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Teachers' conceptions of the nature of science: a comparative study from Pakistan and England

Nelofer Halai and Jane McNicholl

What do science teachers from two continents understand about the nature of science and what are the implications for science teacher educators?

ABSTRACT
Curriculum designers in both Pakistan and the UK accept that science education for today's young people should not just be about learning science, it should also include learning about the nature of science. However, together with other research evidence, this article suggests that for many science teachers, teaching about the nature of science might be problematic as they do not have the necessary understanding of the nature of science themselves. This article also argues that there are benefits in teachers across cultural divides sharing their understandings about the nature of science.

This project arose as a way of strengthening an already existing partnership between the Aga Khan University Institute for Educational Development, Karachi (AKU-IED), and Oxford University Department of Educational Studies (OUDES). Faculty members at the two institutions started to work on a joint research project involving the concept of the nature of science, with the first author (NH) taking the lead role as her expertise resided in that area.

School science curricula in both Pakistan and England include ideas about the nature of science. Pakistani curriculum documents (Government of Pakistan, 2000) indirectly accept this notion by including 'scientific literacy' as one of the goals of science. In addition, one of the ten recommendations in the influential UK report *Beyond 2000: science education for the future* (Millar and Osborne, 1998) strongly advocates preparing children to become informed consumers of scientific knowledge or to become scientifically literate:

> *The science curriculum should provide young people with an understanding of some key ideas-about-science, that is, ideas about the ways in which reliable knowledge of the natural world has been, and is being, obtained.*
> (Recommendation 6).

As a consequence, the latest revision of the National Curriculum in England and Wales (*Curriculum 2000*) now advocates aspects of the nature of science to be studied in the Sc1 strand called *Ideas and Evidence*.

However, research has shown that teachers, at best, have a very limited understanding of the nature of science (Brush, 1989). This is problematic because, while the relationship between teachers' nature of science knowledge and their pedagogical decision-making is not straightforward, a complex interplay does exist (McComas, 1998). Teacher trainers need to understand teachers' conceptions about the nature of science and the problems associated with it, in order to address them in teacher-education programmes.

In an in-depth case study of a science teacher in Karachi, Halai (2002) found that the teacher had very positivist conceptions of science. Science was considered to be objective knowledge that could be obtained by following the scientific method. The teacher saw science as superior, value-free and a stable form of knowledge. Two earlier studies, Halai (1999) and Ahmed (2000), tried to assess the impact that science methods courses offered in AKU-IED's in-service programmes had on teachers' conceptions of the nature of science. Both the studies found that the programmes of study offered have limited influence on teachers' conceptions and suggest that a more direct, overt and explicit mode of teaching about the nature of science may be necessary. This last conclusion finds support in the literature from other parts of the world too (for instance, Abd-El-Khalick, Bell and Lederman, 1998).

A considerable amount of literature is available in the UK on teachers' conceptions of the nature of science, and research findings echo many of the issues raised in Pakistan, including teachers' lack of knowledge about the nature of science, differing views about the nature of scientific method and science being perceived to be a body of knowledge (Lakin and Wellington, 1994; Nott and Wellington, 1996). In addition, Nott and Wellington (1998) advocate very strongly the use of critical incidents/questions to elicit teachers' understandings of the nature of science. In particular, they argue that the use of critical incidents facilitates the investigation of teachers' knowledge in action as opposed to more traditional instruments that focus on academic or 'subject' knowledge and pigeon-hole teachers' ideas in predetermined categories.

The aim of this comparative study was to enable the science teacher educators to learn from each other and to find out what conceptions of the nature of science teachers hold. More importantly, this study would enable an understanding of the nature of, and reasons for, observed differences. It is essential that educators from different nations be more informed about each other's perspectives and broaden their worldviews to understand those of other societies.

