

Teaching pupils 'ideas- about-science': case studies from the classroom.

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Abstract

In this paper, we report work undertaken with a group of 11 teachers over a period of a year to teach aspects of the nature of science. The teachers, who taught science in a mix of elementary, junior high, and high schools, were asked to teach components of the nature of science for which consensus had been established using a Delphi study in the first phase of the project. Data were collected through field notes, videos, teachers' reflective diaries, instruments that measured their understanding of the nature of science and the role of discussion in the classroom. In addition, data were collected of their pupils' understanding of the nature of science, pre- and post-intervention, and that for a control. In this paper, drawing on a sample of the data we explore the factors that afforded or inhibited the teachers' pedagogic performance in this domain. Using these data, we argue that there are 5 critical dimensions that distinguish and determine a teacher's ability to teach effectively *about* science. Whilst these dimensions are neither mutually independent nor equally important, they serve as a valuable analytical tool for analysing and explaining the success, or otherwise, that individual teachers have when confronted with teaching components of the nature of science. In addition, we argue that they are an important means of identifying salient aspects of pedagogy for initial and in-service training of teachers for curricula that require the teaching of the nature of science.

Introduction

Given that there is an emerging core consensus that components of the nature of science are an essential and central element of the school science curriculum (Millar & Osborne, 1998; McComas & Olson, 1998; Smith & Scharmann, 1999), can these aspects be taught successfully? This paper reports the research undertaken in the second phase of a two phase project. The first phase sought to explore whether the community engaged with the practice and communication of science could agree on an account of the nature of science that should form the basis of the compulsory school curriculum; whilst the second phase, the subject of this paper, sought to examine what were the issues and problems raised for teachers who attempted to teach aspects of this core conception of the nature of science to school students.

The first phase of this work has been reported previously last year (Collins et al, 2001). Essentially, that research and its findings sought to make a contribution towards clarifying this debate and dilemma around what should be taught to school students *about* science. It sought to do this by establishing empirically the extent of consensus within the relevant communities about a simplified or 'vulgarised' account of science – that is to determine the characteristics of scientific enquiry and those aspects of the nature of scientific knowledge that should form an essential component of the school science curriculum. The study was undertaken using a Delphi technique with a group consisting of 23 individuals drawn from 5 groups – scientists, philosophers, sociologists of science, science educators, and science teachers. Members of the first four groups were recruited on the basis that they held an international reputation in the field, or were Fellows of the Royal Society. Science teachers were selected on the basis that they had either received awards for the quality of their teaching, or had published notable textbooks in the field. As is standard in all such Delphi studies, none of the participants were aware of who the other participants were.

From this work nine themes (see Table 1) emerged where two thirds of the participants rated their importance as 4 or above on a 5 point Likert scale over the last two rounds of the study and which were also stable across two rounds – criteria which were considered to indicate a consensus.

Table 1: The 9 Themes from phase 1 of this study that form the components of a simplified or core account of the Nature of Science.

<i>Theme 1</i>	Scientific Methods and Critical Testing	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 a single experiment is rarely sufficient to establish a knowledge claim.
<i>Theme 2</i>	Science and Certainty	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
<i>Theme 3</i>	Diversity of Scientific Thinking	Pupils should be taught that science uses a range of methods and approaches and that there is no one scientific method or approach.
<i>Theme 4</i>	Hypothesis and Prediction	Pupils should be taught that scientists develop hypotheses and predictions about natural phenomena. This process is essential to the development of new knowledge claims.
<i>Theme 5</i>	Historical Development of Scientific Knowledge	Pupils should be taught some of the historical background to the development of scientific knowledge.
<i>Theme 6</i>	Creativity	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.
<i>Theme 7</i>	Science and Questioning	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 techniques which are then tested empirically.
<i>Theme 8</i>	Analysis and Interpretation of Data	Pupils should be taught that the practice of science involves skilful analysis and interpretation of data. Scientific knowledge claims 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 legitimately to come to different interpretations of the same data, and therefore, to disagree.
<i>Theme 9</i>	Cooperation and Collaboration in the Development of Scientific Knowledge	Pupils should be taught that scientific work is a communal and competitive activity. Whilst individuals may make significant contributions, scientific work is often carried out in groups, frequently of a multidisciplinary 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, we worked with a group of eleven teachers over the period of a year whom we asked to develop and implement a series of a minimum of 8 lessons which incorporated aspects of the nature of science represented by the themes. Three of these teachers taught in elementary schools at key stage 2 (age 8-11), four in junior high schools at key stage 3 (age 11-14) and four at key stage 4 (age 14-16). The intent here was to examine what were the dilemmas and issues raised for

the teaching of this account of science for these teachers within the context of their normal teaching.

Background and Issues

Teaching the nature of science in schools has been much talked about, discussed and debated (Abd-El-Khalick & Lederman, 2000a; Abd-El-Khalick & Lederman, 2000b; Alters, 1997; Brush, 1989; Collins & Pinch, 1993; Donnelly, 2001; Driver, Leach, Millar, & Scott, 1996; Efflin, Glennan, & Reisch, 1999; Hodson, 1988; Jenkins, 1996; Matthews, 1994; McComas, Clough, & Almazroa, 1998; Osborne, 1998) but underexplored where it matters – that is in the classroom. As Schwartz and Lederman (2002) comment:

instructional intentions, and approaches to NOS instruction have not been the focus of much research. Nor has there been a full exploration of the factors that influence one's knowledge and practice relative to NOS and the possible relationships among them. Identification of such factors could begin to inform those constructing teacher education programs about the needs and limitations of teacher as they develop a knowledge base for teaching NOS.

Therefore, this research sought to explore the difficulties normal teachers of science faced in teaching about the nature of science.

Some insights into the particular problems faced are provided by previous research and scholarship. For instance, Reichenbach's (1938) distinction between the context of historical discovery and the context of epistemological justification offers some insight into why the nature of science is often ignored in school science. In the context of discovery, ideas are tentative, if not speculative, and presented in language which is interpretative and figurative (Sutton, 1995), often using new metaphors (Eger, 1993). The central concern of most science teachers, in contrast, is the transmission of the products of 'the context of epistemological justification' - that is a narrow focus of 'what we know' rather than 'how we know' – what Duschl (1990) has termed 'final form' science. Gallagher (1991), in looking at prospective and practising secondary school science teachers' knowledge and beliefs about the philosophy of science, provides a reminder that, for science teachers, science is perceived as an established body of knowledge and techniques which require minimal justification. Such teachers often work from weak evidence, use inductive generalisations (Harris & Taylor, 1983), and renegotiate classroom observations and events to achieve a social consensus (Atkinson & Delamont, 1977), persuading their pupils of the validity of the scientific world-view (Ogborn, Kress, Martins, & McGillicuddy, 1996). In such a context, deliberations about the nature of science, the tentativeness of scientific knowledge or its social dimensions are perceived as essentially marginal to their project.

Gallagher comments that, even if science teachers consider the history of science for inclusion in the curriculum, it is generally only in terms of humanising science for the purpose of fostering positive attitudes to science, rather than for the purpose of understanding the nature of science. For many teachers of science, only the development of an understanding of science concepts and the nature and methods of science are essential to an education *in* science. The rest lies beyond the boundary of 'what we now know', which, as Haywood recognised in 1927, is the criteria that

curtails science teachers' incorporation of the nature of science into their schemes of work. Hence, the first obstacle is gaining acceptance by teachers, or what Harland and Kinder (1997) term 'value congruence', is that the nature of science is an important and significant component of the curriculum. A major impetus for this research was the growing body of arguments emanating from work in which two of the authors were involved (Millar & Osborne, 1998) and elsewhere (AAAS, 1998) which argued for more attention to teaching 'ideas-about-science'¹ or the nature of science. Nevertheless, whilst recent policy documents such as *Inquiry and the National Science Education Standards* (National Research Council, 2000) and the inclusion of 'scientific enquiry' as a separate strand in the English and Welsh science national curriculum (Department for Education and Employment, 1999) have raised the profile and importance of the nature of science, there is still a large gap between policy and practice.

