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Students' Learning about the Nature of Science

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BACKGROUND

There is a double learning context in studying science through learning about the nature of science. Epistemology is the method of gaining knowledge as well as the grounds on which such knowledge stands. This means that the history of human learning in the field of science cannot fail to instruct us about the nature of science. There is more doubt, however, on the cultural, social and personal nature of the history required for this purpose.

Popper placed the whole of the nature of science firmly in his 'Third World' along with the science knowledge which it produces. By this action he identified it as 'knowledge without a knower' (Popper 1972 p106). The contents of this Third World were not the objects of personal belief but the 'objective' knowledge which could be totally contained in the written works of libraries and archives. He claimed that it was so remote from human foibles that the next generation (or even, as he said, creatures from Mars) could in principle use it to rebuild our science from scratch without our human help. It followed that epistemology could be taught in our schools in the same way as the facts of physics and chemistry. Stories about actual scientists might add fun to the lessons but would constitute no more than misleadingly personal illustrations.

But the activities of scientists are the human instruments of epistemology. Both Bloor (1976) and Ziman (1967) have examined how communication within the scientific community establishes the necessary intersubjectivity which decides what shall be considered as orthodox knowledge. This does not match well with the objective nature of epistemology given by Popper. Indeed Ziman (1978) redefined Popper's third world as "a noetic domain which is collectively created and maintained as a social institution" (p106). Now, it seems, stories about the activities of scientists become more important. They are evidence from the world of practising scientists which will illustrate the epistemology of science.

The analysis of epistemology continues, now more from the perspective of society than of scientists. The important message for education is that it is not only the practice and logic of the method, but also its sociology and psychology, which directs the construction of knowledge. Fuller (1991 p23) refers to the thoroughly human ways in which scientists evaluate each others' outcomes; he also explores their intentions and their attitudes towards the process of making knowledge. Under such recognizable social and psychological influences scientific activity becomes far more accessible. It builds up a human picture of the related epistemology which can, in turn, give science education a new freedom to use history.

Studies of the public understanding of science (eg Wynne 1990 and Solomon 1990) have shown that it is precisely through the medium of such social and psychological common-sense knowledge about the actions of people that most members of the public best understand the science and scientists that are involved in public issues. Indeed duringh the study of how school students discuss science-based social issues reported on the television it became clear (Solomon 1990) that reported speech, almost amounting to role-play in some instances, was a common way of evaluating conflicting evidence given by 'experts'.

Hence it seems that at least two substantial advantages accrue to science education from the new epistemology:-

* It permits description of the almost scandalously person-related images of scientific knowledge that pupils hold, which may be considered central to their naive epistemologies of science.

* It allows pupils to use their much better developed understanding of social interaction and human intentions for constructing an understanding of scientific epistemology by means of stories about scientists.

PREVIOUS RESEARCH

Cartoon images of scientists have been explored by means of children's drawings ever since the classic work of Mead and Metrau (1957). The pictures usually show clearly enough their comic intention, which marks them out as stereotypes. Indeed the very request to "Draw a scientist" seems tantamount to asking for fantasy rather than reality. Nevertheless these cartoon figures may have epistemological implications (Fleming 1986), even though a recent study which interviewed pupils about such drawings showed that most pupils seemed quite aware of their cartoon unreality (Williams 1990).

Children's naive notions about scientific epistemology have been well documented (eg. Lederman and O'Malley 1990, Aikenhead et al 1987, Rubba and Anderson 1978). There have also been studies which probed the students' reflections on their own laboratory work (eg. Aikenhead 1989, and Kuhn et al 1988). This is a more valuable methodology for our purpose, although it may avoid tackling the question of how far the students really believe that their laboratory exercises resemble the work of those whom they regard as 'real scientists'.

Particularly interesting results were obtained by Carey et al (1989) where a three week unit of study was used, and significant student progress reported. The questions that these authors used referred both to the epistemology of science and to the activities of scientists. Since the unit of work these authors prepared and used seemed to contain no reference to any named scientist the second type of question seemed designed to draw upon the students' reflections on their own work.

Learning science in school cannot reflect all the activities of scientists (Millar 1989). For this reason, perhaps, many science educators have advocated using stories from the past about scientists eg. Brouwer and Singh 1983, Gruender and Tobin 1991 Matthews 1989, Wandersee 1986 and Winchester 1989. Their objectives could be the better learning of science concepts, more understanding the nature of science, or a social and personal context for the activities of science.

