J. CURRICULUM STUDIES, 2006, VOL. 38, NO. 6, 623–640

# The intellectual positioning of science in the curriculum, and its relationship to reform

JAMES DONNELLY

This study first offers a defence of the view that natural science has transcultural intellectual characteristics relevant to its educational purposes and examines those characteristics under their ontic, epistemic, and value-related aspects. While the epistemic domain has been most prominent in relation to the science curriculum and its reform, it is the ontic stance of science that is its most distinctive characteristic. Science stands in an attenuated relationship to forms of human valuing, but curriculum reform has attempted to bring value-related, and particularly ethical, matters into its remit. Science curriculum reform can be understood as an intellectual repositioning in relation to these three domains. This study relates this repositioning to the educational purposes of science, focusing particularly on a tension between liberal and instrumental purposes. Reform of the science curriculum is most coherently based on its distinctive ontic and epistemic characteristics, within a broader curricular framework.

Keywords: curriculum; epistemology; ontology; reform; science education; values.

It might plausibly be argued that natural science is the most revised of established curricular areas, at least in respect of proposals for reform. In 1997, Hurd (1997: 6), a veteran in these matters, suggested that, in the 1980s alone, science had been a central theme in most of nearly 400 national reports on educational reform in the US. To this can be added the many papers and books advocating reform. England and Wales offers a less extreme picture, but also displays a sustained reform effort. In a study sponsored by the Organization for Economic Cooperation and Development (OECD), Black and Atkin (1996) pointed out that this pressure is detectable across a wide range of developed countries, and that it displays a good deal of consistency in its emphasis.

The reform effort reflects a perception that science fails sufficiently to appeal to students when it is compulsory, and that too many young people do not wish to study it in post-compulsory education. ‘Too many’ in these contexts is commonly interpreted not in terms of a judgement of the desirable balance of young peoples’ interests (assuming that such a judgement could be made), but in terms of the quantitative social and economic need for scientifically-trained personnel (Roberts 2002). The most recent English

*James Donnelly* is Professor of Science Education and Director in the Centre for Studies in Science and Mathematics Education, University of Leeds, Leeds LS2 9JT, UK: e-mail: j.f.donnelly@education.leeds.ac.uk. After teaching in schools for several years, he worked in the UK Assessment of Performance Unit from 1984 to 1989. He is presently Editor of *Studies in Science Education*.

*Journal of Curriculum Studies* ISSN 0022–0272 print/ISSN 1366–5839 online ©2006 Taylor & Francis
http://www.tandf.co.uk/journals
DOI: 10.1080/00220270600822228

government reform proposals continue to interpret the issue largely in these terms (Department for Education and Skills 2005).

The source of these perceived problems in recruitment often appears to be understood in terms of extrinsic pressures that 'distort' the science curriculum. These supposed pressures, which are also said to display common international patterns, ostensibly lead to a failure to exploit the potential appeal of science to young people. Some commentators suggest that professional scientists have undue influence, leading to a 'pre-professional' emphasis within the school curriculum (Cross 1997, Millar and Osborne 1998, Aikenhead 2002). Others point to the influence of a political culture of accountability, suggesting that regulatory bodies over-emphasize well-defined and easily assessable bodies of knowledge, to the detriment of wider and presumably more appealing purposes of science education (House of Commons Science and Technology Committee 2002). Yet others emphasize the conservatism of science teachers, often in symbiosis with that of their pupils (Tobin and McRobbie 1996).

In this paper I am not concerned directly with such extrinsic influences on science in the curriculum. I focus instead on its 'intellectual' qualities, as I understand them. I will examine three intellectual domains under which science, and science education, can be understood:

- the ontic (concerned with the modes of being science recognizes);[1]
- the epistemic (concerned with how its knowledge claims are justified); and
- that of value, understood principally, although not exclusively, in terms of ethics.

I will argue that, despite their apparent abstraction, these domains are critical to an understanding of science in the curriculum and its vicissitudes, and curriculum reforms can be understood as an attempted repositioning within them. It can also be argued that the position of science in these domains provides a plausible source for some of the general patterns of difficulty the science curriculum displays across the developed world.

