Large-scale exploration of pupils' understanding of the nature of science

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Summary

The methodology of this research tried to span the small scale and the large, the qualitative and the quantitative, present knowledge and proximal development. It took into account the results of previous small scale questionnaire studies, interviews of groups of students and action research in the classroom. These informed the results of a large-scale questionnaire study of the nature of science.

Few questions were asked which referred to knowledge acquired from two different domains:

a. out-of-school images of science and scientist;
b. ideas drawn from their own school experiences of science in the classroom and the laboratory.

Knowing the strong effect of context we were anxious to keep the questions as general as possible. They were to probe the connection between theory and experiment in terms which, we had found, students of age 15 years, could understand.

The results showed a strikingly significant relation between the class teacher and the responses to most questions. The exceptions were in out-of-school knowledge and confirmed our hypothesis about the two origins of students' knowledge about the nature of science.

Looking for significant correlations between the students' answers to different questions revealed the presence of two interesting groups of students: the 'Explainers' and the 'Imaginers'. The first of these seemed to be reflective, and as having a more explanatory perception of science. However this was limited to their own laboratory experiences and did not extend to other cultures, or to the use of imaginative mental models. The second group - the 'imaginers' - were far fewer in the large sample of 15 year olds, but comparatively more numerous in a small sub-group of older students at age 17. Separating out this disappointingly small group of pupils we found that they were more interested in what goes on in the minds of scientists. From

their comparative success in questions about school experiments it would also seem that they are more receptive than others to teaching and also retain this knowledge better.

It was somewhat disappointing to find so little increase in the number of 'imaginers' from age 12 to age 15.

In the case of older students (age 17-18) the sample was small and comprised students who had chosen to study at least one science subject at Advanced level. The comparison of their responses with those of the younger pupils may well demonstrate the effect of a more detailed study of science, as well as simple age progression.

The British National Curriculum stipulates that pupils should learn to use theoretical models for prediction and explanation, and to appreciate the uncertainty of evidence. We can report from our questionnaire data that few teachers seem to be encouraging such work. Special strategies may be needed to move pupils on from a worthy but limited empiricism towards the uncertainties of genuine scientific speculation.

1. Introduction

In previous papers (Solomon et al., 1992; 1993; Duveen et al., 1993) we have reported on pupils' understanding of the nature of science using data obtained by interviews, action research, short tests and simple questionnaires. In the research presented here our aim has been different. This time we were interested in larger scale and longer term effects. We worked with slightly older pupils who had been exposed to secondary school science for more than three years. We not only interviewed pupils extensively in small groups and watched them in lessons, we also administered a set of simple questions to a very large sample of pupils in different British locations.

1. Our prime sample totalled nearly 800 pupils in Year 10.
2. Embedded in this were some seven Year 10 classes in three schools whom we watched closely throughout one year. We talked with them at regular intervals and also interviewed their teachers.
3. In addition to the Year 10 classes, we also administered the questionnaire to about 120 Year 8 pupils and 80 sixth-form science students.

Some researchers (e.g. Aikenhead et al., 1987; Klopfer & Cooley, 1963; Rubba & Anderson, 1978) have deliberately asked students about the nature of science in its social and political setting.

These researchers posed questions like:

- 'Do you think scientists have a responsibility for the social implications of their discoveries?' or
- 'Do you think that scientific knowledge is value-free?'

We judged that these questions would not be useful for our purpose because they seemed to be too socially demanding, and could make very little contact at all with the pupils' school work in science.

On the other hand there have been researchers who have asked about the purpose of one or two simple experiments (e.g. Leach et al., 1993; Carey et al., 1990). Bearing in mind the strong effects that situations have on pupils' thinking, this seemed a risky procedure.

2. Questions

In the event we used just a few questions which had been carefully chosen and evaluated by extensive interviewing and other methods. Some of these referred specifically to 'scientists' and their activities, and others to the pupils' own work at school. At the heart of the epistemology of science lies the nature (social and procedural) of two entities, and the interaction between them - *the observation or experiment and the theory or mental model.*

Notions of 'experiment' and 'theory' figure in everyday language where they have vague and often diverse meanings. These contribute to the common, out-of-school perceptions of science. In a previous paper (Solomon e.a., 1993) we have examined such out-of-school images of science and of scientists, and the naive epistemologies that they induce in the minds of school pupils. That research was carried out with pupils, aged 11-14, who had only just begun to learn science in secondary schools. In the present research it would be fair to assume that the pupils' original views of science might have been supplemented, or at least modified, by their school experiences.