THE WORK OF THE PROJECT

The study took place in five classrooms in three British schools located in very different regions. In the pressurised school climate produced by the recent introduction of the National Curriculum it was an essential prerequisite that all the work carried out in lessons should teach the content that pupils of this age-range (11-14) would normally cover in their science course. No extra time was available.

A resource book (Solomon 1991) containing 13 units of work, each lasting between 2 and 4 hours, had been prepared prior to the school year in which the study was carried out. Each unit aimed to teach science concepts which were embedded in the context and time of its discovery, giving the story in terms of the activities of the scientists or people involved. The exercises included laboratory work, role-play and poster exercises based on written passages.

Five class teachers were enlisted to give help with the work, to choose which units to use and to comment on their students' progress. A researcher was attached to each school to watch the lessons and to interview the teacher and the students. The following data was collected:-

(a) a short pre- and post-course questionnaire,

(b) interviews with groups of pupils based on thier responses to the questionnaire,

(c) other interviews administered during the course,

(d) some occasional class tests.

It is important to stress that no explicit instruction on the nature of science was given. The students relied on the stories they had heard and when interviewed this was the source of the knowledge about the construction of science from which they drew their ideas.

THE ROLE OF EXPLANATION

In the pioneering work of Kimball (1968) in this field it was curiosity, comprehensiveness and simplification, rather than the drive to find explanation, which were cited as the major characteristics of the nature of science about which all students should be made aware. Similarly in the early levels of the statements of attainment in the British National curriculum it is the ability to ask questions - "such as 'how..?' 'why?...' and 'what will happen if ....'" which is identified as essential to Scientific Investigation. If, however, such questions do not really involve the students in a search for an explanation on some theoretical level they will be no more scientific than the flood of everyday questions about "why" supper is not ready, or "why" we have to go out to see Granny. Indeed both in the work of Piaget (1926) and Solomon (1987) there is a great deal of empirical and developmental evidence which suggests that causal explanation is not on the agenda of many young students.

There was also worryingly little evidence from interviews on the students' understandingof the search for explanation as a reason for scientists' work. In responses to the questionnaire explanation obtained a more substantial showing.

Table 1 Why do you think scientists do experiments?

These data raise two questions:-

* Why did so few students talk about scientists seeking for explanations?
* What was the students' understanding of scientific explanation?

When pupils had responded in interview that scientists did experiments 'to try out their explanations for why things happen' it was often hard to get them to expand on this. Those who did so were often vague not only about examples of explanation but also, it seemed, about the meaning of the term itself.

'They might explain about the dangers of science'

'When you explain how an experiment works. What you wanted to do in an experiment.

Int. So you are actually describing what is carried out? (Pupils nod in agreement)

'When you explain an experiment you say like 'We are going to do this', and 'This is how it works'.

'Say for the first time Mrs L (teacher) is explaining an experiment. Then perhaps she might describe a bit of it.'

The example shows a lack of differentiation between 'explanation' and 'description' which has been noted before (Piaget and Solomon op cit). We felt that this was a sufficiently important point to explore further in some of the classes in the study. Pupils in one Year 7 class had just been taught about pressure as weight spread out over area. They used a pressure box to find out that a weight of 4kg on a large area produced the same pressure as a weight on 1kg on one quarter of the area. They were then given a plastic beaker which had a side-arm attached to it near the base. They poured water into the beaker and were asked to fill in a sheet where they first described what happened, and then tried to explain it.

Diagram here (Figure 1)

All 21 pupils described correctly that the water came to the same level in beaker and tube.

Explanation was more difficult. The following was a common attempt to explain

"because however much water you put in the cup it will be the same in the tube."

Whenever this happened the researcher checked with the group of pupils involved that this was the explanation they had intended, and that they did not want to change their answer.

9 (4 groups) out of the 21 pupils gave this kind of reiteration of description,

2 (1 group) omitted the explanation altogether, and

10 (4 groups) made a more or less successful attempt to identify a cause in terms of pressure or forceon area.

The teacher carried out some brief teaching about the difference between description and explanation in the context of dissolving (about 10 minutes). In the following week a second test sheet was given to the pupils. This time they responded individually.

17 pupils were present.

9 pupils successfully described what happened in the pressure box.

