1.1 What is science?

Teaching science in secondary schools

Michael Reiss

> I have found Ms … has had to deal with another problem: the history of science is almost entirely the history of *Western* science, and Ms … has almost no knowledge of European history since classical times. This is obviously a considerable drawback in coming to a general view or coming to grips with many broader problems in the development of science …
>
> (Copied from a 1981 end-of-term supervision report of a student from Pakistan doing the second-year undergraduate course in History of Science at Cambridge University)

Who are scientists?

A while ago, I happened to see a new set of postage stamps produced in the UK, entitled 'Scientific achievements' (issued 5 March 1991). It's worth spending a few moments imagining what you might expect (or hope!) to see on these stamps. Well, whatever you thought, the Royal Mail produced four stamps under the heading Scientific achievements' with the captions 'Faraday – Electricity', 'Babbage – Computer', 'Radar – Watson-Watt' and 'Jet Engine – Whittle'. I find it difficult to imagine a narrower conception of what science is and who does it. The image seems to be that real science is hard physics, with military applications, done by males who are white and worked on their own between about 1820 and 1940. No wonder so many students drop science at school as soon as they have the chance! Children come to school science lessons with clear impressions of what science is, how it operates and who does it (Driver *et al.* 1985; Osborne and Freyberg 1985). There is a limit to what science teachers can realistically be expected to achieve in terms of challenging social perceptions and changing received wisdom.

It seems sad that the Royal Mail could produce a set of stamps that portrayed such a biased view of science. Stamps to feature scientists could convey the notion that women do science, that science didn't start in the nineteenth century and finish around the time of the Second World War, that it isn't a Western construct, that it is done by people working in groups and that it permeates every area of life. […]

The nature of science

The popular view of what science is and how it proceeds probably goes something like this:

> Science consists of a body of knowledge about the world. The facts that comprise this knowledge are derived from accurate observations and careful experiments that can be checked by repeating them. As time goes on, scientific knowledge steadily progresses.

Such a view persists, not only among the general public, but also among science teachers and scientists despite the fact that most historians of science, philosophers of science, sociologists of science and science educationalists hold it to be, at best, simplified and misleading and, at worst, completely erroneous (Latour 1987; Woolgar 1988; Wellington 1989; Harding 1991).

It is not too much of a caricature to state that science is seen by many as *the* way to truth. Indeed, a number of important scientists have encouraged such a view by their writings and interviews (e.g. Peter Atkins and Richard Dawkins). It is generally assumed that the world 'out there' exists independently of the particular scientific methodology used to study it (Figure 1.1.1). The advance of science then consists of scientists discovering eternal truths that exist independently of them and of the cultural context in which these discoveries are made. All areas of life are presumed amenable to scientific inquiry. Truth is supposed to emerge unambiguously from experiment like Pallas Athene, the goddess of wisdom, springing mature and unsullied from the head of Zeus. This view of science is mistaken for a number of reasons, which I now want to discuss.

Scientists have to choose on what to work

What scientists 'choose' to work on is controlled partly by their background as individuals and partly by the values of the society in which they live and work. Most scientific research is not pure but applied. In particular, approximately one half of all scientific research funding is provided for military purposes. To give just one specific example of the way society determines the topics on which scientists should work: the 1980s saw a significant reduction in Great Britain in the level of research into systematics, taxonomy and nomenclature (the classification, identification and naming of organisms). This was a direct result of changes in government funding which, for instance, required the Natural History Museum in London, the major UK centre for such research, to generate much of its own income. As a result, the number of scientists working there in these disciplines more than halved as such scientists generate very little income.

Now, my point is not specifically to complain at the demise of systematics, taxonomy and nomenclature in the UK, but to point out that society and individual scientists have to choose on what to work. To a very large extent that choice is not determined on purely scientific criteria (if such criteria exist), but by political machinations and by the priorities (some would describe them as quirks) of funding bodies.

Scientists do not discover the world out there as it is

Scientists approach their topics of study with preconceptions. There is no such thing as an impartial observation. In the classroom, this is seen to be the case every time a group of pupils is asked, for the first time, to draw some cells or sulphur crystals under the microscope. It isn't possible until you know what to draw. Unless you know that a leaf of pondweed consists of numerous small, brick-like structures, all you can see is a mass of green with lines and occasional air bubbles. [...]