At this point I perhaps ought to indicate that I will routinely use the word 'science' to refer to the instrumental and physicalist account of the world given within the Western tradition. I will occasionally reinforce this point by referring to 'natural science'. It seems necessary to make my usage explicit as there is a growing tendency within writing on science education to refer to any mode of engagement with the material world, including animistic and anthropomorphic perspectives, as 'science'. I do not take these modes of engagement to be 'science' in the usual sense of the word. This limitation is not meant to suggest that 'Western' science is the most important way to understand the world; it is intended merely to allow some purchase on the word 'science', concordant with its usage within most contemporary cultural and political environments.

That it is necessary to make this point reflects the proximity of a large argument, of which it is necessary to say a little here. There is a tendency to represent science as a mere localized practice, without essential intellectual qualities of the kind with which I am concerned. I think this type of account rests on an over-loose usage of 'local'. Sandra Harding, for example, writes in the mode to which I am alluding. In one of her books she offers an extended commentary on the 'costs' of science's universality claims. However, she rather gives the game away at one point, when she suggests that one of the effects of the presumed authority/universality of science is that its implications are not empirically tested in the various local settings in which they are used (Harding 1998: 184). Does not this claim imply that the protocols of empirical testing are transcultural? Science is not local, in my view, if by this is meant that people in different settings, undertaking similar experimental activities, under conditions of *ceteris paribus*, might, in principle, achieve different outcomes. I am appealing here to the presumption of the uniformity of nature. I do not believe that this principle is seriously questioned, even through Collins's (1985) well-known demonstration of the difficulty, perhaps impossibility, in practice, of full replication, or Cartwright's (1999) rather different notion of the 'dappled world'.

The view, which rather goes by default in Harding's argument and that of some educational commentators, that scientific realism is no longer a defended philosophical position is simply wrong (Aronson *et al.* 1994, McComas 1998, Kuipers 2000, Bartholomew *et al.* 2004). The flirtation with anti-realist assumptions in some science-education writing, and with notions of the under-determination of scientific ideas,[2] is sometimes compounded; authors take a realist interpretation of scientific knowledge to imply an absolutist understanding of its knowledge claims. Yet the two are only loosely connected (Devitt 1984: 18–19). I cannot pursue the argument further here, and it is perhaps enough to state as forcibly as may be that I will take the view that there is an identifiable and transcultural domain of natural science that can be understood in intellectual terms (Nanda 2003, Cobern and Loving 2004).

The intellectual domains with which I am concerned (ontic, epistemic, and that of value) speak to another issue that runs through my argument: *the educational purposes that science education serves*. For the most part in this paper I will have in mind a view of those purposes drawn from within liberal education. To have a knowledge of science and its particular mode of understanding the world as a significant and distinctive form of human intellectual activity is part of what it is to be educated. Such knowledge is a precondition for, and deployed within, intellectual autonomy and criticality. The force of these statements, and their curricular implications, depend, in part, on defining what is intellectually distinctive about science. They, thus, link directly to the domains that I identified earlier. I return to this issue in my conclusion.

The educational claims of science have proved problematic since it first became part of mainstream education during the mid-19$^{th}$ century (Donnelly 2002). Nearly 150 years ago, a witness to the Clarendon Commission, sceptical about the place of science in the curriculum, remarked that:

> [A] scientific fact … is simply a barren fact, which (the pupil) remembers or does not remember for a time. … It leads to nothing. It does not germinate, it is a perfectly unfruitful fact. (Clarendon Commission 1864: question 494)

Modern accounts critical of science education in its present form often direct sceptical attention to its representation in schools:

> School programmes have usually portrayed the discipline as a relentless, linear, and dispassionate search for truth. (Black and Atkin 1996: 33)

Both of these observations may contain some exaggeration, with the latter in particular in some danger of setting up straw men or women. Nevertheless, they give expression to a broader unease. I interpret that unease as concerned with the capacity of science to promote those independent, critical, and creative qualities of mind which the tradition of liberal education aspires to promote. The attempted repositionings I discuss here can be construed as responses to that unease in relation to some or all of the three domains that I identified earlier, and to which I now turn.

