Reforming school science education in the light of pupil views and the boundaries of science

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What are the boundaries of science and how should science be represented in schools? There is a need to develop science curricula and teaching approaches to broaden what is commonly taught in school science

ABSTRACT

The science education provided in schools is still a narrow version which generally gives pupils only a partial understanding of either the scope of science or its achievements. Yet consideration of what most pupils want and of the boundaries of science argues for a richer science curriculum. Such a move makes intellectual sense and is feasible. It should lead to science teaching being more satisfying for pupils and science teachers alike.

> Where was the chap I saw in that picture somewhere? Ah, in the dead sea, floating on his back, reading a poem with a parasol open. Couldn't sink if you tried: so thick with salt. Because the weight of the water, no the weight of the body in the water is equal to the weight of the. Or is it the volume is equal to the weight? It's a law something like that. Vance in High school cracking his fingerjoints, teaching. The college curriculum. Cracking curriculum. What is weight really when you say the weight? Thirtytwo feet per second, per second. Law of falling bodies: per second, per second. They all fall to the ground. The earth. It's the force of gravity of the earth is the weight.
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> Joyce (1922/68) p. 73

Ulysses is not a book principally concerned with attempts to reform science curricula but Joyce succeeds in capturing in Mr Bloom's recollections what must be typical of many people's memories of school science: a hodgepodge of half-remembered scientific laws (Archimedes' principle) dressed up with the occasional attempt to enable understanding, enhance memory or regain interest through the mention of an apparently surprising phenomenon (floating in the Dead Sea).

Nor are Mr Bloom's recollections of his school science lessons atypical. Six years ago, as part of a longitudinal study I am undertaking, I asked the parents of a group of 21 pupils about their memories of science at school. Most of them had had fairly negative experiences (Reiss, 2000). Peter's mother, for example, told me that she had stopped doing science before she did her CSEs. 'All I remember is Bunsen burners and test tubes and being fined 5p.' The fine was for breaking some science equipment. They used to do dissection in biology and she found that 'horrible ... Also had to go out and collect snails and collect worms and make a wormery and my Mum was disgusted'.

Paul's mother, when I asked her 'Could you tell me a bit about your education please?' initially replied 'Don't bother with me. Not worth it'. The school she went to was for 'the 11+ failures ... There was no intake for a year because they weren't sure whether to close us'. All pupils 'had to do chemistry and biology or physics and chemistry. I did chemistry and biology. I couldn't understand chemistry. If I'd been allowed to do physics I would have understood it ... chemistry teacher hated me and said in front of me “She came from a council estate so what can you expect”'. Paul's mother told me that they 'all failed biology because they put us in for the wrong syllabus ...'.

There were some positive memories of school science among this sample, but, for both the mothers and the fathers, these were in the minority. What I found particularly interesting was that almost all of the parents, despite their own fairly negative experiences, were emphatic that science should be taught to all pupils in schools. When I asked the parents why they felt this, the most frequently given answers were to do with science deepening one's understanding, for example:

> ... Science is life really. It's everything around us. It's important to give children a chance to look deeply into natural science as well as all the other scientific areas. (Catherine's mother)
>
> It's a basic part of understanding the world we live in ... (Edward's father)
>
> I think it's very noticeable that when you meet people who don't have any science, they don't realise how much they don't know. (Jack's father)
>
> ... I think it's nice to know how everything functions in your body ... (Martin's mother)
>
> ... I certainly think they should be taught how the world works ... (Martin's father)
>
> ... we live in such a technological age ... (Mary's mother)

My research was an in depth study of just one group of school pupils. Jonathan Osborne and Sue Collins have run focus groups with parents, teachers and 16-year-old pupils in London, Leeds and Birmingham (Osborne and Collins, 2000). One of their findings, similarly, was that pupils and their parents all considered science to be important. It was seen as a prestigious subject and valued for the understanding it offered of the natural world.

Indeed, in almost all countries science is privileged with regard to its position in school curricula. Here I shall attempt to argue how we should represent science in education. In the space available this is, I admit, a somewhat ambitious enterprise as it requires some consideration both of the scope of science and of the purposes it might serve within education.