Instances are legion where we can look back and see how scientists have unconsciously interpreted what they have seen in the light of their cultural heritage. In his book *Metaphors of Mind,* Robert Sternberg points out that much of the present confusion surrounding the concept of intelligence stems from the variety of standpoints from which the human mind can be viewed (Sternberg 1990). The geographic metaphor is based on the notion that a theory of intelligence should provide a map of the mind. This view dates back at least to Gall, an early nineteenth-century German anatomist and perhaps the most famous of phrenologists. Gall investigated the topography of the head, looking and feeling for tiny variations in the shape of the skull. According to him, a person's intelligence was to be discerned

Figure 1.1.1 What is the relationship between science and that which it describes? (Copyright: Chris Madden.)

in the pattern of their cranial bumps. A second metaphor, the computational metaphor, envisions the mind as a computing device and analogizes the processes of the mind to the operations of a computer. Other metaphors discussed by Sternberg include the biological metaphor, the epistemological metaphor, the anthropological metaphor, the sociological metaphor and the systems metaphor. The point is that what scientists see and the models they construct to mirror reality depend very much on where their point of view is.

A clear example of how the work that scientists do is inevitably affected by who they are is provided by Jane Goodall's seminal (if that is not too sexist a term!) research on chimpanzee behaviour. When she first arrived to study the chimpanzees on the banks of Lake Tanganyika, the game warden who took her round made a mental note that she wouldn't last more than six weeks. She has stayed for forty years, producing the definitive accounts of chimpanzee social organization and behaviour in her fascinating and moving books *In the Shadow of Man* (van Lawick-Goodall 1971) and *The Chimpanzees of Gombe: Patterns of Behavior* (Goodall 1986).

An important point about Jane Goodall is that she had no formal training in ethology (the science of animal behaviour), having trained as a secretary after leaving school. As she herself wrote, 'I was, of course, completely unqualified to undertake a scientific study of animal behaviour' (van Lawick-Goodall 1971: 20). However, she spent some time with the celebrated palaeontologist Louis Leakey and his wife, Mary, on one of their annual expeditions to Olduvai Gorge on the Serengeti plains. Louis Leakey became convinced that Goodall was the person he had been looking for for twenty years – someone who was so fascinated by animals and their behaviour that they would be happy to spend at least two years studying chimpanzees in the wild. Leakey was particularly interested in the chimpanzees on the shores of Lake Tanganyika as the remains of prehistoric people had often been found on lake shores and he thought it possible that an understanding of chimpanzee behaviour today might shed light on the behaviour of our Stone Age ancestors.

Goodall couldn't believe that Leakey was giving her the chance to do what she most wanted to do – watch chimpanzees in their natural habitat. She felt that her lack of training would disqualify her. But, as she later wrote:

> Louis, however, knew exactly what he was doing. Not only did he feel that a university training was unnecessary, but even that in some ways it might have been disadvantageous. He wanted someone with a mind uncluttered and unbiased by theory who would make the study for no other reason than a real desire for knowledge; and, in addition, someone with a sympathetic understanding of animal behaviour.
>
> (van Lawick-Goodall 1971: 20)

Now the point, of course, is not that Jane Goodall could approach chimpanzees with a mind 'uncluttered and unbiased by theory' but that the clutter and theory in her mind was crucially distinct from that in someone who emerged from a university course in ethology. In the 1960s, one of the great heresies of academic ethology was to be anthropomorphic – to treat non-humans as if they had human attributes and feelings. That is precisely what Jane Goodall did and it allowed fundamentally new insights into chimpanzee behaviour. A flavour of her approach can be obtained by reading the following quote:

> One day, when Flo was fishing for termites, it became obvious that Figan and Fifi, who had been eating termites at the same heap, were getting restless and wanted to go. But old Flo, who had already fished for two hours, and who was herself only getting about two termites every five minutes, showed no signs of stopping. Being an old female, it was possible that she might continue for another hour at least. Several times Figan had set off resolutely along the track leading to the stream, but on each occasion, after repeatedly looking back at Flo, he had given up and returned to wait for his mother.
>
> Flint, too young to mind where he was, pottered about on the heap, occasionally dabbling at a termite. Suddenly Figan got up again and this time approached Flint. Adopting the posture of a mother who signals her infant to climb on to her back, Figan bent one leg and reached back his hand to Flint, uttering a soft pleading whimper. Flint tottered up to him at once, and Figan, still whimpering, put his hand under Flint and gently pushed him on his back. Once Flint was safely aboard, Figan, with another quick glance at Flo, set off rapidly along the track. A moment later Flo discarded her tool and followed.
>
> (van Lawick-Goodall 1971: 114–15)

Other writers at the time did not give names to their animals; nor did they use language like 'getting restless', 'wanted to go', 'set off resolutely' and 'pottered about'; nor did they impute to their subjects the ability consciously to manipulate one another.

