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Reflecting the Nature of Science in Science Education

Keith S. Taber

Why teach science?

Science is now an accepted, indeed often a core, part of the school curriculum around the world. However, no matter how much time is put aside for teaching science, there always has to be a severe selection of material as there is much more potential science content than could realistically be fitted within a pupil's school career. In selecting curriculum, we should always keep in minds our purposes for teaching science. There are a number of good reasons that might be suggested for teaching science. In particular it is worth considering the following arguments:

• It is important to teach science because of the need for future scientists, engineers, technologists, and others who will need a strong science background for their work.

• It is important to teach science as it is an important aspect of modern culture and everyone should appreciate this aspect of culture.

• It is important to teach science because a knowledge of science is needed for citizenship in modern technological societies.

The first argument has two aspects. Societies need a supply of suitably qualified people to work as scientists, doctors, engineers and so forth, and that requires sufficient pupils completing school who are qualified and motivated to enter science and related areas in further and higher education. The other aspect of this is that many young children do aspire to be scientists, or to work in areas applying science such as medicine and engineering. Perhaps not all have the potential to reach their aspirations, but schools should give pupils suitable opportunities (through suitable science and mathematics teaching, for example) such that those with the desire and aptitude are able to progress to scientific careers.

The second argument is related to the importance of a liberal education. School should introduce young people to all of the important elements of their culture, so they are in a position to engage with that culture through their lives. This would include such areas as music and fine art (which in some educational contexts might include both indigenous traditions as well as those of more Western ‘classical’ traditions), but would also include such areas as politics and science. The idea here is that schooling should enable anyone to feel enabled to visit an art gallery, or attend a concert, or to visit a natural history museum or read an article in a popular science magazine, and to have sufficient background to appreciate and not feel alienated by that aspect of culture. It could be suggested that a ‘liberal’ education enables a person to feel they can join in with an intelligent conversation about different aspects of a society’s culture. In modern societies, that would include aspects related to science and technology.

The final argument to be considered here goes beyond feeling able to join in a conversation about science, but rather is based on the assumption that to function effectively in a modern democratic industrially advanced society - or indeed in a society aspiring to be democratic and/or technologically advanced - the citizen needs to have a basic understanding of science. The citizen who is advised by a doctor about treatment options for themselves or a sick relative can only make an informed decision if they understand some basic science. The citizen who wishes to live their life in an environmentally responsible way (without producing undue waste and pollution) needs a basic understanding of some science so they can make choices about their purchases and sensible recycling behaviour. The citizen asked to vote in an election where different options are presented as best meeting future power supply needs (e.g. should the country invest in new nuclear power stations?) can only make an informed choice when they understand some basic science.

These different purposes are not necessarily contrary to each other, but they do bring different emphases. Ideally a good science education is meeting all of these needs by providing a curriculum which allows some students to qualify for higher level study, and leads all students to know enough basic science to make informed choices, and to feel comfortable with engaging with science-based issues when they arise.

Balancing science process and science product in the curriculum

Given that the development of a science curriculum necessarily involves a selection of content from the vast amount of science that could be taught, it is important to make principled choices (see the chapter '*Curriculum Development in Science Education*'). Indeed, there is evidence that in some ways 'less is more'. This has been seen for example in England where a prescribed National Curriculum set out a large number of topics from across the sciences that all students should study during their schooling. This was seen to ensure that everyone knew something about what were considered important topics in biology, chemistry, physics, and earth and space sciences. Yet with so many topics to 'cover' teachers had limited time to delve into topics in any depth. Often students who found science difficult tended to feel they were always moving onto new material before they had really got to come to terms with the previous topic. Those students who performed at high levels, the 'gifted' learners, tended to feel that science was a subject where they were constantly being given more material to learn - but with limited opportunity for the kind of in-depth treatments needed to challenge them. Unfortunately the curriculum tended to deter a lot of pupils from wanting to study science further once they reached the end of compulsory schooling. Of course that did not apply to all students: but many of those potentially suitable for scientific careers thought other academic areas offered more opportunity for deep engagement, and many of the rest left school bewildered by science rather than enchanted with it. So a very dense curriculum seems to generally fail in meeting the key purposes for science education discussed above.