Year 10 pupils, aged 15 years, might be expected to have created a mental image of a scientist out of information available to them from reading resources at school, general reading, television, or cartoons. They would also, we thought, be able to use their own school experiences of learning science and carrying out investigations to have added this image of science. Whether or not these experiences would have been articulated and fitted into a simple working epistemology taught by their teachers, we did not know. Even if their teachers had attempted to present them with such an overarching system it would be naive to suppose that the two kinds of knowledge would exactly match. People choose knowledge for specific occasions, and research about children's alternative ideas has often shown that contradictory understandings can co-exist and come into use under different conditions (Engel-Clough and Driver, 1986; Solomon, 1992). We assumed that when the pupils answered our questions about why scientists did experiments, or about how they used theory, they could draw on ideas from either or both domains. The two kinds of knowledge might well interact in at least three different ways:

1. They might produce an amalgam or well stirred mixture of the two kinds of knowledge.
2. They might keep the two kinds of 'science' quite separate.
3. They might be able to reflect on the similarities between their own work in science and that of scientists if the students had been enabled to discuss the purposes of experiments and the status of theory in their own work.

The three questions for which students could draw on both domains of knowledge ran as follows:

1. Why do you think that scientists do experiments?
a. To make new discoveries?
b. To try out their explanations for why things happen?
c. To make something which will help people?

2. Do you think that scientists know what they expect to happen before they do the experiment?
a. Yes.
b. No.
c. Don't know.

4. Scientists think of all matter - solids, liquids and gases - as being made up from tiny particles.
Is this because:
a. Scientists can see the particles under their microscopes?
b. Scientists have proved by experiments that particles exist?
c. Scientists can explain what happens by imagining how particles move?

We had two reasons for putting these essentially epistemological questions into a form where they related to what people called 'scientists' do. One was that this device added an authoritative and communal sense to the question. The other was that we had found that personalising the question made it possible for the pupils to enter into how the scientist might be thinking.

Int *So do you think that imagination is important?*
Lisa *Yes... If they come up with some experiment that they have proven, and they want to show it to other people, and they've got to, like, show a diagram or something that they think might be true. And they want to bring it to other people. And they draw a diagram and stuff and say 'This is what I imagine.'.*

There were also two questions which did not specify whether they concerned the activities of scientists or school science.

3. What is a scientific theory? Is it
a. An idea about what will happen?
b. An explanation about how things happen?
c. A fact which has been proved by many experiments?

5. Many of the old theories have been replaced by new ones. Is this because
a. We have better technology now?
b. More evidence has become available?
c. People living at different times have had different ways of explaining?
d. We have now proved the experiments were wrong?

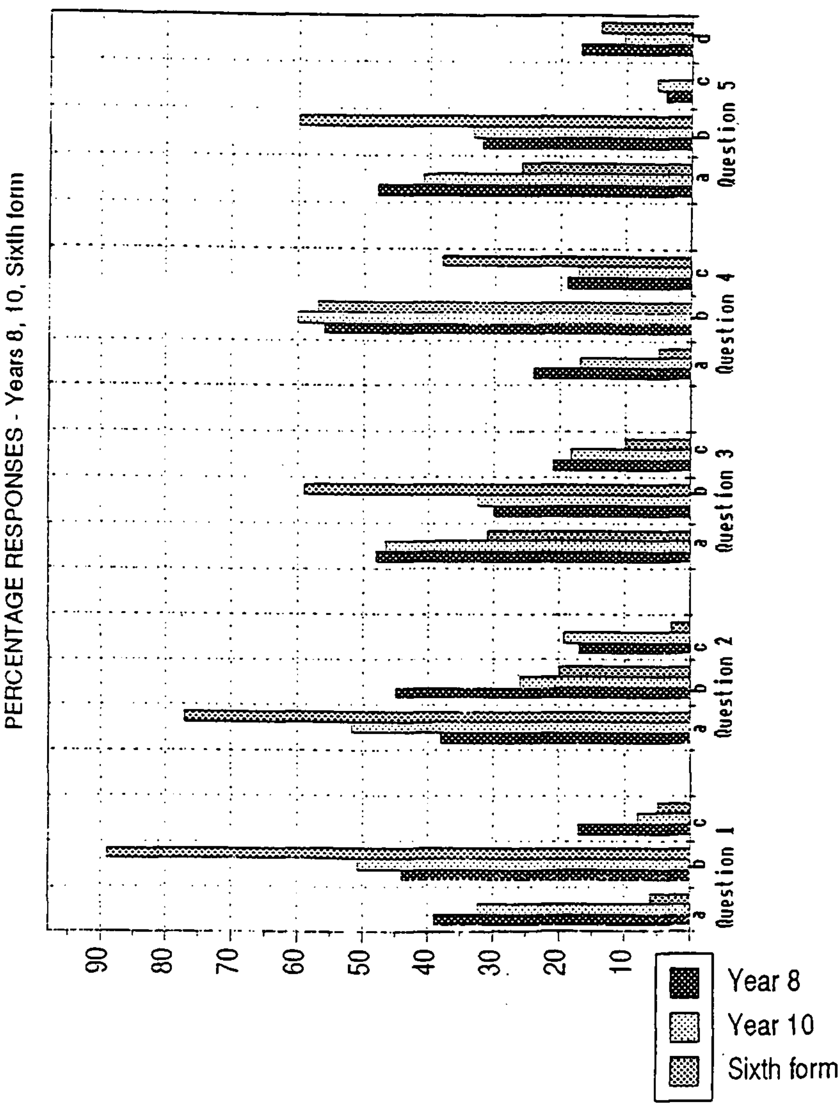
Finally there was a double question which referred specially to the science that these students had themselves carried out in school, and asked for more extended writing.

