Taber, K. S. (2010). A comprehensive vision of 'the nature of science' in science education. *Studies in Science Education*, 46(2), 245-254. https://doi.org/10.1080/03057267.2010.504550

A comprehensive vision of 'the nature of science' in science education

A review of

Hodson, D. (2009). Teaching and learning about science: Language, theories, methods, history, traditions and values. Rotterdam, The Netherlands: Sense Publishers.

Derek Hodson has written an impressive book concerning teaching and learning about the nature of science (NOS): the most impressive aspect being its sheer scope. Teaching about NOS is currently one of the key concerns in science education (Clough & Olson, 2008), and Hodson has done a service to the community in putting together this volume.

Arguments for teaching about the NOS take varied forms. One perspective might be in terms of considerations of the purposes of the school curriculum. If education is intended to induct youngsters into the ways of human knowing, then science clearly has a major contribution to make, and in terms whereby the nature of scientific knowledge and knowing are made explicit and not expected to be somehow inferred from learning some examples of scientific knowledge. From what might be termed a liberal studies perspective, where education aims to introduce the young to the major features of human culture, then science undoubtedly has a key place alongside mathematics, the arts, the humanities etc. This of course was the point made by the scientist-cum-novelist C. P. Snow (Snow, 1959/1998) in his critique of the 'two cultures'. Again, a true appreciation of the cultural role of science would require an understanding of NOS, and not just knowing some science.

In more recent years, teaching about NOS has seemed to be linked to somewhat more pragmatic aims than introducing the young to disciplines of knowledge or the breadth of their cultural heritage: aims often expressed in terms of the attainment of 'scientific literacy'. The drive to improve scientific literacy is often considered as an urgent imperative for various reasons: to increase the number of talented young people seeking to enter science (and so to support economic development in 'developing' nations, or to maintain the industrial economic base in 'developed' nations); to counter a perceived conflict between science and non-science/anti-science (sometimes considered as a threat to rationality at individual and collective levels); to ensure responsible public decision-making in areas of major economic, technological and environmental importance; and so forth. In this book, Hodson suggests "there is value in thinking about different scientific literacies for different purposes and for different sociocultural contexts" (p.10), and argues for the value of "critical scientific and technological literacy" (p.16).

A further consideration is the role of learning about the NoS in supporting learning about the actual 'products' of science introduced in the curriculum. The outputs of science are commonly of the form of models and theories, and the explanations that can be developed with them: and anyone who does not understand their nature as models or theories cannot really be said to understand those 'products'. (In the same way that anyone who followed the *narrative* of Gulliver's Travels, or of the Chronicles of Narnia, without appreciating they were reading a work of fiction intended to be satirical, or allegorical respectively, could not be said to *fully* understand it.)

That many students find science difficult, struggle to achieve conceptual understanding, and often either disengage from the learning process or complete their studies without acquiring understandings close to matching the target knowledge set out in science curricula is a commonplace problem. Indeed, this is the basis of one of the most extensive research programmes in the field of science education (Taber, 2009). Whilst a better understanding of the nature of the products of science, and the processes by which they come to take on the status of scientific knowledge, will not of itself solve students' conceptual problems in the subject; nonetheless there are good grounds to think that such appreciation can help overcome some of the most frustrating features of science education as experienced by many learners (Taber, 2010b).

For various reasons, then, there has been an increasing focus on this aspect of school science (McComas, 1998). As a subfield of science education, there is already a considerable literature on teaching and learning about NOS. Indeed *Science & Education*, the journal of the International History and Philosophy of Science Teaching Group, offers a major outlet for work in this subfield, alongside more 'general' journals in the field, and some interdisciplinary journals which publish work in this area - for example, the journal *Foundations of Chemistry* which invites educators (*inter alia*) to 'discuss conceptual and fundamental issues' relating to chemistry. Chapters about the issue feature in general books about the academic field of science education (Duschl, 2000) and about science teaching practice (Osborne, 2002); and the issue is recognised as important enough to be the focus of major books in its own right (Matthews, 1994).