The other aspect of this particular curriculum that did not meet its designers' intentions concerned the extent to which it enabled learners to develop a feel for the nature of science. That is, a good science curriculum needs to not only teach *some* science, but also teach *about* science. There needs to be a balance between teaching some of the products or outcomes of science (such as the periodic table; the theory of natural selection; the ideal gas law) and teaching about the processes of science - how science goes about producing new knowledge.

This is important in terms of our reasons for teaching science. A young person who aspires to be a scientist or work in a related field (as a doctor, or an engineer) certainly needs to know some science. Universities and other advanced educational institutes will expect to select students who already have a good background in key basic science, and who have demonstrated they are able to learn and apply scientific ideas. The more science students know at the end of school, the easier it is for those teaching on advanced courses. However, as long as students are carefully selected for the subject they go on to study, it is not actually difficult for the university to teach material not covered in school. A good understanding of fundamental ideas that demonstrates strong interest and aptitude is more useful than a broad, but shallow, knowledge across a wide range of topics.

However, as well as some background knowledge, the future scientist should have a good feel for the nature of the work they will do if they qualify in and enter a scientific field. That is school science should give them a feel for what it is to be a scientist and do science. This consideration also applies in terms of a liberal education. Scientific knowledge moves on very quickly. Some of the science a person learns in school will be discredited or substantially modified during their adult life. During that life, quite a lot of the science learnt in school will be of limited importance to new developments, and whole new areas of science with major applications will open up that were never mentioned in school as they were unanticipated. What will not substantially change is the nature of science as a cultural activity which produces, evaluates, develops and sometimes demotes, scientific knowledge.

This argument becomes even more important in terms of the third purpose of science education discussed above - to prepare young people for citizenship. Inevitably most of the 'products' of science in the school curriculum tend to be pretty secure knowledge claims that are no longer the subject of active disagreement. Yet the science that people are asked to take a view on in the political or civic realm tends to be in areas where there remains controversy. One example, nuclear power, has already been mentioned. Other areas include such important themes as global warming, deforestation, and biodiversity, where even when there is a clear majority of scientists arguing that science suggests urgent and new policies are needed: some other scientists will appear in the media denying that this is the case. If school science is presented as a 'rhetoric of conclusions' (Schwab, 1962) - as a series of accounts of consensual, settled science - then students are not prepared to understand how they should respond to bitter arguments between different scientists who are each claiming the scientific evidence supports their view. Yet, actually, that kind of argumentation is typical of the scientific process - which is quite unlike the straightforward accretion of successive models, theories, laws, etc., that science education can easily portray with the benefit of decades or even centuries of hindsight. In science, the account presented in school can reflect the 'winners' of various scientific debates rather than the argumentation that was at the heart of the scientific process itself.

The argument here is not that school science education should be about the processes of science *instead of* the content - even if that were possible (as some contexts are needed to effectively teach about the processes). The argument is that teaching about the nature of science is essential to a science education that wishes to prepare future scientists, cultured members of society, and informed citizens, and that accordingly great care is needed to balance the teaching about science itself as a cultural and intellectual activity, and teaching about some of the important, fascinating, and highly applicable, scientific knowledge that this cultural activity we call science has produced.

The nature of 'the Nature of Science'

Having established that there are good reasons to teach students about the nature of science as a key part of school science, it is important to acknowledge a number of potential problems. These issues may explain why despite many high profile calls for the importance of teaching about the nature of science (Clough & Olson, 2008; Duschl, 2000; e.g., Matthews, 1994), the nature of science is still not well reflected in the school curriculum in countries. These issues are:

- science is a broad area of activity, so it is not always very obvious what is common to all areas of science;
- there is not always strong consensus on how to best understand, and so represent in teaching, the nature of science;
- scholarship about the nature of science from areas such as philosophy, history, psychology and sociology can be quite technical and specialised, and is often too sophisticated for most school learners;
- there is less expertise amongst science teachers, curriculum developers and textbook and other resource authors, regarding the nature of science compared with the level of expertise in areas of science themselves.

