Teaching the Nature of Science in Schools: what makes a lesson effective?

Hannah Bartholomew, Jonathan Osborne and Mary Ratcliffe


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Teaching the Nature of Science in Schools: what makes a lesson effective?

Hannah Bartholomew and Jonathan Osborne, King’s College London and Mary Ratcliffe, University of Southampton.

Current debates within science education

There is a widespread consensus that the school science curriculum is in need of radical reform. It is regarded by many pupils as being difficult, remote from their own experiences and irrelevant, and by many teachers as being overloaded with content to the extent that, particularly in the upper secondary years, there is little time for activities and teaching approaches which might stimulate their students’ interest.

The introduction of the national curriculum means that all students now learn science throughout the years of compulsory schooling, and performance in National curriculum and GCSE science has improved steadily over the last decade. However, even with the rapid expansion over the past decade in the proportion of school leavers entering higher education, the numbers of students opting to study science subjects beyond 16 has at best remained static. In recent years number of universities have stopped offering physics as a degree subject because they have been unable to recruit students in sufficient numbers to keep their courses viable.

This apparent failure of the National Curriculum to inspire more young people to study science, and the worrying inability of many to apply the science that they have learnt at school (ref), has led many to question the nature of the science curriculum. It is argued that the secondary curriculum, particularly at Key Stage 4, is very content heavy, "presenting science as a body of knowledge which is value-free, objective and detached - a succession of 'facts' to be learnt, with insufficient indication of any overarching coherence and a lack of contextual relevance to the future needs of young people" (Millar et al. 1998). It is suggested that if, instead of being required to learn a canon of scientific facts, students were given opportunities to engage with the nature of science and scientific knowledge – to consider contemporary scientific issues and debates, to think about the ethical issues involved and to form opinions of their own – then not only would the subject become more meaningful, empowering and exciting for them, but it would also better equip them for participation in a modern democratic society (Driver et al. 1996; Millar 1997; Millar et al. 1998).

A number of recent policy documents, reports and initiatives have addressed these concerns (see for example House of Commons Science and Technology Committee 2002), yet while this case is being argued by many university educators, and increasing numbers of policy makers and curriculum developers, the day to day realities of life in schools continue to pull many teachers in the opposite direction. The setting of targets and publication of league tables exerts a powerful pressure on teachers to optimise the performance of their students in National Curriculum and GCSE examinations, and this can distort the teaching of school science (and other subjects). Teachers naturally focus on what will / can be assessed, and a shift in emphasis from students’ understanding of scientific ideas to their knowledge of scientific facts is seen by many as the most pragmatic approach to increasing students’ chances in examinations which predominantly assess recall. A consequence in many science classrooms has been that in recent years lessons have become more didactic, as teachers rush to get through the syllabus. Trying
something new in the classroom has become riskier as the stakes attached to the various sets of examination hoops through which students must pass have become higher.

For these reasons it is important, if we are to take seriously the need to incorporate elements of the nature of science into the curriculum, that we consider what this means for the individual teachers who will be implementing that curriculum. In this paper we draw on research in which we worked with a group of teachers who were asked to teach a number of lessons which addressed aspects of the nature of science. Through an exploration of some of the issues that emerged for these teachers, we consider implications for the effective teaching of ‘ideas about science’ more generally.

The study

The study on which this paper draws is one project within an ESRC funded network looking at evidence-based practice in science education (EPSE), and is concerned with the teaching of ‘ideas and evidence’ in school science lessons. In an initial phase, a three round Delphi study (Dalkey et al. 1963) asked a panel of 23 individuals drawn from 5 communities with an interest in science education – scientists, philosophers of science, sociologists of science, science educators and science teachers – about aspects of the nature of science that they felt should be part of the compulsory school science curriculum. This generated nine ‘themes’ relating to aspects of the nature of science about which there was substantive consensus (see Table 1). (This phase of the study is written up in Collins et al. 2001)

<table>
<thead>
<tr>
<th>Theme</th>
<th>Delphi theme</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theme 1</td>
<td>scientific methods and critical testing</td>
<td>Pupils should be taught that science uses the experimental method to test ideas, and, in particular, about certain basic techniques such as the use of controls. It should be made clear that the outcome of single experiment is rarely sufficient to establish a knowledge claim.</td>
</tr>
<tr>
<td>Theme 2</td>
<td>science and certainty</td>
<td>Pupils should appreciate why much scientific knowledge, particularly that taught in school science, is well-established and beyond reasonable doubt, and why other scientific knowledge is more open to legitimate doubt. It should also be explained that current scientific knowledge is the best we have but may be subject to change in the future, given new evidence or new interpretations of old evidence.</td>
</tr>
<tr>
<td>Theme 3</td>
<td>diversity of scientific thinking</td>
<td>Pupils should be taught that science uses a range of methods and approaches and that there is no one scientific method or approach</td>
</tr>
<tr>
<td>Theme 4</td>
<td>hypothesis and prediction</td>
<td>Pupils should be taught that scientists develop hypotheses and predictions about natural phenomena. This process is essential to the development of new knowledge claims.</td>
</tr>
<tr>
<td>Theme 5</td>
<td>historical development of scientific knowledge</td>
<td>Pupils should be taught some of the historical background to the development of scientific knowledge.</td>
</tr>
<tr>
<td>Theme 6</td>
<td>creativity</td>
<td>Pupils should appreciate that science is an activity that involves creativity and imagination as much as many other human activities, and that some scientific ideas are enormous intellectual achievements. Scientists, as much as any other profession, are passionate and involved humans whose work relies on inspiration and imagination.</td>
</tr>
<tr>
<td>Theme 7</td>
<td>science and questioning</td>
<td>Pupils should be taught that an important aspect of the work of a scientist is the continual and cyclical process of asking questions and seeking answers, which then lead to new questions. This process leads to the emergence of new scientific theories and</td>
</tr>
</tbody>
</table>
techniques, which are then tested empirically.