Apart from her lack of formal training, there is another factor about Jane Goodall that may well be significant. She is a woman. The longest-running studies on animal behaviour have all been carried out by women including: Jane Goodall on chimpanzees (1960 to present); Dian Fossey on gorillas (1966 to 1985 when she was murdered, probably because of her dedication to the gorillas); and Fiona Guinness on red deer (1972 to present). All three worked/work quite exceptionally long hours with what can only be described as total dedication. In 1978 and 1979, I spent a couple of months working alongside Fiona Guinness. On average, she worked fourteen hours a day, seven days a week.

My point is not that research scientists ought to work this long, nor that only women can show the empathy with animals that these three did or do. Rather, it is that the personal and social pressures that shaped Jane Goodall, Dian Fossey and Fiona Guinness were crucial to the type of science that they carried out or do carry out. And this is true for all scientists. It's just that it is easier to see in these three cases. Donna Haraway, in her book *Primate Visions: Gender, Race and Nature in the World of Modern Science,* argues that scientific practice is story-telling. The work that primatologists do is moulded by the environment in which they operate and by the sort of people they are, so that the stories that they tell reflect the social agendas that surround them (Haraway 1989).

It is possible to suppose from the above that only bad science is affected by the presuppositions of the individuals that carry it out, influenced by the hidden assumptions of the society in which they live and move and have their being. Indeed, most practising scientists are happy with the notion that this is the case. However, many sociologists of science want to go much further than this. They argue that every science inevitably reflects the interests, the values, the unconscious suppositions and the beliefs of the society that gives rise to it (Longino 1990). For an example of how even what is almost universally acknowledged as being among the best of science may have critically been influenced by what might be described as extra-scientific forces, consider some of Newton's thinking in his *Principia* (Freudenthal 1986; discussed by Chalmers 1990).

One of Newton's key advances was to argue that the properties of wholes are to be explained in terms of the essential properties of their parts. For instance, Newton asserted that the extension, hardness, impenetrability, mobility and force of inertia of the whole result from the extension, hardness, impenetrability, mobility and force of inertia of the parts. From this, he concluded that the smallest of particles are also all extended, hard, impenetrable and moveable and are endowed with their proper forces of inertia.

Newton's assertion that the whole is simply the sum of its component parts provided the crucial foundation stone for his pivotal work on gravity, but from where did he get the idea? The assertion cannot, of course, be proved. Indeed, every biologist knows that the properties of an organism (say, a giraffe) cannot be deduced from the properties of the molecules of which it is comprised. Biology is all about understanding that the properties that one level of organization possesses are not necessarily apparent from studying lower levels of organization.

Freudenthal traces Newton's assumptions back to the individualistic understanding of society that emerged in the seventeenth century as European feudal society came to be replaced by early forms of capitalist society. He points out that, while the various new conceptions of society formulated in the seventeenth century by Thomas Hobbes, John Locke and others differ from each other in significant respects, they have one thing in common. They all attempt to explain society by reference to the properties of the individuals that make up society. Further, individuals are assumed to have these properties independently of their existence in society.

At this point, it may be worth drawing attention to the fact that accepting the essential premise of sociologists of science that science and society are inevitably, inexorably intertwined, does not necessarily require one to abandon all belief in the objectivity of science. As Alan Chalmers puts it: 'The natural world does not behave in one way for capitalists and in another way for socialists, in one way for males and another for females, in one way for Western cultures and another for Eastern cultures' (Chalmers 1990: 112). This seems reasonable. However, a scientist's *perceptions* of the natural world, as well as his or her interpretations of it, come through their senses, themselves as a person and their culture. What is of significance for science education is that there can be no single, universal, acultural science. Rather, every sort of science is an ethnoscience, as I shall now argue.

