky had realised that learning is not an all-or-nothing process. He decided that intelligence tests that showed what a student could currently do unaided were not that useful to teachers. What was more informative was to see what the learner could not yet do alone, but could achieve with a limited amount of support, as this indicated where the child had the potential or readiness to develop new capabilities. The ZPD was the 'learning space' near enough to the child's current achievements for development to take place if suitable support was provided.⁷

This idea brings us back to the common teachers' dilemma of how hard to make a task. Make a task too easy and it is boring and does not bring about learning. A task that is too difficult will not be achieved, is de-motivating, and does not bring about learning either. The teacher needs to get the students working 'in the zone', and to provide the support that enables them to develop.

Scaffolding learning (3): what does scaffolding mean in practice?

'Scaffolding involves changing support over the course of a teaching session.'⁸

In practice, teachers have to be able to set tasks that students are not yet able to succeed in when totally unsupported. The teacher then provides the support, which is gradually reduced as the learner is able to master the ideas, until no support is needed. At this point the learner is able to mentally chunk material so that tasks that were too involved and overwhelmed their mental 'working space', are now perceived as having fewer separate components. Also, at this point, these tasks are no longer within the ZPD, as they are now within the child's capabilities. The child's ZPD has also moved on, as the recently acquired capabilities provide the basis for working towards new targets that are now just out of reach.

A large part of teaching involves oral exchanges, and it is often through these that teachers gauge the learner's readiness to tackle new challenges, and detect when to move in with support. (The answers to teachers' questions are often 'signposted' as they are designed to teach, more than question: after all the teacher generally already knows the answers.) These teaching skills develop naturally with experience, although explicit reflection on ideas such as scaffolding and 'the zone' may be helpful. However, it is in setting written or practical tasks that the notion of scaffolding may be more obviously applied. Whereas classroom dialogue can be endlessly tweaked in real-time, worksheets and the like are presented to the class 'as seen', and calling for too many amendments in situ tends to undermine teacher authority and student confidence.

Planning to scaffold learning through written materials means thinking carefully about the conceptual and information processing demands of each task, and designing materials

where the onus on the learner is gradually increased. One piece of good news is that some of the same ideas will be helpful when thinking about notching up the demands on individual learners as when planning to differentiate learning tasks and outcomes within a group.

Preparing teaching materials: DARTs

One of the points made above is that it is generally acknowledged that simply copying information does not lead to meaningful learning, as effective learning requires active processing of information. Of course, this is not the same as saying that learning never accompanies copying. As intelligent people who think about their own learning and thinking processes, teachers are among those who could probably think about the meaning of material whilst copying it. However, we all know that many students will either focus on the mechanical task of copying, or will allocate their minds (and perhaps their tongues) to some other activity whilst 'mindlessly' copying.

One alternative to asking learners to copy notes is to set them the task of making their own notes. However, to do this effectively is a skilled task which requires considerable practice, and teachers are commonly worried about the final results being incorrect or incomplete. As students' notes often form the basis for reference and revision, it is usually judged important that they are correct.

The purpose of DARTs is to provide a middle way which;

- (a) gives a good chance of the learner having a full set of appropriate notes; and
- (b) requires learners to think about the materials.

DARTs are Directed Activities Related to Text.^{9,10} The simplest type of activities are passages with missing words, where the learner has to read the material to work out what the missing words are. (Sometimes Cloze procedure is used - removing every tenth words say - but it may be more effective to remove a number of selected key words. Variants include leaving the initial letter of the missing word, or providing the key words in a separate list.) Other activities can include labelling diagrams using information given in text or completing text using information given in diagrammatic formats.

It is possible to vary the degree of difficulty of DARTs to match students' needs. For example in a passage with words omitted, slow writers could be asked to fill in spaces on a sheet, when others in the group have to copy and complete the passage; and more words could be removed from a passage in the version given to the more able students in a group. There are a variety of DARTs type activities, but what they have in common is that they direct learners' attention to aspects of the text, rather than just copying. A number of the classroom resources provided in the companion volume include DARTs. The teaching exercises on Precipitation; Elements, compounds and mixtures; and on Constructing chemical explanations all have deliberate omissions which require students to think about the text they are reading. The less demanding versions of concept mapping activities discussed in Chapter 3 could also be considered as examples of DARTs.

The principle behind DARTs is not new. One variation is to provide a text passage, and have learners answer key questions about the passage in full sentences. The answers make up their notes, and this used to be called a 'comprehension' exercise!

Preparing teaching materials: scaffolding PLANKs and POLES

DARTs are designed to ensure that learners' minds are active when working on text. However, this alone does not ensure that the activity is effective at bringing about learning. As with all tasks teachers set, DARTs may still be pitched inappropriately. For example, a complete-the-missing-words- in-line-passage type activity might keep a group busy for twenty minutes without stretching most of the students.