| Theme 8 | analysis and interpretation of data | pupils should be taught that the practice of science involves the skilful analysis and interpretation of data. Scientific ideas do not emerge simply from the data but through a process of interpretation and theory building that can require sophisticated skills. It is possible for scientists to legitimately come to different interpretations of the same data, and therefore to disagree. |
| Theme 9 | co-operation and collaboration in the development of scientific knowledge | pupils should be taught that science is a communal and competitive activity. Whilst individuals may make significant contributions, scientific work is often carried out in groups, frequently of a multi-disciplinary and international nature. New knowledge claims are generally shared and, to be accepted by the community, must survive a process of critical peer review. |

In the second phase of the study, on which this paper is based, we worked with a group of teachers, whom we asked to develop and implement a series of 8 lessons which incorporated aspects of the nature of science that were represented in the themes. The aim of this part of the research was to explore the issues that were raised for teachers when incorporating aspects of the nature of science into their teaching, and to investigate the factors that contributed to the successful teaching of these ideas.

Twelve teachers (4 at each of Key Stages 2, 3 and 4) were recruited to work with one of their classes in this collaborative venture to see whether and how the top-rated nine Delphi themes could become an integral part of their teaching. In recruiting the secondary school teachers we aimed for a balance across type of school (single-sex / mixed; comprehensive/selective) and background in main subject discipline (biology /chemistry /physics). Invitations were sent to schools where there was considered to be good practice in science teaching, but where little was known about the extent to which ideas about science were addressed in day to day teaching. Recruits were thus volunteers – experienced teachers who were interested in the project but whose understanding and practice in teaching the nature of science were unknown at the outset. One primary teacher dropped out of the project after the first two meetings because of pressure of work. The remainder showed considerable commitment at a time when each was experiencing pressures of conforming to existing curriculum and professional expectations. Table 2 summarises relevant biographical details of the teachers participating in the research.

Our input comprised a series of 6 training days for the teachers, in which we discussed the themes and provided teaching materials and resources which we felt might be helpful (Lederman et al. 1998; Ratcliffe 1999; Goldsworthy et al. 2000; Naylor et al. 2000; The Charis Project 2000). We raised questions about some of the issues involved in teaching these ideas, and, in later sessions, invited teachers to feedback on activities they had tried out. They also had opportunities to discuss any constraints and challenges that they were encountering. Each teacher was visited in their school three times, and two of the lessons were videoed (one of the earliest and one of the last in each case); in some of the training sessions at King’s short clips of some of the videoed lessons were shown and discussed. As well as this video and observation data, we asked each teacher to keep a diary, recording their planning of, and reflections on, the lessons they were teaching, and we interviewed each teacher about their involvement in the study at the end of the project. We also asked them to complete an evaluation sheet after each lesson, and to ask their students to do likewise, and we administered questionnaires designed to access their conceptions of the nature of science (Cotham 1079) and attitudes to classroom discussions (Connelly et al. 1977) at the beginning and end of the study. In order to gain some measure of
the learning gains to pupils within the target classes, teachers administered pre- and post-tests to pupils, the post-test also sampling a group of similar background within the school as comparator. We developed these tests as part of other research seeking to develop and evaluate suitable written items for large-scale testing of the nature of science.

Table 2: summary biographical details of the teachers

<table>
<thead>
<tr>
<th>Key stage 2</th>
<th>Degree subject</th>
<th>School Post</th>
<th>Years of teaching experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andrew</td>
<td>Geography</td>
<td>Acting deputy and year 6 teacher</td>
<td>20</td>
</tr>
<tr>
<td>Emma</td>
<td>Physics</td>
<td>Science co-ordinator and year 6 teacher</td>
<td>5</td>
</tr>
<tr>
<td>Becky</td>
<td>African Studies and anthropology</td>
<td>Science co-ordinator, KS2 co-ordinator and year 4/5 teacher</td>
<td>10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Key stage 3</th>
<th>Degree subject</th>
<th>School Post</th>
<th>Years of teaching experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pauline</td>
<td>Physics</td>
<td>Head of science</td>
<td>24</td>
</tr>
<tr>
<td>Clare</td>
<td>Geology with chemistry</td>
<td>Assistant head teacher and head of science</td>
<td>10</td>
</tr>
<tr>
<td>Mike</td>
<td>Chemistry</td>
<td>Science teacher</td>
<td>5</td>
</tr>
<tr>
<td>Jo</td>
<td>Biology</td>
<td>Science teacher</td>
<td>9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Key stage 4</th>
<th>Degree subject</th>
<th>School Post</th>
<th>Years of teaching experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brenda</td>
<td>Biochemistry</td>
<td>Head of science</td>
<td>18 (previous career as clinical biochemist)</td>
</tr>
<tr>
<td>Sue</td>
<td>Physics</td>
<td>Head of science</td>
<td></td>
</tr>
<tr>
<td>Harold</td>
<td>Physics</td>
<td>Vocational science co-ordinator and deputy head of year 8</td>
<td>27</td>
</tr>
<tr>
<td>Daniel</td>
<td>applied chemistry</td>
<td>Acting head of chemistry</td>
<td>4</td>
</tr>
</tbody>
</table>

