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Exploring the Curriculum Model for teaching about the Nature of Science

Keith S. Taber

The Cambridge 'Teaching about Ideas and Evidence in Science' project developed out of two existing interests – the nature of explanations in science, and challenging able students in science – and focused on the idea of the 'curriculum model' for what is sometimes called the nature of science. This commentary for teachers describes the background to the Cambridge project, and some of the work that was undertaken with a group of trainee teachers, and by individual trainees in schools. A range of related material is included on the CDROM, and this is flagged (with the symbol) where it is most relevant.

What do we mean by a curriculum model?

School science is not the same as 'real' science as experienced by professional scientists (Kind and Taber, 2005). This is obvious perhaps, but sometimes, when we are working with the school curriculum and examination specifications for so much of the time, we can easily forget this, and treat what we do school laboratories as if it *is* science.

Of course, professional scientists work at their science full-time, often in well-resourced workplaces, usually focus on one small aspect of science for months (if not years), and have been well prepared for their professional role. It would be quite ridiculous to imagine a KS3 pupil expected to be able to match this level of work in science, either in terms of conceptual understanding or in carrying out enquiry.

School science should be something that is *authentic*, in the sense that it *reflects* professional science to give pupils a good feel of what science is about and what it involves. However, school science has to be pitched at a level that pupils can be expected to engage with successfully. So there is always a balance to be achieved in preparing a curriculum, syllabus or scheme of work. The science in the curriculum should *reflect* Science whilst still being suitable for learners of a set age, intellectual development, and existing conceptual knowledge.

Science teachers would all accept that science has to be simplified for learners – but another way of putting this is that the material specified in the curriculum *is a model* of aspects of Science. All teachers also know that pitching material at the right level for a particular group of students is a skilled operation, and not always something we get right the first time. So considering the descriptions of science found in the National Curriculum as curriculum models, does not in itself tell us whether they are good models or not. The process of simplification always means we have to leave details and complications out, and different teachers we may well have different views about what should or could be left out in explaining key scientific ideas.

My own trainee science teachers have sometimes latched onto a term used by Jerome Bruner – intellectual honesty,

Quote from Bruner

> "We begin with the hypothesis that any subject can be taught effectively in some intellectually honest form to any child at any stage of development"
>
> (Bruner, 1960, p.33.)

Our curriculum models need to simplify the complexity of science, but if we *over*-simplify, then we end up with something that no longer authentically reflects the science we are trying to teach pupils about: it is no longer an intellectually honest model.

So a good curriculum model would show the 'optimum level of simplification': simple enough for the pupils to understand, but still intellectually honest. To just illustrate this point, let's consider three scientific concepts we might wish to model in the curriculum: photosynthesis, energy and ionic bonding.

Photosynthesis is a very complicated process, where a thorough scientific understanding involves some rather complex ideas about photons being absorbed and electrons being promoted in molecules. At the secondary level we do not need to go into these details – we can present a model in terms of sunlight being absorbed by a pigment called chlorophyll and this allowing a chemical change to take place. This is not a thorough model, but it is intellectually honest.

Energy is a fundamental idea in science, and quite rightly considered a 'key idea' at Key Stage 3 (DfES, 2002). Yet, it is also a very abstract idea, so it is difficult to know how best to present it in the school curriculum. All the common approaches – the potential to do work, what we need to get things done, the go of things – can run into problems, so there is a genuine issue of what might be the best curriculum model for the energy concept? (Millar, 2003).

Ionic bonding is one of the main types of chemical bond studied in secondary and college chemistry. Upper secondary students are often taught that the ionic bond is the transfer of an electron from (for example) a sodium atom to a chlorine atom to form ions of sodium chloride. It is common for students to learn that (a) the bond is the transfer of electrons, and that (b) therefore in NaCl each ion is bonded to one other ion. For many students this is an idea they find difficult to overcome later if they decide to study chemistry at higher levels.

Teaching secondary level pupils that the ionic bond is the transfer of an electron from a metal atom to a non-metal atom, or even just implying that the ionic bond is always formed by the transfer of an electron from a metal atom to a non-metal atom, is not only likely to mislead learners about the nature of ionic bonding, but it is actually 'bad science'. This is a poor curriculum model because - although it is simple enough for the learners to understand - it does not reflect the scientific model. To present ionic bonding in this way (which many text books do!) is intellectually *dis*honest – it gives learners the impression they understand something, but is a false representation of the science. (In case any reader is not convinced of this, consider how it is possible to understand the ionic bonding in a precipitate, or even in NaCl formed by neutralisation followed by evaporation, if you teach that an ionic bond is formed where electron transfer has taken place.)

So here we have considered three science concepts where we present curriculum models. In one case we can simplify fairly unproblematically, and produce a model of photosynthesis that is a suitable basis for understanding and further learning; in the case of energy there is still something of a live debate on how best to teach the topic – what the most suitable curriculum model would be – although helpful advice is available; and in the case of ionic bonding we have a curriculum model with much currency, but which is both inconsistent with science, and a poor basis for progression in understanding.