Science teachers & their socialisation

Another fundamental difficulty identified by a variety of authors is that many science teachers, themselves the products of an archetypal education which has largely ignored the epistemic base and nature of its own discipline, have a range of misconceptions or naïve understandings of the nature of science (Brickhouse, 1991; Gallagher, 1991; Kouladis & Ogborn, 1989; Koulaidis & Ogborn, 1995; Lakin & Wellington, 1994; Lederman, 1992; Mellado, 1998). The main picture to emerge from this research is that science teachers have no consistent view about the nature of science and that, in the light of contemporary scholarship, most of the views they hold could be termed 'inadequate' (Abd-El-Khalick & Lederman, 2000a). A significant proportion of teachers, for instance, have no recognition of the tentative nature of some scientific knowledge and others hold outmoded positivist or empiricist views of the nature of science. Koulaidis and Ogborn (1989) also found distinctions between teachers from the separate scientific disciplines and that student teachers hold somewhat different views from those of experienced teachers. Moreover, an additional problem is that our understanding of the nature of science has, in the last thirty years, undergone a significant transformation as a product of the growing and burgeoning studies emerging from the sociology of science – a body of scholarship which it would be totally unreasonable to expect science teachers to know given all the other constraints and demands on their time. And, given that it is now commonly accepted that one of the necessary conditions of effective teaching is a good knowledge and understanding of the content or ideas to be communicated (Osborne & Simon, 1996; Shulman, 1986; Turner-Bissett, 1999), it follows that teaching about the history, philosophy and nature of science requires a well-developed understanding of the body of scholarship that exists about these subjects. Consequently, it is reasonable to presume that science teachers' lack of knowledge about NoS undermines their confidence and ability to teach about science.

Moreover, a further complexity is that several studies have now consistently shown that there is complex relationship between teachers' declared conceptions of the nature of science and the manner in which they present the subject in the classroom (Brickhouse, 1991; Duschl & Wright, 1989; Hodson, 1993; Lederman & Zielder,

¹ In this paper, the term 'ideas-about-science' (Millar and Osborne, 1998) is used interchangeably with the Nature of Science (NoS). The former has the advantage of conveying in less academic language the reference commonly represented by the latter term.

1987). This research shows that concerns about the nature of science are often subjugated to a set of imperatives that are a product of the constraints of the curriculum, classroom management, lack of time and student engagement with the topic. Thus science teachers' philosophical stance towards science invariably play second fiddle to a more fundamental set of exigencies that dominate classroom life. As Lederman (1999) has found, even teachers who have a large degree of flexibility in their teaching and planning of the curriculum do not significantly address the nature of science in their teaching. In short, as Abd-El-Khalick & Lederman (2000) point out, knowledge of the nature of science is a necessary condition for teaching the nature of science but not a sufficient condition.

Aim of the Study

Thus, given the eclectic and heterogeneous nature of teachers' views and the imperatives of managing and structuring learning for large groups of students, it is, perhaps, not surprising that incorporating more of the nature of science into the curriculum is a substantial task. For the findings of these studies discussed in the preceding paragraph invite the question of what are the sufficient conditions to develop in students an effective understanding, albeit vulgarised, of the nature of science? Having explored our first question (Collins et al., 2001) and found a significant degree of consensus about what should be taught about science, our research then sought to explore what does constitute sufficiency for the effective and successful teaching of the nature of science by using a set of case studies of a range of teachers (elementary, junior high, high school) attempting to teach aspects of the nature of science embodied in the nine themes.

In approaching our work, we were conscious of the growing body of work that suggests that teaching about science must be done explicitly (Monk & Osborne, 1997; Abd-El-Khalick & Lederman, 2000a; Schwarz & Lederman, 2002). Many syllabi, and many teachers for that matter, assume that concepts about the nature of science can be picked up *en passant*. Not only does this do a disservice to the body of significant scholarship and intellectual endeavour that has led to our current understanding of the practices and processes of science, but it fails also to recognise that understanding any process is a *reflective* endeavour. Reflection cannot occur unless salient components of the practices and processes of science are highlighted and identified for students by the teacher. Therefore, it is essential that the significant features of NOS and the insights of contemporary scholarship are *explicitly* taught and explicitly considered. Central to our view of an appropriate pedagogy for teaching the nature of science, therefore, is a conception of a process which is reliant on activities which stimulate the *process* of reflection through which students may acquire conceptual understanding. Such a view requires the nature of science to be taught explicitly.

Methodology

Initial work with teachers

Twelve teachers (4 primary, 4 early secondary and 4 late secondary) were recruited to take part in a 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 elementary 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.

Table 2: Summary Biographical details of the teachers

	<i>Degree subject</i>	<i>School Post</i>	<i>Years of teaching experience</i>
Elementary School			
Andrew	Geography	Acting deputy and year 6 teacher	20
Emma	Physics	Science co-ordinator and year 6 teacher	5
Becky	African Studies and anthropology	Science co-ordinator, KS2 co-ordinator and year 4/5 teacher	10
Junior High			
Pauline	Physics	Head of science	24
Clare	Geology with chemistry	Assistant head teacher and head of science	10
Mike	Chemistry	Science teacher	5
Jo	Biology	Science teacher	9
High School			
Brenda	Biochemistry	Head of science	18 (previous career as clinical biochemist)
Sue	Physics	Head of science	
Harold	Physics	Vocational science co-ordinator and deputy head of grade 7	27
Daniel	applied chemistry	Acting head of chemistry	4

During the first 3 months, four initial one-day meetings were held which enabled collaboration between researchers and teachers. These meetings provided an opportunity to explore and plan for the explicit teaching of themes; to examine the pedagogical implications; to develop materials for addressing the themes; provided an opportunity for teachers to improve their own understanding of the nature of science; and to consider methods of evaluating the learning outcomes for pupils. For instance, an initial activity explored their understanding of the Delphi themes. The teachers' response was to claim that many of the themes were being addressed in the current science curriculum but implicitly. The challenge confronting the teachers and us as researchers was the necessity to develop activities and approaches that taught some of the themes or 'ideas-about-science' explicitly. In meeting that challenge, a number of strategies were adopted. Rather than address the nature of science in isolation, we presented some lesson outlines in which intended learning outcomes to match particular themes were embedded in activities drawn from a range of existing sources (e.g. Lederman & Abd-El-Khalick, 1998; Ratcliffe, 1999; Goldsworthy, Watson & Wood-Robinson, 2000). Other curriculum resources drawn upon included packs aimed at development of ideas with similarity to the themes e.g. Charis Science (The Charis Project 1997, 2000); AKSIS materials (Goldsworthy, Watson & Wood-Robinson, 2000); concept cartoons (Naylor & Keogh, 2000); pupil texts and readers (e.g. Science Web, 2000; Heslop, Brodie & Williams, 2000; Feasey, 2001); and videos showing historical case studies.

In demonstrating approaches, we attempted to model our conception of good practice for the effective teaching of the nature of science. Such models were offered not as prescriptions but more as frameworks which teachers could trial and adapt. Adaptation was often a necessity as the teachers were dealing with a heterogeneous mix of age, content and context. To reduce the problem of different age ranges, teachers worked in age-specific groups to share and develop these and their own ideas in order to be able to implement specific lessons across units of work in the Spring and Summer terms. They welcomed the opportunity to explore how they could adapt curriculum materials for their own purposes. During this period, teachers were encouraged to trial materials. At the following session, teachers would report and share the issues and dilemmas that the experience had raised for them.

The teachers then undertook to teach at least eight lessons over a period of two terms (January to July 2001) to a target class, addressing as many of the top-rated nine themes as they felt able. The subsequent two one-day meetings explored the issues raised in attempting to establish learning environments in which 'ideas-about-science' could be explicitly addressed and explored in lessons. In these sessions, video clips of the teachers gathered in the initial data collection phase were shown and discussed. The methodology for this phase of the project was thus designed to be collaborative and evaluative, and to develop teachers' confidence and expertise to use and appraise both teaching strategies and learner outcomes.