This is the context within which Hodson offers his own discussion of

> "those elements of the history of science, philosophy of science and sociology of science that constitute a satisfactory understanding of the nature of science (NOS), long regarded as a major component of scientific literacy and an important learning objective of science curricula"
>
> (p.7)

Hodson's book is organised into ten chapters, the first of which discusses 'scientific literacy and the key role of HPS'. It is in this chapter that Hodson sets out something of a manifesto for teaching about the NOS:

> "What I am advocating for inclusion in the school science curriculum…are those elements of the history, philosophy and sociology of science that will enable all students to leave school with robust knowledge about the nature of scientific enquiry and theory building, and understanding of the role and status of scientific knowledge, an ability to understand and use the language of science appropriately and effectively, the capacity to analyze, synthesize and evaluate knowledge claims, some insight into the socio-cultural, economic and political factors that impact the priorities and conduct of science, a developing capacity to deal with the moral-ethical issues that attend some scientific and technological developments, and some experience of conducting authentic scientific investigations for themselves and by themselves."
>
> (p.18)

One might imagine that at least the aims spelt out here would be very widely shared. Of course, that is not to say that there would be such ready agreement on "those elements of the history, philosophy and sociology of science" which might actually facilitate such learning. Hodson himself acknowledges that his own notion of NOS includes aspects "that are heavily value-laden, relate to gender and ethnic bias, address topics with a substantial moral-ethical dimension, and so on" (p.71).

After setting out his case for the importance of teaching and learning about NOS for developing scientific literacy, Hodson turns to review some key areas of research. In Chapter 2 Hodson focuses on 'research on students' views of NOS', which provides an opportunity to discuss some of the wide range of studies that generally suggest students have a rather impoverished understanding of NOS issues.

Of course it remains an open question whether this generally disappointing situation reflects something intrinsic to the nature of NOS as 'subject matter'; the traditional lack of substantive attempts to teach NOS; or generally weak teaching in this area. Hodson's book offers grounds for considering each of these factors as contributing.

The lack of widespread and explicit focus on NOS issues may have characterised traditional science curricula, but this is clearly becoming less and less the case in many parts of the world. At least, as Hodson points out, the curriculum rhetoric has shifted (p.x). This might lead one to expect that research into student understanding of NOS issues should begin to show a positive trend as the effects of shifting curriculum expectations take effect. Perhaps in many national contexts it is too early to expect to find such trends in the research currently available.

The inherent nature of the material to be taught is clearly a possible factor influencing the generally weak state of student knowledge and understanding that is revealed by research. For example, concepts such as 'law', 'theory' and 'model' are abstract, and tend to be used in nuanced ways. As Hodson points out (p.44) formal discriminations between what should be considered 'laws' and 'theories' tend to be ignored in the usage of many scientists themselves.

A central question is how we can get pupils to accept that science is a source of reliable, but not infallible, knowledge. In his Chapter 6 Hodson effectively spells out what this challenge involves:

> "It is important that the school science curriculum achieves a sensible balance between the view that science is absolute truth, ascertained by value-free disinterested individuals using entirely objective and reliable methods of inquiry…and the relativistic view that 'scientific truth' is any view that happens to suit the prevailing cultural climate of reflects the interests of those in positions of power"
>
> (p.152).

Developing a non-trivial understanding of how science progresses through an intermediate path – given that a number of quite distinct and not entirely compatible, versions of what that path might be (each supported by historical examples and championed by different philosophers of science) are widely touted – may require so-called 'post-formal' thinking that is able to deal with inconsistencies in a sophisticated way. That is, the type of thinking that Perry (1970) found was still being developed by elite students during their undergraduate years. In Perry's model intellectual development does reach its pinnacle with formal operations that can apply mathematical schemas and linear logic (à la Piaget), but proceeds to allow the appreciation of how contrary perspectives may be supportable from different perspectives, and the evaluation of such 'fuzzy' contexts to make rational decisions. Hodson refers to more recent research, which reflects Perry's general model (p.273). At one level, then, NOS offers an unpromising basis for target knowledge in the school curriculum.