The road towards a curriculum model of scientific enquiry

So some curriculum models do a good job for us, but others may be far from being the 'optimum level of simplification' that best meets pupils' learning needs.

In effect, Sc1 in the National Curriculum for Science, presents us with a curriculum model of science (i.e. science *as an activity*, that is) as well as various curriculum models of areas of scientific knowledge. This model of the nature of science has two distinct components, i.e. 'scientific investigations' and 'ideas and evidence'. The scientific investigations component provides pupils with a model of empirical work in science. In effect this consists of the process of planning, carrying-out and then evaluating a controlled experiment. Much empirical work in science is of the form of controlled experiment, and so to some extent the curriculum provides an authentic model.

The note of caution here is that not all science works this way – there are many sciences that use non-experimental 'practical' work. There is a concern then that as the controlled experiment is the form of practical work that is currently valued in formal assessments, and especially at a time when field trips seem to be under pressure in many schools, pupils in some schools may not fully appreciate that this is only a partial model of empirical work in science (Kind & Taber, 2005).

The 'scientific investigations' thread of Sc1 is complemented by the 'ideas and evidence' strand. This makes up the curriculum model for understanding how scientific knowledge is debated, developed and applied.

In view of the importance of teaching pupils about the nature of Science, it is important that the curriculum model we present should be 'at the optimum level of simplification' – to make sense to the pupils whilst still being an intellectually honest reflection of the ways science actually works. In view of the limitations of the 'scientific investigations' strand at modelling the way scientists undertake empirical work (think of ethologists and anthropologists for example, let alone cosmologists), it seems appropriate to consider whether the 'ideas and evidence' strand of Sc1 provides an optimum level of simplification of the nature of science.

This was the impetus behind the Cambridge project – to explore the idea of a curriculum model of the nature of science, to help inform teachers how to go about pitching teaching about ideas and evidence in science. It is only fair to point out here that this was a rather ambitious aim for a modestly-resourced project of limited time-span! The Cambridge KS3/SEP project *set out* on a path towards developing a suitable curriculum model for teaching about ideas and evidence. We would not claim to have completed that journey, but we did undertake some useful reconnaissance, and hopefully readers will find the account of our scouting parties interesting and useful when thinking about their own teaching.

Models of models?

Before proceeding to discuss the Cambridge project in detail, it is useful to make a point about models that could otherwise be a source of confusion. Some readers may have noticed that the curriculum model of ionic bonding criticised above was described as a model of a model ("this is a poor curriculum model because although it is simple enough for the learners to understand, it does not reflect the scientific model").

It may be suggested that models are at the very heart of the scientific enterprise – that indeed the main 'products' of scientific activity are the models developed by scientists. Models are, of course, human constructions, but *scientific* models are constructed to represent aspects of the world. There are many different types of scientific model. These include classification systems (the five kingdoms in biology), formulae (H_2O) and equations ($v=u+at$), schematics (typical insect body plan, or the mammalian skeleton), system diagrams (feedback cycles showing how changes in the atmosphere influence the oceans and vice versa; the water cycle), as well as scale models. These different types of models are all ways of representing something in a simplified form. In science we expect these models to reflect some aspects of the word: so the five kingdoms typology is useful if living things can usefully be considered to fit into one of the five kingdoms.

To be useful the models have to both be simplifications and correspond in some way to 'the real world'. Now some philosophers of science spend a great deal of time and energy arguing about *if* and *how* we can ever be sure there is any correspondence between our models and reality: here we will take it that most science teachers assume that science can be considered to be discovering knowledge about the world in which we live – that in principle scientific models and theories can reflect nature.

An example: scientific and curriculum models of the ionic bond

So chemists have a model of the ionic bond. (It might be more accurate to talk about sets of models at different levels of sophistication, but I've chosen to keep my description as simple as possible here!) For example, they might see the ionic bond as the electrical binding between oppositely charged ions in a regular lattice arrangement. This will only be a simplification of the complexity of any real structure we would label ionic – but it is a model that is useful for many purposes. Real structures are likely to have complications – such as rogue ions, perhaps an Mg^{2+} ion in an 'NaCl lattice causing some distortion - and sometimes more subtle ideas from quantum chemistry may need to be considered to explain certain properties. This does not negate the model, but indicates its limitations, and its useful range of application.

A good *curriculum* model will be an educationally appropriate simplification of the scientific model – which is itself a simplification that scientists find useful in describing and explaining certain phenomena. The notion that an ionic bond is the transfer of electrons between atoms is not a simplification of the scientific model, but a totally different idea altogether!

By contrast, consider a related example. In school science we often present bonding as if it is a dichotomy (compounds have bonds that are *either* covalent *or* ionic) but when students enter college they not only discover other types of bond - hydrogen bonds, van der Waals' forces and the like - but are also told that many bonds are best considered intermediate between ionic and covalent. This is difficult for some students to accept, and they find it hard to shift ideas (i.e. from a dichotomy to a continuum) that they have learnt in good faith for their GCSE examinations.