## The ontic

There is nothing controversial in the claim that natural science recognizes certain characteristic modes in which the world is to be understood. The scientific mode of understanding is physicalist in relation to entities, and mechanistic in relation to processes. The overall approach is sometimes called naturalistic, although that term has a broader reference. It also has epistemic and value-related associations, to which I will refer later, and which reflect the difficulty of separating the three domains with which I am concerned.

I draw attention to three aspects of this ontic take on the world. Within science, the world is attributed a merely physical presence, and its processes are viewed as the blind working-out of mechanism. This is the case whether that mechanism has the esoteric and perhaps non-deterministic quality of modern physics, or the (until the last half-century) less obviously mechanistic, but equally purposeless, character of evolutionary biology. All of this has important consequences for a wider interpretation of and relationship with the world. Critically, the scientific world is void of any purposive or teleological aspect. Nor is it possible to enter into a mutually interpretive relationship with scientific entities, *qua* scientific. Our dealings with such a world are limited to that attenuated sense associated with predictability and physicalist/mechanistic coherence. They are narrowly instrumental rather than properly hermeneutic dealings (in Habermas's (1972) famous tripartite division).

Instrumentality can be a kind of epistemic category, because predictive success or control can offer a criterion for knowledge. It can also help define what it means for an entity to be physical. I will try to clarify this point by an example from our everyday usage. We describe as 'manipulative' someone who deals with other human beings within an instrumentalist or means-ends mode: as a means to achieve his or her own purposes. Such a person fails to recognize a mode of being (and ethical status) in the other which is comparable with his or her own. This is the default position of natural science in facing the world. It is a type of ethical, or at least value-related, position that, as I discuss below, is particularly relevant to the case of sentient animals. Its relevance to the Western ethical tradition in human relations can be evidenced by noting its importance within Kant's (1926: 56) second formulation of the categorical imperative: to treat human beings always as ends, and never as means only. How we construe other entities involves values.

Scientific entities, *qua* scientific, do not have any intrinsic value, as they do in some non-Western engagements with the natural world (Habermas 1972, Abrams 1996). The construal of the world that I have just sketched represents an integrated metaphysical perspective (Devitt 1984: 34–47).

I ought perhaps to emphasize here that I am not suggesting that individuals working within a natural scientific intellectual frame understand the world to be best construed in this way, although some do, or affect to do so (Atkins 1995). I am referring to the scientific worldview in the abstract: in particular, I am referring to those modes of argumentation that are able to gain purchase within *scientific* reasoning. This last is my key test of whether an argument or position belongs within science: would it have force in a debate about the merits of a scientific account of some phenomenon?

The third ontic aspect of science that I wish to identify is its analytical, reductive, and universalizing tendency. Science seeks to analyse the world into relatively simple, idealized, and delocalized elements, and then reintegrate these elements so as to understand more complex phenomena. Analysis, abstraction, and even reduction are not the most important issues in my argument here. Almost any intellectual engagement with the world might display these characteristics in some degree. However, the scientific mode of analysis combines these qualities into a project that seeks to submerge specificities entirely. The humanities attempt to examine a moment of history, a work of imaginative writing, or even a human being, in both their fullness and specificity, despite often employing analytical perspectives and abstract categories. Aesthetic responses to art are similarly specific in their quality: it is *this* work of art and its specific qualities with which I engage, though, as Hepburn (2001) has eloquently argued, art still has a place for truth. In the natural sciences the specific entity, moment, or event is lost, programmatically at least. It is perhaps significant that this quality appears in a yet stronger form in the context of mathematics, another curricular subject often thought to be in some difficulty.

Despite the force of these qualities, and the distinctive colouring they give to science as an activity and body of knowledge, the strongest observation that can be made about the ontic domain, in the context of discussions of science education, relates to its absence. This is particularly striking given the numerous discussions that can be found in the science education literature relating to the so-called 'nature of science'. In these discussions ontology is usually absent: the focus is most commonly epistemological (e.g. McComas 1998). I wish to claim, against the thrust, or at least the silences, of this body of writing, that the mode of *being* which Western natural science recognizes (and its implications for matters of value) is more influential than its epistemic qualities in giving science, and the science curriculum, their distinctive character. Contrary to what is sometimes claimed,[3] the epistemic qualities of science are largely shared with other areas of intellectual activity. A partial exception is the prominence of instrumental criteria in sustaining knowledge claims but this, I (Donnelly 2001b) have suggested, is symbiotic with a physicalist worldview.