Data collection

Each teacher was visited in their school three times, and two of the lessons they taught were videoed (one of the earliest and one of the latest in each case). 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. Additionally a focus group discussion at the end of the final one-day meeting involving all teachers and individual questionnaires provided data on their views of

the intentions and outcomes of the project. We also asked them to complete an evaluation sheet after each lesson, and to ask their students to do so, and we administered questionnaires designed to access their conceptions of the nature of science (ref) and their attitudes to classroom discussions and enquiry based teaching (ref) 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.

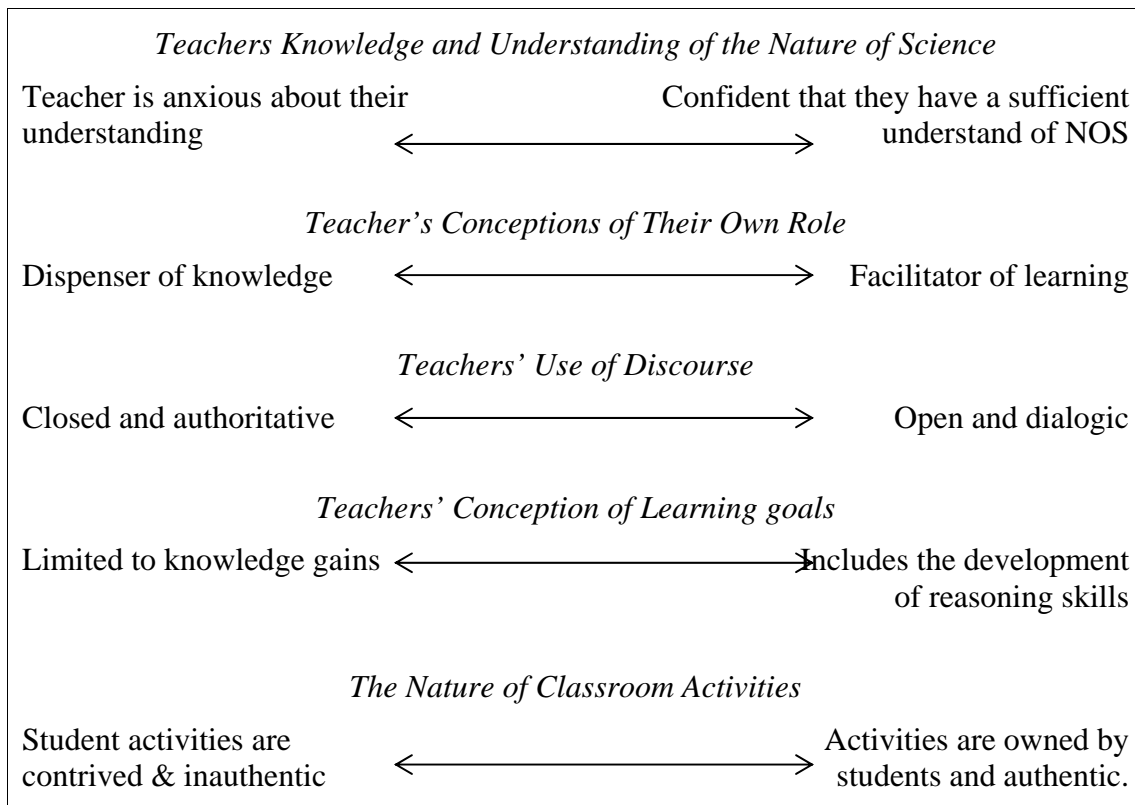
In analysing our data, we have adopted a grounded approach (Strauss & Corbin, 1990), allowing themes and analytic categories to emerge through an iterative process of engagement and re-engagement with the data. In this way, emergent themes informed our subsequent analysis and were tested against other data-sets, so our thinking about the lessons we videoed draws on all of the data we collected.

One feature of the training sessions that we ran for teachers is that we neither provided explicit teaching about the Nature of Science nor prescribed a particular approach to teaching these ideas. The latter would have been difficult to do as the classes of the teachers ranged from pupils of age 9 to age 16 and the contexts and the topics they were teaching varied from school to school. An implication of this is that our data chart these the individual journeys of teachers in making sense of what they were trying to do and finding ways of incorporating teaching about science and these themes 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 these teachers of science were able to overcome such obstacles provides 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’.

Results

Our initial approach to studying the attempts of these teachers to incorporate aspects of NoS was essentially grounded seeking to see the extent to which the themes were explicitly addressed and the strengths and weaknesses of different approaches and strategies. A particular focus of interest initially was the extent to which teachers were prepared to permit dialogic discussion of and reflection on the specific facet of the nature of science seen as the learning objective for that lesson. Another focus of interest was whether the NoS lessons were ‘stand-alones’ or whether they were included as part of a topic or sequence of lessons that would have been taught anyway. However, as our analysis proceeded, we have refined our focus of interest, and begun to consider more precisely what it *means* to integrate teaching about the nature of science, its practices and its processes, with the body of canonical content knowledge in a way which reinforces and adds to the teaching of both. Exploring this issue has become central to our developing analysis, and in seeking answers we have been led to identify a series of ‘dimensions’ along which the performance of teachers can be distinguished which are outlined below:

The 5 Dimensions of Practice



In the section that follows, drawing on the data, we seek to illustrate the evidence and arguments for this analysis. However, before discussing each of these dimensions in more detail, there are a number of general points to be made:

- They are not mutually independent. For example, a teacher who sees her role to be that of dispensing knowledge to her students is less likely to see value in open discussions in which students' ideas are aired, and is more likely to see the learning objectives in terms of items of knowledge that she can pass onto the class (as opposed to increased depth of understanding that may result from students struggling with an idea, say). However this does not imply that they are all effectively indicators of the same thing, and that teachers who are on the left hand side (lhs) for one dimension will necessarily be on the lhs for all the others.
- It is not intended or imagined that we will be able to place each teacher at a particular position along each dimension and that they will stay there; we have found them to be a useful tool for distinguishing teachers, and for thinking about salient features of the lessons we observed, but most teachers move around, maybe drifting further to the right as they became more confident with the ideas in the project. Furthermore, we collected a diverse range of data relating to each teacher, and these did not necessarily fit together to tell a completely consistent story. Part of what is interesting in analysing the data is trying to build up a coherent picture from the different data sources we have, and in doing so, factors which emerge as being important include the interplay between teachers' epistemological and pedagogical beliefs; the extent to which teachers are constrained by the need to get through an examination syllabus; and the nature of the class with which they were working, and the patterns that have been established with them. All of these things will have an impact on what happens in

the lessons that we observed, and may mean that some of what they do or say appears to ‘contradict’ other things. Below we discuss each dimension further and tease out some of these points with examples from our data.

- Locating teachers is necessarily interpretive. This is particularly true of the later dimensions, for which we drew heavily on the observations we made of lessons. In placing teachers along these dimensions, teachers’ stances were read from their actions, which we held to be a reflection of their implicit beliefs.