If the task is too difficult the teacher will spot this when checking work (eg the omitted words are put back in the wrong places in the passage), but - as DARTs are normally designed so that the students' work is likely to be correct - it may be less easy to detect when tasks are undemanding.

In order to provide materials that help students develop their understanding, some of the ideas about scaffolding need to be taken on board. Students need to be provided with something more than just DARTs, they need to be given tasks which enable them to develop their knowledge and understanding - DARTs which act as scaffolding tools (see Figure 5.2).

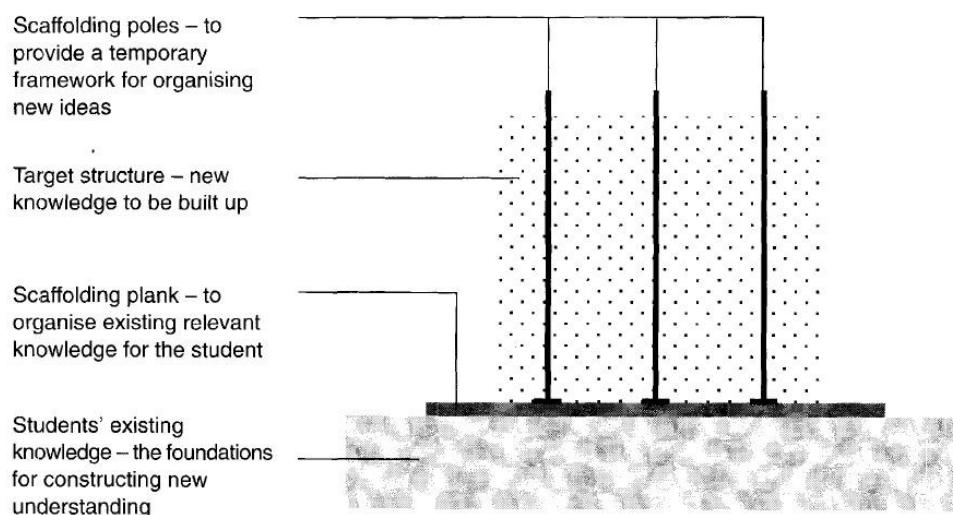


Figure 5.2 Scaffolding student learning

There are two types of support that will help students to develop their understanding, and construct new knowledge. Firstly, even when students have available the necessary prerequisite knowledge for new learning they may not always be aware of which ideas are relevant (see Chapter 4). In addition, the limited register for processing information (see earlier in this chapter) makes it difficult for students to juggle the information so that they can use it effectively as the basis for developing new learning.

Secondly, the logical structure needed to develop the new ideas may exceed the processing capabilities of the student. Although each step in an explanation may itself be manageable, the overall structure may 'swamp' the student and seem much too complicated. It follows that teachers can help in two ways. First, they can identify the necessary prerequisite knowledge, and not only be sure that students have covered the material, but that these ideas are marked out as relevant at the start of the new teaching episode. It may also be possible to organise the ideas for the students, into a form which will best facilitate the new learning. Secondly, the teacher can provide some form of partially constructed outline for the new knowledge, and make this available to the students as a guide for the new learning.

These two types of support may not always be clearly distinguished in practice, but it is useful to think of them as distinct types of support - taking the roles of providing 'horizontal' and 'vertical' support in Figure 5.2.

Scaffolding POLES and PLANKs are designed to be components of the scaffolding which helps learners achieve at levels they cannot reach unsupported. They enable them to practice, become familiar with, and feel successful with new ideas that they can then make their own. They are structures which offer support, but which will soon be outgrown. PLANKs are Platforms for New Knowledge. Scaffolding PLANKs are presentations of ideas that are already available to students, but arranged in a form which aids the student in reorganising their knowledge to build up new ideas.

POLES are Provided Outlines Lending Support.¹¹ Scaffolding POLES are provided by the teacher, and give a framework (outline) for exploring and succeeding in a concept area, that allows the learner to come to know about the topic. They lend support, because they are only to be relied upon whilst the learner is developing understanding and confidence in a topic. Some DARTS may well be very effective PLANKs or POLES, but designing materials to help scaffold learning means taking additional requirements into account.

Principles behind POLES and PLANKs as learning materials

For learning materials to be considered as providing scaffolding, they should (individually, or as a set) meet the following criteria:

1. They must ask the learner to undertake an activity/task which is beyond their present ability if unsupported;
2. They must provide a framework of support within which the learner can be successful by relying on the structured support;
3. They must provide reduced support as the learner becomes familiar with the area, and is able to cope with increased demands;¹² and
4. They must result in the learner being able to undertake (unsupported) the activity/task which was previously beyond them.