In this paper we focus on a subset of those data, and draw mainly on the lessons that we observed and the things that teachers said and wrote about their experiences of participating in this project. We adopted a grounded approach (Strauss et al. 1990) when analysing our data, whereby themes and analytic categories were allowed to emerge through an iterative process of engagement and re-engagement with the data. In this way, emergent themes informed our subsequent analysis and were triangulated against other data-sets. This resulted in a ‘holistic’ analysis in which apparent contradictions within the data were exposed and explored, and the individual contexts of the different teachers involved were seen to add to the richness of the analysis. Our data chart these teachers’ individual journeys in making sense of what they were trying to do and finding ways of incorporating it into an already overcrowded curriculum. The similarities and differences between these journeys highlight a range of constraints and pressures that pulled the teachers in particular directions. The different ways in which (and extents to which) they were able to overcome them provide insights into both individual and structural factors which come into play for teachers trying to deliver a science curriculum which incorporates ideas about science as well as scientific ‘content’.
Thinking about the lessons

One interesting element of our data is that a number of activities were tried by more than one teacher during the course of the study, and so there were a few instances when we observed the same materials being used by different teachers. These lessons, which ‘on paper’ looked very similar to each other, were often very different indeed, providing a graphic illustration of the complexities of introducing a new component of this sort to the curriculum. It quickly became apparent to us that many of the features of lessons that determined whether they were successful (in our eyes) were relatively independent of explicit elements such as the materials used, and rather, related to more subtle and implicit factors such as how the manner in which a task was set up affected the demands that were made on students. Furthermore, although we generally had ‘gut feelings’ about the lessons that we observed, it was often surprisingly difficult to tease out the elements that led us to these reactions, or to identify systematic differences between the lessons we regarded as most successful and those we regarded as least successful.

In the remainder of this paper we shall argue that the effective teaching of ideas about science demands that the teacher adopt a less didactic and more facilitatory role in lessons. The three subheadings below represent three closely inter-related themes which emerged from our analysis of our data, and which we use as vehicles for exploring a range of implications for teachers attempting to incorporate ideas about science into the curriculum.

Shift from content to process

Teachers are used to being an authority in the classroom. It is they who ask the questions and know the answers, and it is their job to pass on to students the information that they need to know in order to pass the next exam. This is perhaps particularly true of science teachers, given the authoritative nature of the discipline itself (ref); there are unlikely to be many situations in most science classrooms, as there might be in English or history classrooms, when 2 students can hold different, but equally valid, opinions on something they are learning about. Furthermore, as referred to in the introduction to this paper, curricular pressures are likely to exacerbate the tendency for much science teaching to focus on covering the factual content base, and so further entrench the traditional student teacher roles. Andrew, one of the primary teachers taking part in the study, speaks of this during an interview, and relates it to the pressure that the school is under to maximise the performance of its students in key stage 2 tests:

Andrew In a school like ours, where one of the few academic successes we have is that quite a few of our children get a level four in their science SATs. And we are not a high achieving academic school. I think we sometimes lose sight of the fact that science is a creative subject. (...)

Int. That’s interesting.

Andrew I think schools, primary schools, I think the difficulty with the science is that all schools want to do well in the SATs, and the SATs is the easiest test to teach to. It’s very simple, you know, when you want your children to get, eighty per cent of children get a level four or what have you, I think the science is the one, you can cram their head with scientific facts for their age group and you’ll get a reasonable amount of success, which I think is unfortunate because it discourages a more creative approach to your science teaching.

For many of the teachers, therefore, one of the earliest challenges that the project presented was that the nine themes which we were asking them to incorporate into their teaching were not
scientific facts that they could ‘cram their head with’ but rather related to the processes through which scientific ideas became established. While most teachers were enthusiastic about the prospect of doing something other than focusing on ‘content’, the role with which they were most familiar was that of ‘dispenser of knowledge’, and the shift to teaching about scientific processes proved a difficult one for many.

The ‘process vs content’ debate has a long history in science education, and during the 1970s and 80s a number of policy documents advocated the teaching of ‘process science’ and a number of projects were developed and had a substantial influence on the thinking of many practitioners (for example Scottish Education Department 1969; Leicestershire Education Authority 1985; Screen 1986; Inner London Education Authority 1987). The rationale for teaching ‘process science’ was that, given the vast amount of scientific knowledge, it is clearly impossible for the school curriculum to cover more than a tiny fraction of it. Furthermore, rapid developments in many branches of science, mean that it is unlikely that curriculum developers would be able to predict what might prove to be most important for adults of the future. Far better, it was argued, to give children an education in the methods of science that they would be able to apply in a wide range of contexts than to teach lots of scientific facts that may have little or no relevance to their future lives, and which may even be outdated by the time they are adults.

However, the ‘process science’ movement was criticised for its failure to appreciate the inter-relatedness of ‘process’ and ‘content’. Those advocating process science have generally presented it as the alternative to a content-based approach in which students are required to learn scientific facts by rote, but Millar and Driver (1987) argue that this is an artificial dichotomy, that “learning content does involve processes” and “that to criticise the ‘process’ approach does not necessarily entail endorsing the rote learning of content”. They go on to argue that to isolate a set of scientific processes and teach these in the hope that students will then be equipped to apply these tools in a range of situations is misguided, both because of what is known about the difficulty students have in transferring what they have learnt in one context to another (Annett et al. 1985), and because the basic underlying assumption that there exists a context-independent ‘scientific method’, is flawed. Quoting Koertge (1969), they point out:

Many elements of what is often called scientific method, such as observing carefully, keeping records, and reasoning in an orderly fashion, are as typical of the supermarket manager as of the scientist.

