What Sort of World do Children Live in Nowadays? Understanding how Children Understand Biological Reality

MICHAEL J. REISS
Homerton College, Cambridge, UK

SUE DALE TUNNICLIFFE
Homerton College, Cambridge, UK

Correspondence to: M. J. Reiss; e-mail: mjr1000@cam.ac.uk

What Sort of World do Children Live in Nowadays? Understanding how Children Understand Biological Reality

ABSTRACT: *Most historians of science, sociologists of science, philosophers of science and science educators now accept that there is no such thing as 'the scientific method'. We explore the implications of this view of the nature of science for biology education in particular. Accepting that there is no single way of investigating and describing the world scientifically presents both challenges and opportunities, especially when teaching biology. We illustrate these opportunities by suggesting fresh approaches to the teaching of drawing in biology, the teaching of classification and the teaching of human biology.*

What Sort of World do Children Live in Nowadays? Understanding how Children Understand Biological Reality

INTRODUCTION

In this paper we begin by examining whether there exists a single science or a diversity of sciences with relatively little in common. We then go on to explore the relevance of this debate to biology education in particular.

HOW MANY SCIENCES ARE THERE?

The eighteenth to nineteenth century poet and artist William Blake was a visionary. Visionaries see the world differently to the way that most of us do. A science educator would expect to teach about the Sun in various ways according to the age of her pupils but what would most science educators make of Blake's (cited in Ackroyd, 1995, p. 301) assertion?

> ‘What it will be Questioned When the Sun rises do you not see a round Disk of fire somewhat like a Guinea O no no I see an Innumerable company of the Heavenly host crying Holy Holy Holy is the Lord God Almighty.’

Manifestly, Blake's visionary experiences, and much else of human understanding, lie outside of science but even within science, the message still presented in many school textbooks is that science provides a single way in which the world may both be investigated and understood.

The single way in which it is presumed that science allows the world to be investigated is captured in the phrase 'the scientific method'. Here the use of the definite article, 'the', and the singular word 'method' are employed as if unproblematic. This unity of approach is ably served in England and Wales by even the latest version of Sc1 (Department for Education, 1995).

Yet most historians of science, sociologists of science, philosophers of science and science educators accept that there is no such thing as 'the scientific method' (e.g. Feyerabend, 1988; Woolgar, 1988; Chalmers, 1990; Cunningham & Williams, 1993; Aikenhead, 1997). Paul Feyerabend (1988, p. 1) even goes so far as to argue that:

> ‘the events, procedures and results that constitute the sciences have no common structure’

and that (1988, p. 3):

> ‘there can be many different kinds of science. People starting from different social backgrounds will approach the world in different ways and learn different things about it.’

A possible way to illustrate the assertion 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, 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 (Rackham, 1976). 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 the 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, philosophers 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 it 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. We won't rely on this more radical view in the rest of our paper 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. We 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 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. Gradually 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?

MISCONCEPTIONS, ALTERNATIVE CONCEPTIONS AND THE PARTICULAR PLACE OF BIOLOGY

There has been by now a long-running debate about the extent to which when pupils' understandings of the natural world fail to agree with the scientifically accepted ones they are to be regarded as misconceptions, naive beliefs, alternative conceptions and so forth (e.g. Matthews, 1998). Our belief is that biology shows a number of features which make this debate particularly pertinent and especially difficult to answer in any simple fashion.

For a start, every organism in biology is a product of physics, a product of chemistry, a product of evolution and, for that reason, a product of history. When we ask the question 'What is a grey squirrel?' the question can be answered on more levels than when we ask 'What is a hydrogen atom?' or 'What is igneous rock?' (though even in the rock cycle, as in astronomy, we see the importance of history not just for organisms but also for other entities). A grey squirrel is a mass of cells that individually and collectively obey the laws of physics and chemistry. And a grey squirrel is the descendent of an unbroken line of ancestors that go back some three and a half thousand million years to a small, simple single-celled creature. And a grey squirrel is a member of a species that exists naturally in North America but became established in the UK as a result of repeated nineteenth century introductions. And a grey squirrel is a creature with drives and intentions, some of which may even be conscious ones, though that is uncertain. And a grey squirrel is a herbivore that eats seeds, foliage and fungi and is in turn preyed upon by foxes. stoats. some raptors and owls. And a particular grey squirrel is an individual that interacts with (is born from, competes with, co-operates with, mates with, may give birth to) other individual grey squirrels. And so on.