At fist sight this is a very similar situation to the learner who has take on board a definition of the ionic bond as an electron transfer event: teaching at one level that needs to be 'unlearnt' later. Yet, teaching about the nature of science might help us here. If we bear in mind that the products of science are themselves models, and if we teach accordingly, then we may be able to help students deal with the apparent contradictions they meet in science classes.

To present chemical bonds as either ionic or covalent (or perhaps metallic) at secondary school is a problem *if* the learners take this as absolute knowledge. Perhaps it would be less of a problem for learners if they understood science as being largely about the development of models which are fit for a purpose, and which sometimes need to be extended or made more sophisticated. After all, many professional chemists still use the idea of 'covalent *or* ionic bonds' a lot of the time.

So a curriculum model that considers bonds as ionic or covalent can be quite appropriate is *if is understand as* a way of classifying things that has a limit to its range of application, rather than as a 'fact' about nature. It can be an intellectually honest model to present in school science, but only if we teach science as a set of models rather than proven facts.

So our bonding example provides us with two very different types of curriculum model:

- 'Ionic bonds as electron transfer' is a model which does not reflect scientific knowledge, and impedes understanding;
- 'Bonding as either covalent or ionic' is a model which reflects scientific knowledge, and which can support progression in learning as long as learners appreciate it as a model.

Of course, this leads us to the very real question of whether our pupils can cope with this image of science, or whether 'science as developing models of the world' is too abstract and subtle for them. There is plenty of research evidence that school pupils often have quite unsophisticated appreciation of the nature of science. This could reflect the nature of science being too subtle or abstract for most learners of secondary age: but it may be that such findings reflect the teaching these pupils have received. It may simply be that the teaching they have experienced has usually presented an image of scientists 'uncovering truth' and 'proving theories'. We are left with the question of *whether seeing science as about model construction, development and testing is too difficult to be a part of a suitable curriculum model.*

Modelling science

We need to understand scientific models (e.g. of photosynthesis, the ionic bond, energy) before we can devise suitable curriculum models to present to pupils, otherwise we risk asking pupils to learn something for the sake of passing examinations that has no scientific validity (e.g. the ionic bond = transfer of electrons). In the same way, we need to have a clear model of science itself before we can decide how the nature of science should be reflected in the curriculum.

For example, consider Figure 1. This is a model, showing the role of models in science. In this representation the notion of 'model' is related to the notion of 'phenomena' (that scientists study), 'concepts' (basic categories we use - the 'things' that we perceive as making up the world: elements, acids, insects, wasps, insulators, charges, etc.), 'relationships' (such as proportion to, is a type of, causes etc.) and 'theories' (seen as systems of ideas). This is only a partial model of science, but it is simplified representation of the central role of models in science (Gilbert, et al. 2001). Note that one way of understanding this figure is that models are intermediate between phenomena and theories (as phenomena are represented in a simplified form, suitable for incorporation into theories), and that they link concepts and relationships (as the model shows how different conceptual entities are linked). The double-headed arrows can also be read to imply that phenomena, concepts, relationships and theories are all modelled in, and can be components of models in, science.