And:

The commonly cited ‘processes of science’ cannot be divorced from content and context, and that it is the content and context which actually give meaning and value to so-called ‘process-based’ activities.

Op cit, p42

Despite the fact that these debates were taking place some 15 years ago, they still have relevance to science education today. The over-emphasis on ‘content’ in science classrooms remains a central preoccupation for many who wish to reform the curriculum, and, though different in the details, current arguments in favour of teaching ‘ideas about science’, or the nature of science have much in common with those put forward by the proponents of process science. For these reasons, some of the criticisms which Millar and Driver made of process science, and in particular, their points about the artificial separation of process and content, are equally pertinent.
to the teaching of the nature of science. The successful integration of process with content or context proved to be one of the greatest challenges for the teachers with whom we worked.

One tendency that was common in the lessons that we observed (particularly the early lessons) was for teachers to identify very concrete ‘factual’ learning objectives from the themes, and focus on teaching these atomised components of the nature of science in ‘stand-alone’ lessons that were unrelated to other work the class had been doing. While it is possible that our nine themes, and the request that teachers teach 8 lessons addressing elements of them, may have unwittingly led some teachers towards taking this approach, it also seems likely that this was the most accessible route into teaching these ideas for teachers who were used to the demands of delivering an assessment driven curriculum. Indeed, it seemed at times that some teachers were treating the themes in much the same way that that they might view an examination syllabus, regarding them as a kind of check list of items to be taught and ticked off.

A lesson taught by Mike, one of the key stage 3 teachers, provides an example of the way in which the context of an activity often became subjugated to very specific learning goals which, although relating to aspects of scientific processes, were treated as items of factual information. This was the first “EPSE” lesson that Mike had taught, and he based it on an article he had found in New Scientist. He said before the lesson that he hoped that students would be motivated by the fact that the article was from the current edition of a magazine aimed at adults, and that it reported on the work of real scientists (with names!). The article concerned some research that suggested that Dolphins may use sonar to stun or kill their prey as well as to locate them, and the aim of the lesson was to think about the observations made by the scientists, and the theories that they developed from them. He also hoped to develop the idea that scientists might not agree about the meaning of a particular set of observations, and so conflicting theories might be developed to account for them. Thus Rob began the lesson with enthusiasm for what he was about to do, and lots of ideas about what he hoped to achieve, but despite this the lesson ‘fell a bit flat’ (this was his reaction afterwards) and students appeared bored by the activity and unclear as to its purpose. As we explain in the following paragraphs, we believe that the problems with this lesson related to the way in which the processes through which the scientists developed their ideas became decoupled from the contexts in which they were working; the processes were focused on, the context ignored.

The lesson began with Mike putting up an overhead transparency with the words ‘observation’ and ‘theory’, and telling the class that today they will be doing something a bit different from usual. He then handed out the article, explaining where it had come from, and students read it aloud, taking a sentence each. This method of reading the article, while involving the whole class, rendered it somewhat disjointed and difficult to follow and it seems unlikely that very many students had drawn a great deal of meaning from it at this point. However, rather than have any kind of discussion about what the article might mean, or indeed, any consideration of the article as a whole, students were asked to go through the article underlining individual words that they didn’t understand, and a sheet on which ‘difficult’ words from the article were explained was handed out. Next students are asked to go through the article again, this time underlining observations in blue and theories in green. While they work on this Mike moves round the class offering help to students, and the lesson ends with a question and answer session to wrap up what they have done:

Mike wraps up the individual part of the lesson (my impression is that this is because things are getting out of hand, rather than that he particularly wants to pull things together at this point, but maybe this is unfair!). A very factual q and a session follows:
“which were the older type of observation?” “Are the scientists completely sure?” “How could they be more sure” – a girl near me says they could do more observations, and Mike says that’s exactly what he hoped she’d say, Simon starts to say what observations, but Mike stops him and moves on. Conversation goes on like this until bell, and students hand in work and leave.

So what went wrong with this lesson? First of all, the activity as set up, was a closed one—as far as the students were concerned, it was about extracting information from the article, and the subject of the article was almost incidental. Furthermore, the help that Mike offered to individual students tended to close it down further:

“Sir, I’m stuck on the greenies!”

“They think the dolphins use their sound – it’s what they think, so that’s a key word that tells you it’s likely to be a theory. And over here they think something else”.

The focus was very specific, and this tended to limit the scope for drawing meaning from the article as a whole, for contextualising, for moving beyond identification of theories and observations to begin considering how theories might grow from observations. The question and answer session that wrapped up the lesson was again closed, and focused on factual information rather than on ideas – Which were the older observations? How could scientists be more sure? In relation to this second question, it is interesting that when one of the boys in the class started to suggest what observations might be carried out in order to settle the matter, Mike stopped him. The lesson was about process in a general sense, so any contributions that moved it towards a more specific consideration of the interesting avenues of inquiry in this case were deemed inappropriate. This suggests a model of science in which ‘process’ and ‘content’ are separable, and general ‘rules’ can be applied universally to generate new knowledge. In this sense the context provided by the article was a foil for a lesson on ‘observations’ and ‘theories’, but we feel that the reluctance to engage more fully with the context meant that the potential for learning about these were diminished.