The nature of science

It is difficult to define the nature of science, partly because it is a construct that is neither stable nor universal. Philosophers, sociologists, and historians of science do not agree on a specific definition. It has been said to stand for a '*cluster of values, methods, activities and not a sharply defined concept, more in line with what Wittgenstein has called a family resemblance concept*' (Eflin, Glennan and Reisch, 1999, p. 108). It is often used to refer to the epistemology of science, science as way of thinking and the values and beliefs intrinsic to science (Lederman and Niess, 1997). Hodson (1991, p. 21) writes '*while it is apparent that no single, universally accepted view of science emerges from a consideration of the literature, there is a measure of agreement on a number of points relevant to the school science curriculum*'. The basic concepts of the nature of science considered important for school science in the NSTA position paper (see reference) have been taken as the basic definition of the nature of science for the purpose of this study. Very briefly, the position paper states that science is at once a reliable and tentative form of knowledge, that no single universal step-by-step scientific method captures the complexity of doing science, but a number of shared values and perspectives characterise a scientific approach to understanding nature. A primary goal of science is the formation of theories and laws; these terms carry very specific meanings in science and contributions to science can be made by people all over the world, but the science that gets done is to some extent influenced by the social and cultural context of the researcher.

The research study

The project that evolved over a year of discussion had three phases:

- piloting the research tool;
- identifying and comparing conceptions of the nature of science held by teachers from two continents;
- developing curriculum materials to teach those concepts of the nature of science that needed strengthening.

This article confines itself to a report on the second phase of the project. We discuss and compare findings about the conceptions of the nature of science held by teachers in Karachi and Oxford, using the Nature of Science Research Protocol (NOSRP) as a tool for conducting interviews with teachers (Halai, 2001). The research questions that guided the study include:

- What are the conceptions of the nature of science held by in-service and pre-service science teachers in Pakistan and the UK respectively?
- What are some of the similarities and differences between science teachers' conceptions of the nature of science in Pakistan and the UK?

The sample

Twelve in-service teachers from both government and private schools in Karachi, with at least a BSc degree and teaching science to grades 6 to 8 were selected.

In Oxford, nine pre-service teachers (three specialists in each of physics, chemistry and biology), enrolled in the OUDES Postgraduate Certificate in Education, participated in the study. The samples from Karachi and Oxford were clearly different: the Karachi participants were all practising teachers whereas the Oxford participants were all beginning teachers. However, the key issue for us was that none of the participants had experienced any teaching about the nature of science, either in their formal science education or their subsequent teacher training or teaching careers. Given the focus of our research we felt this difference in the samples was justifiable, but, in the event, we found that the 'beginning teacher factor' impinged on the research in an interesting way.

The research tool

NOSRP as a tool for collecting data is based on the idea of engaging teachers in a discussion of the nature of science by allowing them to respond to critical incidents (Nott and Wellington, 1998) and open-ended questions (Abd-El-Khalick *et al.*, 1998) instead of responding to structured questions. It is particularly important for Pakistan because very little is known about teachers' conceptions of the nature of science. Hence to try to understand these ideas using a tool with predetermined ideas guiding the questions would be counterproductive. NOSRP contains three parts:

- Section A – eight critical incidents intended to generate discussion on the teachers' selected concepts of the nature of science.
- Section B – five questions inviting discussion on these concepts.
- Section C – a 'drawing test' (Barman, 1997) where the participants are expected to draw a scientist at work.

For the purpose of the study the tool was modified in two important ways: it was decided to drop section C of the test to limit the interview process to just about an hour; an Urdu translated version was used for teachers in Karachi. For the NOSRP version we used, see Box 1.

Prior to the interviews both sections of the instrument, along with the kinds of questions that would be asked, were explained to the participants and they were given the protocol to scrutinise for 10–15 minutes. The nature of science is not a familiar area for many science teachers, and we believed that they should be given some time to think about the ideas contained in the NOSRP and respond thoughtfully. Then the interview began with some background and demographic questions and was conducted informally. All questions were asked of each interviewee in the same order and prompts and probes were used for clarification when necessary. With the participants' permission all interviews were audio-recorded. The same process was used to administer the instrument in both contexts, except that the teachers in Karachi were free to respond in either Urdu or English, whereas only English was used in Oxford.

Findings

The interviews were taped and transcribed. The data were analysed by reading and rereading the text, coding for themes that arose from the data around the concepts of the nature of science, and then sorting/clustering these themes to form categories. The findings showed some similarities and some differences between the views of the two samples. We think that the differences, in some cases, could be attributed to the different cultural and religious contexts of the participants or to the fact that the Oxford cohort were student teachers and therefore had less experience.

Common views held about the nature of science in the two samples were:

- Scientific laws are 'mature' theories.
- Science and scientific methods provide truth.
- Scientific observation is theory-based and value free.
- A general and universal scientific method exists.
- Models are representations of scientific fact.