The last point is something that can be overcome in time, if teaching about the nature of science within the school curriculum is recognised as a priority (as argued here). The other points are important, but need not be major impediments. Indeed the diversity of science may be seen as a positive feature in a sense, as it implies that teaching about the nature of science should focus on features that are common across the wide range of sciences.

The lack of consensus on some aspects of the nature of science (for example, exactly how to distinguish scientific fields from activities we would not consider science) is important, but actually there seems to be a widespread agreement on those key features of science that need to be represented in school science (as discussed below). The issue of the sophistication of the level of professional scholarship in areas related to the nature of science does present a challenge, but in principle this is no different than when teaching about scientific content itself. School science includes many content areas where scientific thinking is nuanced and where the detailed scientific theory or model is too sophisticated for school age students.

In developing curriculum, complex and abstract scientific ideas are represented in curricular models that offer learners the essence of those ideas at a suitable level of complexity to be grasped as meaningful. Topics such as the theory of natural selection, the nature of chemical bonding in metals, or the formation of heavier elements in stellar nucleosynthesis - to offer just a few examples - are not suitable for teaching in school at the level of current scientific knowledge, but can be taught through appropriate simplifications that are accessible to learners whilst offering an authentic basis for later progression in understanding. Finding the optimal level of simplification (Taber, 2000) for presenting such topics is a key task for science education, and this is true of representing aspects of the nature of science as well as aspects of science content knowledge (Taber, 2008).

Key aspects of the Nature of Science

There is a vast literature on the nature of science or what is sometimes called 'science studies'. The aim in school science is to get across a flavour of some key features of our understanding of the nature of science. This brief introductory account is intended simply to alert readers to some important topics and ideas. There are many good sources for learning more (see the list at the end of the chapter for some examples), and other chapters in this section fill our much more detail on some of these themes. The focus here will be on:

- The nature of scientific knowledge
- The nature of scientific method
- The limits of science

- The cultural embeddedness of science
- Logic and creativity in science
- The human aspect of science
- The institutional aspect of science
- The rhetorical nature of science

These are presented below as short vignettes on distinct themes, but the astute reader will notice many areas of overlap and connection. As a teacher, it is important to remember that in teaching about these areas the aim is to introduce students to perspectives, rather than to seek to teach models and theories from science studies as if they are facts. In effect, the teacher should try to adopt a social sciences or humanities pedagogy where the am is to help students understand the different perspectives, rather than to accept them as 'true' accounts.

The nature of scientific knowledge

If this approach to teaching seems outside the normal way of working for science teachers, then it may be useful to bear in mind that an appreciation of the nature of science suggests that a common problem with school science teaching is that it often presents science content as true accounts of nature, so that students see science as about facts (see the chapter on '*Beliefs and Science Education*'). Yet primarily science is not factual in nature, but theoretical. The essence of science is developing explanatory schemes that make sense of extensive volumes of data and that have predictive value. Scientists often talk as if they are describing how nature is, but they are actually presenting theories and models and other kinds of constructs that derive from the human imagination. Scientists invent categories such as acids and stars which helpfully put order into how we can think about a very complex universe. But often these categories only approximately work. Think about a category such as homo sapiens. A little thought suggests that although we have little difficulty telling humans from non-humans today, it is not always so clear cut whether hominid fossil remains belonged to individuals we would consider part of our own species. Chemists have changed their minds over time in how best to characterise acids and oxidising agents. Physicists have changed their minds about the nature of time and space and for many purposes use Newtonian models they now believe to be flawed (but still very useful) representations of reality.

Scientists refer to laws as if they are universally applicable descriptions of aspects of nature - but usually on the basis of data collection that is limited. (The evidence that 'universal gravitation' applies across the universe is necessarily indirect given how little of the universe we have been able to visit.) Students often think that theories are scientists' guesses or hunches that they are waiting to prove by experiments. Yet actually theories are the very basis of scientific knowledge. They are far more than guesses, as they must be based on extensive evidence, but they are always open to being surpassed when new data or a new interpretation of existing data comes along. All scientific knowledge is technically provisional - that is, in principle open to re-examination in the light of new information. This leads to one of the major challenges in teaching about the nature of science - how science offers knowledge that is generally robust and reliable, yet always somewhat tentative in nature.