Teachers Knowledge and Understanding of the Nature of Science

The teachers with whom we worked on this project came from a range of backgrounds and, accordingly, there was considerable variation amongst the teachers in terms of their confidence in teaching these ideas. At one extreme Becky, one of the elementary school teachers, voiced considerable anxiety about incorporating these themes into her teaching, saying in a discussion at the final teachers meeting that, since she didn’t even have GCSEs² in science subjects, she had found the whole experience initially very daunting. It might be expected that such anxieties would be stronger for those elementary school teachers who did not have any substantive background in science, but while Becky was the only teacher to express this degree of anxiety, she was certainly not unique in having some doubts about her ability to teach ‘ideas-about-science’. For instance, Clare, one of the junior high school teachers and the head of science for the whole school, commented, in the same discussion, that “the more you go into it, the more you find out that you don’t know at all. It’s made me realise how much I don’t know”. Thus, although the junior high and high school teachers (and one of the elementary school teachers) had all taken a science subject to degree level, this background did not imply that they were all equally confident that they understood the Nature of Science sufficiently to teach it well. As remarked in the introduction, the prevailing mode of science teaching is transmissive, with the emphasis on its canonical content rather than its processes and practices. Science is quite remarkable in ignoring the history or nature of its discipline in educating the next generation of scientists and undergraduate education is very similar (Collins, 2000; Tobias, 1990). Thus, even teachers who have studied science at degree level commonly have little more than a rudimentary understanding of the nature of science.

At the beginning of the study we administered a questionnaire designed to assess teachers’ understanding of philosophic aspects of scientific theories (Cotham, 1979) and this provided us with some insights about the conceptions of the nature of science held by the different teachers. The value of this instrument, rather than other well-known ones, is that it is the product of a substantive piece of research with subscales that are statistically independent of each other. This instrument contains 4 subscales, each with 10 items with responses that use a Likert type scale which are outlined in Table 1. Questions relating to each of the subscales were distributed through five sections, four of which concerned particular scientific theories (e.g. evolution) and one of which comprised decontextualised general questions. A low score on this instrument is associated with a relatively unsophisticated view of the nature of science such as that commonly generated by a conventional education in the subject (Driver et al., 1996). Individuals obtaining a higher score are likely to have been exposed to and influenced by more contemporary interpretations of the nature of science and, therefore, have a more extensive exposure and understanding of NoS.

² GCSE’s are the lowest level terminal examination in science, normally taken at age 16.

		Responses range			
		From		To	
		1	2	3	4
subscale	Testing theories	conclusive	↔		tentative
	Ontological implications	realistic	↔		instrumentalist
	Generation of theories	inductive	↔		inventive
	Theory Choice	objective	↔		subjective

Table 1: Summary of subscales on COST (conception of scientific theories) questionnaire

Scores on each subscale can be represented by a number between 10 and 40, and all of our teachers had scores between 20 and 30 on all 4 subscales. The scores can then be translated into a particular conception of the nature of science (Cotham, 1979:100). Table 2 shows the categorisation of the individual teachers views on the four subscales and the final column is simply a summation representing where they are positioned between the two ends of the spectrum, between a realist and objective view of science (----), and a tentative and subjective body of knowledge (++++). The most obvious feature of the responses from teachers on this instrument was that the majority were situated in or around an indeterminate view of science. Furthermore, within the narrow range that the teachers responses fell, those differences that do occur do not appear to follow any strong patterns. It is apparent that the elementary teachers' responses are somewhat less sophisticated than the secondary high school teachers' responses, for example, but then there is considerable variation within each grouping of teachers. Moreover, there is no evidence that responses differed according to teachers' subject specialism.

Table 2: Teachers' responses to COST questionnaire

Beliefs	Ontology	Testing	Generation	Choice	
Teacher					
<i>Elementary School</i>					
Andrew	Indeterminate	Indeterminate	Induction	Objectivist	--
Emma	Realist	Conclusive	Invention	Subjectivist	
Becky	Indeterminate	Indeterminate	Indeterminate	Indeterminate	
<i>Junior High</i>					
Pauline	Realist	Conclusive	Indeterminate	Indeterminate	--
Clare	Indeterminate	Indeterminate	Induction	Indeterminate	-
Mike	Realist	Tentative	• ³	Subjectivist	+
Jo	Instrumentalist	Indeterminate	Indeterminate	Subjectivist	+
<i>High School</i>					
Brenda	Indeterminate	Indeterminate	Induction	Subjectivist	
Sue	Indeterminate	Tentative	Indeterminate	Subjectivist	++
Harold	Indeterminate	Indeterminate	Induction	Subjectivist	+
Daniel ⁴	•	•	•	•	

Whilst this instrument provided us with information about individual teachers' conceptions of scientific theories, it tells only one part of the story about these teachers' confidence in teaching these ideas. As, when these findings are considered in conjunction with some of the other data that we collected, teachers' view about the nature of science did not appear to be a major determinant of their self-assurance to teach these ideas. For example Brenda, who had one of the lower scores on the COST questionnaire (suggesting a relatively 'unsophisticated' view of the nature of science), gave a very clearly articulated response when asked in an interview about the aims of this project. As the extract below indicates, Brenda's views derive less from her own understanding of the nature of science than from her pedagogical beliefs; beliefs which demonstrate a strong commitment to a student-centred approach to teaching; that scientific facts should be embedded within a curriculum which highlights the connections between ideas evidence; and that science teaching should emphasise the idea that science is a human endeavour:

- Int. What do you see as being the principal aim of the work that we've been doing?
- Brenda I see the major benefit of it as setting science into its historical perspective. Because when you have grown up with a subject and you have done it in depth you appreciate the development of ideas, but I think we have failed to realise that the kids need to appreciate the development of ideas as well, and not just be splatted with something that is what we

³ This teacher failed to complete one item, and so no score could be calculated on one of the subscales.

⁴ This teacher was absent when the test was undertaken

know now.... I think that all the work we've been doing is to do with developing a coherency about the subject. So they tie together and one thing leads to another..... And putting the history into science. We need to teach science as sociology. You know, put it in a human context.

Andrew had an even more unsophisticated view of the nature of science to Brenda and was much more uncertain about what the project was trying to achieve. From the interview carried out with him at the end of the study, one gains the impression that he has understood this project as being about moving away from an exclusive focus on scientific 'content', but it is not so clear what he sees it as moving *towards*; he talks in terms of "breathing some life into the subject" and his "desire to make science more interesting", but says that in terms of the specific aims of the project, and of developing lessons which covered the 'themes', he was uncertain about what he should have been doing:

Andrew I've always understood the kind of, the thrust of what the project's about. Perhaps, didn't get my head around the real nitty gritty of what it was pushing for. I think I had a slightly vague, or not specific enough understanding of what the project was aiming at with the themes.... And I think I needed a clear.... I would have liked to have tied my lessons in more tightly..... I think I needed to be more certain about how I could tie a specific theme into a you know, into a sort of science topic we were doing. And I think I only really got to grips with that quite late in the project. After I'd done some planning. I think I did some planning in the spirit of the themes, I don't think I did as much planning specifically linking to the themes as people would have hoped.

Taken together, these data suggest that, in itself, a teacher's understanding of the nature of science is not a major predictor of their confidence to teaching the themes, nor, as we shall see in relation to other dimensions, a predictor of the approach that they take in their teaching. Our data would suggest, rather, that a teacher's understanding of the nature of science is only one of many factors that contribute to what these teachers actually do and feel when attempting to teach something of the core themes and 'ideas-about-science'.

Teachers' Conception of Their Own Role

The second dimension relates to data obtained from a questionnaire and supported by classroom observation. The questionnaire aimed to assess teachers' willingness to conduct 'enquiry based teaching' which encompassed the use of dialogic discussion. Our theoretical perspective is that understanding the nature of science requires an opportunity to engage in epistemic dialogue with others i.e. one's peers or a teacher. Only such dialogue initiates a process of reflection on the processes which are inherent to the practice of science. The normative IRE dialogue of school classrooms whose function is strongly authoritative, and essentially univocal, is concerned with the transmission of well-established consensual knowledge and has a fixed outcome. Whereas epistemic dialogue is multi-vocal and has a generative intent whose outcome cannot be anticipated (Scott, 1998). We therefore sought to establish these teachers readiness to use dialogic discussion using the instrument developed by Connolly et al. (1976). In this instrument, teachers are asked to indicate on a scale running from 1 to 7 whether they felt that their authority as a teacher would be weakened by their putting aside specific content topics and temporarily giving up their role of conveying

knowledge (lower numbers indicate greater unease with the idea). Table 3 shows the responses teachers made to this question at the beginning and end of the study, and illustrates the ‘drift to the right’ indicating that most teachers did become more comfortable with the idea of adopting a less didactic role during the course of the project.