However, the same would be true of many scientific concepts, models and theories themselves. Yet this is not (in principle) an issue because the actual target knowledge in the school curriculum is *not* these products of science in their most sophisticated forms, but rather curriculum models developed to represent 'intellectually honest' (as Jerome Bruner might say) simplifications of them. Of course, in practice, this becomes a major issue for teachers and learners when we fail to get the level of treatment right so that curriculum models are not well matched to the current knowledge and abilities of groups of students. This then is a key task for curriculum developers – to prepare suitable target knowledge for students at different ages and levels. This applies as much to representing NOS in the curriculum, as it does to representing scientific knowledge itself (Taber, 2008).

Hodson wrestles with these issues in his final Chapter (Chapter 10), when he considers whether it is acceptable to construct "stylized and mythical stories about great scientists" to engage pupils, or "to 're-write' historical accounts somewhat in order to reduce conceptual complexity and focus on sociohistorical issues or, conversely, to focus attention more clearly on conceptual issues, without too much distracting social, political and economic detail" (p.333). The logic of Hodson's exposition suggests 'yes' in both cases, although with the proviso that any 'mythical' biographies should themselves be *presented* as taking on the role of models of a kind, and not 'true' accounts. Similarly any simplified historical accounts should be presented as just that, and indeed this could offer a valuable cross-curriculum link with history, as the science teacher's colleagues in the history department are likely to be asking learners to consider historical documents as narratives selectively compiled by their authors for particular purposes (Aldridge, 2006).

Yet developing suitable curriculum models is only one part of the process of transforming professionally produced public knowledge – whether the consensus models and theories that are state-of-the-art (sic) in the natural sciences; or the latest scholarship in science studies – into a form suitable for engaging the interest of, and being perceived as related to the existing conceptual structures of, young learners. The second major stage involves the work of the classroom teacher who devises sequences of learning episodes using various activities, teaching models, examples, accounts of applications, analogies with what is known to already be familiar to learners, and so forth.

Effective teachers are those that are skilled in producing such transformations to help students construct personal knowledge that shifts towards the target knowledge represented in curriculum models. Such skill tends to develop with teaching experience, but also depends upon a wealth of subject knowledge and pedagogic knowledge relating to the teaching subject. The old adage that 'a good teacher can teach anything' is at best discussing a necessary not a sufficient condition. A good history teacher may have neither the enthusiasm nor the background knowledge to be a good teacher of mathematics.

By the same token a good teacher of biology is not necessarily a good teacher of physics; and a teacher who is skilled in teaching children about the products of science - the consensus models and theories – will not automatically be good at teaching about NOS. For one thing, few current science teachers have ever taken substantial courses in science studies, and most have largely developed their own NOS knowledge implicitly in courses in the science disciplines or through their informal reading around their subject. This could well explain what Hodson, at the end of this book, describes as the "cumulative message" of much science education,

> "that science has an all-purpose, straightforward and reliable method of ascertaining the truth about the universe, with the certainly of scientific knowledge being located in objective observation, extensive data collection and experimental verification. Moreover, scientists are rational, logical, open-minded and intellectually hones people who are required, by their commitment to the scientific enterprise, to adopt a disinterested, value-free and analytical stance"
>
> (p.342)

Perhaps most science teachers are much more familiar with an ideal that scientists might aspire to, than with what the philosophy of science suggests is actually possible, or what the history of science suggests actually happens.

This is demonstrated in Hodson's Chapter 3, which reviews 'research on teacher's views of NOS'. The literature reviewed presents a generally worrying perspective on how well teachers are placed to teach effectively about NOS issues, as much of the NOS teaching:

> "is separated from other learning and presented as content to be learned, almost in rote fashion. What these teachers lack, of course, is robust pedagogical knowledge in relation to NOS, that is, a repertoire of related examples, explanations, demonstrations and historical episodes that would enable them to translate their NOS ideas into a form that makes it accessible and interesting to students."
>
> (p.74)

The phenomenon described here, presentation of "content to be learned, almost in rote fashion", reflects what is often seen with new teachers lacking confidence and teaching experience. There seems to be an influential 'folk-model' of teaching that informs the way most people think about education, and which colours what they expect teaching to 'look like'. This is sometimes called a transmission model, although it is more a notion of copying: that the teacher 'has' some knowledge, and one person's knowledge can be copied into other minds by clear and well sequenced exposition (Taber, 2009).

