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Review article:

Shifting the culture of science education to teach about the nature of science

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How Science Works: Exploring effective pedagogy and practice. Rob Toplis (Editor). Abingdon, Oxon: Routledge. 2011 Hardback: ISBN 978-0-415-56279-9. £80.00

Socio-scientific issues in the classroom: teaching, learning and research. Troy D. Sadler (Editor). Springer. 2011 Hardcover: ISBN 978-94-007-1158-7. $139.00

Evolution and Religion in American Education: an Ethnography. David E. Long. Dordrecht: Springer. 2011. Hardcover: ISBN 978-94-007-1807-4. $139.00

Science teachers have traditionally called upon some historical anecdotes in their teaching, whether Newton discovering gravity by observing a falling apple; Galileo demonstrating that everything falls at the same rate by dropping balls from the leaning tower of Pisa, or Darwin overturning religious dogma after insights on the Galapagos Islands. Sadly such anecdotes are often poor history and poor science. Isaac Newton may have wondered about a falling apple, and it may have inspired his theory of universal gravitation, but gravity and the falling of apples was hardly a new discovery in the seventeenth century. If Galileo Galilei really did demonstrate his theory about falling bodies from the tower in Pisa (and it is often suspected that this was a gedanken or thought experiment) he was unlikely to find the two balls of different masses actually landed at precisely the same time – unless he 'adjusted' the synchronisation of letting go - given the differential retarding influence of the atmosphere (as the surface area of the balls would be in different ratios to their volumes). Charles Darwin's observations in the Galapagos certainly, inter alia, influenced his thinking over the subsequent years, but the reception to his book on the *Origin of Species* was quite mixed, and it certainly did not trigger an immediate wide scale crisis of faith. Many Churchmen (and of course they were all men at the time) saw Darwin's work as perfectly consistent with a form of natural theology (Grumett, 2009) that had long been influential in the English Church - where many clerics were happy to see Biblical accounts of the creation as poetic and metaphorical, and science as a way of revealing the wonder of God's creation. This rather liberal take on the interpretation of scripture as offering theological truth but not technical accuracy might surprise some of the American students discussed by Long in his monograph reviewed here. Darwin himself certainly had serious doubts about the kind of God that could have created such a wasteful and much-suffering biota, but to many who read his book he was working in the tradition of well-known religious scientists - such as Hooke, Faraday, and indeed Newton and Galileo.

Presumably generations of science teachers have seen no reason why historical authenticity should get in the way of a good anecdote, especially when it sparks interest in students. The amazing tales of the discoveries of the scientific greats, as they unpicked nature's secrets, were tools in the science teacher's pedagogic repertoire. However, in recent decades there has been considerable concern that science education does not do enough to help students understand the actual nature of science (Hodson, 2009; Matthews, 1994). One part of this agenda is certainly the issue of science for all: that is, if we ask all students to study science, then what science do all future citizens need as part of a compulsory science education? Scientific thinking skills might be a candidate for a key component of the curriculum, in which case more authentic treatments of the history of scientific ideas – how, following some initial flash of inspiration, they are developed, justified, and debated - are indicated. An ability to make sense of reports of science in the media, especially where these have strong social, political, economic and/or environmental relevance, is certainly now recognised as important (as explored in Sadler's edited volume, reviewed here). Consequently, a focus on the processes of science, or 'how science works' as it has become known in the English curriculum context (QCA, 2005), is now seen as just as important as teaching some of what science has found out. Indeed, perhaps we should avoid over simplistic references to what science has 'found out', and refer instead to what scientific activity has *produced* through building models of nature to be tested against data, and then forming arguments to persuade the scientific community that these ideas should be admitted to the citadel of current scientific theory.