Table 3: Teachers’ responses to the item on the ETiS questionnaire asking whether they felt their authority would be weakened if they temporarily gave up their role of conveying knowledge⁵

Teacher	Beginning	End
Jo	6	7
Becky	2	7
Brenda	7	7
Andrew	2	2
Pauline	5	2
Clare	1	3
Sue	5	5
Mike	6	6
Emma		7
Harold	4	7
Daniel		7

Data from interviews with teachers at the end of the study, and less formal conversations before and after the lessons that we observed, elucidate further this difference between the teachers. Clare, one of the teachers with the lowest responses to this question, spoke directly at one of our teachers’ meetings of the insecurity she felt when she did not know the answers to her students’ questions, and she worried that this might undermine her authority. Essentially, as the justification for teachers’ authority is that they are an authority (Peters, 1966), any situation that exposes a lack of knowledge on their behalf thus undermines their power and control of the class.

Similarly Pauline, the only teacher whose response was lower at the end than at the beginning of the project, when asked in an interview conducted at the end of the project about the work involved in preparing these lessons, alluded to the need to be able to answer students’ questions:

- Int: Has it been time consuming? The preparation?
 Pauline: Most of it no, but the last two I did, I found I had to beef up my background knowledge a bit more.
 Int: And that’s background knowledge of what?
 Pauline: GM foods, Kyoto and that. I’ve read around it. I’ve got the worksheets but I feel I need to know more about it in case of questions.

It is notable that, when discussing the teaching of a controversial issue in science, Pauline’s concern is with beefing up her ‘content knowledge’ rather than with deepening her understanding of more abstract ideas concerning the nature of science. She is keen to ensure that she will be in a position to answer her pupils’ questions *for*

⁵ Incomplete data from the beginning of the study means that some teachers have been omitted

⁶ These teachers were absent when the data was collected.

them, but does not appear to recognise how she might help her students to think about the reasons why scientists might disagree for themselves and, furthermore, what such disparity might show about the nature of scientific knowledge in the making. This does not mean to say that we would want to suggest that it is inappropriate for a teacher to want to have the factual base necessary to answer questions from students. Rather, we are drawing attention to these teachers' concerns and priorities because they imply that they are working within a model where they perceive their primary function as 'dispensers of knowledge' providing students with factual information. In both Pauline and Clare's case, this conception of their own role was also evident in their teaching; lessons tended to be characterised by a great deal of 'teacher talk', and questioning generally followed a typical IRE format, meaning that students' ideas were never pursued very far. Data that illustrate this point will be discussed in the next dimension on teachers' approach to classroom discussion.

At the other extreme, Brenda's lessons were characterised by very open discussions in which she very rarely evaluated students' responses and where the outcome of the discussion was indeterminate. Talking to her after one of the lessons that we videoed, she remarked that she had "always thought 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 which is explored in the next dimension. 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:

Brenda It's OK to waste a lesson..... waste you know, there is no content in this lesson. ... The group that [I've been working with] have done no differently, no worse than any other group that has been through the same course. You just re-jig the other material around it and 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 [less time]..... but if you actually get them to do something then use that information, you have actually gained an enormous amount, I think.

This extract suggests that Brenda regards the transmission of scientific facts as peripheral to *the ability to use* these facts and, moreover, that it is through their use and application that the real learning takes place. In this way, time spent on activities that make use of scientific ideas is seen to reinforce, rather than undermine their learning. In this respect Brenda was unique among the teachers with whom we worked. For all other teachers involved in the study (even those whose lessons had much in common with Brenda's) the tensions that they perceived between the need to cover the syllabus and finding the time to teach about the nature of science were a common feature of their interviews and discussion. The comment below, made by Mike during an interview, is typical:

Mike The biggest problem was having time within the time allocated to do them, and it was obviously quite a treadmill of stuff you've got to do before this test and stuff you've got to do before the next one. And that really does have an effect on what goes on in lessons, because you don't have a free hand to do things.

Teachers' Use of Discourse

The third dimension emerged out of a consideration of what happened in the lessons themselves, and the nature of the discourse that we observed. In all of the lessons that we observed, some dialogue between teacher and students was a feature, but the form that this took varied considerably, both between teachers and over time between the two extremes of authoritative and IRE based and dialogic. At a number of the teachers' meetings we held, the topic of how to manage classroom discussion was raised. A common theme was that many teachers were keen to lead open discussions with their students, but felt they lacked the necessary experience to do so. Again, Mike speaks for many of our teachers in the extract from his interview below:

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, when teachers did make use of classroom discussion, there was a tendency for them to 'close them down' so that in effect, they were more of an IRE question and answer session than a discussion. Where discussions were kept very closed in this way, it seemed that the students' task was simply to 'guess the answer that's in the teacher's head', diminishing the possibility for students to actually *think* about or reflect on what they were doing. This was a common tendency in the lessons that we observed illustrated by the field note below, which relates to the beginning of a middle ability year 8 lesson on global warming taught by Pauline:

Students are asked to write down the 'learning objective' written on the board:

"Scientists need to consider whether the greenhouse effect causes global warming"

Pauline 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 info. 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).

The next extract comes from the beginning of a lesson on mobile phone safety and taught by Clare. In common with the extract from Pauline's lesson above, the focus remains very factual, and pupils are not required to reason or reflect:

On the board are written three questions:

Are mobile phones safe?
How can we find out the answer to this question?
Can we all agree on an answer?

Clare asks for some suggestions about how we can find answers to these sorts of questions.

- Joe: Scientists
Clare: Scientists may report – how do we find out about what they have found out?
Ian: Something happens to someone so they investigate it.

Clare repeats this and asks for more ideas.

- Kate: Scientific website
Clare: Yeah, and some of you have used those doing this project. Any other places – How do you actually find out yourself (she's probing for them to talk about carrying out experiments, doing research)
Max: Books
Clare: Books, yeah. And I suppose as well doing experiments yourselves maybe. Anything else at all. How would you *hear* for example – what are the most likely places where you would hear."

The news, newspapers etc. are suggested by students

In both of the extracts above, the teacher remains very much in control of the discussion and students' input is limited to answering questions that are posed by the teacher. The purpose of these discussions seems to have more to do with establishing factual foundations for the lesson than with getting students *thinking* about the scientific processes involved and this type of approach to discussion predominated throughout.

In this dimension too, Brenda provides an example from the opposite end of the spectrum. The account of a discussion in one of her lessons, below, illustrates the ways in which Brenda is able to step back, creating an environment in which students have space to develop their own ideas and reasoning about a problem. 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. Whilst, this episode does not address the nature of science explicitly as students' attention is not drawn to the fact that they are relating observations to theories to confirm or deny alternative hypotheses, it is typical of her style and does model authentic epistemic reasoning in science – a process which we believe is essential if aspects of the nature of science are to be taught in school science. For, if understanding is to come through a reflective and analytic process, it is only this kind of discourse which enables students to engage in authentic epistemic reasoning, and that is the essential substantive experience from which explicit teaching of the nature of science can be formed.

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.

A central difference between this discussion, and those discussed above from Clare and Pauline's lessons, is that in this extract Brenda asks open-ended questions. Whereas the other two teachers steer the discussion by asking closed questions that require singular precise answers raising the particular points that they want to highlight, Brenda defines the *context* for the discussion (through the concept cartoon that she uses) but then allows her pupils to offer extended responses that require the construction of an argument relating theory and observation. In this way students are not only given opportunities to recall scientific facts, but also to think for themselves about how they might use their knowledge to solve a problem, and decide which pieces of information are most relevant. The essential difference between Brenda and other teachers is a reduced concern for the particular factual information her students will take away from the discussion. Rather, her focus here is on the processes in which they are engaged while thinking about the problem.