It is difficult to comment on the degree to which science's ontic take on the world influences children's response to the curriculum. Attitudinal studies tend to focus on the response to different and, in my judgement, less fundamental aspects of science education. They concern themselves, for example, with the attention paid to outdated industrial processes rather than 'contemporary' science, or with phenomena that are 'relevant' to daily life (Osborne and Collins 2000). Several reasons for this avoidance of the more fundamental issue are possible. Discussion of the ontic perspective of science may be judged too 'boring'. It may be thought intellectually too difficult. Yet it is possible to argue that the issues involved within ontological discussions are no more intellectually demanding, or boring, than those epistemological matters (or, increasingly, their sociological proxies) that are commonly urged as belonging at the centre of the science curriculum. A certain ethical restraint when dealing with children may also be in play. The issues raised in confronting the idea of a mechanistic, meaningless, and purposeless universe are such that any responsible person might hesitate to bring them to the attention of children. This is true also of the depiction of human beings as in essence simply part of such a universe.

Despite these silences, such issues may be influencing the situation of science education. They are perhaps embedded in the commonplaces of conventional attitudinal studies' findings that science is 'boring' or 'irrelevant'. Such analyses and proposals often appear insensitive to the question of what it is that makes science 'boring' or 'irrelevant'. Some part of the answer might stem from a symbiosis between the mechanistic and authoritative quality of the knowledge it offers (Donnelly 2004).

The role of the ontic domain in proposals for the reform of the science curriculum is essentially negative, as a foil against which reform agendas can be defined. The educational purposes that the science curriculum is able to fulfil when it focuses on the substance of the scientific account of the world are seen as trivial, or worse. Its emphasis on the world as a mere physical presence limits the linkage of science to the network of human purposes that give life value and a sense of narrative and meaning (Cooper 2003).

All of these ontic qualities are problematic, and invite an intellectual repositioning of school science. They are also symbiotic with the perceived quality of science as dealing, beyond other areas, with established and authoritative 'facts'. This is an epistemic point, and so I now turn my attention to that domain, recalling the observation that it has received much more positive attention within reform agendas than has the ontic.

## The epistemic

The epistemic domain is concerned with the status of the knowledge claims of science and their warrants. It also, although less clearly, addresses the processes by which scientific knowledge is obtained. It is inevitable that science education should find itself engaged with these themes. Yet the extent of the engagement is striking, and arguably greater than that in most other curricular areas. The epistemic quality of science represents both part of the (perceived) problem of science in the curriculum and part of a possible solution.

Why should the epistemic be of such concern in the case of science, beyond other areas of knowledge in the curriculum? Epistemology is not the focus of so much explicit attention in, say, history, where, it might be thought, knowledge claims are more contested, and less prone to becoming established. This apparent paradox is a clue to an answer. The interpretive and contested character of historical knowledge is a theme that is embedded in both curriculum and pedagogy in a way that is not the case in science. Recognition of this quality is central to the substance of history as discipline and pedagogy. By historical knowledge I mean an understanding of the causal, conceptual, and narrative relationships between events, and interpretations of the human motivations and judgements within them. There is almost no expectation that such knowledge will be authoritative in any strong sense. History is thoroughly interpretive, and filled with the intrinsic openness of human purposes and actions. The teaching of history is centrally concerned with this openness, and thus with epistemological aspects of historiography. It is significant, however, that these issues are rarely thematized explicitly (Donnelly 1999).

Matters could scarcely be more different in science. Epistemology is very visible. This is because of such apparent qualities as the capacity of science to generate agreement, its instrumental power and success, the cumulative character of its central understandings, and, in consequence of all of this, the authority that is often attributed to scientific knowledge. These distinctive qualities of science force themselves on the attention and demand explanation. I have already indicated that discussions about how science comes to possess these qualities are usually framed epistemologically. For my part, I wish to argue that they (the qualities of natural science I have just listed) are at least as much ontically determined. That is, they reflect the modes of *being* under which science construes the world. That construal allows a degree of epistemic closure unavailable in the hermeneutic disciplines.