Science and reality

Let me assert baldly that science is one way of representing reality. I am not so interested here in the fact that there are other ways of representing reality – something that is unlikely to be news to those with a knowledge of other disciplines but is still deeply troubling to a number of vocal scientists who believe that only science can validly represent reality. Rather I am interested in the extent to which every representation of requires the excision and positioning of reality.

Michael Matthews has emphasised how in his work on pendulum motion Galileo consistently went beyond what his results showed him, something for which his opponents at the time continually criticised him (Matthews, 2000). Let us return briefly to Joyce's Mr Bloom with his recollection of 'Thirtytwo feet per second, per second'. As we know, this is a constant, approximately the value (in imperial units, now more or less outlawed from UK science textbooks as from our shops) of the acceleration of an object as it falls under the influence of gravity.

Except, of course, that it isn't. It is the value of the acceleration of an object as it falls in a vacuum under the influence of gravity. Now in Galileo's time, a vacuum, in a very real sense, did not exist on Earth. It did, though, exist in Galileo's mind. Part of the genius of Galileo was to wonder how an object would fall under gravity if there was no air resistance, i.e. in a vacuum. It was the same quality of thinking that led Einstein to wonder what would happen if he could travel at the speed of light and that led Darwin to realise that inheritance and the everyday effects of competition could lead to the huge diversity of life we see today in direct descent from the humblest inorganic precursors many hundreds of millions of years ago.

Sadly, school and even college textbooks of science almost always fail to discuss this important way in which science is an abstraction of reality as well as an approximation to it. For example, Maria Rodriguez and Mansoor Niaz have studied over 50 general physics textbooks and laboratory manuals to see how they portray Millikan's classic series of oil drop experiments. These oil drop experiments are beautifully elegant. Thanks to Nuffield advanced level physics, under Paul Black and Jon Ogborn, they were introduced to English VIth form students some thirty years ago. I remember being fascinated, indeed entranced, by them when I was at school. The observations Millikan made allowed him to conclude that the electrical charges found on objects all have exactly the same value or else exact multiples of that value. We know this value as the charge on an electron.

This is the conclusion preached in every science textbook that covers the subject. However, R. A. Millikan and F. Ehrenhaft spent the best parts of their careers disagreeing about this. As late as 1941, over 30 years after Millikan first reached his conclusions, Ehrenhaft was still concluding that charges considerably less than this were consistently found. It has been argued that there was never a laboratory disproof of Ehrenhaft's (Rodriguez and Niaz, 2001).

Representing the ways in which scientists work

Ever since the introduction of the National Curriculum in England and Wales in 1989, the notion that there is a single best way of carrying out a scientific investigation has been enshrined in legislation. Although the current revision of the science National Curriculum has improved affairs, it remains the case that most pupils end their mandatory science education (sometimes overenthusiastically referred to as their 'entitlement for science education') with a very narrow understanding of what science is and how it is carried out (Driver *et al.*, 1996; Donnelly and Jenkins, 1999).

For one thing, we don't do a very good job of getting children in school science lessons either to ask the sorts of questions that scientists actually ask or to ask the sorts of questions that the rest of us ask and to which science can make a contribution. Instead we restrict pupils to mind-blowingly dull questions about the bouncing of squash balls or the dissolving of sugar in what are misleadingly termed 'scientific investigations'. We also succeed in persuading most people that they aren't good at science. Here, for example, is the start of an article titled 'Science quiz' published in the Spring 2001 issue of *Insight*, 'The Magazine for Education and Business' published by the then Department for Education and Employment:

> Which is the most common alkali? Who invented the motorcycle? In which city did the world's first public television service start in 1936?
>
> Questions like these feature in the School Science Race 2001. Run by the Engineering and Physical Science Research Council (EPSRC) and sponsored by telecom company Alcatel, the Science Race is held during National Science Week.
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> Anon (2001) p. 16

I am delighted to say that I don't know the answer to any of these three questions nor have I the faintest interest in so doing. On a more positive note, research has shown the extent to which people when faced with issues of personal significance where a knowledge and understanding of science is of value are capable not only of understanding a great deal of science but of being able to appreciate the limitations of scientific understanding – for example about the concept of risk – in a way which many scientists are not (ESRC Global Environmental Change Programme, 1999).