Of course, teacher education is commonly informed by a constructivist perspective on learning that highlights the limitations of the folk-model, and so sets out a characterisation of the role of teachers that is quite different. An initial challenge here is to shift new teachers' existing ideas of what teaching involves – to bring about conceptual change. Yet the literature from science education makes it very clear that such shifts may be difficult to achieve, and that learners may 'acquire' and demonstrate new ways of thinking which exist alongside existing ideas that continue to be more influential. This applies to teachers-as-learners as much as students. Hodson reports that pupils taught by more 'constructivist' teachers seem to demonstrate similar perceptions of scientists as those taught by more 'didactic' teachers (p.55), perhaps in part because even experienced teachers may revert to 'telling' when moved out of their comfort zones. And, as Hodson points out later in his Chapter 5 (in the context of learning about evolution), learning for understanding does not equate to adopting beliefs (p.122): teachers have to be convinced that constructivist approaches to classroom teaching are likely to be effective in facilitating student learning before they fully commit to adopting them.

Hodson's book makes a strong case for employing the types of teaching and learning activities indicated by constructivist thinking. Indeed, much of the discussion of reading, writing and talking in Chapter 9 discusses features of teaching which might well be considered good practice well beyond science education, such as the use of DARTs (directed activities related to text, p.294) and the value of exploratory talk (p. 287). The recommendations here are valuable, if not specific to teaching about NOS. However, it is not enough just to persuade teachers of the merits of more constructivist approaches: these approaches depend upon teachers being confident and supported by a flexible repertoire of resources. These are things that Hodson's book suggests are often lacking in the context of teaching about NoS.

So asking teachers to teach something that is both new, and rather different to their familiar curriculum (arguably in effect teaching social science rather than natural science), makes irrelevant much of the resource base that experienced science teachers are likely to have in their areas of teaching strength, and may well lead to them reverting to 'telling' until they develop expertise, and so flexibility, in the new areas of teaching. Hodson suggests that NOS should be regarded as 'knowledge-in-action', which he suggests means that it is "to be learned, applied and refined in specific contexts of use" (p.69): but that may involve a steep learning curve for many teachers.

In Chapter 4 Hodson turns to the thorny issue of how NOS should be tackled within the science curriculum, and in particular the extent to which teaching and learning should be explicitly organised around NOS issues. In an undergraduate course in the history and philosophy of science, or in a course of science studies offered as part of a general studies programme designed to broaden students' programmes of study, it would be clear that NOS issues are very much the 'figure' rather than background. These would be social science or humanities courses in the context of science. Yet in the school science curriculum this is not the case, and an approach is needed that enables NOS learning objectives to be met alongside other objectives relating to the understanding of particular scientific ideas. Two extreme approaches would be to either consider the NOS aspects of the curriculum as discrete topics alongside topics from biology, chemistry, physics and so forth, or to seek to completely integrate the teaching of the science with teaching about NoS. There are clearly problems with either approach.

NOS can only be taught through contexts, and to separate it artificially in the curriculum could in effect mean replacing science topics with units or modules of something else (history, philosophy, sociology etc.) This is unlikely to be welcomed by science teachers, and is likely to be confusing to students who will have an uneven curriculum experience. Indeed, given the difficulty students sometimes have in making links between the same scientific ideas when they appear in different contexts, it may well lead to isolated learning about NOS issues that do little to provide the contextual background for studying specific science topics. When students commonly fail to appreciate, for example, how the interactions between electrical charges they accept in physics are also present and significant in learning chemistry, it seems optimistic to feel that relatively discrete teaching about NoS will inform learning about science topics subsequently studied.

Integrating the teaching of NOS into the teaching of existing science topics seems a more promising approach, but this will require careful planning. For one thing, the NOS aspects are unlikely to be learnt unless they are made explicit (Duschl, 2000). Yet simply adding to the learning demand (Leach & Scott, 2002) placed upon students by incorporating additional learning objectives into lessons may also be problematic when many students are already struggling to make sense of the scientific concepts themselves.