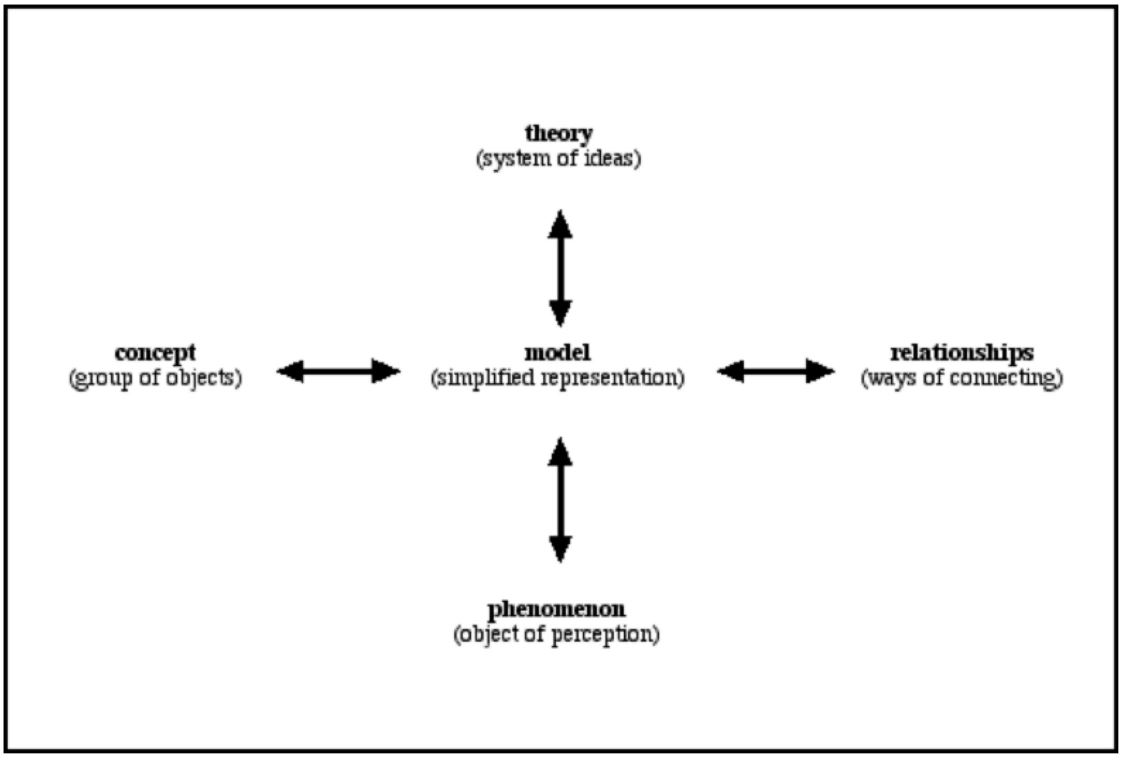

Figure 1: A model of some key terms in science (Gilbert et al, 2001)

Scientific explanations

Explanations, like models, are at the very heart of science. Science is about understanding the world – and that means being able to explain it. Sometimes our explanations are designed to help us predict (tomorrow's weather), or control (destroying tumours), although understanding is sometimes seen as reward enough. We might suggest that science is about producing models that can act as the source of explanations! So, scientific explanations do not exist in isolation, but rely on scientific knowledge being applied in particular contexts. In particular, scientific explanations draw upon theories and models.

A key aspiration for science education should be that learners are able to understand, and produce, explanations that we might judge 'scientific': we would like pupils to make sense of, and to actually be able to offer, 'scientific explanations'.

We would hope that pupils entering secondary school would already have some experience of working with explanations in science, and that this would develop through their schooling. Those learners who select to study science beyond school *might be expected* to become quite adept at formulating scientific explanations.

Students' explanations in science

However, it is always foolish to make assumptions without good grounds. So, we could ask whether we can expect learners to appreciate the nature of scientific explanations, and be able to judge whether something should be considered as 'a good scientific explanation', if we do not make this an explicit aim of science teaching.

An analysis of explanations given by A level students studying chemistry during a research project suggested that *even at this level* students were not always able to provide good scientific explanations (Taber & Watts, 2000). Leaving aside questions of whether they understood the science in orthodox ways, it was found that sometimes these students would use 'explanations' that:

- were too vague to provide predictive power
- were circular
- confused the reason why something happening with how they know it to be the case
- were anthropomorphic

That advanced students should present such 'explanations' suggests that we should not assume that secondary students, and especially those at KS3, will appreciate or be able to generate acceptable explanations that meet scientific criteria. This was a starting point for the Cambridge project.

The research discussed in this section was reported in a paper in the internet journal Chemistry Education: Research and Practice. A copy of the paper is included as a pdf file on the CDROM, with permission of the editor, Prof. Georgios Tsaparlis.

KS3 pupils' understanding of scientific explanations

A top science set Y9 class in a city comprehensive school spent two lessons exploring the idea of explanations in science. At the start of the first lesson, the pupils were asked about their existing notions about scientific explanations. Some of these KS3 pupils were able to suggest some quite coherent and appropriate definitions:

"A logical, clear explanation of why something is like it is or why it happened. Using what you know to help you explain."

Quite a few of the responses made reference to the explanation being based on "evidence to support it" (even "conclusive evidence") or proof, and there were quite a few references to explanations including reasons or explaining *why*. Despite this, quite a number of the pupils were not able to suggest an example of 'a good scientific explanation?'

Activities to develop understanding of scientific explanations

The Y9 students were given a talk about the nature of scientific explanations, using the examples of the size of the universe and of evolution by natural selection to give a feel for the role of evidence (sometimes indirect or conditional) in scientific explanations.

The view of an explanation presented was as an answer to a 'why' question: a good scientific explanation should be logical, and should draw upon accepted scientific ideas. The term 'theory' was used, and the pupils were told that *scientific theories are ideas about the world that are well supported by evidence; are internally consistent; and which usually fit with other accepted theories*.

The pupils were taken through a number of activities, to help them focus on the role of explanations in science.

The Y9 work on explanations was reported to teachers at a seminar on 'Meeting the Needs of the Most Able in Science' at Cambridge, as part of the Able Pupils Experiencing Challenging Science (APECS) project. A report of the seminar, from the website <http://www.educ.cam.ac.uk/apecs/>, is included on the CDROM.

The sessions were designed to have two main pupil activities concerned with sequencing and critiquing explanations. There were also two introductory activities, which pupils seemed to quite enjoy – especially the 'suggest an explanation' activity.

Suggesting explanations

This was intended as a warm-up activity to introduce the notion of an explanation being a response to a 'why' question. A series of 'why' questions were prepared, including a number where it was not expected the students would 'know' the accepted answers (thus '*suggest* an explanation').