A slightly different example is provided by a lesson that Pauline (another of the key stage three teachers) taught to her class. Again, this was the first lesson that we observed her teach. In this lesson Pauline hoped to address the theme relating to scientists often working in groups, and to this end she had adapted a unit taken from a text book about the reflection of light and sound waves. The learning objectives, written on the board for students to copy into their books at the beginning of the lesson, stated:

Copy the way scientists work together to solve problems…

Do light and sound reflect in the same way?

The lesson then started with a short question and answer session, following a typical IRE format (ref), in which Pauline first asked students about situations in which scientists might work in groups, and later on the properties of light and sound. She appeared more comfortable with the latter, seeking and praising scientifically correct answers. Students were then asked to begin working in pairs or small groups on an activity which involved reading through several pages of text about light and sound, and answering the questions, in order to answer the overarching question “Do light and sound reflect in the same way?”. In this sense the ‘scientists working in groups’ element to the activity is ‘tacked on’ to an existing resource (Science Web
2000), and Pauline has modified the worksheets slightly, adding a few questions of her own, and instructions on the front of the first page stating:

You are going to pretend to be one of a group of scientists working together to find out Do light and sound reflect in the same way?

However, despite these modifications, the activity that students were involved with during this lesson bore very little relation to the work of real scientists. It was clear from the question and answer session at the beginning that the students in this class had already done work on light and sound waves, and so this was essentially a revision exercise; the questions set were almost all low-level, requiring students to extract factual information from the text. As with Mike’s lesson on dolphins, students in this class appeared bored during this lesson, and it seems that the activity did little to further their appreciation of the way that ‘real scientists’ work. Like Mike, Pauline has focused on one very specific aspect of scientific enquiry taken from the themes, and in doing so, created an activity that lacked the authenticity that might have allowed students to gain some insight into what it is like to be a scientist working with others on a problem.

**Giving ownership to the students**

We would argue that what is missing from Mike and Pauline’s lessons, described above, is students’ ownership of the activities. The lessons to be learnt were the teacher’s, and the activities set did not do a great deal to move students’ thinking beyond the factual input provided by the teacher. In this sense, students’ own engagement in these activities appears incidental—it may be regarded as a necessary precursor to the teacher telling students’ ‘what they need to know’, but it is not seen to be integral to their developing understanding of it. Reflecting on his own practice, and the impact that his involvement in the project has had on him, Andrew made a similar point:

[The project renewed my] desire to get children thinking.  And not just learning some things, you know, like learning a conclusion that you could take... in a sense trying to get away from that old scientific thing that I know I’ve taught in the past, where you have an hour’s science lesson and in fact it would take the children two minutes to learn the one piece of information you wanted them to learn. … I think sometimes it’s been a traditional thing about getting them to do the experiment for the sake of it.  And I think there’s a value in that, getting them to go through the process of an experiment.  There is use in that.  But I think sometimes it’s a bit unnecessary for them to just do something that they knew before they started.

Andrew

As is made clear from this quote, Andrew recognises that highly transmissive science lessons do not generally give students much opportunity to think for themselves, and he is keen to find ways of changing his own practice so as to ‘get children thinking’. Yet in common with many of the teachers participating in this study, making the shift from a highly transmissive model proved challenging.

A number of the activities that we modelled for teachers during the inset sessions that we held at King’s involved the use of class discussion work, and this was something that we encouraged teachers to try with their students as a way of getting them thinking and involved in the lessons. Most teachers were keen to incorporate discussion-based activities into their
teaching, but found this difficult in practice, and often felt that they lacked the necessary skills and experience to make a success of class discussions:

Mike There may be approaches which I would be much more comfortable with if I was say, a history teacher, or an English teacher, especially when it’s got to do with text or discussion or something like that. (...) The pupils (...) may be gaining more from those types of lessons. But (...) I’m not as skilled in that. I’ve either avoided it in the first place, [or] it hasn’t gone as well......

Consequently, many of the discussions that we saw remained very closed, following a typical IRE format; they were really question and answer sessions rather than discussions. Boulter and Gilbert (1995) distinguish between discussion of this kind, in which the teacher is in control of what is to be learnt and the purpose of discussion is to structure and assess students’ learning of predetermined factual content, with what they term ‘collaborative problem-solving discourse’ in which students’ input goes beyond responding to the teacher’s questions and helps shape the lesson. Table 3, adapted from Boulter and Gilbert, contrasts questioning and collaborative discourse:

<table>
<thead>
<tr>
<th>Questioning dialogue</th>
<th>Collaborative problem solving dialogue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teacher defines the fine grain of the content</td>
<td>Teacher defines the general content frame</td>
</tr>
<tr>
<td>Assymetrical control—the teacher’s role is to control</td>
<td>More symmetrical control—the teacher guides and summarises</td>
</tr>
<tr>
<td>Focus on content</td>
<td>Focus on investigative and interactional processes</td>
</tr>
<tr>
<td>Talk disembodied from pupils’ experience</td>
<td>Pupils’ individual and shared experiences are valued</td>
</tr>
<tr>
<td>Teacher talks most</td>
<td>Teacher listens within the frame set</td>
</tr>
<tr>
<td>Teacher reformulates the question until she gets the expected answer</td>
<td>Teacher’s probing is to clarify the pupil’s voice</td>
</tr>
<tr>
<td>Pauses minimal</td>
<td>Time is allowed for reflection</td>
</tr>
<tr>
<td>Interactional rules are not explicit and are learnt through participation</td>
<td>Interactional rules are explicit and strongly teacher-directed</td>
</tr>
<tr>
<td>Children’s initiatives are ignored</td>
<td>Deliberations are initiated by both teacher and pupils</td>
</tr>
<tr>
<td>Planning is the property of the teacher</td>
<td>Planning is made explicit and sometimes shared</td>
</tr>
</tbody>
</table>