Then there is the fact that biologists can ask more questions that can chemists or physicists. Aristotle pointed out that four causes can be identified for most objects or events. What causes a house, for example? One answer is the matter from which it is constructed; a second is the builder; a third is the plan of the house; and a fourth is the house's purpose. Similarly (Dockery & Reiss, 1999), the Dutch ethologist Niko Tinbergen realised that when people ask why a certain behaviour occurs, they may mean one or more of four things. They may mean:

- what are the mechanisms that enable that behaviour to occur?
- how did the behaviour develop during the life of the individual showing it?
- what is the function of the behaviour?
- how did it evolve over the generations?

Consider, for example, a grey squirrel building its drey. We can ask what are the mechanisms that enable nest building to take place. (The answer will have something to do with muscles and nervous control.) Or we can ask how the behaviour develops as a squirrel grows up. (To answer this question we might try videoing a squirrel's attempts at nest-building to see whether it changes during an individual's life. We might also see whether squirrels need to see other squirrels build dreys before they can build one themselves.) Then we can ask what the function of the drey is. (Is it for warmth, for protection against predators or for some other reason?) Finally, we can ask how grey squirrels evolved the abilities to build dreys. (This will be quite difficult to answer as dreys probably don't fossilise very well. One approach would be to use the comparative method in which related extant species - there are 267 species in 49 genera in the family Sciuridae - are studied to suggest possible evolutionary pathways.)

THE RELEVANCE OF ALL THIS FOR BIOLOGY TEACHERS

OK, but is any of this relevant for biology teachers? For a start, does it mean that teachers of biology need to collapse into an extreme relativism when teaching biology accepting, as did the author(s) of Judges that 'Every man did what was right in his own eyes'? No. However, one of us has previously argued at some length that the view that there is no single, true science may mean that a helpful way forward is to view all of science as a collection of ethnosciences (Reiss, 1993). Each ethnoscience, including contemporary Western science, is inevitably and intrinsically a particular culturally-specific way of looking at the world.

This is not the place for an extended treatment of multicultural, anti-racist and feminist science (see Peacock, 1991; Reiss, 1993; Thorp, Deshpande & Edwards, 1994; Cobern, 1996; Guzzetti, & Williams, 1996; Murphy & Gipps, 1996; Siraj-Blatchford, 1996; Reiss, 1998; Rodriguez, 1998). Rather we conclude by examining three case instances deliberately chosen to be somewhat different from the usual examples (such as teaching about food) given when pluralist biology education is proposed.

Drawing in biology

Drawing is an activity which comes as naturally to children as do play and speech. Good schools foster children's artistic abilities enabling them to enlarge their repertoire of techniques, increase representational precision, explore degrees of abstraction and so on. For some reason, though, biological drawing seems to have taken on a life of its own, and that a life constrained within artificial, precise and unnecessary limits. In secondary school biology lessons, pupils are generally told 'how to draw'. In particular, colouring and shading are to avoided at all costs. Why? These rules appear the more bizarre the more one dwells on them. Fortunately they are completely ignored by professional biology illustrators. Indeed, one excellent guide to biological illustration - published in the UK by the Field Studies Council, hardly the most heretical of all biological institutions - begins with a lovely quote from Ruskin's 1857 The Elements of Drawing (cited in Dalby & Dalby, 1980 p. 307):

> ‘only remember this, that there is no general way of doing any thing; no recipe can be given you for so much as the drawing of a cluster of grass.’

Teaching biological classification

The need to classify that which one sees in front of one seems to be a fundamental human need - one that presumably evolved because of its adaptive significance. For example, the ability to classify foods as 'edible' or 'poisonous' and other individuals as 'kin' and 'non-kin' would have had obvious advantages and, indeed, is not restricted to humans. Research we have carried out suggests that as pupils age, they pass through a number of levels with regard to the reasons they use for grouping animals (Tunnicliffe & Reiss, 1999). Children move from regarding each animal in isolation through recognising shared anatomical features to recognising attributes connected with behaviours and habitats. Older pupils also recognise the embedded knowledge of hierarchical taxonomies - e.g. they know at least some of the reasons why an animal is a bird.