A large set of questions were prepared, so that pupils could choose questions where they either already had ideas, or where they were interested in thinking about possible reasons. Pupils worked in pairs. It was originally intended that each pair would only answer 1 or 2 questions, just to get them thinking about explanations, but this was extended as the class seemed to be enjoying the activity, and producing responses that were often either drawing well upon their science knowledge, and/or demonstrating some imagination! A few examples are given here as a flavour of what these Y9 pupils produced:

Why do we sweat?

Explanation: We sweat because

"our body sometimes gets overly hot, whether it is from radiation from the sun or respiration in your muscles. Sweat is useful because it is mainly water; and water generally evaporates when it gets enough heat energy, which it will be able to 'steal' from the surrounding. The end result is that we lose heat energy thus cooling you down."

Why don't people lay eggs?

Explanation: People do not lay eggs because

"our developing babies require more energy and the like provided, and if they developed externally then they would have limited supplies, whereas if the egg was inside the mother's body then the child would get virtually unlimited supplies through the placenta which is connected to the mother's blood stream."

Why do only some planets have moons?

Explanation: Only some planets have moons because

"when the big bang happened and the mass distributed but not evenly the larger masses of rock were drawn in by stars while some of the smaller masses got drawn in by the larger masses of rock because of their gravitational pull however some of the medium masses of rocks did not have a small mass of rock go near them or did not have enough gravitational pull to send the smaller rocks into orbit around them."

Why do people age?

Explanation [age]: *People age because*

"they get worn out. Eventually the vital parts of the body become un-repairable and the limbs slowly become more useless. Cells diminish over the years and eyes become over-used. Nothing lasts forever. As the brain is used it cannot be repaired, limbs are worn and bones become weak."

Why do some animals sometimes eat their own young?

Explanation: Some animals sometimes eat their own young because

"they feel threatened or hungry and feel that their young are not capable of handling the style of life and don't want to make them suffer."

Why do we each have 2 nostrils?

Explanation: We each have two nostrils because

"if one gets blocked, we can breathe through the other one (for colds and other illnesses)."

Although many of the explanations offered were credit-worthy, they were certainly not all adequate explanations: some demonstrated poor logic, or limited scientific knowledge.

The set of questions used to get pupils to suggest explanations is included on the CDROM.

What explanations do pupils want?

Pupils were also asked to report 'what are the questions you would most like to know the answers to'? This activity, along with the 'suggest an explanation' activity was meant to orientate pupils to thinking about the nature of explanations. This can also be useful as a way of exploring the kind of interests that pupils have in science.

The group of Y9 pupils were able to suggest a wide range of phenomena they would like explanations to – many would be suitable for follow-up within school science. The following list gives a flavour of their questions:

Why do we go red when we are embarrassed?
Why is urine not always the same colour?
Why are breasts the shape they are?
Why do men have nipples?
Why can't your brain remember everything you have done in your life?
Why can you not remember being born if it was such a big thing?
Why are some things instinctive and others you have to learn?
Why are our voices different?
Why do we have 2 legs and most mammals have 4 legs?
Why do dogs wag their tails when they are happy?
Why do viruses exist?
Why do humans exist?
Why is there time?

Who made the first straight line and how?

Why are all planets round?

Why are there 3 states: solid, liquid and gases?

Why is glass transparent?

Why haven't we encountered any other sentient beings yet?

The sheet, inviting pupils to offer the questions they'd most like to know the answers to, is included on the CDROM.

Sequencing explanations

This task consists of providing pupils with the components of potential explanations (including some 'red herrings') and asking them to try and produce a sequenced explanation. Although a 'cut and stick activity', this does require a good deal of thinking, and is suitable as a small group (e.g. 3 pupils) task.

The materials were provided in the form of an A3 sheet with a suitable heading (a 'why' questions) and the statements that could make up parts of an explanation. Pupils arrange the components they wish to use on the page, and added lines and additional words ('because') to complete the explanations.

It is worth noting that this can be a very challenging task, especially when branched explanations are allowed (as in science full explanations can rely on considering several different factors).

Three examples were provided,

- Why do solid substances melt when they are heated?
- Why do plants die if kept in the dark?
- Why is it important to use renewable power sources?

Clearly many more examples could be devised.

When this work was carried out with the Y9 class the melting example was undertaken on the OHP with the class, and groups given a choice of the two other examplars. Only one group completed the 'power' option. This group were able to sequence an explanation with three separate 'threads' or aspects - the greenhouse effect, the production of acid rain, and the disparate timescales for the production and use of fossil fuels. Each of the threads was relevant and logically constructed.

Most groups chose to work on the question about plants, and responses of varying levels of complexity were produced. Some groups tended to produce longer, more involved explanations than others (the task certainly offers scope for differentiation). Some of the suggested explanations included connections that included quite complex sequences of statements. However, there also tended to be flaws in the logic of the explanations!