Let me be personal. In my own, brief, career as a research scientist, I worked in the zoology department of a reputable university. Yet I carried out two quite different types of scientific work. One involved field work on the behaviour of red deer. Here, being a good scientist meant such things as being able to find particular deer (which might take an hour or more), identify them, record their behaviour using techniques adapted from field anthropology and so on. The other type of scientific work involved constructing mathematical models to try to predict why animals were the size they were. Trying to explain why both types of work could be carried out in the same zoology department is quite difficult. Apart from the fact that each involved original work on animals they had little in common. Interestingly enough, neither bit of work would have got me a high level on Attainment Target 1 (Sc1) of the science National Curriculum.

A possible way further to illustrate the position that there is no one scientific method is to imagine a particular wood and then think of the ways in which a scientist might study it (Reiss and Tunnicliffe, 2001). There are many. For a start, a biologist would be most interested in the organisms in the wood, a climatologist would study such things as insolation, rainfall, aspect and wind and a geologist would focus on the underlying rocks and the consequences of these for the soil.

Further, there are a great variety of ways in which just the biologists might work in such a wood. Even eschewing such obvious niche-specific roles occupied by those who define themselves as microbiologists, botanists, mycologists and zoologists, our wood will be full of ecologists, anatomists, biochemists, physiologists and even such difficult to classify creatures as Oliver Rackham, interested in the history of the wood as revealed by a variety of different approaches including dendrochronology, field archaeology and the study of place names.

Indeed, we can subdivide further: our ecologists will include population biologists (counting the numbers of individuals within species and organising these individuals by age classes), ecological geneticists (concerned with any relationships between genomes and differential fitnesses), autecologists (each occupied with the ecology of a single species), synecologists (attempting to unravel the interrelationships between species), conservation biologists (concerned to prevent, through careful management based on thorough monitoring, the loss of species from the wood) and so on.

In addition to the plethora of scientists now found investigating every aspect of this overcrowded wood, many other types of scientists exist though they are unlikely to be found studying this wood or any other or, which is perhaps more important, using the methods of biologists, climatologists and geologists. An analytical chemist, a theoretical physicist, a palaeontologist and a professor of cardiac surgery share little in common from a methodological standpoint. Indeed, attempts to produce a list of what unifies such a disparate group of people tend to end up generating criteria that would include geographers, historians, economists and just about any one who seeks after testable truth.

How many scientific truths are there?

Someone might grudgingly agree that there are a wide variety of both scientific approaches (crudely, the 'processes' of science) and scientific domains (crudely, the 'contents' of the various sciences) but still insist on the existence of one actual reality. This fairly conventional view would entail believing that the universe (more formally, that large part of it susceptible to scientific enquiry) is so rich that no single scientific way of exploring it suffices; instead a variety of approaches are needed with these approaches being situated within relatively distinct (albeit overlapping) domains. In other words, there is a biology of a wood, a chemistry of a wood, a geology of a wood and so on, but there is just the one wood being studied!

A more radical view, informed by post-modernism, would cheerfully assert that the wood being studied, while undoubtedly a single wood in everyday language, actually exists – or, at the very least, reveals itself – differently to different investigators. I won't rely on this more radical view but it is important to mention it here. To many, it may seem an absurd view but it may be easier to see its force if one imagines not a whole wood but a single species, say the grey squirrel, in the wood being studied. I need not rehearse again in any detail the various biological approaches to studying grey squirrels – anatomical, biochemical, physiological, behavioural and so on. But consider just the behavioural approach.

At one extreme, imagine how such behaviourists as Pavlov (of Pavlov's dogs) and Skinner (designer of the Skinner box in which the learning of rats, pigeons and other animals can be quantitatively investigated) might proceed. They would probably obtain a number of grey squirrels and keep them in isolation or in small groups in carefully controlled laboratory settings. Here individual squirrels would be tested to see to which particular features of the environment allowed effective learning to take place. For example, do squirrels innately prefer certain materials from which to fashion a drey (nest)? How long do they take to learn which foods are edible and which are not? And so on.

At the other extreme, imagine how Jane Goodall (the pioneer of long-term, fieldwork in an animal's natural setting) might proceed. She would probably spend many months acclimatising the squirrels to herself and herself to their habitat. As she did so she would begin to notice patterns in their behaviours and to see the various squirrels as individuals. Undoubtedly she would give her study animals their own names, see signs in them of individual differences in personality and behaviour and begin to appreciate how they relate to one another.