Science as a collection of ethnosciences

The term 'ethnoscience' first became widely used in the anthropological literature of the 1960s (Bulmer 1971). It has been used in two ways:

> It refers first to the 'science', in the sense of modes of classification of the material and social universe, possessed by societies unaffected or little affected by modern international scientific thinking and discoveries. Second, it refers to a particular anthropological approach which has as its objective the systematic scientific investigation of ways in which particular societies classify the universe …

Such ethnoscientific research has contributed much that is of value to those hoping to fashion a science education for a pluralist society, but we need to broaden this definition slightly. To restrict the term 'ethnoscience' to societies 'unaffected … by modern international scientific thinking and discoveries' is both to misunderstand the nature of science and to risk adopting a patronizing and racist attitude to such ethnosciences. It misunderstands the nature of science because, as I have argued above, all science is set in a cultural milieu, so that we cannot validly distinguish a number of ethnosciences from a single international non-ethnoscientific science. It risks being patronizing and racist because accepting such a definition of ethnoscience inevitably makes it likely that a writer, however impressed she or he is with a particular ethnoscience, ends up comparing it with 'modern international scientific thinking and discoveries', which then act as a benchmark against which the particular ethnoscience is judged.

Further, we should not assume that, within a particular society, all scientific thinking operates within the same paradigm. By virtue of differences between individuals in such important characteristics as gender, religious beliefs, ethnicity, age and disability, individuals may differ significantly in their scientific understanding and conception of the world. There are two extreme ways in which a teacher may react to such differences. The more common is to adopt, implicitly, what we can call a 'deficit' model of science. Here all inter-individual (and inter-cultural) differences in scientific understanding and practice are held to exist because individuals and cultures differ in the extent to which they understand and practise the one, true science. The role of a science teacher clearly is to remove obstacles to the understanding of this single true science and then teach it (cf. Layton 1991).

The second extreme way in which a teacher could react to inter-individual and inter-cultural differences in scientific understanding and practice is to adopt what we can call an 'all sciences are equal' model. Here, there is no objectivity in science. All scientific methodologies and findings, however much they differ, are of equal validity.

I suspect it is because this second model leads to conclusions which, to practically every science teacher, are so manifestly absurd, that the first model – with its assumptions of the one, true science – is so often adopted.

What I will attempt to argue is that there is a middle ground between these two models, a middle ground which genuinely allows for inter-individual and intercultural differences without abandoning all claims to real scientific progress.

Published or be damned

Once a scientist or group of scientists has discovered something or produced a new model to interpret a phenomenon, it is necessary for their work to be disseminated in some form, usually through publication. Getting work published, read, recognized and cited depends greatly on the personalities of the individuals involved and on what society values.

As a single example of the importance of society's world view in accepting a scientific theory, consider the circumstances that surrounded the publication of William Harvey's ideas on the circulation of the blood. Although the circulation of the blood had been established in China by the second century BCE at the latest, in Europe the idea was proposed by Michael Servetus (1546), Realdo Colombo (1559), Andrea Cesalpino (1571) and Giordano Bruno (1590). These men had read of the circulation of the blood in the writings of an Arab of Damascus, Ibn Nafis (died 1288) who himself seems to have obtained at least some of his ideas from China (Temple 1991). Harvey published his 'discovery' in 1628. It is possible that the early seventeenth-century accounts of a huge diversity of pumping engines for mine drainage and water supply caused the scientific community and general public to be in an appropriate frame of mind to accept the notion of the heart as a mechanical pump (cf. Russell 1988). In other words, most people remember Harvey as the person responsible for the discovery of the circulation of the blood because earlier proponents of the idea published their announcements at times when the understanding and acceptance of them were more difficult for people.

Mention can also be made of the importance of the language that scientists use. Some scientists are simply much better at writing up their work so that it is more likely to be published, read and cited. What people then remember is the language used as well as the science. Indeed, the two cannot be separated. We cannot sift out the language of corruption to reveal a pure, unsullied science.

An illustration of the intimacy of the relationship between language and science is provided by the attempts of newspapers and magazines in the UK, on 24 April 1992, to describe the reported discovery by a NASA satellite of radiation from the Big Bang. The word most often used was 'ripple'. The first two paragraphs of the *Independent* report (which dominated the front page of the paper) were as follows:

> Fourteen thousand million years ago the universe hiccuped. Yesterday, American scientists announced that they may have heard the echo.
>
> A NASA spacecraft has detected ripples at the edge of the Cosmos which are the fossilised imprint of the birth of the stars and galaxies around us today.

Even the *Sun* weighed in. Under a headline 'We find secret of the creation' (page 6) the ripples were said to 'look like wispy clouds'. The publicity attending the news was heightened by Stephen Hawking, who was reported on the front page of the *Daily Mail* as describing the finding as 'the discovery of the century, if not of all time'.

It's easy to make fun of reports which talk of wispy clouds and the universe hiccuping, but my point is that all science has to be reported in a language, even if it is the language of mathematics. And all languages, including the language(s) of mathematics, are human constructs.