The nature of scientific method

A simplistic account of science has scientists testing their ideas by doing experiments that will prove or falsify their ideas. An experiment ideally explores a phenomenon under laboratory conditions, where variables of interest can be manipulated and measured and the potential effects of confounding variables controlled by keeping values constant. This is a problematic simplification in at least two regards. For one thing, not all scientists do experiments as such. In some branches of science it may be impractical or unethical to undertake experiments. It is not possible to manipulate the conditions at the centre of stars, or compare how life develops on a planet under different starting conditions. It is not generally considered acceptable to subject people to potentially dangerous conditions to see how their physiology reacts (although such research has been undertaken in the past).

So often scientists working in some scientific disciplines use observational approaches, looking for 'natural experiments' where features of interest naturally vary and allow conditions to be compared. Scientists also use simulations and models to test their ideas, being aware that the results are only as good as the (inherently uncertain and limited) simulation or model. One well known philosopher of science, Paul Feyerabend (1975/1988) argued that there is no such thing as the scientific method, but rather than scientists have to develop their own customised methods that will work in their own areas of research.

Even where genuine experiments are possible, the simple logic of 'proving' or refuting a hypothesis is over-simplistic. An experimental prediction may be correct for a reason other than the verisimilitude (closeness to the truth) of the hypothesis that led to its prediction. It is always possible to produce alternative theories to explain any set of data (even if sometimes the alternatives seem cumbersome and forced). Any experimental data set intended to test some general hypothesis is necessary sampling a very small proportion of the population of possibly relevant events. (Consider how you would test for certain that adding salt to water *always* lowered its melting temperature; or that the human heart *always* has four chambers; or that the electron *always* has a charge of 1.6×10^{-19}C.)

The difficulty of proving general statements from a limited sample of instances (known as 'the problem of induction') led the famous philosopher of science Karl Popper to recommend that scientists focus more on refutations which at least seemed to rule out hypotheses where experiments did not agree with theoretical predictions (Popper, 1989). However, this is just as problematic. Experiments can go wrong for all kinds of reasons - impure chemicals, laboratory (e.g. technician) error, instrument error, faulty power supplies, unexpected and unnoticed temperature fluctuations, and so forth. Moreover, most modern science uses complex apparatus of measurement and analysis that relies on its own theory of instrumentation. A hypothesis that is correct may seem to need to be rejected if the theory behind the instrumentation is flawed - so scientists need to be wary of too easily rejecting ideas as well as being careful about when considering them supported. Science is a more complex business that many school practical activities would suggest!

The limits of science

One key question in the philosophy of science is the demarcation of science: how we can distinguish what is and is not science. It is fairly straightforward to list some good candidates: physics, chemistry, biology, astronomy, geology, etc. It may be less obvious if we should include psychology (certainly some parts, but all?). For example there has been discussion over whether Freud's theory and practice of psychoanalysis should count as scientific. Claims that aspects of the social sciences are genuinely scientific also lead to debate. Marx suggested he had a scientific take on history (but many commentators would not consider his research programme as scientific), and there have schools of sociology set up to adopt a model based upon natural science. Given that natural sciences do not seem to have a common characteristic method (see above), it does not seem reasonable to exclude other scholarly areas on grounds of methodology. By its nature, history does not involve the setting up of controlled experiments - but it does present theories which can be tested against new data and cases. That is not so different from some work in astronomy.

One philosopher of science, Imre Lakatos (1970), has suggested that the criterion for scientific work is the existence of what are referred to as 'progressive' research programmes - where there is a programme of activity informed by a set of pre-established tenets (core commitments) and where the interplay between the development of theory and collection of new data continues to be productive. Although applying this criterion requires judgement and is not straightforward, this does offer an inclusive approach that allows areas of work which admit diverse methodologies, such as science education (Taber, 2014), to be considered scientific.

One contentious question is whether aspects of indigenous cultures should be included as scientific. Such cultures often have long-standing traditions of using traditional ecological knowledge to harvest nature in sustainable ways: yet unlike in Western science, such knowledge is not separated out from other aspects of culture. So often this knowledge is learnt through legitimate peripheral participation in cultural activities (such as farming), as knowledge in action, and is commonly integrated with strong spiritual values reflecting the assumption that people, the rest of the biota, and the land (and seas and rivers) are spiritually connected as part of an interdependent creation. The atheoretical nature of this traditional technological knowledge, often learnt through practice and through the use of narrative and ritual, makes it quite distinct from how scientific knowledge is understood in formal scientific traditions. (This issue is explored further in the chapter '*Science Education and Indigenous Learners*').