After all, the notion that science unproblematically discovers 'the way the world is' is now recognised as rather simplistic. All scientific discovery is facilitated by creative imaginative acts in the minds of scientists (Taber, 2011), and ultimately we can only say that the evidence currently available supports some particular idea or other in terms of matching our observations of some feature of the world. Our scientific theories, principles and concepts are the products of human thought, and so the way we understand nature is channelled and limited by human cognition – and perhaps at least some aspects of nature would in principle be better described by accounts that were not restricted in this way. We might wonder whether some extra-terrestrial alien scientists would be able to develop insights into the nature of the world beyond human imagination, and understand phenomena that will always seem mysterious to us (such as - if some popular accounts are to be given credence - why such alien scientists seem so interested in abducting and probing citizens of the United States). Newton, Galileo and their contemporaries such as Hooke would probably reject the idea that fully understanding nature might be being beyond human intellect, as their worldview included a metaphysical commitment to a World created by a God who also created mankind to appreciate the creation. There are many scientists today that still believe this, but it can no longer be considered a shared commitment of the scientific community in general, and indeed there are those within that community working hard to argue that belief in God should actually be considered inconsistent with the scientific mindset (Cray, Dawkins, & Collins, 2006).

There is also a strong argument that a science curriculum based upon asking students to learn about a succession of examples of *products* of science (without problematising the process of production) is not ideal either for attracting creative young minds into science, nor for preparing them to contribute if they take up the invitation. Much of the attraction and excitement of scientific work relates to the state of the not-yet-knowing-but-contributing-to-the-enterprise-of-finding-out: and sometimes there has often been too little of that in school science. This was especially so in the English National Curriculum, where a content-heavy curriculum, a notion of 'investigations' as based on simple control of variables, and the distortion of linking assessed practical work to high stakes testing (Taber, 2008) contrived to give many thousands of school children the sense that investigative work comprised of testing an already well-established scientific idea (e.g., the rate of a reaction increases with concentration of a reactant, the rate of photosynthesis depends upon the level of illumination of a plant, etc) through a standard experimental protocol, and hoping to get results that all fell upon a nice straight-line. Or, even better, all but one datum fall on the line: giving one point that could be circled and labelled as an unreliable datum, to demonstrate the ability to recognise anomalous results. Perhaps many students these days are too assessment-savvy to think that real science is like that: but school science investigations commonly were. One can imagine that Darwin would soon have tired of that, and would quite likely have skipped classes to see if he could find any rare beetles for his collection.

How science works

The supposed solution to this well-recognised problem in England, was the revision of the science curriculum to emphasise something called 'How science works' (QCA, 2007) or 'HSW', which is the subject of Rob Toplis's edited volume. In his introductory chapter, Topic offers background on curriculum developments that led up to that point, and so sets up the following chapters looking at the HSW themes from differing perspectives. These chapters provide a diverse and informative set of contributions.

Sue Collins considers how students have experienced science teaching and considers the potential role for science education in helping young people form a sense of themselves and their identity. Similar arguments can be made, of course, for such subjects as history, geography and religious studies, and this could be seen to hint at one facet of how HSW has been understood and received beyond science teachers. There is a sense that some takes on the 2007 English secondary science curriculum consider it could just as well be part of a humanities or liberal studies course. That is not to disagree with Collins at all, but just to acknowledge that the enactment of the curriculum, and the perception of it formed by external observers such as some parents and the media, had given the impression that learning science content should take a back seat to classroom discussion of 'issues' to which everyone can contribute – because, after all, we all have our opinions. Yet facilitating effective discussion of socio-scientific issues is anything but an easy option for science teachers – a will be clear to anyone reading Levinson's chapter in this book, or the Sadler volume, reviewed below.

The 2007 curriculum certainly was presented very differently from earlier incarnations such that the subject content to be covered no longer dominated the documentation to such an extent that wider teaching aims seemed like afterthoughts or sops to liberal intellectuals appended to a traditional and extensive list of topics to be taught and learnt. The irony here, is that despite media reports and popular discussion of a new science curriculum only fit for the pub (i.e. suitable for light-hearted banter after a hard day at work: but not the substance of the day's serious work), teachers that I discussed the curriculum changes with reported that whilst they would ensure they were including the newly specified material, they did not feel they could drop any of the topics from their existing schemes of work. The culture of teaching that has developed in English schools seems to mean that teachers expect to be asked to do more, but do not believe they might be given latitude to do less. Criticisms of previous national curriculum documents as being over-filled with content may have led to a much sparser document - but teachers considered that this was just presentation and that really everything specified before was still required.