6. Now describe one experiment which you have done which helped you to understand a scientific theory.
a. The experiment I did ....
b. The scientific theory it was about ....

3. Results

By using this range of questions it was hoped not only to discover some of the features of the pupils' understanding of science, but also gain an insight into how the two sources of knowledge might have contributed to pupil thinking.
(See table 1 on the next page.)

Table 1: Percentages of pupils responding to each question in each way



In table 2 below we have set out the significance at better than $p < .02$ in the overall patterns of correlations obtained from cross-tabulations between the questions (Pearson Coefficients).

Table 2: Significances in response patterns between questions

Pearson coefficients

	1	2	3	4	5	6(Ex)	6(Th)	Gender	Class
1		-	-	.001	.02	-	-	-	-
2			-	.02		.05	.001	.02	.0001
3				-					.0001
4					.02				-
5						.005	.02		.0001
6(Ex)							.0001	.02	.0001
6(Th)									.0001
gender									
class									

We see a strikingly significant relation between the class in which the pupils were taught and how they answered most of the questions. This shows what may be both the effect of the teacher on the pupils' views and also some indication of the relative effect of in-school and out-of-school knowledge. Previous studies (Brickhouse, 1989; Ledermann & Zeider, 1987) have also pointed to the over-riding influence of the teachers' views on the nature of science on what their pupils come to believe, whether or not it is explicitly taught.

However there are important gaps in the column of significance under 'class'. It seems that responses to two of the questions about what scientists do, questions 1 and 4, are almost totally unaffected by class teaching. This suggests that no teaching was carried out on these points. The pupils could only use life-world knowledge, which is equally accessible to all. The figure of significance at $p < .001$ for the correlation between patterns of response to 1 and question 4, strengthens this conjecture. Nevertheless this does not imply that these answers are completely unrelated to school learning, and that other correlations for questions 1 and 4 should be ignored.

A glance at table 2 shows that such correlations do exist and could be interpreted in the sense that pupils who spontaneously chose response 1(b) from their 'social stock of knowledge" (Schultz & Luckmann, 1973) may be those who can most readily learn school science and have answered other questions in interesting and significant ways.

Gender effects could be clearly seen in answers to question 2 where girls were significantly more likely than boys to answer 'not sure' (see Grant, 1987; Murphy, 1990). In question 6 boys were significantly more likely than girls to describe an inappropriate experiment. Both these features probably relate to the well documented cautiousness of girls, or impetuosity of boys under test conditions. Smaller gender differences were to be found in three other questions where girls were slightly more likely to choose answers with 'explanation' (e.g. 1b, 3b, and 'evidence' in 5b) than were the boys. This is of interest since these responses were to prove interconnected in other ways.

Explainers

Those pupils answering in question 1 that scientists do experiments in order 'to try our their explanations for why things happen' (1b) are also significantly *more likely* to:

- answer 'yes' response 2a;
- answer 'idea' response 3a;
- answer 'imagine... explain' response 4c;
- describe an experiment correctly in question 6(a);
- identify a theory correctly in question 6(b).

They are also *significantly less likely* to

- answer 'can see' in question 4(a).

As mentioned above there are slightly more girls than boys in this general group.