The ‘questioning dialogue’ column captures many of the key features, discussed in the previous section, of Mike and Pauline’s first EPSE lessons, and indeed, elements of it apply to the majority of the lessons that we observed during the course of the project. (There were some notable exceptions to this, discussed in Bartholomew et al. 2002). We would suggest that granting students a degree of ownership of the science they are learning in school demands a shift towards the ‘collaborative’ column, in which some responsibility is handed over to students and the teacher relinquishes some control over the question of what (precisely) is to be learnt.
Yet such a shift is fraught with difficulty for teachers who are used to planning lessons around concrete, factual learning goals, and although most of the teachers with whom we worked began to incorporate more discussion-based activities into their lessons during the course of the study, they generally remained closer to the ‘questioning’ mode than to the ‘collaborative problem solving’ mode. Where discussions were kept very closed in this way it often seemed as though the students’ task was to ‘guess the answer that’s in the teacher’s head, diminishing the possibility for students to actually think about what they were doing. The fieldnote extract below, from a lesson Pauline taught on global warming, illustrates this point:

Students are asked to write down the ‘learning objective’ written on the board:
“Scientists need to consider whether the greenhouse effect causes global warming”
She says that scientists don’t agree, and that we need to consider what the greenhouse effect is, what causes it, how we might stop it and whether it’s responsible for global warming. Students have a sheet in front of them which describes the experiment they’ll be doing and gives some background information. Pauline asks, “What’s global warming?”
Arran says that the globe is heating up. “Good, how much? Look on the worksheet to see if you can see”
Daniel says 100km, almost to the core – 100km is the first number to appear on the worksheet! – Pauline says that she asked for a change in temperature, so the answer will be in degrees, and students then supply the correct answer of 1/2 a degree (this is the second number on the worksheet – so far this is an exercise in extracting decontextualised information).

Boulter and Gilbert’s characterisation of collaborative problem-solving dialogue offers some insights into the source of the difficulties for teachers. The difference between this mode and the ‘questioning dialogue’ mode is not simply to do with what the teacher says, or the sorts of tasks that they set for their student, but rather it relates to a fundamental shift in the roles of teachers and students, whereby the students are given greater responsibility for their own learning, and the teacher becomes a facilitator. While the teachers with whom we worked were keen to give their students opportunities to think, they were generally less keen (or less able) to make the changes to their own role that this demanded, and this led some of their efforts to backfire.

The extract below relates to an activity that Jo tried with her year 8 class. Students worked in groups, and each group was given a cube with a three letter word ending in AT on each face. The idea was that they work together to develop hypotheses about what the word on the bottom (and therefore hidden) face of the cube might be. It is illustrative of the sort of thing that happened when teachers tried to get their students thinking about a problem while at the same time remaining the authority on the subject; the intention is that students think for themselves, but in fact what is required of them is that they identify an approach to the problem that is deemed appropriate by their teacher. It is clear from this extract that these students are playing a different game from the one Jo wants them to play, and her input consists of trying to encourage them to play by her rules whilst maintaining the fiction that it is their thoughts and ideas that count. A number of activities that we observed seemed rather ‘contrived’ in this way:

One of the group asks Jo to help them: “miss, does it have to be a word that rhymes with them – ends in AT?” Jo says that would be part of their hypothesis, and they then complain that there are loads of at words. Jo tries to encourage them to think about how they could decide and they then start making up sentences using the words, and they develop this – “the fat cat sat on a mat, wearing a hat, holding a baseball bat”, and they think they are getting there when one girl says “hang on, it might not be, because we’ve got to do something to do with science”, and then they
start trying to think of other ways of thinking about it, and after a while they call Jo over and read their sentence to her.
Jo talks them through the task: The first part of their hypothesis is that it is going to have AT at the end. “Is it going to be THAT?”
“NO”.
“Why not?”
“Cos it’s got 4 letters.”
“OK, so the second part of your hypothesis is that it is a three letter word.”
A girl comes up with ‘they take fat out of a bat and a cat…’ but is told that ‘now we’re just getting stupid’ by others in the group. But they are still fixated on the meaning of the words, and with making them into a sentence. Jo goes to them again and suggests that they write down all the -AT words they can think of.
Then Jo tries another tack: “OK this is a science activity, but the science is not in the words is it? So in science we look for patterns. We’re looking for patterns”. Students continue in the same way, thinking about the words, and trying to group them into a sentence – they are simply not hearing what Jo is saying to them. Jo says that they’ve seen the pattern that CAT and BAT are both animals, and suggests they look for a different sort of pattern.
“The cat ate the rat” someone says.
Jo asks “Is the word the important thing?” and a student says “I dunno”.
Silence as they think then one of them starts to summarise what they know: “It’s got to be a scientific word.” Jo interrupts “no, it doesn’t have to be a scientific word but there’s a pattern in this” “I know – the mat could be a heat proof mat. Is it a door mat?” “You’re worrying too much about the words, and what the words mean.” “Is it door mat?”