It is suggested that this is an activity that pupils would benefit form revisiting over a longer period of time, looking at different examples (perhaps linked to different KS3 topics as they are met in the scheme of work).

The worksheets with the components of the 3 explanations, and an instruction sheet, are included on the CDROM.

Evaluating explanations

The final task, which in some ways was intended to be the culmination of the sequence of work, asked students to select examples of poor and good scientific explanations. Again working in groups, students were provided with a set of 'explanations' on a range of topics. They were also provided with two A3 sheets on which to glue their chosen examples. One sheet was headed 'poor scientific explanations' and had a series of boxes for students to complete the statement 'This is a poor explanation because ... '. The other sheet, headed, 'good scientific explanations' had a single box to be completed: 'A good scientific explanation ... '

Students were required to select examples of poor scientific explanations or good scientific explanations, and, also, to justify their choices. For poor explanations they were asked to explain the faults in each selected example, where with good scientific explanations they were asked to give an overall justification for their selection. (This approach was chosen, as it is hoped that students will apply a common set of criteria for evaluating explanations - the dubious examples fell down in different ways, but all the good scientific explanations would need to meet all the criteria).

It was found that a number of the options selected as examples of good scientific explanations by pupils were in fact flawed. Also, some of the critiques of 'poor scientific explanations' were at the level of 'it is wrong' or 'it does not make sense'. However, there were also examples where pupil were able to offer reasons that were more specific. Again, this is an activity that is best not seen as a ‘one-shot’ activity, but as an introduction to evaluating scientific explanations, to be regularly followed-up in the context of different science topics when explanations are met.

Some examples of the mooted explanations that pupils were asked to consider were:

> Chlorophyll is green because plants need chlorophyll to photosynthesise, and plants are green.
>
> The apparent movement of the stars through the night sky suggests that either the earth spins round, or that the rest of the universe rotates around the earth.
>
> The planets reflect the sun’s light, but some planet surfaces reflect a larger proportion of the light reaching them. Pluto is much less bright in the sky than Venus because Pluto’s surface reflects a smaller proportion of the sun’s light.
>
> A balanced diet should include sources of carbohydrate, proteins, fats, minerals, vitamins, fibre and water. Foods from animals - such as meat, egg and cheese - are sources of protein. Vegans (people who do not eat animal products) will not be healthy because they will not have balanced diet.

Students were asked to consider acceptable scientific explanations as well as suggestions that were less than perfect: i.e. with cause and effect confused; alternative options; relevant factors ignored etc. Again, this activity invites success at a range of levels, and some science content knowledge is needed to judge many of the examples. The Y9 class were given the full set of mooted explanations and invited to select examples of good and poor explanations, so they were not expected to be able to judge each of the ideas.

The worksheets for this activity (answer sheets for good and poor explanations, and the explanations to be judged) are included on the CDROM.

Pupils’ notions of key terms in science

As the work on Y9 pupils’ understanding of scientific explanations exemplifies, we need to explicitly teach *about* science, as well as teach science, if we want pupils to appreciate the nature of science. As part of the KS3 SEP project a group of trainee teachers, science graduates on the

PGCE course, interviewed top science set pupils to find out their understanding of some key terms in science.

There is existing research in this area (e.g. Driver et al., 1996), although most of it predates the introduction of the KS3 strategy. If was thought to be a valuable experience for trainees to find out for themselves how well KS3 pupils appreciated the use of the terms 'theory', 'hypothesis', 'experiment' and 'model' in science. The research group (about a dozen trainees) each interviewed a small number of pupils in three top sets, and a mixed-ability form group (Y7 and Y8 top set pupils at St. John's College School, Cambridge, and Y9 top set, and Y7 mixed-ability pupils at Chesterton Community College, Cambridge), and then the group met at the University and shared their findings.

The questions in the interviews are reproduced below, with a small selection of answers from pupils in one KS3 group (the top set Y7)

Have you come across the word 'theory' in science? (and if yes)

Can you explain what a theory is?

> The theory is what people think. They don't have proof, but it's what they feel/think.
>
> What you think will happen but you can't actually see it, it's what you think will happen
>
> People think up/invent theories – how they think something works – it may not be correct.
>
> An improved opinion when you have looked at facts, and made an informed opinion.

Do you know any examples of scientific theories?:

> Isaac Newton – Gravity; movement; Einstein
>
> Theory of an infinite universe as an inflating balloon.
>
> Theory of gravity – Newton; Evolution – Darwin; Einstein; Archilles [sic] – water in the bath going up.
>
> Theory of relativity – Albert Einstein; Gravity – Isaac Newton.

Have you come across the word 'hypothesis' in science? (and if yes)

Can you explain what a hypothesis is?

What people think before they do an experiment.

An intelligent guess what they outcome may be.

A summary about something scientific.

Could you suggest an example of a hypothesis?

What something weighs, they see at the end if they are right.

If you were burning a metal you could form a hypothesis whether it gets heavier or lighter – you must give a reason.

If measuring different weights after burning a substance you would summarise the results after measuring them.