In his chapter, James Williams highlights the diversity of scientists' actual work, which creates a challenge for developing any curriculum model of what scientists do that is both authentically inclusive and yet suitable for presenting to school-age learners. This is indeed a major challenge - to offer an 'intellectually honest' simplification (Bruner, 1960) of the nature of science, when professional philosophers continue to debate what precisely that nature is. Williams points out that key terms such as 'theory' have a technical meaning in science quite distinct from the vague way they are used in everyday life, and that teachers need to appreciate this and take it into account in their teaching. Indeed, the 'constructivist' programme into science teaching which has investigated learners' ideas and how to respond to them in specific science topics, needs to include learners' ideas of the nature of science itself (Taber, 2009b).

In his chapter, Michael Allen addresses the issue of how students are meant to make sense of teaching about HSW that includes authentic opportunities for scientific enquiry if this occurs alongside the type of assessed practical work where answers are known in advance, and a good 'investigation' reproduces textbook claims. This combination seems ideal for confusing many students and inviting cynicism among those capable of engaging in genuine enquiry work. This challenge is reflected to some extent in the theme of Ralph Levinson's chapter on teaching controversial issues in science – topics where scientific background can inform decision-making, but cannot determine action because human values have to be applied in evaluating and comparing options. Levinson points out the danger of students responding to this challenge by simply offering their opinions and failing to engage in meaningful discussion. This should not surprise us given that the common response to a loss of certainly (as school science has often appeared to offer in the past) is a retreat to an unsophisticated relativism. The common response is to assume that if there is no right answer, then all opinions are equally valid (D. Kuhn, 1999). Arguably shifting beyond this stage to find a principled way of dealing with the complexities (and uncertainties) of real-life issues is often only achieved during higher education, and sometimes not even then (Perry, 1970). Given that, the increasing emphasis on teaching about argumentation in school science - the focus of Shirley Simon's chapter – is very welcome.

In their chapter, Mike Watts and Helena Pedrosa de Jesus consider the role of questions in science education, and in particular learners' own questions. Ideally, school science enquiry could originate from learners' own questions, and this approach is certainly widely recommended in early science teaching in parts of the United States. Realistically though, such approaches demand teacher skills and confidence that may not be shared by many science teachers: who in any case will feel that in some educational contexts such an approach risks drifting too far from the set curriculum and assessment objectives. Yet, as Alan West's chapter shows, developing more authentic investigations in school science remains an important and realisable goal.

Jocelyn Wishart's contribution looks at the potential role of information and communications technology in teaching about science. She emphasises the use of such technology to collect, store and analyse data, and to model and simulate - as in real science - rather than just to access websites to harvest information. Justin Dillon, in the final substantive chapter reinforces the idea that there is not one single scientific method, and explores how science can be taught outside the classroom – where Darwin would have been very comfortable.

These chapters make up a set of informative and valuable accounts on themes important to science teaching, and do much to demystify teaching about the nature of science, or HSW. In his 'final thoughts', editor Toplis makes the important point that for teachers to innovate and develop their pedagogies to address the different challenges and opportunities discussed in the book they need to be given a high degree of freedom. Therein lies the rub. It already seems that the notion of HSW is to be discarded from the curriculum, and with further curriculum reviews underway there is a widespread suspicion that the focus will return to teaching facts and theories - the products of science - to the detriment of teaching about the nature of the processes of science itself. Let us hope not, or Toplis' volume may become something of a subversive science teacher's handbook, at least in England. That would be unfortunate as there is too much of importance and value here for the book to be dismissed once HSW joins the scrap heap of educational ideas ditched in response to political ideology and whim.