This collection of significancies in their responses seems to identify these pupils as reflective, and as having a more explanatory perception of science. However it must be admitted that in questions 4 and 6(b) only a minority of these 'explainers' (15% and 23%) managed to answer in the ways indicated above. It is also disappointing to find that very few of them have chosen the response 5c that 'people living at different times have different ways of explaining'.

Imaginers

We were particularly interested in pupils' understanding of the status of particle theory since it was the theoretical model most commonly encountered, and one which could be manipulated for predicting the results of simple experiments. Separating out the disappointingly small group of pupils (N = 137) who chose the interesting response 4c, about explaining and also the role of imagination, we explored their special characteristics.

This small group were significantly *more likely* to:
- answer 'yes' in question 2 ($p<.001$);
- choose the response about 'different explanations at different times' in question 5;
- describe an experiment correctly in question 6(a);
- identify the theory correctly in question 6(b).

They are also *less likely* to:
- answer 'discovery' in question 1;
- answer 'technology...' in question 5.

Again there are slightly more girls than boys in the group.

This group seems even more interested in what goes on in the mind - imagining, expecting, explaining - than were the previous and larger group of simple 'explainers'. They are also more likely to shrink, it seems, from the technological explanation for our different theories which had proved unexpectedly popular in our pilot work. They have rejected the answer about 'seeing particles under microscopes'. We might dub them the 'mentalist' group. From their comparative success in questions 6(a) and (b) it would also seem that they are more receptive than others to school teaching and remember it better.

The overall percentages in table 1 show that less than half the pupils were capable of correctly describing an experiment related to theory. Even fewer, some 20%, could correctly describe the theory involved. This unfamiliarity with theory was also demonstrated in interviews with the pupils. Again and again when asked to give an example of any theory at all these pupils were reduced to defeated silence. A further problem, which was well illustrated in many interviews, was the difficulty some pupils had in identifying causal explanations. We have described this in more detail in a previous paper (Duveen et al., 1993). The following extract is similar to quite few which came after the interviewer had suggested that we now believe that the Earth goes round the Sun in contrast to earlier people's beliefs (question 5). Purpose was often undistinguished from causal links.

Int	*Why does the Earth go round the Sun?*
Amy	*So that you've got light.*
Gavin	*You've got day and night. And heat to keep you warm.*

Int *But that doesn't tell me why the Earth goes round the Sun, does it?*
Gavin *Yes it does. It gives you light: it gives you warmth.*

Comparison between the scores of pupils in Year 8 and Year 10 (see table 3) show that steady progress has been made. In particular the older pupils are now significantly more likely to answer that scientists know what they expect to happen in an experiment before they do it (2a). It is tempting to conclude that a steady diet of investigations in which they are asked to predict what will happen before they begin has convinced many students that scientists would do the same and may also be subject dependent. Scrutiny of the science subjects taken by these students suggests that those studying physics, chemistry and mathematics (male dominated) are more likely to take this severely empirical stance, emphasising 'evidence' and 'proof' than are those studying biology (female dominated). Further work is needed to validate this point.

4. Conclusion

The first step that pupils make is away from 'the cartoon image of science' (Fleming, 1986; Solomon et al., 1993) to that of school experimental science. In terms of our questionnaire and interviews this important step involves rejecting the naive notion of discovery by lucky chance in an experiment without educated expectation (responses 1a and 2b).

While it is true that cartoons succeed precisely because of a 'taken for granted' image we can all pick and choose, in cafeteria fashion, from this knowledge in order to answer unexpected questions, by Year 10 just over half of the pupils have unequivocally moved away from the cartoon image towards a view of the nature of science and a deliberate search for explanation. At sixth form level the percentage averages at over 80%. It is important to stress that a large part of this movement seems to be directly attributable to teaching rather than to a simple maturation.

Few students, even those at sixth-form stage, appreciate the nature of theory and the link between it and prediction. Theoretical models are manipulated in the mind in order to make predictions and it is this important aspect of the nature of science which is probed by questions 4 and 5. In question 5 it was response (a) about our superior technology which first attracted most support. Perhaps this is a result of our materialistic and demanding society. Older students then switched to response (b), 'we have more evidence'.

At the higher levels The British National Curriculum stipulates that pupils should learn to use theoretical models for prediction and explanation in the course of their scientific investigations. They should also learn to appreciate the uncertainty of evidence. Here we can only report from our questionnaire data that few teachers seem to be encouraging such work. We are convinced that it needs special strategies to move pupils on from a worthy but limited empiricism towards the more exiting realms of scientific speculation.

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