These two different approaches to studying the behaviour of squirrels, one experimental and interventionist, the other ethnographic and naturalistic, evidently reveal different understandings of what it is to be a grey squirrel. But in a sense, each approach brings into existence a different kind of grey squirrel. It might be objected that this is ridiculous. After all grey squirrels will carry on doing whatever they do irrespective of the relative extent to which they are studied by these two or any other approaches.

However, even granted the truth of this assertion – an assertion which arguably belongs more to the realm of metaphysics than to that of science – it is certainly the case that what you or I think of as a grey squirrel is not just affected but determined by a blend of who each of us is and how squirrels have been studied and reported. After all, in the UK are grey squirrels vermin that should be exterminated, a valuable source of food and pelts or a much loved animal and one of the few British wild mammals people actually see in the countryside?

Retreating now to the more easily accepted notion that while there may be a diversity of representations, that which they represent is a part of a single, objective reality, it remains the case that, as I have argued, there are a tremendous number of valid sciences. It is because of this that I have argued for some time that it can be useful, at least on occasions, to avoid the word 'science' and instead talk about 'ethnosciences' (Reiss, 1993). It is because all science is set in a cultural milieu that we cannot validly locate a single global non-ethnoscientific science.

This is *not* to maintain that all methodologies and findings, conducted in the name of science, are of equal validity. I suspect it is because talk of ethnosciences implies this to some people that multicultural science is ridiculed or ignored by some. However, just as there is good historical research and bad historical research and just as we are more confident of some economic conclusions than of others so some scientific research is better than others and some scientific conclusions are more valid than others.

The strengths and limitations of science

Science has already been tremendously successful. One of its powerful successes is in the way in which many people have taken on board its big ideas, its metanarratives. Most people, in Europe, for example, accept that we live in a universe that is billions of years old, that the laws of nature are the same everywhere and at all times, that all matter is composed of only a hundred or so elements, and that humans have the other animals as their evolutionary relatives. Such knowledge, most of it unimaginable only a few centuries ago, is of huge cultural importance, undermining, though sadly not as much as would be healthy, our anthropocentrism.

From a utilitarian point of view too, science has been of inestimable value. Working alongside technology, it has helped give many of us a regular food supply, clean drinking water, vaccines, medicines, long-distance transport, new communication systems and many other benefits.

And yet, the limitations of science are only irregularly appreciated. In the nineteenth century William Whewell, who coined the word 'scientist', believed so strongly in the provisional nature of scientific truth that he argued that not until a century had passed could we be sure that scientific theories were true. Indeed, as every scientist knows, scientific truth, for all that it may be reliable for most purposes, by its very nature is provisional, which is another way of saying 'temporary'. Newtonian thinking may have ruled for three hundred years but even it eventually bowed to Einstein's views. What, though, is less often appreciated is the way in which the sciences represent reality by means of conceptual models. In one of Lewis Carroll's *Alice* books one of the characters talks about what would happen if a map was produced to the same scale and in as much detail as the ground. Would it still be a map? The same point holds about scientific models. They are abstractions of reality. The best ones are especially parsimonious – which is why some physicists still hanker after GUT – the 'Grand Unified Theory', that mythical pearl of great price.

Nor should it be supposed that today's scientific consensus is somehow immune from disruption. To give some examples from physics – because non-scientists sometimes suppose that physics is a more certain science than, for example, biology:

- there is a controversy in aerodynamics as to whether the Bernoulli principle has any validity whatsoever;
- it is unclear how most of the heaviest elements, such as gold and platinum, arose;
- we still have little idea why the universe contains more matter than antimatter;
- it is very unsure whether the standard model of particle physics is correct.

Now, these scientific uncertainties may not cause many of us to lay awake at night. So consider the 2001 foot-and-mouth epidemic in the UK as this illustrates well both the strengths and the limitations of science. Perhaps the core strength of science in this instance was the way in which population biology was utilised directly to bring the disease under control in time for a general election. A disease as it spreads can only be brought under control if something is done to ensure that, on average, each case of the disease leads to fewer than one new case. It was this mathematical truth, combined with a lot of empirical data about infectivity rates, that led to the slaughter policy, in particular to the killing of animals within a certain distance of infection sites whether or not these animals showed any signs of infection.