Brenda, one of the key stage four teachers, was unusual in that she appeared very comfortable with adopting a more facilitatory role in lessons, and it is clear that this accords with her own beliefs about teaching. Talking to her after one of the lessons that we videoed, she remarked that she had “always thought that it didn’t matter what the teacher did in lessons, as long as they were stimulating”, and although she immediately qualified this statement, saying that she didn’t mean it literally, it nonetheless captures something of her approach to teaching. When interviewed at the end of the project, she spoke directly of the fact that she has come to believe that less time is needed to cover ‘content’ if it is supplemented with activities that develop students’ understanding:

And it’s OK to waste a lesson……. waste ….. you know, there is no content in this lesson. And I could justify it and actually, the group that I’d been….. they have done no differently, no worse than any other group that has been through the same course. You just re-jug the other material around it and I think that that….. it’s certainly made me see that you can actually compress the factual base, if you are going to use it. You can’t compress it if it’s just squashing a module into a smaller….. but if you actually get them to do something then use that information, you have actually gained an enormous amount, I think.

She also spent a lot of time developing a safe and supportive environment in lessons (something that clearly predated the project), and for example, spoke of how pleased she was that the whole class was participating in discussions by the end of the study. The comment below is from her evaluation sheet:

*What do you think your pupils have learnt from this work?*
By creating a ‘special’ environment (where I said I wanted to learn from them) they became much more confident in explaining what they thought. To start with only 2/3 were happy to explain their ideas – in the videoed lesson I noticed that most were involved in discussion.

Her lessons often included class discussions, and these were characterised by a high degree of ‘openness’, and the fact that when Brenda intervened it was generally to invite students to contribute rather than to tell them something or evaluate a response. In the extract below, a lesson looking at ways of modelling electrical flow begins with a discussion of some ‘concept cartoons’ (Naylor & Keogh, 2000). The cartoon being discussed here shows a picture of a simple circuit containing a single bulb and battery. Three children are observed looking on. One says that she thinks ‘the current going back will be less than that going out; another that ‘the current coming back will be the same as that going out; and a third that the positive and negative electricity meets in the middle. The class is a high ability year ten group:

Brenda: “This is quite a crunch one, you should be able to make some comment about it.”

Students talk about energy first without really distinguishing energy and current—less energy and so less current. Lydia argues that yes, the current/energy does keep going back to the battery, but not all of it, else why would a battery ever run down. Like a car battery, you can recharge it, but never quite back to the original. One of the Katies’ then asks whether energy affects current, saying she can’t remember, and Brenda says that this is a crucial question (though doesn’t answer it for them). Another student on the most talkative table refers back to the experiment they did, and concludes that the current is the same — “when we tested the current and had a few bulbs in a series circuit, the current was the same after each bulb so it doesn’t really matter if the energy is spent, the current is still the same.”

Brenda: “Now there’s a good argument for coming to school and doing science practicals, because you’re basing it on observations that you made last lesson.”

“Yeah, so after one bulb the current was still the same.”

They then say that they found that in a parallel circuit the current decreased, and a few students dispute this result.

Brenda: So you’ve got two pieces of evidence, and there’s a mismatch between the evidence. Kirsty, what do you think?

“I think the current’s the same in both circuits.”

Brenda: What are you basing that on? (pauses and there is no response) Can you explain what current is?

Electrons

Brenda: And what happens to them when they get to the bulb?

They light up the bulb, but they’ll still carry on.

Other students now chip in too – but they spend their energy in the bulb.

Student: Maybe it’s like a flow of electrons – there’s not less electrons, but they’ve got less energy.

At this point Brenda wraps up this discussion, “enough of that” – no summarising, or giving ‘the answer’ – and they move on to the next task.
What is striking about this extract is that the students are answering their own, rather than their teacher’s, questions. Brenda, having provided the context for discussion (by placing the concept cartoon on the overhead projector), steps back and allows her students to make of it what they will, not even summing up or giving ‘the answer’ at the end of the discussion. In this classroom, at least for the duration of this discussion, the roles of student and teacher have shifted: Brenda has become a facilitator, and her students are engaged in making sense of the cartoon together, developing and refining their ideas and learning from each other.

**Living with uncertainty**

An implication of making the shift towards a more dialogic and collaborative model of teaching in which students’ input makes a difference, is that an element of uncertainty is introduced into the lesson. For many of the teachers, the uncertainties inherent in moving away from their familiar role, in which they were the one with all the answers, were a source of some anxiety, and this related both to their own role and status within the classroom and to the risk that students would perform less well in exams as a result of this shift. While some teachers persisted in transforming elements of scientific process into factual learning goals, thereby eradicating much of this uncertainty, most made some movement towards a more dialogic / collaborative model during the course of the study and had to confront it head-on. Sue, one of the key stage four teachers, devised a number of lessons which addressed the development of scientific ideas over time and the fact that ‘experts’ did not always agree with each other, and she spoke enthusiastically about the fact that an outcome of this had been that students were less inclined to take what they were told on trust, and asked more probing questions about what they were learning. However, she went on to say:

> Well, particularly this business about uncertainty and disagreement between scientists. I think there’s always a bit of a hesitation there in people’s minds because you don’t want them to be uncertain of what they need to write in the exam. And yet you do want them to be critical of things that they read in the newspapers, critical of things that they see on TV. Critical of their own findings in investigations

Sue

For other teachers the unease associated with this uncertainty was much more closely related to the implications for their own authority in lessons. A number of teachers talked of feeling vulnerable in situations where they might not know the answers to students’ questions, and worried that this might undermine their status in lessons. Clare was a particular case in point, and it is again interesting to note that despite her unease, she, like Sue, was most attracted to the themes which explicitly raised this element of uncertainty, and she too taught a number of lessons which dealt with disagreement between scientists or looked at conflicting theories to account for some phenomenon:

Clare: The [theme] I’ve hit far more than any others is science and certainty. The science and certainty one.