The need for scaffolding PLANKs in learning chemistry

Earlier in this chapter the idea of 'seeing chemistry at a different resolution' was introduced. This simply means that the teacher has to try and see the complexity of a subject as it appears to the student. Even able and eager students are unlikely to have organised their chemical knowledge as effectively as the teacher - refining the organisation of knowledge can be a very slow process. This means that even when the teacher is convinced that the learner already knows of all the prerequisite knowledge needed for developing a new idea, the learner may not be able to readily access and order the information in the ways needed to build upon it. The teacher may need to help the students organise their knowledge.

Chapter 9 discusses an example of the type of learning difficulty that students may demonstrate. Research interviews found that some students may believe that when an ionic precipitate forms, there is an electron transfer to form the ionic bond. This finding has been reproduced in responses to a classroom probe included in the companion volume, A reaction to form silver chloride. So, for example, if solutions of silver nitrate and sodium chloride are mixed, then the precipitate of silver chloride may be considered to form, with an ionic bond between the silver and chloride ions. This may be explained (by students) as due to an electron transfer process:

'The outer electron in the silver transfers from the outer shell of the silver to the outer shell of the chlorine. This is called ionic bonding.'

Some students who made such responses had already, a few lines before in the same probe, demonstrated that they were aware that silver ions and chloride ions were already present in the reaction mixture. Yet in the face of an existing alternative conception (that ionic bonding always results from electron transfer to form ions - see Chapter 8), they did not effectively organise their knowledge about the species present in order to produce an explanation that was consistent with their earlier answers. Presumably the perceived complexity of the information available in this context prevents the student being aware of the contradiction in their answers.

An example of a PLANK

Consider, for example, that the idea of hydrogen bonding was to be introduced. There are a number of prerequisites that would be needed for the student to make the intended sense of the new concept.

A conceptual analysis (perhaps in the form of a concept map, as described in Chapter 3) might look something like that shown in Figure 5.3.

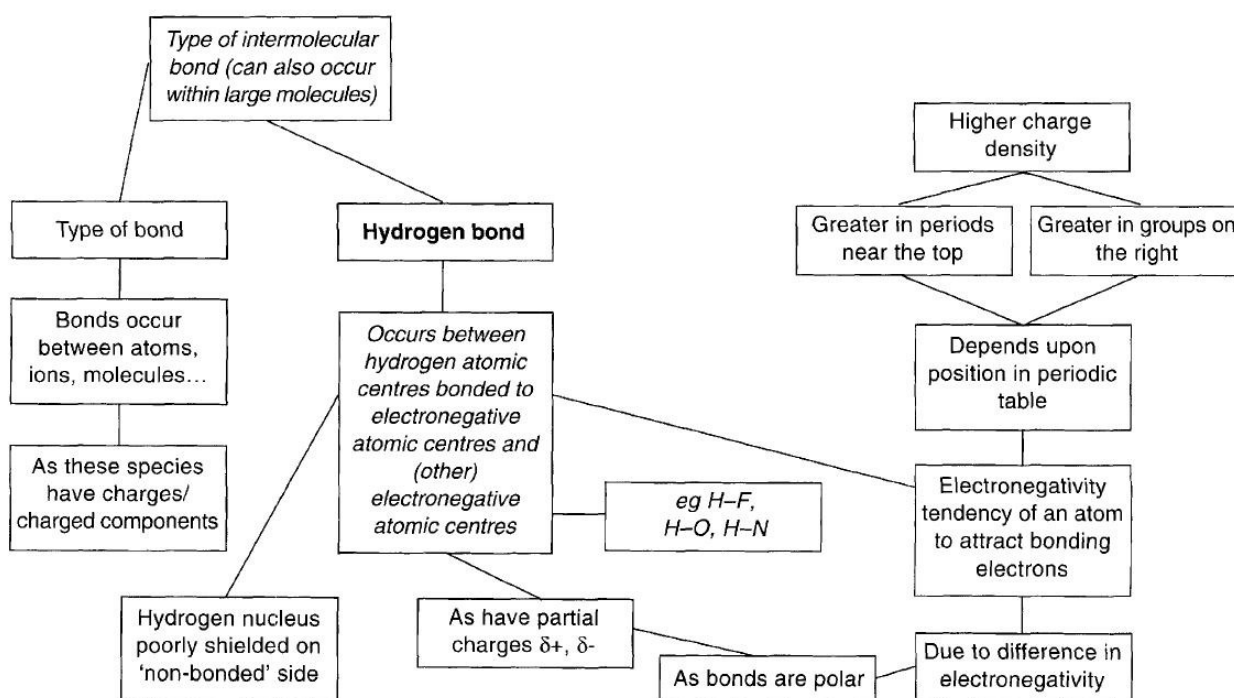
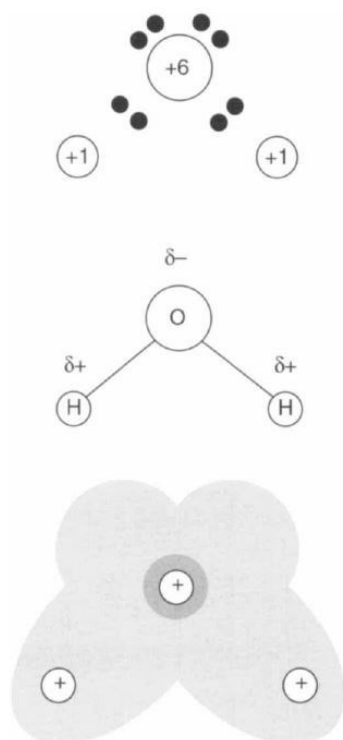