Teachers' Conception of Learning goals

The fourth dimension, the nature of the learning goals that a teacher has for a lesson, again raises this distinction between an emphasis on the ontological aspects of 'what we know' with an emphasis on the processes involved in 'how we know'. In many of the lessons that we observed it seemed that the learning objectives that the teacher had

for the lesson were concerned with its factual content rather than with a concern to facilitate students' learning by engaging them in the process of learning.

As an example, a lesson taught by Mike, one of the junior high teachers, used the *tricky tracks* activity (Lederman & Abd-el-Khalick, 1998) as a vehicle for teaching students the difference between an observation and an inference. He began by recapping the definition of 'observation', and asking pupils to write down some observations about the image on the OHT. He then asked students to feedback, pointing out that most of them were tending to infer rather than simply observe. Students were then asked to make inferences about the picture, and the bulk of the lesson was taken up with students developing 'stories' as the images were revealed in turn. Students were frustrated that they were not being told 'the answer', and Mike added an air of mystery, saying that he is deliberately not telling them what it was about, but that he would explain all at the end of the lesson. The lesson finished with another feedback session, in which the emphasis was again on highlighting the observations and inferences made by students:

Charlene, a student, reads her inference that the bird is speeding up, as its footprints are getting further apart. Mike summarises by saying that she's picked up on the *observation* that the tracks on the right hand side get more spread out, and *inferred* that this means that whatever is making the track is moving faster (throughout he is talking slowly and deliberately, putting particular stress on these 'key words'). He repeats: "the observation is that they are further apart. The inference is that the thing that made them was moving faster".

After the lesson Mike spoke briefly about how it he felt it had gone, and he said that in order to evaluate his students' learning he would test their understanding of the words 'observation' and 'inference'. In the discussion after the lesson, Mike commented that "on the whole he felt the lesson was successful, and a 'safe bet' since it had worked well with a number of other groups too." On Mike's terms, then, this was a successful lesson: it is indeed likely that the majority of the class left with a clearer understanding of the difference between an observation and an inference. However, what they probably did not gain was much of an appreciation of how this related to science as the field notes record that a number of students seemed rather frustrated that they had not seen the point of the lesson. The tasks, as they were set up for the students in this lesson, were intended only to reinforce the meaning of the two words and it seemed that Mike regarded the learning objectives simply as a need for students to grasp the definitions of these two words. The consequence was that opportunities to engage more meaningfully with the processes of observing and drawing inferences, considering the part each plays in scientific enquiry, and perhaps thinking about how one might choose between rival hypotheses, were lost. It is notable here that a lesson that was ostensibly about elements of scientific process did not engage students in these processes, but rather, effectively reduced them to items of content – a procedure which effectively translates the nature of science from a set of processes and practices to a body of content to be learnt and remembered.

This outcome was not a feature of the activity itself, but an implication of the way it was introduced to the class, and the particular points that Mike chose to emphasise during the course of the lesson. The focus of the lesson was the decontextualized content that Mike wanted his students to learn, and there was a sense in which the tricky-tracks activity was a foil for conveying this information rather than any attempt to get his students to theorise about a set of data from which the distinction between observations and inferences could be drawn. For instance,

contributions from students that attended to the details of the context (for example, a student's suggestion that the bird was speeding up) were not followed up, except insofar as they could be used to further illustrate the meaning of the words 'observation' and 'inference'. In this sense the focus of the lesson was both highly specific, in that the meaning of two words were considered in isolation from related concepts, and highly general, in that the details specific to the context being used were not considered, suggesting that Mike held a model of scientific enquiry in which a generalisable 'scientific method' can be broken down into discrete components which can be considered and taught in isolation, much as the standard approach to its content.

A striking contrast in these respects is provided by a lesson Emma taught to her mixed ability year 6 class, in which a sheet headed 'what causes what?' was used as the basis for a lesson about aspects of scientific enquiry. The sheet had on it a number of statements e.g. "running in the rain makes you wetter than walking", "light things float", "people with chest illnesses smoke a lot" and "a watched kettle takes longer to boil". Students were asked first to think about whether they thought these statements were true, and then how they might test them. Emma's intended learning outcomes for the lesson were given as: "that science is about thinking creatively to try to explain how things work; sorting questions that can be investigated scientifically and decide how to find answers; being able to plan a fair test based on a given prediction".

Like Mike in the lesson discussed above, Emma began this lesson by talking to the class as a group about the aspects of scientific enquiry on which they would be focusing during the lesson. But whereas Mike focused on just the 'key words' with which the lesson dealt, Emma spoke much more generally, and involved students in thinking about the steps that they would take when carrying out a scientific investigation. Students were asked to sit on the carpet, and to brainstorm in pairs about the steps involved in a scientific investigation – a process that required the use of dialogic discourse. After a couple of minutes she brought the class together again and students contributed their ideas while Emma recorded them on a flip-chart, placing each step in its appropriate place on a cycle, to indicate that the outcomes from one investigation will often play a part in framing the questions for a subsequent investigation. As the short extract below illustrates, Emma's questioning was characterised by the fact that, though she remained very focused on what she was trying to achieve, she listened carefully to students' contributions and worked with them:

Emma: "Tristram, what's one skill that you would use in an investigation."
Tristram: "Fair test"

Emma asks what he means and he says "everything must be equal, must start at the same time..."

Emma: "will every single thing be equal?"

Students have their hands up, and say that one thing will be changed, that everything else will be kept the same. This goes onto the flipchart, and Emma introduces the word 'variable' – "for example, if we were trying to investigate what keeps a plant healthy, the variables might be amount of water..." She asks class for other variables. Sun, soil and warmth are all offered by the pupils.

Emma summarises: “Those would be the variables, and maybe we wanted to see whether water keeps a plant healthy, so we would keep all the other variables the same and the only thing we would be changing is the amount of water...”

Students are listening attentively as all this is explained. On the flipchart she writes – keeping variables the same, changing 1. “So that’s one skill. Another one?” A student says “Planning.”

Emma wrapped up this discussion by telling students that today they would be thinking particularly about predictions, but that they would need to be aware of where this fits in the cycle of enquiry, and what other skills are related to this process.

During the remainder of the lesson, students worked either in pairs, small groups or as a class, first discussing the statements and deciding whether they thought they were true, and then selecting one and thinking about how they might test it. A key feature of the pupils’ discussions, and of Emma’s input during the lesson, was that, although the lesson was explicitly concerned with the steps in a scientific investigation, the contexts provided by the statements on the sheet were attended to in a way which gave meaning to these steps. Students grappled with ambiguities in the wording of the statements, with ideas of cause and effect, and with the most appropriate ways of testing different statements. The extract from the field notes below relates to an exchange near the beginning of the lesson when students are discussing a few of the statements as a class, before working in small groups on the others. It shows how Emma skilfully manipulates the discussion to show that what counts is not confirmation of a hypothesis but its falsification:

In relation to the statement ‘light things float’, there is some discussion about whether this means floating in air or water. Yates then says that an iron ship floats, and Emma asks whether iron is heavy or light. When pupils respond that it is heavy she indicates that that then goes against the statement. Africa says no, it doesn’t say heavy things don’t float, it says light things do float. Emma then reiterates her point – “Africa is saying that Yates’ argument doesn’t work because he is giving us an example of something heavy that floats...” She asks students how they could go about testing the statement if they wanted to, and students give a few suggestions for ways they could test it – for instance, Emilio: “we would have to find something light that doesn’t float”.