HB: Can you say why you think [that is]?

Clare: I think the certainty one interested me a lot from the point of view of perhaps the type of person I am, or whatever. You know. The sort of can’t be sure, how can you be sure, evidence. And that’s a bit of an angle I seem to fall into taking.
Yet her insecurity, particularly in relation to not knowing the answers to students’ questions, infused much of what she said and wrote about the project. The following comments, relating to three different lessons, were in her diary:

Re Does hot or cold water freeze quicker?
The pupils didn’t like the fact that I couldn’t tell them the answer / that I didn’t know the answer.

Re tippee-tops lesson (in which students considered why spinning tops could flip upside-down and continue spinning)
It again felt vulnerable to not know all the answers but enjoyable and thought provoking for all.

Re gravity poem (in which students had to identify the force being described in the poem):
“I didn’t feel vulnerable on this one as I had about 5 reasons to back up it being gravity”

After all three of the lessons that we observed her teach she spoke of how difficult she had found it to know what to say during the ‘summing up’ part of the lesson at the end, indicating her concern with ‘telling students what they need to know, and suggesting that she feels responsible for ‘managing’ her students’ learning in this way:

HB And just coming back to what you were saying about planning the lessons again and talking about how meticulously they were planned, and as you said that I just remembered you saying at the end, I think of both of the lessons that I videored, you refer to the fact that the summing up had been the bit where you felt you were winging it a bit.

Clare Yeah.

HB And I’m just wondering if you could say a bit more about that.

Clare Just unsure how you are supposed to sum that sort of thing up.

HB OK. OK.

Clare Just from the point of view of not being sure on literally what you are supposed to say. Like, you are supposed to say - ooh, well, you know, there’s no way you can tell this. Or you know, just how you are supposed to sum that sort of thing up? I haven’t perhaps explored enough or haven’t seen too many examples enough, so I’m fumbling around a little bit, thinking what your gut reaction is, what you are going to say, but not knowing what point it is you want to make in the sum up.

Conclusion: working with teachers
Different teachers have different needs and there is no easy ‘one size fits all’ solution to introducing the nature of science into the curriculum. That said, there were also many commonalities in the experiences of the different teachers with whom we worked, and these point the way towards some strategies that may help.

All of us involved in this project - teachers and researchers - were learning and developing our ideas as we went along. In most cases we felt that the later lessons we observed, when teachers had had more experience of working with these ideas, were more successful than the earlier ones, but equally, we feel that if we were setting up the project again, there would be a number of things that we would do differently. In particular, in the early sessions held at King’s, we spent time ‘unpacking’ the nine themes with teachers, and suggesting teaching materials that they might find helpful, but we spent relatively little time exploring the implications for pedagogical style or, crucially, for teachers’ own role in the classroom, of making the shift from
focusing on a body of scientific knowledge to teaching *about* science. Yet in practice, these were often the issues which concerned teachers most, and were the subject of many discussions in later meetings.

A preoccupation among many proponents of teaching ‘ideas about science’ is teachers’ own understanding of the nature of science (or, more often, their lack of it). Yet the factors that we have identified as important in determining the success of lessons are relatively unrelated to these teachers’ knowledge of the nature of science. Indeed, two of the teachers whom we felt were most effective at teaching these ideas in a way that really challenged their pupils’ thinking and gave them some ownership of the ideas, were primary teachers, Emma and Becky, and although Emma is highly qualified scientifically, Becky’s degree is in anthropology and she frequently expressed her insecurity about her perceived lack of understanding of the issues. Yet these primary teachers were much more comfortable than the majority of secondary teachers in working with their students’ ideas, and teaching in a more ‘open’ way. As Emma said:

**Emma**

> HB OK. And what about the easiest things, were there things in particular...?
> Emma I think it was particularly easy for primary teachers because a lot of what was suggested we were doing already. It wasn’t that much of a shift. And so I also think it was easy for the children, because it wasn’t that much of a shift for them, in the way that they’ve normally been taught science.

We are not claiming that a teachers’ own understanding of the nature of science is of no significance in determining the success with which they will be able to teach these ideas – of course it is. However, we *are* arguing that the pedagogical approach, and the teacher’s role within the classroom more generally, are at least as important.

It seems likely that school science will undergo changes in the next few years, and that students will be expected to spend less time learning scientific results, and more time learning about science. We would suggest that in helping teachers make this shift, making changes to the curriculum and then asking teachers to implement them, is unlikely to have the desired effect on its own. Of course, changes to the curriculum and examination syllabi that placed ideas about science at their heart would help. But ultimately, we would argue, the successful implementation of a curriculum of this sort, and the transformation of school science into a genuinely inspiring and empowering subject for young people, demands that teachers be encouraged to take risks and to begin to renegotiate their own and their students’ roles. For this to take place it needs to be acknowledged that teachers will not - and cannot be expected to - always know all the answers to their students’ questions so that they can begin to create classrooms in which everyone can learn from each other, and a degree of uncertainty can be embraced. This is unlikely to happen while the current regime of assessment and accountability persists:

I hope that in some way I will continue to use the ideas and strategies encountered on this project. But I fear that I could quickly become bogged down with outside pressures to get the children to perform. I really don’t think that this excellent and important project can have any influence unless there is a change in thinking from the government, exam boards, Ofsted and all other groups that influence schools.

**Emma**
References