Socio-scientific issues and science teaching

Outside of England, such developments must seem very strange indeed, for most of the rest of the 'developed' world recognises the importance of teaching about how science works, even if not labeled in such minimalist terms. One of the themes addressed in Toplis' volume (in Levinson's chapter) is also the core concern for Sadler's edited book, which considers teaching about socio-scientific issues in the classroom. Sadler tackles the issues of what science education is for, and what kind of education is needed, as the introduction to a set of chapters deriving from a range of national contexts, interlaced with a series of 'metalogues'. These are devices that allow members of the author team to engage directly with chapter authors regarding issues raised by their chapters. This approach combines the authority of a peer-reviewed scholarly volume, with the opening-up of key issues found in the end-of-session respondent/discussion reports sometimes published in conference proceedings alongside the presentations that initiated the discussions.

Sadler sets the agenda for the volume in a consideration of the recent focus within science education on the notions of scientific literacy and of teaching science to support citizenship. He considers the goals of science education both in terms of helping students understand scientific principles, but also in terms of engagement in scientific practices. From these perspectives it is not enough for teachers to present science content (Newton's laws of motion; atomic theory; organ systems, etc) to be learned, but rather student learning must engage with the complexity of how scientific knowledge is mediated by and applied in the wider society. This, the argument goes, is needed to prepare future citizens for the way that they will need to engage with science as members of society. This is a familiar argument as most people do not become scientists, but they will have to face major decisions about their lives where science makes an important input: for example whether to take up medical treatment that has been statistically shown to increase survival rates from a major disease, but which is not always tolerated and may itself have serious side effects. Decision-making in such situations needs to be supported by knowledge and understanding of the scientific evidence, but cannot be undertaken by considering the scientific issues alone. If we wish to prepare people to make effective decisions in such real life scenarios, then science education has to engage them in the kinds of thinking that will be required later in life.

The contributions to Sadler's book have been selected to offer a range of examples and approaches to the kind of science education that allows learners to experience exploring science in a socio-cultural context. As the authors of a contribution on using web-based materials to teach about inheritance point out, this general approach is not new. The 'Science-Technology-Society' movement of the 1980s had pioneered such teaching approaches. In the UK, the Association for Science Education in particular developed extensive teaching materials on 'Science and Technology in Society' (SATIS) which were popular among teachers, but – like so much that came out of the curriculum development initiatives of that era – seemed less relevant with the introduction of the National Curriculum. Arguably what has changed since is less about curriculum or pedagogy per se, but more linked with the theoretical perspectives adopted by scholars in science education. In the 1980s the dominant perspective informing research was a personal constructivism which put the focus on how individuals understood aspects of science, but this has since been supplemented and to some extent demoted by social constructivist/constructionist/socio-cultural/cultural-historical perspectives (Taber, 2009a). Learning about science in society was no less relevant in the 1990s than it is now, and personal constructivism can be just as useful in thinking about how students make sense of socio-scientific issues as it is in considering how they understand electric circuits or ionic bonding. However there is arguably a strong confluence between what are seen currently as the most progressive perspectives on science education, and the kinds of topics and teaching approaches indicated by a focus on socio-scientific issues. One positive outcome, at least, is a programme of revision and republishing of the SATIS teaching materials through a designated website (http://www.satisrevisited.co.uk/m1.asp).

A chapter considering teaching about global climate change, co-written by Sadler himself, makes clear the intention to teach both science content and reasoning skills through socio-cultural issues. This chapter sets out four aspects of 'socio-scientific reasoning' it is hoped learners will develop. These relate to the complexity of the issues considered, the importance of considering multiple perspectives, the need for on-going enquiry (as such issues seldom admit once and for all solutions), and being suitably skeptical about sources of information in the light of the vested interests. This is a very important agenda, if one that work into student reasoning suggests might well be challenging to most school and many college level students (Perry, 1970).

Another study reported in the book used the question of whether HIV caused AIDS as a central theme for work with undergraduates. This derives from questions raised by a leading retro-virus researcher Peter Duesberg who argued that the presence of HIV among AIDS sufferers was not evidence of causality, but rather a side effect of a highly compromised immune system that was the genuine cause of AIDS. Something like twenty years ago I used the 'Duesberg Heresy' as one context for teaching science studies to adult returners to education in a further education context. However, I was surprised to learn that the example is still being used given the intense research around HIV/AIDS since.