Another related issue, is the limits of science itself. Some scientists seem to feel that science can (and perhaps will) ultimately explain everything, whilst other scientists see science as an important way of knowing, but one that has a limited range of application (so that there are some aspects of human experience that will always be beyond scientific explanation). There is *a sense* in which anything in the natural world *could* be reduced to a description in terms of particles, forces, energy etc. So - in principle at least - it may be possible one day to explain why a person falls in love with one suitor and not another in terms of physics: however, even if such an account was feasible, it would not be presented in terms that would seem to relate to the human experience of love.

This links to an important issue in the philosophy of science - how sciences 'reduce' to each other. Even in chemistry, a discipline closely linked to physics, there are concepts which *could* (in principle) be redescribed in purely (but in some cases necessarily convoluted) physical terms but which reflect emergent phenomena at the 'level' of chemistry and which are useful as chemical concepts in their own right (acidity, oxidation, resonance, hydrogen bonding, electrophile, halogen, indicator, nucleophilic substitution, covalent bond, etc., etc). A reductionist perspective has historically proved very valuable in science. Yet increasingly scientists are recognising that complex systems often need to be studied at different levels, and that important new phenomena can arise when systems become complex. A particularly important example might be life itself emerging from the evolution of increasingly complex physico-chemical systems and providing the phenomena studied in biology.

Science teachers should be careful not to imply in their teaching that science (the best means we have of developing knowledge of the natural world) is able to tell us everything about everything. There may well be areas that will always be outside the effective remit of science, and features of human cognition may limit how well we can understand even the natural world.

The cultural embeddedness of science

An important debate about the nature of science is the extent to which scientific discoveries are dependent on the cultures that produce them. Ideally science is independent of culture, as it is intended to be an objective quest for discovering true knowledge of the natural world. However, we have seen above that scientific knowledge is theoretical, and so based on constructs humans have developed to best describe and explain observations and measurements of nature. As there is no foolproof method of developing scientific knowledge that is absolutely certain (again, see above) all scientific knowledge is limited by human understanding and the available data.

Scientists are people who use their imaginations to develop ideas that might represent aspects of nature - ideas that they then test as best they can. Inevitably scientists' thinking is influenced by the widespread ideas in the society where they they live. So, for example, scientists often develop metaphors and analogies as a basis for scientific conjectures - but they are limited to drawing upon sources they are already familiar with Thomas Kuhn, a physicist who moved into historical studies of science, argued that once a particular way of thinking about the world became familiar, and its affordances had been worked out in detail by scientists, it became much harder to see how some alternative scheme might be at least as useful - even if it dealt better with known flaws in existing theories (Kuhn, 1970). Kuhn suggested that different theoretical frameworks, with their different ways of seeing the world, were incommensurable (could not be measured against each other). He meant it was difficult to evaluate different frameworks objectively, as the evaluator would always be working from within their own existing worldview. Kuhn thought that science could make progress towards knowledge that better represented the true nature of things: but that this process was difficult because scientists can never completely step outside of the assumptions inherent in their habitual ways of making sense of the world.

Logic and creativity in science

Science is often associated with logical thinking, and this is indeed an important feature of science (see the chapter on '*Scientific Reasoning*'). Logic is needed to work out predictions consistent with particular hypotheses or models, and logic is needed to interpret data in terms of different principles, laws and theories, and to construct arguments to persuade other scientists of the validity of conclusions.

Yet science relies on creative thought as well as logic. Logic is needed when testing out ideas, but first scientists have to come up with the ideas to test. It is naive to think that scientists can move directly from data to scientific knowledge, as data always have to be interpreted in terms of some conceptual scheme. That scheme is an imaginative construction of the human mind. Science proceeds though the complementary roles of creative (expansive, imaginative, divergent) and logical (rational, closed, linear) thought (Taber, 2011).