This tension has been felt in the English National Curriculum for science, where an explicit area of learning on NoS was mooted, but then dropped in favour of commentary asking teachers to infuse NOS ideas into their teaching of the prescribed science topic (DfEE/QCA, 1999). This was ineffective, as were subsequent attempts to modify the presentation of this aspect of the science curriculum (Taber, 2008). More recent major revisions of the curriculum (QCA, 2007a, 2007b) have taken a very different approach, presenting the NOS objectives in explicit sections of the curriculum document as parallel to, and of equal importance to, the section specifying the topics to be taught. Teachers working with 14-16 years are told that “pupils should be taught the knowledge, skills and understanding of how science works through the study of organisms and health, chemical and material behaviour, energy, electricity and radiations, and the environment, Earth and universe" (QCA, 2007b), i.e. through the prescribed areas of scientific knowledge.

It is too early to know how schools will respond to this, and so how successful this will be. The approach that teachers in some schools have told me they are taking is to assign particular NOS topics to be taught through particular subject topics (e.g. 'doing' models and modelling in, say, a topic on the particulate nature of matter). Whether this is to be successful is likely to depend upon whether the science teaching staff see such an approach as a way to *introduce* the particular aspect of NOS (and then look to revisit, consolidate and develop understandings in other contexts in other topics) or simply see this as a means of 'covering' the curriculum. Science teachers in the UK have been inundated with guidance on how to carry out their professional work in the past decade, often based on sound pedagogical principles supported by research. However, in a curriculum context dominated by high status testing, and where teachers perceive very limited scope for developing new practice, there has been a tendency for such guidance to have been adopted in a rather literal and minimalist sense that undermines the principles upon which it is based (Taber, 2010a). There is a very real danger of a similar minimalist approach being taken to the implementation of the English science curriculum revision with its heavy emphasis on NOS.

Hodson considers the different metaphors that teachers can take on as guiding their roles, and following Glen Aikenhead suggests that teacher as culture broker or anthropologist can be useful in this context - that is that the teacher's role is to induct the students into the strange culture of scientists. Given how influential such role metaphors can sometimes be (Tobin, Kahle, & Fraser, 1990), this could indeed be a promising approach if teachers could be persuaded to adopt this as a preferred way of thinking about their work. Hodson argues that from such a metaphor "locates the purpose of science education in school in equipping students with the knowledge, self-knowledge and confidence to move freely between different worldviews, accepting each on its own terms and for its own purposes" (p.80). How readily most science teachers would 'cross the border' from seeing themselves as teacher-as-physics-expert (for example) to teacher-as-cultural-broker is an open question. It may make more sense to build upon their perception of themselves as being broadly ‘scientists’, and to seek to shift their thinking about teaching to adopt some of the perspective of Thomas Kuhn in terms of how one becomes inducted into science (Kuhn, 1970). From this approach, the NOS learning objectives in the curriculum can be seen as key aspects of the ‘disciplinary matrix’ of science as a discipline represented in the school curriculum (Kuhn, 1974/1977). Of course, this is not a novel suggestion, as it has long been recognised that science teaching can be seen as about introducing learners to a community of practice (Driver, Asoko, Leach, Mortimer, & Scott, 1994), and indeed classrooms have been analysed in these terms (Roth & Bowen, 1995).

In the rest of his book Hodson explores a range of topics linked to his theme: the demarcation of science from non-science; what he calls the ‘substantive’ and ‘syntactical’ structures of science; language issues in science and science learning; and he concludes with a discussion of the history, traditions and values of science. This is indeed a broad treatment of his topic, and a review only allows a limited opportunity to engage with the range of topics that Hodson discusses. However, a few observations and comments will offer some indication of the scope of Hodson’s book and its potential as a source of ideas of interest to the science education community.