Figure 5.3 A suggested conceptual analysis for introducing hydrogen bonding

This particular scheme does not include all the ideas about hydrogen bonding that students may be required to learn (effects on boiling temperature, role in protein structure...), but shows the information being presented to introduce the new concept (shown in italics) and how this relates to the prerequisite knowledge that should be available to the students (but may often have been learnt in a more fragmentary way, and so may not be so well structured).

Once the teacher has made this analysis it may be used to plan the teaching. Figure 5.3 could be used to design a set of questions, or simply to provide set of teaching points that will be reiterated at the start of the lesson when hydrogen bonding is to be introduced. Figure 5.3 could also form the basis of a more specific PLANK for the students (see Figure 5.4).



The water molecule

The diagrams are different ways of drawing the water molecule. They may help you to answer the following questions:

What do we mean by 'bond' in chemistry?

What exactly is the bond between an oxygen atomic centre and a hydrogen atom atomic centre in a water molecule?

How would you describe the average position of the bonding electrons in the O–H bond?

Why are the bonding electrons not found half way (on average) between the oxygen atomic centre and the hydrogen atomic centre?

What type of bond holds the water molecules together?

Why are the bonds in a water molecule not strictly 'covalent'?

How would you describe the pattern of electron density (the shape of the 'electron clouds') in a molecule of water?

How well are the three atomic nuclei in a water molecule 'shielded' by the electrons?

Figure 5.4 A PLANK for organising prior learning

Figure 5.4 shows a student worksheet that might be used as an 'advanced organiser', to get students thinking about relevant ideas (bonds as attractions, electronegativity, bond polarity etc), and to organise these ideas into a suitable logical framework for learning about a new idea – hydrogen bonding.

Although some students may well find this activity sufficient to construct the idea that there will be forces (and therefore bonding) between different water molecules, the activity in Figure 5.4 does not explicitly lead students to construct this new knowledge. In order to help most students move beyond their prior learning, they will need an explicit input from the teacher. This could simply be a verbal exposition, building upon and developing the prior learning that has been highlighted. Alternatively, a specific learning activity could be provided - such as that shown in Figure 5.5.

Interactions between water molecules

Activity: cut out the cards with the diagrams of water molecules.

Take three copies of the first type of diagram. Place them on a piece of white paper.

Imagine the molecules are in liquid water and are moving around near each other in the liquid.

Repeat this exercise with the different types of diagram.

Can you work out how the molecules will influence each other?

How will the molecules tend to become arranged?

Why does it take energy to pull the molecules apart?

If the liquid were to freeze, how might the molecules be arranged in the solid (ice)?

It has been suggested that there are bonds between water molecules in (a) ice, and (b) liquid water.

Explain whether you think this is correct or not.