However, most of the Karachi cohort demonstrated a belief in the unity of science and religious knowledge, whereas the Oxford group felt that these forms of knowledge were different and separate. These findings are discussed in more detail below, highlighting how cultural and religious differences account for some of the differences and similarities in views.

Theories and laws

The research participants, in both contexts, were confused about laws and theories. The responses from Karachi were complex and diverse particularly in terms of the relationship they perceived between laws and theories. All but two of the Karachi participants believed that theories eventually become laws. Six thought that theories are unproven and incomplete, whereas a law is proven and 'correct', and that a theory becomes a law if multiple experiments yield consistent

Box 1 Nature of science research protocol (NOSRP)

This protocol is not a typical paper-and-pencil test. It is more like research guidelines for developing an understanding of science teachers' understanding of the nature of science. It is divided into two sections: A Critical incidents; B Selected interview questions.

The critical incidents section is based on Nott and Wellington's (1998) article where they have described the use of critical incidents in eliciting, interpreting and developing teachers' understanding of the nature of science. I (NH) have responded to their invitation to use the published critical incidents to generate stimulating and 'talk-provoking' discussions (page 593). I have developed some critical incidents from my own experience of teaching science in Pakistan and others I have adapted and modified from Nott and Wellington's work. Section B consists of five open-ended questions, which can initiate a debate on issues that have been covered in Section A, but the teacher may not have said much about them.

Section A: Critical incidents

Critical incident 1: The teacher is classifying all living things into plants and animals. Then she further classifies living things like cows, dogs, mosquitoes and human beings as animals. One student stands up and quotes the Quran to say that human beings are *ashraful makhluq* [roughly translated as 'the highest of God's creations'] and she could not classify human beings as animals.

List the kinds of things you could say and do at this point.

Critical incident 2: You, the science teacher, want to encourage the students of class 5 to think of air as having weight. You do the very simple activity shown in the textbook of balancing a ruler with an empty balloon on one side and a balloon filled with air on the other side. The side with the air in the balloon is supposed to tilt downwards, but that does not happen.

List the kinds of things you could say to another teacher who is looking on.

Critical incident 3: During a professional development workshop two primary teachers were intensely engaged in an activity that involved the use of litmus paper and a number of liquids that included lemon juice. When one of the teachers, who had some science background, saw that the litmus paper had turned red, he said. '*This is an acid*'. The other teacher turned to her and asked, '*How did you know?*'

List the kinds of things that you could say or do at this point.

Critical incident 4: Class 9 students are doing a practical activity to 'prove' the Law of Conservation of Mass. Students weigh a conical flask containing NaCl solution and a vial of $AgNO_3$ suspended in the flask. After mixing the two solutions, a chemical reaction takes place forming $NaNO_3$ and AgCl. The container is weighed again. Four groups report the two readings to be the same, two groups report a loss in mass, and two an increase in mass.

List the kinds of things you could say or do at this point.

Critical incident 5: You, the science teacher, are discussing the wave theory of light (name any theory that teachers are familiar with) and one of the students wonders out loud when this theory will become law as a very large number of experiments have 'proved' the wave nature of light to be correct.

List the kinds of things you could say or do at this point.

Critical incident 6: You are teaching class 9 students introductory theories about the structure of an atom. During the teaching session you discuss the manner in which neutrons, protons and electrons are placed within the atom and the empty space between the nucleus and the orbit of electrons. One of the students in the class says, '*We were taught before in class 8, that atoms are hard and indivisible. What do you want us to believe?*'

List the kinds of things you could say or do at this point.

Critical incident 7: During a staff development workshop a science teacher educator mentioned that, '*Due to work done by female scientists, explanations about the evolution of humans have slowly changed to include the role of the female as well as the male*.' Some teachers were unsure about this idea and said that it meant that scientific explanations depended on, '*Who was doing the research and the time it was being done*'.

List the kinds of things you could say or do at this point.

(continued)

Box 1 Nature of science research protocol (NOSRP) (continued)

Critical incident 8: Having read the common story that Newton formulated his theory of gravitation after seeing an apple fall, some students are puzzled. They ask the teacher how this story can be true, as there is no data to directly link the 'falling' to gravity.

List the kinds of things you could say or do at this point.