Changing conceptions of science

The notion as to what constitutes science differs over time and between cultures (Hiatt and Jones 1988; Brooke 1991). Attempts by certain historians and philosophers of science to identify a distinctive 'scientific method' which demarcates science absolutely from other disciplines have not proved successful. Though certain principles, such as testability and repeatability, may be central to modern science, it is now widely held that the question 'What is science?' can only be answered: 'That which is recognized as such by a scientific community'. Although this answer, being somewhat tautologous, may appear distinctly unhelpful, its truth may be seen by examining what other times and cultures include in science. [. . .]

In England and Wales, successive versions of the Science National Curriculum Attainment Target 1 have had a model of science which, while there is much that is good about it, would disqualify the inclusion, for instance, of much of the work done by astronomers, taxonomists, palaeontologists and theoreticians. Mayr has argued that after the time of the Middle Ages (in Western Europe), the physical sciences were the paradigm of science:

> As everyone was willing to concede, the universality and predictability that seemed to characterize studies of the inanimate world were missing from biology. Because life was restricted to the earth, as far as anyone knew, any statements and generalizations one could make concerning living organisms would seem to be restricted in space and time. To make matters worse, such statements nearly always seemed to have exceptions. Explanations usually were not based on universal laws but rather were pluralistic. In short the theories of biology violated every canon of 'true science', as the philosophers had derived them from the methods and principles of classical physics.
>
> (Mayr 1988: 9)

Sadly, it is still the case that much school science has too narrow an understanding of the *methods* of science. This, I suspect, is one reason why pupils too often find their school science unsatisfying. They know that it's too restricted a way of looking at the world. And they're right.

References

Brooke, J. H. (1991) *Science and Religion: Some Historical Perspectives*, Cambridge: Cambridge University Press.

Bulmer, R. N. H. (1971) 'Science, ethnoscience and education', *Papua and New Guinea Journal of Education* 7 (1): 22–33.

Chalmers, A. (1990) *Science and its Fabrication,* Milton Keynes: Open University Press.

Driver, R., Guesne, E. and Tiberghien, A. (eds) (1985) *Children's Ideas in Science*, Milton Keynes: Open University Press.

Freudenthal, G. (1986) *Atom and Individual in the Age of Newton*, Dordrecht: Reidel.

Goodall, J. (1986) *The Chimpanzees of Gombe: Patterns of Behavior*, Cambridge, MA: Belknap Press of Harvard University Press.

Haraway, D. (1989) *Primate Visions: Gender, Race and Nature in the World of Modern Science*, London: Routledge, Chapman and Hall.

Harding, S. (1991) *Whose Science? Whose Knowledge? Thinking from Women's Lives*, Milton Keynes: Open University Press.

Hiatt, L. R. and Jones, R. (1988) 'Aboriginal conceptions of the workings of nature', in R. W. Home (ed.) *Australian Science in the Making* (pp. 1–22), Cambridge: Cambridge University Press.

Latour, B. (1987) *Science in Action: How to Follow Scientists and Engineers through Society*, Milton Keynes: Open University Press.

Lawick-Goodall, van, J. (1971) *In the Shadow of Man*, Glasgow: Collins.

Layton, D. (1991) 'Science education and praxis: the relationship of school science to practical action', *Studies in Science Education* 19: 43–79.

Longino, H. E. (1990) *Science as Social Knowledge: Values and Objectivity in Scientific Inquiry*, Princeton, NJ: Princeton University Press.

Mayr, E. (1988) *Towards a New Philosophy of Biology: Observations of an Evolutionist*, Cambridge, MA: Belknap Press of Harvard University Press.

Osborne, R. and Freyberg, P. (1985) *Learning in Science: The Implications of Children's Science*, Birkenhead, Auckland: Heinemann Education.

Russell, N. (1988) 'Teaching biology in the wider context: the history of the disciplines as a method 2: worked examples', *Journal of Biological Education* 22: 129–35.

Sternberg, R. J. (1990) *Metaphors of Mind: Conceptions of the Nature of Intelligence*, Cambridge: Cambridge University Press.

Temple, R. (1991) *The Genius of China: 3000 Years of Science, Discovery, and Invention*, London: Prion/Multimedia.

Wellington, J. (ed.) (1989) *Skills and Processes in Science Education: A Critical Analysis*, London: Routledge.

Woolgar, S. (1988) *Science: The Very Idea*, Chichester: Ellis Horwood.