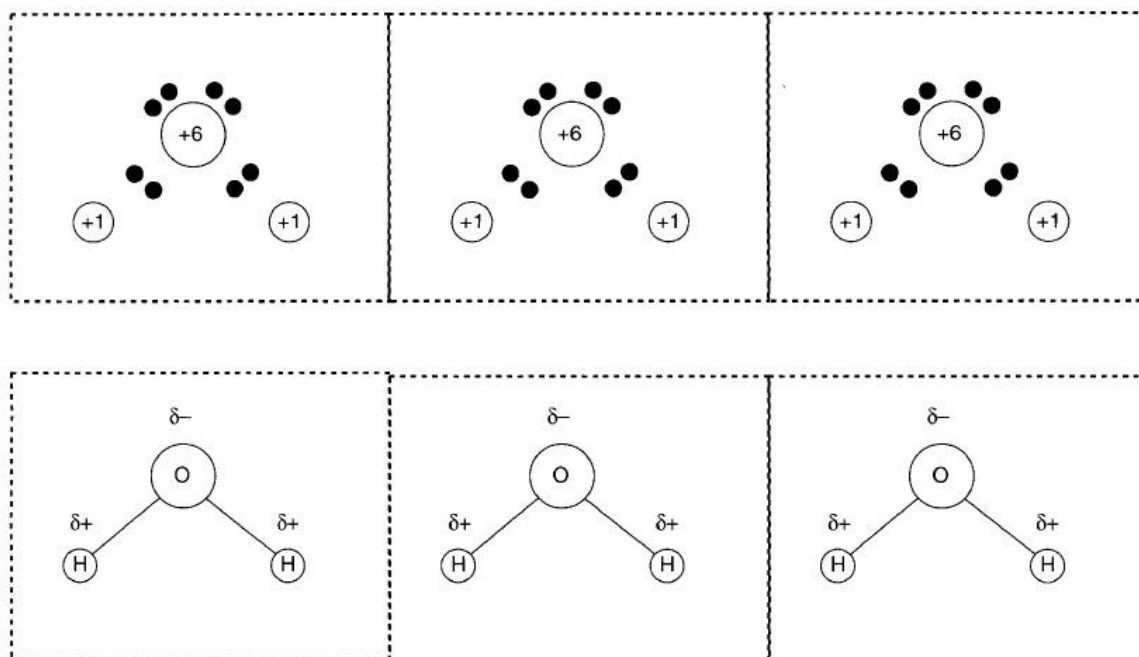


Figure 5.5 A scaffolding activity for developing new learning

The activity shown in Figure 5.5 provides a structured set of questions and an associated activity, designed to help learners construct a new understanding from a re-arrangement of their existing knowledge.

Whereas Figure 5.4 provides the 'advanced organiser' to 'prepare' the mind of the learner, Figure 5.5 provides a framework for building upon that preparation. The modelling activity provides a context to notice that molecules will attract - in certain configurations. The questions lend the outline of a logical argument to support the construction of new understanding (see Figure 5.6).

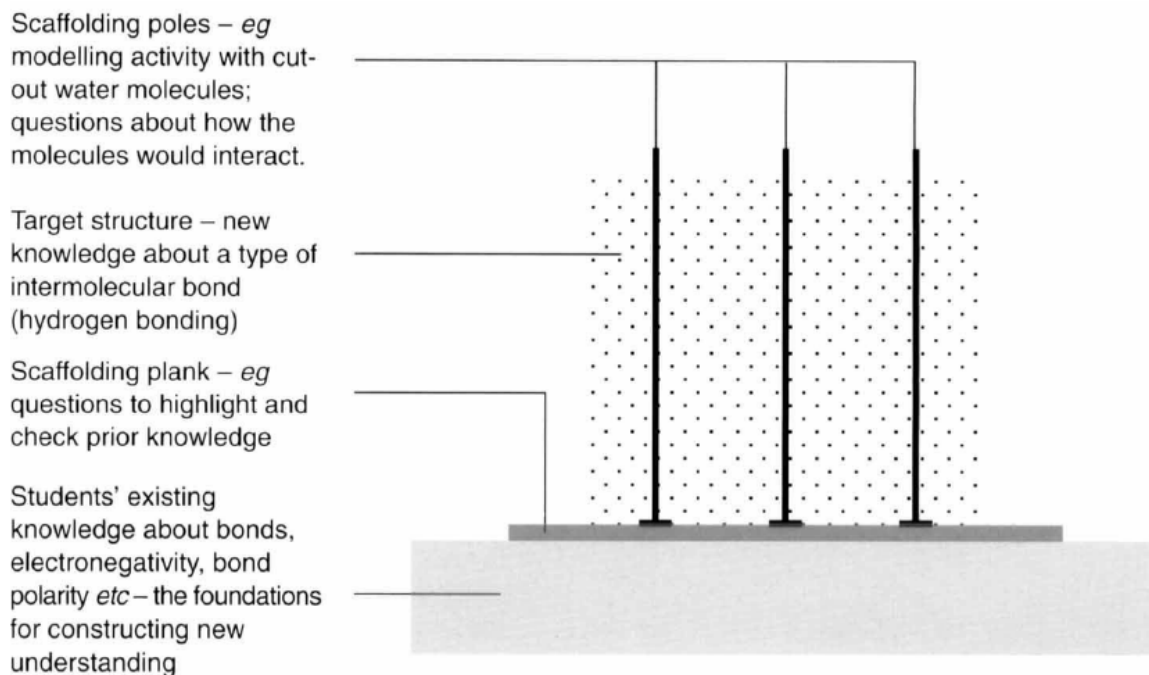


Figure 5.6 Scaffolding learning about hydrogen bonding

Examples of using scaffolding POLES in teaching chemistry

There are many places in a chemistry course where the teacher can provide a suitable outline to lend support to learners. For example, some learners find mole calculations to be particularly difficult. A traditional approach would be to introduce the key ideas, provide a few worked examples, and then set some practice exercises.