Unfortunately, biological classification in secondary schools, as currently taught, is preoccupied with classification into the accepted phylogenetic classification system. We are not against the phylogenetic approach but believe that, on its own, it is insufficient. Three are three main problems with simply teaching the accepted phylogenetic classification system as 'the truth'. One is that such a classification system is meant to reflect evolutionary relationships. For a significant minority of pupils, this presumption conflicts with important cultural beliefs held by them and/or their parents. Both of us are firm believers in evolution and in the theory of natural selection.

Yet, we acknowledge that to some religious believers, though by no means all, an acceptance of evolution is seen as incompatible with religious belief (cf. Jackson, Doster, Meadows & Wood, 1995). Teachers should be wary of trampling, even implicitly, on the cultural values of families.

A second problem is that any classification system, even if intended to reflect evolutionary origins, is very uncertain. Many readers of this article will remember from their own schooling the simple division of organisms into animals (including one-celled protozoa), plants (including algae and possibly fungi) and bacteria - those were the days. By now, the prevalent near world-wide shibboleth is to maintain that there are five kingdoms. Indeed, because the current version of the Institute of Biology's Biological Nomenclature booklet (Institute of Biology, 1997) recommends that the five kingdom classification of Margulis and Schwartz be recognised at secondary level, this is the system which has now been adopted by all publishers and examination boards in the UK. (As an aside, the Institute of Biology booklet also outlaws the use of the term' invertebrate' as a taxonomic term in secondary education and the use of such adjectives as 'simple' and 'complex' when describing organisms - the latter perhaps from a point of political correctness which considers bacteria and amoebae to stand on an evolutionary platform alongside elephants and Einstein.)

Interestingly, for over a decade the consensus among professional taxonomists has been that "the five kingdom classification system is archaic and inaccurate" (McInerney, pers. comm.), largely because there is more variability within one of these five kingdoms, the Prokaryotae, than between the other four put together. The current dominant theory is probably the three domain theory, as first proposed by Carol Woese in the 1970s (Woese, 1987).

Our point is not that 11-16 year-olds should now be taught Woese's three domain theory as fact but rather that they should learn about the various ways in which biologists have tried to classify organisms and about the advantages and disadvantages of various approaches. We may never know for sure the 'right' way to classify organisms within an evolutionary framework.

A third problem with the way biological classification is taught in secondary schools is that all too often it fails to accept that so-called 'artificial' (i.e. non-evolutionary) classification systems can be just as valid as 'the' evolutionary one. Just as there are merits into classifying organisms on the grounds of their feeding habits (herbivores, carnivores, saprotrophs, etc.) or their habitats (woodland organisms, stream organisms, etc.) so there are merits into classifying organisms as edible (as opposed to poisonous), common (as opposed to rare / requiring conservation), legal to kill (as opposed to protected) and so on. What 16 year-olds would benefit from is realising that there are a whole host of valid ways in which organisms can be classified, each way being valid for a particular context. Depending on whom I am talking with I might describe a tiger as Panthera tigris (with eight subspecies), a mammal, a carnivore, an endangered species, as furry, as beautiful, as dangerous, as the subject of one of Blake's most famous poems, etc..

Teaching human biology

One of the unfortunate things about recent reforms to school biology curricula in England and Wales has been the increasing extent to which organisms other than humans are marginalised.

However, what is just as sad is that what is generally taught about human biology in school biology lessons is actually a generalised mammalian anatomy and physiology. In itself there is nothing wrong with pupils knowing how mammals digest, breathe, hear, excrete and so on. But these are not the things that make us truly human. To be human is to possess the most remarkable product of evolution in the world: the human brain with its capacity to enable us to think, reflect, talk, create and appreciate beauty, display both virtue and vice and so on.

Now, we don't expect 11-16 year-olds to be subjected in biology lessons to full-blown courses on linguistics, neurobiology, epistemology, aesthetics or moral philosophy. But we do think that school biology courses for this age range would be a sight more interesting and relevant if within them they found time to tackle such issues as:

- What do we mean by intelligence? Is there only one sort of intelligence or are there multiple intelligences?
- Are differences between males and females innate or cultural?
- To what extent is human behaviour the result of selfish genes? Can we be truly altruistic?
- Is life-long marriage natural? Are there right ways to behave sexually?
- Is there a biological basis to aggression? Can biology tell us anything about warfare?

CONCLUSION

In conclusion, our hope is that a more nuanced appreciation of the nature of science will allow richer and more valid ways for biology teachers to teach and for pupils to learn.

REFERENCES

Ackroyd, P. (1995). *Blake*. London: Quality Paperback Direct.