Another chapter reports a study based on work with primary school children about the locating of a pig farm, with a focus on learners' argumentation skills – a theme that has had considerable attention in science education in recent years (Newton, Driver, & Osborne, 1999). Interestingly, in this case it seems that students were making progress in incorporating different pieces of evidence in their considerations of the case – up to the point where they visited a real pig farm, after which the direct experience, and in particular the smell, seemed to dominate their thinking. Another chapter reported on an aspect of a secondary science course (*Twenty-first Century Science*) that explored a scenario relating to environmental decision-making and air quality. The description of this teaching module, with its use of role-play and debate, drew on approaches that had been used in the SATIS materials referred to earlier. Other chapters look at work on biological determinism and a public health emergency (a SARS outbreak), and one considers teaching about reproduction and related technology in a Catholic girls' school. The chapter considering the SARS outbreak raises the issue of relevance. A topic that is recent and local in one educational setting, may be les engaging to students elsewhere and may have a limited shelf-life. Science teachers know that topicality soon fades. So, for example the Chernobyl nuclear accident engaged the imaginations of many school children at the time, but within a very few years it only evoked blank stares if offered as a teaching example. Unlike teaching about Newton's laws and the periodic table, this kind of science teaching may need regular updating to keep it current and relevant. (The team that developed the *Twenty-first Century Science* course recognised this and built in opportunities to regularly update contexts in response to areas of science considered to be of current public interest.)

Sadler's volume is clearly primarily an 'academic' book: it is theoretical, and scholarly. It would not be a light read for a busy teacher. Yet there is much in it that would be valuable to teachers who are interested in developing teaching approaches and material for teaching socio-scientific issues. The chapters, from different parts of the world, cover a range of science topics (although health-related issues are strongly represented), and different phases of education. Researchers and graduate students will certainly find much of interest here, and the different chapters draw upon a range of theoretical perspectives and a range of methodologies – yet, partly due to the metalogues, stand together as a coherent volume. The book certainly makes a substantial contribution in seeking to develop our understanding of the challenges and affordances of this focus of science teaching.

Learning science in a creationist culture

Unlike the two edited books, Long's volume is an account of a single research project: an ethnographic study that looks in some detail at the teaching of, and reception to, a key scientific topic. Evolution by natural selection is one of the most influential scientific ideas ever, and is fundamental to an understanding of modern biological science. A leading evolutionary theorist claimed in writing for biology teachers that nothing in the subject made sense except in the light of evolution (Dobzhansky, 1973)! Of course evolution is a theory, not a fact, and it has not been proved. That however is not really a statement about evolutionary theory, but rather the nature of science itself. Science does not prove theories – and they do not become facts. That much of the population does not seem to appreciate such distinctions demonstrates a major failing of science education in the past, and is one strong indicator of why science education should focus as much on teaching about the nature of science as teaching specific science content knowledge. Well-established theories have high status in science, despite not being facts. Theory means something specific in science (along the lines of a well-structured, coherent explanatory scheme, with a specified range of application), which, as pointed out above in considering the Toplis book, is not reflected in the everyday notion of something being '*just* a theory'.

Long's study is set in the United States of America (US). The US is one of the most technologically advanced nations in the world, and puts a great value on the importance of science and technology and science education. After all, the US sent men to the moon! The irony of course is that a good many US citizens today do not believe that really happened, whilst many do believe (as alluded to above) that aliens are regularly visiting Earth and abducting US citizens. Science education in the US has been subject to quite vigorous debates (Berube, 2008; Cromer, 1997), where pedagogy has become something of an intellectual battleground (Taber, 2010).