Many teachers will carefully choose the examples, so that once a few questions have been successfully completed, some slightly more complicated examples are included. This approach will usually ensure the task is not too straightforward to challenge the most able (or most mathematically confident) in the group. However, it is common experience that weaker learners often find even the most basic questions too difficult, and it is these learners especially that may need POLES.

The first level, beyond the totally worked examples, may be an example which is completely worked, apart from a one or two places where the student's input is required. These 'gaps' may be simply the result of numerical stages in the calculation (*eg* $12.0/3.0 =$). This will help learners to see that the actual mathematical stages are quite straightforward, and rely only on the familiar arithmetic they use all the time. Once assured, they can start to focus on the chemistry. In subsequent questions the level of support is gradually reduced. Each exercise should build on the previous either by being slightly more complicated (involving the relative molecular mass of a ternary compound rather than a binary compound; an additional significant figure in the data given), or by requiring an additional step to be undertaken by the learner.

This type of approach may be useful with both elementary mole calculations, and when introducing advanced students to the calculations involved in quantitative titrimetric analysis.

Similar approaches may be used with other types of calculations involved in chemistry, such as from Born-Haber cycles, electrode potentials, enthalpies of combustion, or oxidation

numbers. In each such area, a 'script' can be produced, from which components can gradually be removed until the learner is working with nothing but the question data and a blank sheet.

Scaffolding POLES in chemical explanations

Another area where learning may well need careful scaffolding is that in providing explanations. A common feature of chemistry lessons, and of chemistry examinations, is of using various models and chemical principles to provide explanations.¹³ The range of explanations students are required to provide in an advanced course is quite large:

- patterns in ionisation energies;
- variations in lattice enthalpies;
- shapes of molecules;
- differences in covalent and ionic radii; and
- differences in melting/boiling temperatures, *etc.*

In principle, a keen student should be able to learn the various principles involved, and so readily produce the appropriate explanations when needed. After all, once the principles are understood, it should be fairly obvious which ideas are needed. Yet to many students these types of questions are quite mysterious, and the process of producing an explanation seems to be little more than guesswork - 'there was a question a bit like this last year, and the answer was hydrogen bonding, so I'll go for that...'.

Sometimes it may be quite frustrating to the teacher when the 'right' answer seems to be obvious to anyone who thinks about the question, but the learners shrug their shoulders and settle for their favourite catch-all, be it steric hindrance, entropy, d-level splitting or the presence of a lone pair.

Keen, hard-working, students 'know' that questions about ionisation energy tend to need one of the stock answers ('it's in the p-orbital not the s-orbital', 'the electron is in a shell nearer the nucleus', 'the effective nuclear charge is greater', or 'it's due to spin-pairing'), but often seem to make a random selection.

Of course the teacher not only has a much greater familiarity with the subject matter, and a much better appreciation of how the different ideas fit together, but often also has years of experience of working through similar examples with successive classes.

Often the teacher is convinced that the learner 'knows' all the information needed to produce the right answer, that the student has learnt their notes, and only has to analyse the question logically. To the teacher the question can readily be answered without exceeding the 7±2 capacity of the working memory: but not for the student. The student is trying to remember all the factors relating to patterns in ionisation energy, and think about the electronic configurations of the species specified in the question, and work out which orbital the removed electron was in, etc all at the same time.

The teacher may be carrying out the same set of logical operations, but is able to manage the process so that only the relevant points are kept in mind at each stage. As with the example of mole calculations, the student needs to be provided with a structure which helps them limit the amount they need to deal with at once.

Although this may seem like reducing chemistry to a set of algorithms, it is important to realise that the algorithms are only intended to lend support. As the student practices examples successfully (and therefore gains confidence as well as expertise) the outlines given with questions should be phased out.

Modular explanations

Students may be given quite minimal tasks as they set out on learning a new skill. Most explanations required of chemistry students may be broken down into a discrete number of steps. The teacher may map out such explanations in the form of a simple schematic, such as a flow chart. The schematic may be used as the basis for POLES to be provided for students.

Consider the question: explain why aluminium has a lower standard molar first ionisation enthalpy than magnesium.

This is the type of item that a post-16 level (ie 16-19 year old) student would be expected to be able to answer in an examination or test, by producing a few lines of logical, coherent, and literate prose. The level of detail to be provided in the explanation will depend upon the amount of credit available. However, it is possible to prepare a schematic (see Figure 5.7) for the type of points that could be made.