Aikenhead, G. S. (1997). 'Toward a First Nations cross-cultural science and technology curriculum'. *Science Education*, 81, 217-238.

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

Cobern, W. W. (1996). 'Constructivism and non-western science education research'. *International Journal of Science Education*, 18, 295-310.

Cunningham, A., & Williams, P. (1993). 'De-centring the 'big picture': The Origins of Modern Science and the modern origins of science'. *British Journal for the History of Science*, 26, 407-432.

Dalby, C., & Dalby, D. H. (1980). 'Biological illustration: a guide to drawing for reproduction'. *Field Studies*, 5, 307-321.

Department for Education (1995). *Science in the National Curriculum*. London: HMSO.

Dockery, M., & Reiss, M. J. (1999). *Behaviour*. Cambridge: Cambridge University Press.

Feyerabend, P. (1988/1991). *Against Method*. London: Verso.

Guzzetti, B. J., & Williams, W. O. (1996). 'Gender, text and discussion: examining intellectual safety in the science classroom'. *Journal of Research in Science Teaching,* 33, 5-20.

Institute of Biology (1997). *Biological Nomenclature; Recommendations on Terms, Units and Symbols*, 2nd edn. London: Institute of Biology.

Jackson, D. H., Doster, E. C., Meadows L., & Wood, T. (1995) ‘Hearts and minds in the science classroom: the education of a confirmed evolutionist’. *Journal of Research in Science Teaching*, 32, 585-611.
Matthews, M. R. (1998). ‘In defence of modest goals when teaching about the nature of science’. *Journal of Research in Science Teaching*, 35, 161-174.
Murphy, P. F., & Gipps, C. V. (Eds.) (1996). *Equity in the Classroom: Towards Effective Pedagogy for Girls and Boys*. London: Falmer Press and Paris: UNESCO.
Peacock, A. (Ed.) (1991). *Science in Primary Schools: The Multicultural Dimension*. Basingstoke: Macmillan Education.
Rackham, O. (1976). *Trees and Woodland in the British Landscape*. London: J. M. Dent.
Reiss, M. J. (1993). *Science Education for a Pluralist Society*. Buckingham: Open University Press.
Reiss, M. J. (1998). ‘Science for all’. In M. Ratcliffe (Ed). *ASE Guide to Secondary Science Education*. Hatfield, Herts: Association for Science Education.
Rodriguez, A. J. (1998). ‘What is (should be) the researcher's role in terms of agency? A question for the 21st century’. *Journal of Research in Science Teaching*, 35, 963-965.
Siraj-Blatchford, J. (1996). *Learning Technology, Science and Social Justice: An Integrated Approach for 3-13 Year Olds*. Nottingham: Education Now.
Thorp, S., Deshpande, P., & Edwards, C. (Eds.) (1994). *Race, Equality and Science Teaching*. Hatfield, Herts: Association for Science Education.
Tunnicliffe, S. D., & Reiss, M. J. (1999). ‘Building a model of the environment: how do children see animals?’ *Journal of Biological Education*, 33, 142-148
Woese, C. R. (1987). ‘Bacterial evolution’. *Microbiological Reviews*, 51, 221-271.
Woolgar, S. (1988). *Science: The Very Idea*. Chichester: Ellis Horwood.

Michael J. Reiss and Sue Dale Tunnicliffe
Homerton College, Cambridge CB2 2PH, UK

Tel: 01223 507111
Fax: 01223 507120
E-mail: sue_dale_tunnicliffe@compuserve.com & mjr1000@cam.ac.uk

Author for correspondence: Michael J. Reiss

Running title: Understanding how children ur

Key words: biology education, plants, mental models, classification, informal learning
nature of science, post-modernism, drawing, classification, human biologybstract

We appreciate that the argument we advance is controversial but hope to stimulate debate which will lead to richer approaches to the teaching of biology at school and undergraduate level and by the science curricula of other countries. Depending on whom we am talking with we do not want pupils to leave school thinking that science is unreliable but nor do we want them to leave school thinking that it is a certain way to truth. Perhaps the strongest argument for why science should be taught to all pupils in school, whether or not they will go on to use science in their careers, is that an understanding of what science is and the ways in which it operates is of value to all of us as citizens and consumers. A good science education should help people appreciate the certainties and the uncertainties about such issues as climate change, food safety, human health and so on. Biology has a central part to play in such a science education.