This next extract is an account of an exchange that took place among a small group of students discussing the statement ‘people with chest illnesses smoke a lot’. This group (and others) had discussions like this about each of the statements, typically continuing until they had reached a consensus and found a convincing reason for their answer:

Someone from the group reads ‘people with chest illness smoke a lot’
Africa immediately says that it isn’t true, then interrupts herself with ‘sorry go on’.
The boy fades out, at which point Africa comes back in with “I was reading a newspaper article about – they’re really old now – people who used to work in mines and the dust is just going to kill them, and even though they’re only 60, they’ll still die, because they inhaled so much dust. So it doesn’t really matter whether you inhale the nicotine and the tar or whatever”
Fuka says, “Yes it’s true”
Africa: “why do you think it’s true Fuka?”
“I don’t know”
Another pupil adds, “you have to have evidence”

Africa asks “what’s your evidence Fuka? Tell us what you told me yesterday about when you sweep up the clay and it goes down your throat and you can just die”

“Yeah you can die, right.”

“Die by what?”

“I don’t know what it’s called but as the clay goes down your throat the dust, yeah.”

He explains that the dust can clog up your lungs, with constant prompting and encouragement from Africa. When he finishes she summarises with “so that’s just as bad as smoking. But it ISN’T smoking, just like if you work in a mine. Because you might not have no choice. You might be really really poor and the only job you can get is a cleaner.

Someone else says: “so basically, you do get chest illness if you do smoke, but you also get illness if you do other things...”

Africa agrees and says “But what this is saying is ‘people with chest illnesses smoke a lot’ – it doesn’t say *some*⁷ people, it says *people* meaning every person. So I’m going to call that false because it isn’t specific enough”

The discussion between these children reflects an established culture in the class and is not simply a product of the way that this particular lesson was managed. However, the introductory part of the lesson, in which students first thought about the steps in a scientific investigation, and then about some of the statements together as a class, gave students a clear model for their group discussions about the other statements. Two days after this lesson, Andrew, another teacher of a year 6 class, was observed teaching a lesson based on exactly the same material. His aims for this lesson (as expressed in his diary) were very similar to Emma’s and involved encouraging students to think about designing fair tests to answer scientific questions. However, despite these similarities the lessons were very different, and some of these differences can be understood as reflecting the fact that the students in Andrew’s class were not equipped with the tools with which to discuss and argue about the statements in the way that the students in Emma’s class had been.

Andrew’s lesson began with students being told that they had in front of them a sheet with “newspaper headlines” on them. They were asked to individually cut out the statements and then to sort them into two piles according to whether they were “things a scientist might have said – a scientist’s idea or a prediction” or not. When students had done this they were asked to discuss them with their neighbour. Field notes record that the discussions that students were having had none of the richness of the discussions taking place in Emma’s class; pairs of students compared notes, and if they agreed they moved on, or if they disagreed they made a note of the fact and then moved on. There was very little critical engagement with the statements or any epistemic dialogue that sought to justify their own beliefs or challenge others’ arguments. So, for example, when discussing the statement “people with chest illnesses smoke a lot”, there were no groups that appeared to question its phrasing; rather, most seemed to be agreeing that it is true “because if you smoke it’s bad for your lungs”.

It is perhaps not surprising that these students did not engage in the activity in the way that Emma’s had done. They had been asked to decide whether each statement was something ‘a scientist might say’, which was interpreted universally by the students as “is it true?” Beyond that, no connections were made with steps in a scientific investigation, and no consideration was given to the means by which students might justify such a decision. When Andrew asked students to begin discussing the statements in pairs, his instructions focused on the procedure by which

⁷ Emphasis added to show emphasis given in dialogue

they were to do this: they were to read out the ones they think a scientist would say and see if their partner agrees, if there are any differences, ask them why they think they are different. With the task defined in this way, there is nothing left for the students to think about; Andrew's instructions tell them how to 'get it done' rather than define a means by which they can find resolve the issue independently. From our perspective, this lapse is due to a failure to address explicitly the epistemic features of science – that is to show that what is required is the identification of the variables and to consider then whether the relationships are causal or merely associative. Without making these salient features of the practice of science explicit, the students lack anything substantive on which to reflect and develop an understanding of the nature of science.

After students had compared notes with their partner, they were asked to think about a statement to test – “to discover something to either make the world a better place or to make a lot of money for our company” – and they discussed this in their pairs for a few minutes before a feedback session. The field note extract below describes this, and again, the differences with Emma's lesson are striking:

A popular statement to test was “chickens come before eggs” – Andrew asks, “why would you be interested in investigating that one?”

Student: “Cos in order to have an egg you need a chicken, but before the egg there comes a chicken”

There is no comment on this from Andrew, he asks the next student for the one they would investigate:

Student: “What goes up must come down”

Andrew: “You'd like to investigate that. Can anybody think of any of those statements that you would think that perhaps scientists have investigated and maybe made lots of new ideas and made lots of money from? Are there any that are obvious to you? Melita”

Student: “What comes up must come down”

Andrew: “You think that one. What else have scientists investigated do you think?”

Student: “People with chest illnesses smoke a lot”

Andrew: “OK. Lacy”

Student: “Running in the rain makes you wetter”

Although they are discussing which of the statements they would like to investigate, there is no discussion at all of how they might carry out this investigation, or how feasible it would be. In some respects this is similar to Mike's 'tricky tracks' lesson, but one difference is that Mike's lesson did have a clear learning objective, albeit a narrowly conceived factual one. It seems that in the absence of a clear content base to this lesson, Andrew is at something of a loss as to what it is that he is trying to achieve, and he struggles to find ways of moving students' thinking on. Emma's lesson, based around the same material, is much more successful in this regard, and it is apparent that she has a clear sense of what it is that she wants her students to take from the lesson – essentially a development in their ability to think about scientific questions rather than any particular knowledge gains. A finding that substantiates the points made about the nature and role of discussion in the previous dimension of 'questioning style'. Likewise, Emma, using a similar style, succeeded in involving her students in a critical evaluation of the statements, in which the scientific methods by which the statements would be tested remained in the foreground:

Emma stops the class and tells them that Sophie wants to devise a test for the statement “putting a spoon in your mouth when you peel an onion stops your eyes

watering”. Emma then asks what it is they were going to be testing – “is it because it’s a spoon, or is it because of what the spoon is made out of? So are we going to be testing whether different materials work better? what will we need to keep the same? – well, we don’t want different strength onions because then you can argue that the person’s eyes are watering because the *onion*’s changing. Does it make a difference whether it’s a spoon or a fork if it is made out of the same material? And then the whole thing changes. You do need to think quite carefully about what exactly you are investigating – what it is you want to change, what you want to keep the same. Because there is more than one fair test for these statements I think.”

In summary, the major point that we would wish to make here is that many of the teachers experienced varying degree of difficulties formulating specific learning goals for their lesson. Many attempts were observed where learning goals were seen as developing a knowledge and understanding of processes as *distinctive and separate* from the content. At their worst, knowledge of these processes was then transformed into aspects of content to be learnt and remembered. At their best, process and content were integrated in relevant contexts where pupils were provided the space to engage in meaningful dialogue and reflection.

The Nature of Classroom Activities

The fifth dimension arose out of a feeling that in a number of the lessons that we observed, students were not engaging very meaningfully with the activity. It often seemed that the teacher had chosen a task as a vehicle for conveying a particular point, and in many lessons, there was a feeling that the activity set was ‘busy work’ or academic work (Doyle, 1983). Whilst such work was a necessary precursor to the teacher highlighting salient features of the task, it was not seen as integral to developing their understanding of these aspects.

The notion of a ‘contrived activity’ as a way of capturing something of this lack of engagement arose from a lesson that Clare taught about burning magnesium, where students were given rival theories to explain what happened. The class was a high ability year 9 group. Half the students were given background information about the formation of oxides, the other half had information about phlogiston escaping, and they were asked to make predictions on the basis of the theory they had read, and then carry out the experiment to test their predictions. Clare’s hope was that the results students obtained in their experiment would accord with the predictions they had made, and she would then suggest that scientists may be prone to seeing what they want to see in this way, or manipulating results slightly to support their ideas. The lesson was carefully ‘stage managed’; students were not told that they did not all have the same theoretical information, and were kept in the dark about the purpose of the lesson until the end. Discussing the lesson with Clare about it afterwards, we agreed that the lesson had fallen a ‘bit flat’ because, although the students did what they were asked to do, they did not have sufficient investment in the theories they had been given to have any motivation to fiddle their results. Essentially the premise that they were scientists looking into what happens to magnesium when it is burnt lacked authenticity, so students ‘played along’ without conviction.