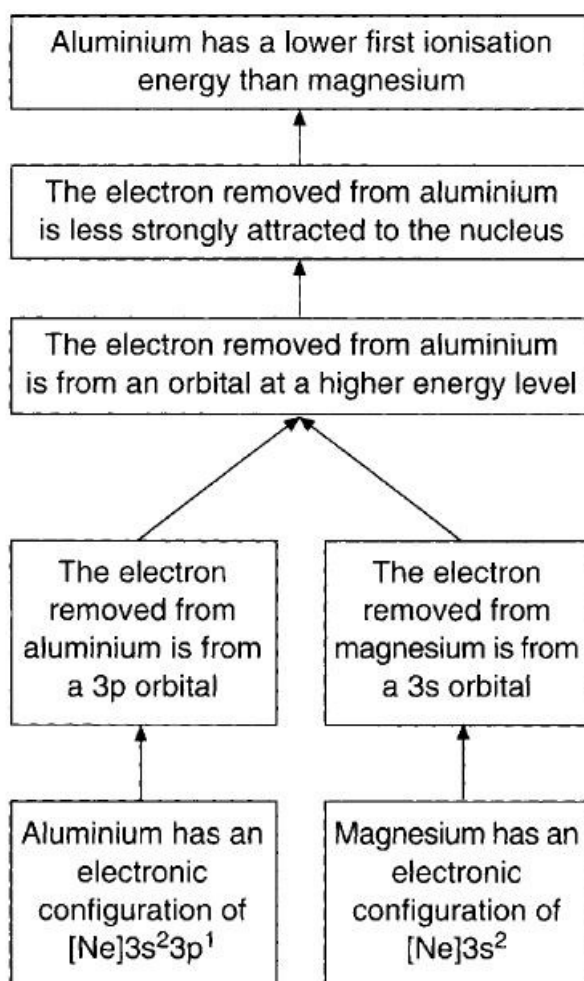


Figure 5.7 A schematic explanation

The value of the schematic is that;

- it provides a logical analysis of the material;
- it provides a starting point for producing scaffolding POLES; and
- it demonstrates the constituent parts of the explanation.

The latter point is important because it will help students recognise the common elements that are often used as the components of explanations.

In using such schematics as the basis for scaffolding learning, there is a spectrum of possibilities that bridge between (at the highest level of support) providing the schematic, and then asking the learner to use it to prepare a short prose explanation of why aluminium has a lower standard molar first ionisation enthalpy than magnesium (*ie* a basic DART activity); and (when support is no longer needed) just setting the question itself. Two possible intermediate stages are shown below (Figures 5.8 and 5.9).

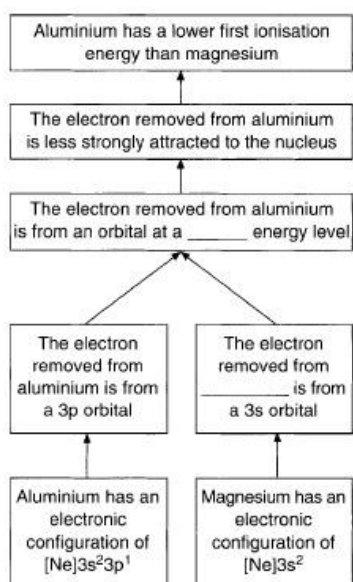


Figure 5.8 A DART of low level demand

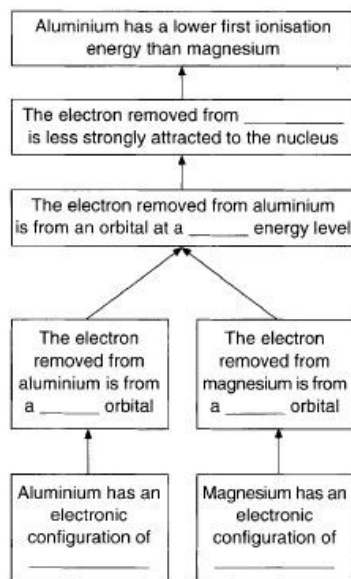


Figure 5.9 A DART of higher level demand

Figure 5.8 shows a version of the DART which provides nearly all the information, so that the missing words should be obvious from the logic and symmetry of the schematic. The second version (Figure 5.9) still provides a complete logical structure for the explanation, but requires the student to think much more about the direction of the logical relationships. Clearly the first version will be too simple for many students, but, similarly, some students would not immediately be able to cope with the demands of the second, and would need to 'build up to it'.

The brightest students can be asked to develop the provided schematics further - for example incorporating additional factors such as the effects of increasing core charge and the amount of repulsion between electrons in the M shell, or extending the schematic to relate the electronic configuration to the elements' places (group and period) in the Periodic Table.