Section B: Selected interview questions

Put the questions to the teachers and engage them in a discussion.

Question 1: After scientists have developed a theory (e.g. such as the atomic theory or the wave theory of light) does the theory ever change? Explain your response.

Question 2: What does an atom look like? Does the model of an atom given in textbooks match reality? How do scientists know about the structure of the atom?

Question 3: Some astronomers believe that the universe is expanding while others believe that it is shrinking; still others believe that it is neither expanding nor shrinking. How are these different conclusions possible if all of these scientists are looking at the same experiments and data?

Question 4: The things that scientists observe depend on the ideas that they have about nature. In short they see what they believe. Comment.

Question 5: When scientists engage in investigations, do they follow a specific method?

results (however, two others thought only a few experiments were needed to do so). In addition, one Karachi participant thought that laws are compiled by taking the commonalities from a number of related theories. Only one research participant thought that there was no difference between a law and a theory. The only other view, expressed by two participants, was that laws often have formulaic representations. The Karachi group had a good understanding of the tentative nature of scientific knowledge, as all the participants thought that theories did change.

Three of the Oxford research participants thought a law was 'a rule of thumb' or a general principle, just like the Karachi participants who thought that a law could be represented mathematically with the help of a formula. Five others actually didn't know or didn't choose to comment on the difference between theories and laws. However, all the Oxford participants agreed that theories did develop and change. Three thought that changes in theories could be quite radical, depending on the evidence produced, and one mentioned the falsification of theories.

In summary, the findings in this area suggested to us that we may need to do more work on developing our teachers' ideas about the difference between scientific theories and scientific laws.

Science as truth

The interview responses revealed that participants' held a wide range of beliefs about 'science as truth' and other issues related to the nature of a model. Nine of the Karachi participants spoke of science having one truth. Many spoke of the 'fact' that in science only one answer is admissible. However, the critical incident that particularly probed this issue was misinterpreted by some of the Karachi participants as having an intentional gender slant to it. They therefore interpreted the critical incident as focusing on the capabilities of males versus females and this led the responses into a discussion about gender differences in science. However, in a later related question, although many of the Karachi participants held fast to their concept of 'one truth', many did mention the fact that different people have different opinions based on their own unique perspective and approach. Thus some did appear to have a notion that scientists and science are influenced by the cultural, religious and political context.

In the Oxford sample two research participants indicated that they felt science was now much more objective than in the past, suggesting a tendency to believe that scientists are now getting closer to the truth. One participant, a physicist, believed that there is a body of knowledge out there to be discovered *'if only humans didn't interfere with it*'! However, all the others in the Oxford sample believed that scientists are influenced by the society in which they live, but they did not explicitly use words such as 'cultural', 'political' or 'religious'. This suggested to us they had a notion that scientific ideas or theories may be context-dependent and so there is not 'one truth'. A question about the nature of models revealed further issues about truth in science. The Oxford sample had a fairly consistent understanding of the nature of a model. They all felt it was a device that could be used to explain scientific ideas, that models were not real and that different models, for example of an atom, could explain different aspects of our scientific ideas about the atom. Some of the Karachi sample also held this view but felt that models, although not a copy of reality, were a simplified version of reality. In addition, a few did believe that a model is a copy of reality and therefore in some ways 'the truth'.

We felt that in both contexts work was needed to clarify the issues of truth in science for teachers, particularly as many participants seemed to think scientific theories could change but still held to the belief that science was truth or certainly more objective than it had been in the past.

Science and religion

The Oxford sample, without exception, held the view that religion and science are different. In the context of the question we asked there was a general view that classification is a scientific tool and that any religious belief is different; therefore the classification of humans as animals was not problematic for any of this group. The responses from the Karachi sample were more complex. Eight of them, like the Oxford sample, acknowledged that there were different systems of classification and attempted to separate science and religion as two different belief systems. Two Karachi participants merged science and religion; for example, one said that there should be three divisions '*plants, animals and humans*'. One participant made a clear separation between science and religion but believed that science is wrong to classify humans as animals. Indeed, one of the other participants felt that evolutionary theory borders on blasphemy, since suggesting that humans are related to and descended from animals as opposed to Adam is blasphemous. It might be of interest to mention here that in the pilot study conducted in Oxford, one of the participants, a Muslim, believed this as well. However, the Oxford sample for this particular study, although religiously diverse, did not include a Muslim. Given the ethnic and cultural diversity in the UK, it is very likely that there will be Muslims amongst future trainee teachers on the Oxford PGCE course, and this means that the responses from Karachi are very pertinent for the UK context too.