Often the scientists who become most well known do so not because they were more logical than other scientists, but because they were able to use their imaginations to develop possible new ways of thinking which could then be compared to data. For some scientists, such as Einstein, this imaginative process is primarily visual - they are able to imagine pictures that represent novel relationships and concepts. Visualisation is also important in running thought experiments (mental simulations) that may be useful in ruling out some options without needing to run real experiments, and which may help predict the outcomes to be expected in experiments according to particular hypotheses.

Much human knowledge is tacit in nature, and this includes much of the knowledge of professional scientists (Polanyi, 1962). Scientists develop intuition based upon their implicit knowledge (see the chapter '*Tacit Knowledge in Science Education: the role of intuition and insight in teaching and learning science'*). Imaginative processes, such as visualisation, can be very important in providing explicit awareness of a scientist's tacit knowledge (see the chapter '*Developing Visual/Spatial Thinking in Science Education*').

The human aspect of science

Science is in principle an objective activity. There is a stereotype of the scientist who has put aside personal feelings to focus on scientific work - sometimes to the neglect of such personal needs as sleep and food. Many scientists see their work as in the interest of wider humanity and/or for the joy of better understanding nature - and at times they will become engrossed to the exclusion of distractions.

Realistically, though, scientists are human with all the usual flaws. They may cling to their pet theories in the face of contrary evidence. They often seek professional advancement if not financial rewards. Some covet awards and titles and prestigious honours. Sometimes some scientists may show prejudice - towards their close colleagues, or to their co-nationals, or against those of different faith or ethnicity.

There is a major literature on issues around gender and science - both questions of whether Western formal science is inherently masculine in nature (for example in focusing on controlling nature, rather than relating to it), to the exclusion of women and the detriment of science, and whether female scientists today still regularly face sexism from individual scientists and institutions.

There are many historical cases that can illustrate these themes. An especially potent one concerns the discovery of the double helix structure of DNA. As well as relating to a iconic scientific discovery this work has been much documented. It illustrates the extent of co-operation within science (with and between institutions: Crick, Watson, Wilkins) as well as competition (again within and between institutions: Wilkins with Franklin; Crick and Watson, with Pauling). It reveal how prejudices, friendships, and chance, can play a role in science. It also reveals how science can proceed through examining mistakes (such as Linus Pauling's three strand structure for DNA) and through the interaction between creative exploration and tedious laboratory work (relating results from Franklin's meticulous preparation and analysis of X-ray photographs to Crick's theoretical work on helical diffraction and Watson's exploratory model building).

The institutional aspect of science

The same case study can illustrate some of the institutional features of modern science, where the work of individual scientists relies upon institutional support in a laboratory, and may be subject to local norms and practice - as when Rosalind Franklin (co-discoverer of the structure of DNA, see above) discovered she was not allowed to take refreshments in the same common room as her male colleagues, and was therefore excluded from the informal professional conversations that inevitably take place in such settings. That particular indignity is less likely today. However, modern scientific research laboratories are places of hierarchy, protocols and procedures, and financial restraints (Knorr Cetina, 1999; Latour & Woolgar, 1986).

From an anthropological perspective, science is a sub-culture with its own rituals and priesthood. The scientific societies, the journals, the research funding councils and the formal conferences, are essential institutions in supporting scientific debate and in ultimately recognising what counts as successful science. Science is a relatively democratic enterprise in the weight given to the peer review process (such that any one can publish in the top journals if their work is judged as original and rigorous), but inevitably as a human activity can only take place within a supporting structure of formal institutions. The stereotype of the lone scientist making great breakthroughs in their shed or basement is - with the very occasional exception like James Lovelock (who invented the electron capture detector, surveyed the levels of chlorofluorocarbons (CFCs) in the atmosphere, and proposed the Gaia theory of the biosphere) - now a historical anachronism.

The rhetorical nature of science

It follows then that success in science does not in practice mean discovering the truths of nature (as we can never be sure how well our theories give an account of nature, and how long they might go unchallenged) but rather persuading the scientific community, or that part of it working in the same field at least, that particular scientific results and ideas are important and progress the field forward. This then depends upon argument: making a case that data can be best interpreted in a certain way, and persuading those who may currently think quite differently about certain natural phenomena (see the chapter '*Epistemic practices and scientific practices in science education*'). In recent years it has been increasingly recognised that authentic science education needs to have a strong focus on engaging students in argumentation (see the chapter '*Language, Discourse, Argumentation, and Science Education*').