Have you come across the word 'experiment' in science? (and if yes)

Can you explain what an experiment is?

A thing you do to find out something.

Trying different ways of doing things, to see what works. Testing things.

If you had an idea you would design an experiment to see if your idea is right.

A test to see e.g. if something has oxygen or hydrogen in it.

Can you give any examples of experiments that scientists have done?

Einstein tried to split the atom; The spaceship that went to Mars to do an experiment.

Newton – apple tree – still counted as a test even though unplanned; Hooke – looking at the stars – designing telescopes.

Electricity – kite, standing on rubber so they knew then about conductors and insulators because he did not die.

Can you tell me about an example of an experiment that you have done in science?

Heating up water in test tubes. Putting different metals into it and seeing how they reacted (magnesium).

Displacing metals (looking for reaction); Which cup keeps hot chocolate warm best; Bunsen burner – which part of flame is hottest?; Cement mix.

Test for starch in fruit – using iodine; Tested conductors and insulators, used ammeter to give voltage

Potassium, sodium, calcium – reactivity series.

Have you come across the word 'model' in science? (and if yes)

Can you explain what a model is?

Model experiment: you do it to show to others how to do it, model: how to set up experiment.

Something you make – creates a 3D object, maybe of a cycle.

Smaller version of e.g. the solar system – so you can look at it in detail.

Something to explain the way something works.

Can you tell me about any models you have seen or used in science?

Model skeleton Freddi

Atoms – model kit to make compounds; Eye.

A model of the solar system; A globe showing the countries and seas of the world.

Apparatus – bell bottom side-armed flask to make ethanol.

When reported in such brevity, some the responses do not give a very full idea of pupil thinking. Even so, some of these answers would make interesting starting points for a class discussion! The trainees found it very useful to talk to pupils first hand about their ideas, and this informed their own work on school placements. This is probably something that many teachers might find useful when meeting a new class, especially when unsure how much emphasis has been placed on these terms by previous teachers.

The interview schedule used by the trainee teachers is included on the CDROM. Teachers may wish to use this as the basis for surveying their own

The schedule could be modified to use as a written probe, or pupils in a class could even be trained to interview each other as a data collection exercise! One of the trainees modified this idea, producing a simple one page question sheet to survey her pupils' understanding of key words in science - (see 'Teaching the Solar System at Y7 – Tamsin Lowe', in Chapter 3).

Pupil perceptions of why accepted ideas change

The three top set science groups (one each in Y7, Y8 and Y9) who were surveyed to find out individual pupils' associations for key science words were also asked to undertake a small group task on why they thought ideas change.

For this a set of written probes was prepared. In each of the probes a brief scenario was presented in terms of what people used to think, and what scientists now think. The groups were asked to suggest:

- Why people held the original ideas/beliefs
- Why scientists now think those ideas were wrong
- Why scientists now hold the new ideas

To give a flavour of this activity, here are some examples of group responses:

Scenario (***Moving continents***): Some people used to think that the surface of the earth has been largely the same for thousands of millions of years. Scientists no longer think the earth's surface is fixed. Scientists now believe that the surface is divided into very large pieces ('*plates*') that slowly move around, so that the continents slowly change their positions.

Example of a Y7 response

Why do you think people might have thought that the earth's surface was fixed and	Why do you think scientists now think this idea is wrong?	Why do you think scientists now believe that the continents can slowly move around the earth's
Because they did not travel around and they did not have advanced technology. They all believed in God and didn't know much about science. They believed that God made the earth and it must have stayed like that for ever after and not changed.	***Because we now have satellite pictures of the earth's continents moving around. Scientists can see things changing over years when they write down their results.***	***Because they can prove it and monitor it for hundreds of years. Scientists have found fossils of the same species of animals in totally different parts of the world, so that means that a long time ago, it could have been the same continent, but it split and***

Scenario (***The four elements***): Some people used to think that everything on earth was made of four elements called earth, water, air and fire. All materials were thought to contain a mixture of these different elements. Scientists no longer think that that earth, water, air and fire are the elements. Scientists now believe that all substances are made from a much larger number of elements (such as oxygen, carbon, hydrogen, iron, copper, nitrogen, sulfur, helium etc.)

Example of a Y8 response

Why do you think people might have thought that everything was made up of earth, water, air and	Why do you think scientists now think this idea is wrong?	Why do you think scientists now believe that there are a large number of elements?
People did not understand science at the time and all they could see was what they thought existed.	***Scientists have found some as pure metals and they have also found things that react with other substances, therefore knowing there must be other elements on earth or in the air.***	***Because they have found many more different substances with different characteristics to all other substances. Also they have found many more substances that react very differently to anything else they had already found. That means that they have deduced that there may be many others. Also the pattern of the Periodic Table, says that there are many others to be found. The table can also tell what properties that element would have, and how it would react with***

Scenario (***Burning***): Some people used to think that materials would burn (would be '*combustible*') if they contained a special substance, *phlogiston*. It was believed that the phlogiston escaped during burning. Scientists no longer think that phlogiston exists. Scientists now believe that burning occurs when a substance reacts with oxygen.