Providing a set of outlines (based on an explanation schematic) with different amounts of completion needed, for each of a range of exemplar questions about ionisation energy (or shape of molecules etc) is clearly a task that requires time and effort. However, once such materials are produced they should enable the teacher to match the task to the student to allow for both the range of abilities within a group, and to scaffold students at different stages to build up competency in providing appropriate explanations.

One of the classroom resources included in the companion volume, *Scaffolding explanations*, provides students with a set of questions, requiring explanations, similar to the example discussed above. Explanations set out as flow charts (with some missing elements) are provided to help support the student.

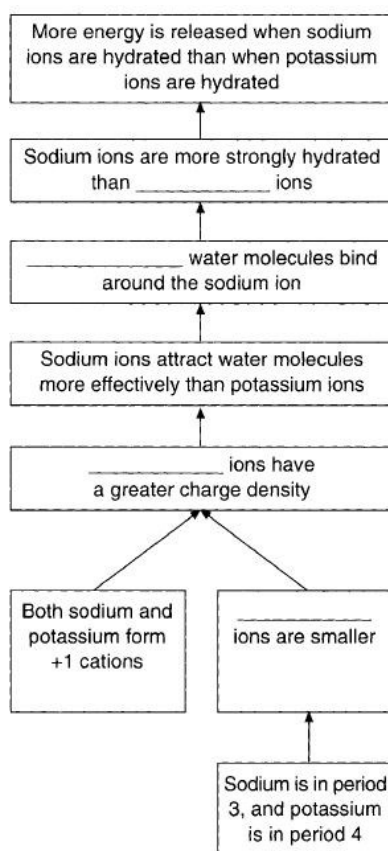


Figure 5.10 Explaining difference in hydration energy

For example, one of the statements that needs to be explained states that 'more energy is released when sodium ions are hydrated (390 kJ mol^{-1}) than when potassium ions are hydrated (305 kJ mol^{-1}).

One student, who was unable to give any explanation of this on the pre-test, Explaining chemical phenomena (I), despite making attempts at other questions, was able to use the flow chart (see Figure 5.1 0) to construct an explanation:

'because more water molecules bind to sodium than to potassium because sodium attracts the water molecules more effectively as sodium ions are smaller and have larger charge density whereas both are +1 cations.'

This, in itself, is hardly proof that this student has understood the ideas at a deep level, or will be able to reconstruct this explanation (or a related one) later when needed. However, being able to construct a valid explanation with the support of scaffolding POLES is seen as part of a process of gaining confidence and familiarity with the types of explanations used in the subject.

Notes and references for Chapter 5

1. K. S. Taber, An analogy for discussing progression in learning chemistry, *School Science Review*, 1995, 76 (276), 91-95.
2. For example, one study showed that although adults were better at recalling random digits than 10-year old chess experts, the youngsters outperformed the adults when asked to remember chess positions. See A. D. Pellegrini & D. F. Bjorklund, *Applied Child Study: a Developmental Approach* (3rd Edition), Mahwah, NJ: Lawrence Erlbaum Associates, 1988, 128.
3. A. H. Johnstone, Some messages for teachers and examiners: an information processing model, in *Research in Assessment VII: Assessment of Chemistry in Schools*, London: Royal Society of Chemistry Education Division, 1989, 23-39.
4. G. A. Miller, The magical number seven, plus or minus two: some limits on our capacity for processing information, in *Psychology of Communication: Seven Essays*, Harmondsworth: Penguin, 1968, 21-50.
5. V. Barker, It's my party - and I'll cry if I want to!, *Education in Chemistry*, 2000, 37 (3), 72-74.
6. P. Scott, Teacher talk and meaning making in science classrooms: a review of studies from a Vygotskian perspective, *Studies in Science Education*, 1998, 32, 45-80.
7. A. Drukovskis, The Zone of Proximal Development, at http://chss2.montclair.edu/sotillos/_meth/OOOOOO14.htm (accessed October 2001).
8. J. W. Santrock, *Life-Span Development* (7th Edition), Boston: McGraw-Hill, 1999.
9. L. Bulman, *Teaching Language and Study Skills in Secondary Science*, London: Heinemann, 1985.
10. F. Davies & T. Green, *Reading for Learning in the Sciences*, Oliver & Boyd, 1984.
11. The acronym POLES was originally intended to stand for Provided Outlines Lending Epistemological Support - as epistemology is about how we come to know, ie our grounds for believing in something.
12. In other words, as the perceived demand of the original task seems less to the student.
- 13.1. K. Gilbert, K. S. Taber & M. Watts, Quality, Level, and Acceptability of Explanation in Chemical Education, 2001, available at <http://uk.groups.yahoo.com/group/learning-science-concepts> (accessed October 2001).