Likewise, one of Pauline’s lessons, which aimed to cover theme 9 that science is a co-operative and collaborative enterprise, used material from a physics reader on light and sound (Science Web, 2000). At the beginning of the lesson students were asked to copy a learning objective from the board which read:

“Copy the way scientists work together to solve problems...
Do light and sound reflect in the same way?”

Yet although students were told they would be ‘copying the way scientists work’, what they were actually asked to do was read through four pages of text about light and sound waves, and then answer questions on the material they had read. The only concession to the premise that they were scientists was that on the top of the first page Pauline had added:

“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?”

Her idea was that students would work in small groups and that when they had answered all the questions they would be able to answer the original question about the behaviour of light and sound. Question and answer sessions at the beginning and end of the lesson had made the link with the work of real scientists who work collaboratively in groups to answer big questions, but the task the students worked on in their groups was essentially a revision exercise for the students and again, lacked authenticity. It is unlikely that, without an opportunity to engage in explicit reflection on the nature of the task, its completion added to their understanding of manner in which scientists work.

Another of Mike’s lessons provides a further example. The lesson involved analysing fictional data on the distances a group of children swam in a given time, and after a brief question and answer session about forms of data and the idea that “scientists often try to link to kinds of data”, Mike wrote on the board:

Using data
Is swimming distance related to age?
Is there a difference between boys and girls?
How can we be sure of our results?

The students then discussed briefly as a class how they might answer these questions, and suggested that they could find averages. Mike then said that he would like them to draw a scatter plot, and drew the axes on the board for them to copy. As students were working on this task we spoke to some of them about what they were doing. Our field notes show that that many were working rather methodically through the task of plotting points on the graph without drawing very much meaning from it. When the students were asked what patterns they might expect in their data, many said ‘they hadn’t thought about it’. Yet again, and rather like the student in Pauline’s class, who appeared to simply look for the first number to appear on the worksheet in front of him when asked a question demanding a numerical response, these students were simply engaging in the task because this is what the teacher and the nature of school work required rather than because they had any intrinsic interest or engagement in the work.

Whilst all lessons were not necessarily as ‘contrived’ as these lessons, classes in which students were required to engage in an artificial exercise for which they had little or no ownership were not uncommon. In addition, students were sometimes frustrated at the lack of clarity about the intent of the lesson. In such lessons, their own input was often limited to little more than following the instructions they had been given. Yet, as noted in Andrew’s lesson ‘what causes what?’, very precise,

procedural instructions enabling students to get the task done, can limit the opportunities for them to engage with it in a meaningful way.

In contrast, the lessons which we felt were most successful in both engaging students and developing their understanding of the nature of science were those in which teachers had created an environment where students were able to find ways of tackling problems *for themselves*. These were the lessons in which, rather than providing precise instructions to students, a context was established, and students were given the tools to think about the problem. These lessons were characterised by open discussions in which the students' role extended to posing many of the questions and provided with an opportunity to engage in epistemic dialogue. In addition, some attention had been paid to the details of the context as a means for giving meaning to ideas about the nature of science. Such teachers appeared to give priority to the development of students' conceptual understanding, rather than to the factual knowledge they were acquiring,

Discussion

The first point we would wish to make is that none of the illustrations drawn from the lessons of these teachers should be taken as criticisms of their practice. Teachers are rational, intelligent human beings and they respond to the agencies and structures that condition their working practice in a manner which is appropriate to their own specific context and need. One particular constraint on their freedom are the imperatives of the extant curriculum. The English national curriculum (Department for Education and Employment, 1999) now ensures that all students learn science between the ages of 5 and 16. However, tests at the end at age 11 and 14, followed by terminal General Certificate of School Examinations (GCSE) at age 16, and the relatively high stakes attached to all these tests, mean that teachers feel that they need to focus on developing the particular knowledge and skills that will have the greatest impact on their students' examination performance – the recall of factual content knowledge. Many of the teachers involved in this project expressed frustration at the ways in which the imperatives of the curriculum made it difficult for them to devote lesson time to developing students' understanding of scientific processes. Writing an evaluation of the project in the final teachers' meeting, one of the elementary school teachers, Emma, wrote:

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, OfSTED⁸ and all other groups that influence schools.

Similarly, Andrew, another of the KS2 teachers, referred, in an interview carried out at the end of the project, to the tension he feels between what he describes as a "more creative approach to science teaching" which this project is seen to represent, and the 'tried and tested' approach that enables his school to perform well in KS2 science 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

⁸ Office for Standards in Education: A government body which inspects all schools and monitors standards in Education.

- 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.

In her interview Sue, drew attention to another tension for teaching the nature of science and preparing her students for their GCSE exam:

- Sue I think I've always thought that students should know about those things. But I think it's made me think much harder about how to actually get them over to the children
- Int Could you say a bit more about that?
- Sue 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.

The tension here is between the dilemma of a curriculum which, on the one hand requires the teaching of well-established, consensual knowledge and, on the other hand, the development of the idea that all scientific knowledge has a degree of tentativeness associated with it. Thus, developing a questioning and sceptical attitude to scientific knowledge claims in her students might actually be disadvantageous at GCSE—an examination which assesses students' capacity to reproduce scientific facts more than their ability to evaluate ideas critically.

Yet, clearly despite such constraints, some of these teachers managed to transcend these demands and achieve a level of practice where the nature of science was introduced and explored in more effective manner. In this article, we have sought to identify what we perceive as being the main factors that influence teachers' practice – factors which we have described as a set of 5 dimensions of practice. Whereas, previous research and scholarship has paid significant attention to teachers' understanding of the nature of science (Abd-El-Khalick & Lederman, 2000a; Bell, Lederman, & Abd-El-Khalick, 2000; Brickhouse, 1991; Bybee et al., 1991; Hodson, 1993; Koulaidis & Ogborn, 1995; Lakin & Wellington, 1994; Lederman, 1995; Lederman & Zielder, 1987; Mellado, 1998; Schwarz & Lederman, 2002), we would argue that this is only one factor amongst five critical factors, and even then, our data lead us to doubt its centrality. Even the most recent volume (McComas, 1998) devoted to the nature of science pays only scant regard to what we see as being a more fundamental set of issues that teachers have to confront when required to teach *about* science. In brief, this is the necessity to recognise that the epistemic nature of science cannot be learned as a body of content solely from exposition. Rather, our research points to the need for creating learning environments in which students can engage in problems for which they have some sense of ownership, which are appropriate to their level of knowledge and understanding, and which permit

epistemic discourse of a dialogic nature. The research on discourse points to the importance of establishing procedural guidelines for the students (Herrenkohl, Palinscar, DeWater, & Kawasaki, 1999) engaging in tasks such as argumentation and this we consider to be important. However, more fundamentally, if teachers are to adopt a more positive approach to teaching the nature of science, there must be a transformation in the values communicated by the curriculum. First and foremost are the examinations which communicate our real aims to students and their teachers. However loud our rhetoric about the importance of the nature of science, it is but a tale full of sound and fury unless it is accompanied by a real change in the current nature of summative assessment used in science education. Even then, our limited exploration of the issues and dilemmas raised for teachers in attempting to teach the nature of science suggests that teachers of science will need considerable assistance and training to relinquish the IRE dialogue which is such a dominant feature of their practice – a discourse which is an inevitable reflection we believe of one of the last remaining authoritative socio-intellectual disciplines in the school curriculum. Finally, and not least, they will need help and assistance to develop sets of activities which have, at the very least, some sense of authenticity, either within the activity or in their presentation, which enable student engagement and ownership. We feel our work has begun this process of identifying some of the strategies and materials but there remains much to be done.

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