Given human nature, once scientists are convinced of some idea or some particular interpretation of data, they will tend to want to persuade others to their way of thinking. The scientific paper is in effect a rhetorical structure for best presenting a particular interpretation of certain data such that it seems to offer evidence for a particular model, theory, principle, or other such construct (Medawar, 1963/1990). In presenting this argument, the author(s) will select and sequence material to make a case, and will necessarily exclude much information (possibly including some collected data) that is considered less relevant to the knowledge claims being made. Even when scientists are scrupulously honest in their attempts to be objective, other scientists approaching the same evidence base from different perspectives might have made different judgements about what was relevant and should be included, and how the presented data should best be interpreted as scientific evidence. Peer reviewers generally do not have access to omitted details that authors feel should be excluded from their papers.

The scientific literature should therefore not be seen as a series of factual and objective accounts of nature, but rather as a cumulative collection of knowledge claims, each based on some limited data, interpreted through particular frameworks of understanding, and evaluated as of merit by referees chosen as suitable experts by journal editors. Scientific knowledge is therefore not only uncertain, but in areas of current research still in flux. Only in retrospect, once research activity in some programme is long exhausted, can observers start to see that area of knowledge as relatively unproblematic.

Teaching science involves helping learners to appreciate the value of the unfamiliar constructs used in science. Just as scientists orchestrate evidence and present carefully structured arguments to persuade their colleagues of claims made in scientific papers, so similar rhetorical moves are made by science teachers in reconstructing scientific concepts with their students (Lemke, 1990; Ogborn, Kress, Martins, & McGillicuddy, 1996). Science teachers can reflect the nature of science in their teaching by giving learners insight into those rhetorical processes.

Conclusion

In many countries, school science tends to focus on areas of well-established science, where scientific knowledge appears firm and not currently under debate. Such knowledge is still provisional rather than absolute (as new evidence could be uncovered and presented at any time) but can too easily be presented as factual (rather than theoretical) and obviously following from data (that is the data presented as evidence in the papers now seen, after the event, as most significant) rather than being an interpretation based on human imagination.

Many area of science that have reached such impasses can contribute to a useful science education, but if they are taught as unproblematic they are stripped of the nature of the very scientific activity which produced them. This can be avoided by careful presentation and phrasing, and the inclusion of some of the debate and uncertainty that led up to their wide acceptance as robust scientific knowledge . Science teaching that meets our key aims needs to give students an authentic feel of scientific processes, whether through historically contextualising established science; through authentic enquiry activity in the classroom; or the inclusion in the curriculum of examples of current scientific controversies where there is not yet any wide consensus, and so where competing knowledge claims, based on incommensurate interpretations of data, invite genuinely open-ended consideration. Ideally school science education will include all three of these elements to allow learners to learn *about* science itself, alongside learning some science. Science teachers need to regularly consider how they will represent the nature of science in their own science teaching - a theme developed in the next chapter (on '*History and Nature of Science in Science Education*').

Recommended Further Reading:

Brown, S., Fauvel, J., & Finnegan, R. (Eds.). (1981). Conceptions of Inquiry. London: Routledge.

Chalmers, A. F. (1982). What is this thing called science? (2nd ed.). Milton Keynes: Open University Press.

Useful classroom resources:

Allchin, D. (2013). Teaching the nature of Science: Perspectives and Resources. Saint Paul, Minnesota: SHiPS Educational Press. This book presents a strong argument for teaching case studies about the nature of science, and includes examples that can be used in the classroom.

Osborne, J., Erduran, S. & Simon, S. (2004). Ideas, evidence & argument in science: in service training pack. London: Kings College London, 2004.

Taber, K. S. (2007). Enriching School Science for the Gifted Learner. London: Gatsby Science Enhancement Programme. This book and resource pack includes activities around several nature of science themes.

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Keith S. Taber

Faculty of Education,

University of Cambridge