In the next question they were shown a diagram of the beaker with a side arm, and asked to "Explain why the water finishes up at the same level on both sides in this experiment'.

Only 2 pupils gave a description

3 left the sheet blank or wrote "Don't know"

12 gave more or less correct(7)explanations in terms ofpressure

Everyday talk does not often use strictly causal explanations. People describe instances from their own experiences to each other, but they rarely either cross-examine opinions or seek for causes. Requests for explanation - 'Why?' - are commonly satisfied by description of the same or another example (Billig 1989 p 122), so it is only to be expected that students will also describe rather than explain, almost without thinking, whenever it is easier to do so.

DISCUSSION

By the end of the course, when the students were again asked why scientists did experiments, and whether they had expectations about what might happen, they had a new resource upon which to draw. Their life-world motley of images of scientists and scientific activities had been augmented, but not displaced, by a few stories from history. This had added a raw new epistemological element to their thinking. From the perspective of a socially driven epistemology it would be natural to associate the above changes with the stories about scientists which the pupils had encountered. There was some interview data at the end of the year which supported this view.

Int Why did Jenner have this idea that cowpox would do the trick?

Dava Because milkmaids never caught smallpox.

Davl He had some idea what was going to happen.

Int Why did he have some idea about what was going to happen?

Davl Because he 'theoried' about it.

In many cases the pupils had to have a cue to some story in order to use it for answering questions. Often this then made the pupils spontaneously change their image of scientific behaviour, and the related epistemology, so that they contradicted an answer they had given only a moment or two earlier. Here was further evidence for the co-existence of several images.

Combining such different methodologies as exploratory ethnographic interviewing, classroom action research, and intervention evaluated by pre- and post-course tests is not easy to handle. The classroom study produced a continuous stream of lesson observations which cannot all be reported here. The materials incorporated new teaching strategies such as role-play and posters which were hugely enjoyed.

The interview data was carried out to a fairly open schedule which was based on specified opening questions similar to those that figured in the questionnaire. The great advantage of this open-ended method, which included cuing to stories used during the year, was that it allowed for the emergence of different images, and demonstrated the co-existence of several which effectively contradicted each other in the essential way that human knowing so often does (Solomon 1992).

The questionnaire data was interpreted in the same spirit. The apparently "successful' changes" in the pupils' ideas which we recorded do not show that other more simplistic images have completely disappeared. We would argue only that the stories of the actual activities of scientists are memorable enough to create a valuable library of epistemological ideas in the minds of young pupils. Since we had already rejected the notion that epistemology is the kind of disembodied knowledge which could be abstractly encoded in the memory this was a valuable conclusion to our research.

We are still uncertain whether our action research has effected a deeper understanding of the history of scientific ideas, or a more mature approach to the social relations of science. We plan to broaden the scope of our work in order to form more secure conclusions in these respects. It was the unanimous view of the teachers that their pupils had learnt some concepts better through studying them in the controversial situations in which they first arose. Some part of this improvement is undoubtedly due to innovation enthusiasm on our part (Hawthorne Effect), and the new "active learning" materials. Any strategem which extends the short time-span of pupils' attention is likely to improve learning, whether or not it includes history of science.

We also acquired new and unexpected evidence from interviews that studying a change in theory in time past may make the process of conceptual change a little easier to face up to in the present. It might have been encouraging for pupils to know that mature scientists have also had to struggle to see phenomena in a new way, at a time when the same feat is being demanded of them at school.

Finally we found that older students had internalised not only the stories from the history of science and the search for explanation which was the message of the texts we used. In some cases we noted that they had also internalised the social and personal approach to epistemology which was our own research intention.

Int. Do you think scientists use imagination in their work?

Lisa. If they come up with some experiment that they have proved and they want to show it to other people, and they have got to (like) show a diagram or something that they think might be true, and they want to bring it to other people. They draw a diagram (and stuff) and say"This is what I imagine it like..!"

The essential action of role-play in order to present epistemology was a spontaneous tribute to our own intentions during this research.

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Table 1

"Why do you think scientists do experiments?"

	Year 7 %	Year 8 %	Year 9 %
Making discoveries	50 (33)	53 (18)	60 (33)
Testing explanations	38 (64)	38 (71)	40 (67)
Making helpful things	11 (2)	9 (11)	0 (0)

Pre-course responses, post-course in brackets.

Fig 1.