The religious debates that this question set off means that the issues raised here need to be pursued, in both contexts, in a sensitive manner.

Discussion

One of the most significant findings of this study was that the social and cultural backgrounds of the participants did not seem to make a difference to their broader understandings of the nature of science. The differences where they existed lay in the nuances of meanings. On particular aspects of the nature of science, religious beliefs of the participants did seem to make a difference. For instance, all participants, irrespective of where they were from, had difficulty in understanding the difference between theory and law. However, when it came to the difference between science and religion as forms of knowing, contrasting views emerged. In Oxford all the participants thought of science as being knowledge-based and religion as faith-based, but the responses in Karachi were different and more complex – they seemed to suggest that all knowledge arose from the Quran. Hence, religious and science knowledge were not seen as different. Even, if they agreed, for instance, that the classification of humans as animals was 'right' scientifically, they subsequently reaffirmed their belief that humans are superior and should not be classed with animals. Teachers included the Quranic injunction that humans are *ashraful makhlooqat* in their classification of living things. Even in subsequent conversations or while answering other parts of the questionnaire the Karachi teachers gave explanations that showed clearly that the separation of science and religion does not exist in their minds. A number of them said that the Quran has all the knowledge and it is only lately that scientists are finding our what was already given in it.

Even the tentative nature of science is more readily acceptable to participants in Karachi because of the concept that God is all knowing and we can only try to find out in our own imperfect ways the secrets of nature. Hence, our knowledge is imperfect and subject to revision.

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Linking science with other cultures

***Peter Barnes** spent 15 years trying to link his experience of other cultures to the teaching of science. He has found that the hardest part is convincing colleagues that it is possible and worthwhile.*

When in 1986 Voluntary Service Overseas (VSO) accepted me for a two-year placement in Tanzania, I was thinking more of the difference that I could make in a developing country than the difference that the experience would make to me as a person and as a science teacher.

Part of my brief was to help in the production of an A-level chemistry textbook. My role was to train a Tanzanian graphic artist and to take photographs for the book. The job entailed riding around the countryside photographing local industry and small village development projects. I was impressed by the rural Tanzanians' tremendous knowledge of their immediate environment and the amount of innovation that was demonstrated.

Since most of my photographs were on slide film, I soon realised that there was much here that I could translate into teaching material when I returned to the UK. After that, I began to seek out all sorts of commonplace things to photograph – the use of reed beds to filter sewage, biogas digesters, bananas being used as a basis for making both beer and soap, and many more. The number of scientific principles demonstrated was huge.

On my return to the UK, I set about writing up some of these ideas in order to teach the scientific principles in a different context. One of the first projects with which I became involved was an end-of-summer-term activity week for year 8. The theme was 'design a town or village'. This was an ideal opportunity to link lots of ideas together. The children found out about life as lived by many rural Tanzanians and translated this knowledge into a plan for an ideal community. Everything was based on the science and technology practised by the people whose lives they were studying.

This inspired me to write more teaching materials based on my experiences, some more successful than others. The really inspiring aspect was that children could begin to see people from 'less developed' countries using the same scientific principles as we do in the UK but very often developing them into less harmful or wasteful technologies. Perhaps even more importantly they could begin to see that there is often interplay between cultural and religious background and the technology that is developed or adopted.

In trying to disseminate these ideas amongst colleagues, I began to encounter a few problems. By the mid-90s people were starting to worry about curriculum overload and the need to pare things down so as to leave plenty of time to revise for SATs. I took myself off again, this time to India, where I spent the best part of a year travelling around by bicycle with the specific aim of seeking out innovation and looking at how science is taught. I returned with a large amount of information supplied to me by a number of dedicated and very knowledgeable people.

I have now written curriculum materials that specifically link the citizenship programme of study to the key ideas outlined in the science strand of the key stage 3 initiative. It would appear that with the advent of citizenship, it is now 'OK' to link science with other cultures. The key is convincing colleagues that they can do it and that means providing the necessary information and writing materials that slip neatly into existing schemes of work.