However Long's focus is more specific than that. Something like half of US citizens are said to reject evolution/natural selection, and the issue here goes deeper than pedagogy. The problem is well-known, and indeed evolution has become a focus of a supposed scienceversusreligion debate that been played out in the media, especially by those within the scientific community who wish to present religion as inherently irrational and primitive and seek to associate the scientific attitude with an intrinsically atheistic materialistic worldview (Taber, In press). Yet, as Long makes clear, many of those who reject evolution on principle no more adopt a general anti-science stance than those like Duesberg who rejected to the HIV-AIDS hypothesis or those cosmologists who reject string theory as an explanation of the large-scale structure of the universe. Long claims that the likes of Richard Dawkins (probably the highest profile scientist to attack religion in the name of science) do more harm than good to the cause of science education. Whether this should be seen as an 'own goal' depends upon whether Dawkins' main intended target is actually the religious deniers of evolution, such as those he mocks in his television programmes. Only Dawkins knows the extent to which his real agenda is more about establishing his own atheistic Worldview as a norm within the science community: claiming the 'soul' of science, perhaps, for those scientists who do not recognise the existence of souls!

Long introduces us to students and teachers who know that evolution is nonsense and thoroughly reject it. In most developed countries we might consider people who refuse to entertain evolution as a strongly evidenced and well-developed account of the origin of species to be outliers, people with extreme views. Yet in great swathes of the US such a view is the norm. There is a whole industry, including public museums, set up to present and disseminate the 'scientific' evidence against evolution and supporting Scriptural accounts of the recent creation of the world, the special (discrete) creation of different groups of organisms, mankind's fall, and Noah's flood. This requires a cultural explanation. Many learners in parts of the US are brought up in places where evolution is simply not consistent with the worldviews of people in their community. If your parents, and pastor, and school friends, and even your science teacher, hold and espouse metaphysical commitments that are inconsistent with evolution, then exposure to the scientific ideas is hardly going to be persuasive (Taber, In press).

Public schools in the US are expected to teach evolution, and the courts have made it clear they are not allowed to present non-scientific (i.e., religious, young-earth creationist) alternatives. Unlike in the UK where the relationship between science and religion is part of the officially recommended religious studies curriculum, US public schools cannot teach about religion. However, especially in small and homogenous communities, this neither guarantees effective teaching of the science, nor that students remain unaware of the teacher's own convictions on the matter. As Long's detailed interviews with students and teachers makes clear, there are strong issues of conscience at work here.

The core, and very important, message here is that those who reject evolution cannot be assumed to be stupid or ignorant or anti-science. Sometimes an intelligent person, who does understand the theory, and is a fan of science, may reject evolution on grounds that are perfectly rational given their worldview and their community context. Therefore, if the science education community is concerned about this problem (which is slowly becoming more of an issue in several national contexts), it needs to find solutions that reflect the complexity of the problem context. There is an interesting parallel to the Sadler volume here: just as science teachers are being asked to go beyond science content to teach socio-scientific issues, the science education community needs to look beyond issues of student understanding of the scientific principles (certain an issue, but not the only impediment to learning about evolution) to consider multiple perspectives in tackling what is a 'socio-educational' problem (Taber, Submitted).

Long's book, like Sadler's, is academic in nature. However, it is quite uneven in that sense. There are chapters and passages that will largely be of interest to the scholar or graduate student, and may seem too technical to engage the more general reader. However much of the book is extremely readable, and fascinating – as accounts of individuals and their thinking so often are. Whilst Long present an ethnography from the US, it has resonance for anyone teaching science in communities where some students may object to evolution (or other topics such as the big bang) due not to ignorance, but rather because of how such ideas are understood from their own well-established commitments about the nature of the world. This is a good read on a complex and important topic. It also sets out very clearly why this problem is unlikely to just go away, and needs to be faced by science teachers.

Final thought

One of the lessons of scholarship into the nature of science is the realisation that whatever the merits of scientific ideas, their dissemination and reception in the scientific community depends upon cultural and rhetorical factors (Gilbert & Mulkay, 1984; T. S. Kuhn, 1996). The same is true in relation to how scientific ideas are received in the wider society. The three volumes reviewed here each, in their own way, reflect how the science education itself has to shift if it is to effectively represent the nature of science in teaching and learning.

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