In Chapter 5, Hodson considers the very important issue of how science, as commonly understood, might be differentially received by learners from different cultural backgrounds who have adopted different worldviews. As Hodson notes, “because a worldview includes fundamental beliefs about causality and about humanity’s place in the world, it is fairly easy to see how it could be incompatible with the fundamental metaphysical underpinnings of science” (p.120). To some extent, of course, this depends upon the image of science being projected. In the context of science and religion, for example, some popular science ‘apologists’ move beyond the consensus view that supernatural phenomena are (by definition) outside the scope of science to suggest that science intrinsically excludes the possibility of supernatural phenomena – something that presumably sits uneasily with the significant proportion of scientists, and science teachers, who themselves have religious faith. Those who think they are defending science by arguing that religion is irrational superstition that has been superseded by scientific rationality should heed

Hodson's warning that, 'border crossing' (e.g. adopting the specific culture of the science classroom in lessons),

> "is inhibited not so much by the cognitive demand of the learning task as by the discomfort caused by some of the distinctive features of science, features that are often exaggerated and distorted by school science curricula into a scientistic cocktail of naïve realism, blissful empiricism, credulous experimentation, excessive rationalism and blind idealism"
>
> (p.121)

Hodson is informative and insightful in discussing such issues, and this reviewer found much that was thought provoking. In the context of his discussion of worldviews, Hodson comments that the culturally communicated mind-set of many East Asians leads them to "attend more broadly to the field and to the relations between the object and the field" (p.120). Whilst Hodson's focus here is on the way this may interact with the metaphysical assumptions behind science, it also raises interesting questions about perception (especially from a Gestalt psychology perspective) and so whether there are culturally influenced differences in how students draw inferences from school practical work.

Even when disagreeing with Hodson, this reviewer found much to consider and reflect upon. In Chapter 6 Hodson criticises instrumentalist perspectives on science, arguing that if scientific theories do not approximate to truth, then we should be surprised at how often they are successful. This argument rests upon a view that instrumentalism eschews realism, so that we need to make a "choice between realism and instrumentalism" (p.160). Yet instrumentalism may be adopted on epistemological grounds by those who accept a realist ontology (Glasersfeld, 1988), and indeed it has been argued that in this form it is the philosophy of science best suited to being represented in school science to avoid students assuming that models and theories are perfect representations of nature (Taber 2010b). Hodson argues that a mix of realist and (non-realist) instrumentalist perspectives is most appropriate, depending upon the particular science under discussion – an approach that he links to a critical realist perspective. Such suggestions are useful in reminding the reader that that questions about how best to present an authentic image of NOS in education remain open to empirical investigation.

Elsewhere in the same Chapter, Hodson argues that school practical work in science is 'theatre' and that 'conjuring' up the required results through "sleight of hand and other kinds of secret manipulation" is justified in "getting the right results" (p.172). This raises some interesting questions about ethics, values, means and ends, and the nature of teaching!

The book is very readable throughout, although some of the transitions, between sections offering quite dense reviews of topic areas covering a good deal of literature and more expository material where Hodson focuses on key references or expounds his own vision in the context of the background reviews, seem a little awkward. However, both these aspects of the book are of considerable value, so this is something of a minor quibble.

Perhaps inevitably in a book of this kind, then, there is sometimes a sense of uneven writing style. So, the detailed exploration of some topics contrasts with the uncritical reporting of the findings of the many studies that are not treated in depth. As just one example from Chapter 7, two studies suggesting that students who participate in summer science camps are more likely to aspire to or actually enter science careers are reported (p.208) without any comment on whether this could merely be a consequence of the motivations already operating in those choosing to spend a summer at a science camp. The interested reader can, of course, follow-up the original studies. The extensive literature reviewed (the reference list itself runs to over 70 pages) is one of the features of the book which will make it invaluable for readers: whether simply looking for an overview of part of the topic, or looking for starting points to develop their own research in this area. This thoroughness demonstrates that Hodson's own ideas have been grounded in broad scholarship, and they always worth considering (even if few readers will not find some points with which to disagree).

This book then deserves a wide readership, and is a welcome contribution to the debate about the role of NOS in science education, and how it should be incorporated into school science teaching.

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