And yet the UK foot-and-mouth epidemic illustrates the limitations of science in two quite different ways. First of all, almost all the parameters that led to the specifics of the slaughter policy had a degree of uncertainty about them. In a very real sense, this was nobody's fault. No outbreak of a disease is exactly the same. In the case of foot-and-mouth, different strains have different characteristics and the various host species are affected differently. Science when it is used for applied ends almost inevitably oversimplifies complex matters.

But more fundamentally, the slaughter policy was exactly that – a policy, a set of political decisions. Science can play a part in the formulation of policy but so too do other domains of knowledge. The specifics of a slaughter programme depend on its precise aims. If the aim is to minimise the economic damage to UK agriculture, one set of recommendations follows. If the aim is to minimise the wider UK economic damage, another set of recommendations follows. If the aim is to minimise animal suffering and loss of life, then another set of recommendations follows – one that entails the widespread use of vaccination.

Which of these aims is to be held is not a scientific decision. It is a decision about values. The same points about scientific uncertainty and the other limitations of science held about such foot-and-mouth questions as how to dispose of the slaughtered animals and when to lift restrictions on the movements of people and livestock. This leads me onto an argument about the demarcation of school science.

The demarcation of school science

When young people are asked about what sort of science they would like to be taught in schools, they generally talk about 'relevance' (Osborne and Collins, 2000; Reiss, 2000; Levinson and Turner, 2001). The notion of relevance in a school subject can be clarified and deconstructed but essentially it is about the making of meaningful connections between that subject and the world of the person concerned.

None of us can make sense of all the aspects of the world. As we grow up we attend selectively to aspects of our environment and we develop preferred ways of learning and preferred categories of knowledge. Balint drew a distinction between oncophils and philobats. To use psychoanalytical language, oncophils over-cathect their object relationships while philobats over-cathect their own ego functions. This difference can most easily be seen in the behaviour of young children. The oncophil finds safety in objects including other people. At times of stress the intervening periods or spaces between objects are felt as dangerous. The philobat experiences objects as unreliable and hazardous, (S)he is inclined to dispense with them and seek out what are perceived as the safer expanses separating objects in time and space (Balint, 1968/89).

The reason I mention this is that somewhat similarly I suspect that certain people are intellectually attracted to those school subjects that require empathy with people or other organisms, while others are attracted to subjects that inhabit the periods or spaces between living objects. Science is distinctive in that parts of it can give solace to both personality types, one reason, perhaps, why, in my experience, few children or even adults like all of science equally. Most, rather, gravitate either towards the biological or the physical sciences. This means that we should hesitate before giving too strong a human face to all of school science in an attempt to make it more 'relevant'. If we do, we may end up with even fewer students wanting to study physics and chemistry. 'Relevance' needs to be construed from a multiplicity of individual viewpoints rather than absolutised in an essentialist manner.

With that caveat in mind, I would argue that much of school science, especially at secondary level, and not just in the UK but world-wide, is still too narrow in terms of what is covered in science lessons. Encouragingly, the recent history of many school science curricula has been a widening in their content and aims in a number of ways. For a start, more applied science is now taught in schools and the whole science-and-technology-in-society movement has had a considerable impact on school science syllabuses. Science is now more likely to be acknowledged, and, in part, taught, as being embedded in contexts while more nuanced analyses of the relationships between science and technology are now available than was once the case.

In some countries the history of science too makes more of an appearance, limited though this still is, than previously. More generally, while the science curricula of few countries contain any detailed analysis of the place of science, a number of curricula address, at least in part, the question of its nature while Gaell Hildebrand (2001) has argued in favour of what she terms 'critical activism'. She urges that there should be both participation in science (doing science) and participation in debates about science (challenging science).

Associated with the notion of debates about science, an increasing number of people have argued that ethics, too, needs to be added to science and science education and that pupils need to be helped to argue validly in science.

Elsewhere I have argued that science education should aim for social justice (Reiss, in press).

In conclusion, my hope is that we will develop a range of science curricula and teaching programmes that lead to people, including those who go on to study science in one of its manifestations once they have left school, having a better understanding of science. I believe that such science teaching will be more valid and more satisfying for pupils and teachers alike.

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