Example of a Y9 response

Why do you think people might have thought that a substance was released during burning?	Why do you think scientists now think this idea is wrong?	Why do you think scientists now believe that burning is a reaction with oxygen?
They thought that something was released when the object was burned because smoke comes off it (or out of it).	***Scientists now think this is wrong because combustible materials only burn in certain substances.***	***Scientists now believe this because they have conducted experiments to prove it and have found that things don't burn in other gases.***

The pupils seemed to enjoy working on these exercises, and some of their suggestions are certainly creditworthy. Some of the responses produced by the small groups (e.g. "Scientists…have conducted experiments to prove it") would, again, be a good starting point for full class discussion.

There were eight topics considered in the set of probes:

- blood circulation
- burning
- the four elements
- moving continents
- new life? (spontaneous generation)
- origins (evolution)
- sight
- the solar system (geocentric-heliocentric)

Clearly there are many other topics where the same format could be used. It was not expected that KS3 pupils will have been taught the evidence base behind these topics before undertaking the probes: this is actually a more useful exercise where pupils are thinking about what kind of evidence might be relevant, rather than just repeating what they have learnt.

The set of 'changes' probes is included on the CDROm for any teachers who wish to adopt or modify them.

So can pupils appreciate the nature of science?

Various research studies into learners' ideas about the nature of science suggests many children have passed through school science lessons without acquiring a very accurate, let alone sophisticated, notion of how science occurs. In Chapter 1 it was suggested that the nature of science is complex, and even contentious, and any curriculum model has to be simple enough for pupils to understand, yet still be an authentic image of science. This is quite a challenge! Yet the work described above, albeit mostly with pupils in top science sets, at KS3 suggests that

a. when challenged with the right type of task, then many pupils are able to start thinking about issues that are central to the nature of science;
b. yet, many pupils may acquire quite limited notions of the meanings of key terms such as 'experiment', 'model' and 'theory'.

This small-scale exploration seems to suggest there is already potential for pupils to make good progress in understanding the way science operates, but as always we do need to focus our teaching on key objectives. So, for example, many teachers will reinforce the meaning of a new technical term such as 'element', 'pressure' or 'tissue' whenever it recurs: but perhaps we often *assume* that the pupils know what we mean by 'theory' or 'experiment' because they seem to readily adopt the words.

Applying the ideas in the classroom

The Cambridge based project involved a group of trainee science teachers (training as science specialists at KS2-3, or as secondary science teachers with a subject specialism). The trainees attended sessions at the University focussed on teaching about ideas and evidence, including meetings of an on-going Seminar programme on 'Meeting the Needs of the Most Able in Science' (<**http://www.educ.cam.ac.uk/apecs/**>), and took part in the research visits to interview top set pupils in Years 7, 8 and 9.

The trainees were presented with a range of reading material relating to the two themes of the project (teaching about ideas and evidence in science, and for our Cambridge project, challenging able pupils). They were also presented with a draft document as a 'first look' at a curriculum model of the nature of science, i.e. a paper describing how science 'works', to guide their thinking about the image of science we should be teaching in school. It will be no surprise (given the points made in Chapter 1) that the draft curriculum model, whilst a simplification, nevertheless described a rather complex business!

The paper suggesting a draft curriculum model of the nature of science is included in the CDROM.

The draft curriculum model is not being presented as a finished product, but rather as a starting point. Teachers may find it interesting to consider this description of science, and to ask themselves:

- To what extent they agree with the image of science presented;
- To what extent they feel pupils should be taught about the nature of science as presented in the model;
- How their KS3 pupils would cope with the subtlety and complexity of the image of science presented.

The trainees took the ideas into their school placements and - with the support of their school based mentors as well as faculty tutors – tried to incorporate some work on ideas and evidence in science into their timetabled teaching. Those who felt they were able to produce something that colleagues may be interested in hearing about, using or developing, were invited to submit reports of their work.

Curriculum models and teaching approaches

Readers may well have their own views on the appropriateness and feasibility of the draft curriculum model presented to the trainee teachers. Whatever the merits of that particular document, it is important to remember that curriculum models are not the same as teaching approaches. The curriculum model presents the 'target' knowledge and understanding, and – as always – teachers have to *transform* the curriculum through their planning to provide teaching that is best suited to their learners (Kind & Taber, 2005). The sequencing of material, the context used to teach concepts, the approaches chosen etc., all have to be decided by the teacher in view of the needs and interests of particular classes. Sometimes curriculum models may present a target that needs to be attained slowly, and/or in steps. Teachers may use their own 'teaching models' which are further simplifications of the curriculum models, perhaps as 'stepping stones' towards the intended learning.

The CDROM includes some case studies of how trainee teachers attempted to incorporate aspects of 'ideas and evidence in science' in their own teaching. These are described in another commentary for teachers included on the CD: '*Case studies of classroom practice*.'

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