This is echoed in the peculiar etymological history of the word ‘science’, with its shift in the mid-19$^{th}$ century from a reference to systematic knowledge generally. In the Anglo-American tradition (by 1867, according to the *Oxford English Dictionary*) ‘science’ acquired a narrow meaning, referring to physicalist knowledge of the world. It also gained a further association as an intellectually privileged form of knowledge. The sources and legitimacy of this privilege are increasingly contentious. It has historically involved appeals to the ‘scientific method’. This is commonly taken to refer to a supposedly enhanced, and perhaps even paradigmatic, rationality. Elevator words (Hacking 1999: 21) such as ‘objective’ and ‘rational’ are also commonly applied to science, and can in turn become the focus of both positive and, nowadays, negative evaluation. Overall, to say that a domain is part of natural science has been tantamount to claiming that it is of a particularly dependable and authoritative status, and that it allows confident prediction and control of the material world. Correspondingly, the adjective ‘scientific’ carries a powerful, if often vague, epistemic association. This special quality of science constitutes the centre of gravity about which its educational positioning has turned. Systematic reform attempts tend to define themselves and their agenda in epistemic terms, with both positive and negative elements.

Reform has addressed this epistemic quality of science in two modes, or at least there have been two ideal-typical positions. The first, and much older, made a positive evaluation of epistemic authority, and the epistemological and methodological principles on which that authority was said to be grounded. The origins of this tradition are associated, in England, particularly with Thomas Huxley (1825–1895) and Henry Armstrong (1848–1937). Attempts to embody these qualities more explicitly within the practice of science education have continued until the present day, through initiatives such as the UK Nuffield projects and the many curriculum reform projects in the USA (McCulloch *et al.* 1985, Rudolph 2002). They are premised on the view that children should be taught, usually through emulation and participation rather than precept, to understand and practise specifically scientific modes of engaging the world. It is often expected that the force of these epistemic engagements will lead students also to an understanding of established scientific knowledge.

These formulations may appear dated, but they remain not far from the surface when the modern-sounding language of 'skill' or 'inquiry'[4] is used. They strongly inform the US National Science Standards (National Research Council 2000), in terms that Thomas Huxley would have recognized. Practising scientists have in the past often participated in such projects, because they (the positions) focus on the admirable epistemic characteristics supposedly associated with the practice of science. These alleged characteristics are associated to a degree with individual scientists as well as with science as a collective professional practice, although the individual/collective distinction is often elided in discussions of science education. As a result, it is sometimes not clear whether the outcomes are intended to be personal qualities and capacities, or knowledge about the institutions and methods of science.

Within this approach, which might loosely be called 'pre-Kuhnian', the attempt to undermine the impact of the givenness and authority of science as an educational medium has tended to be based on an appeal to the child as a rational, thinking individual: famously, 'a scientist for a day'.[5] Yet the approach has an ambivalent character in relation to promoting these intellectual qualities, because it is generally associated with a strong commitment to an established body of scientific knowledge that the child must achieve mastery of or 'discover'. These difficulties are reflected in the criticisms of such notions as 'guided discovery', and in the attempt to promote more authentically *open* inquiry work (although still, somehow, articulated with established science) (Stevens 1978, Donnelly *et al.* 1996). Its present-day manifestations include the investigatory element of the National Curriculum in England and some versions of inquiry in the US. More recent manifestations in the English National Curriculum have employed the notion of 'evidence', and implied that the practice of science employs evidence in some distinctive or paradigmatic way. However, the English National Curriculum has displayed ambivalence in this area: it has embodied two strands, the other of which offers a more sociological account of the qualities of science (Donnelly 2001a).

These ambivalent views about the educational role of the epistemic qualities of science have echoed a wider debate, both in the academy and in more populist settings, about the characteristics and perils of science. Scepticism about the worldview of physical science, sometimes giving way to hostility and suspicion, has as long a history as science in its modern form. They were expressed in Blake's image, in 'Milton', of 'dark satanic mills', for some an amalgam of the mills of Newton's mind, materialistic philosophy and the educational institutions of the time. They also found a place in Keats' famous critique of Newton in 'Lamia', in Goethe's Romantic *Naturphilosophie*, and many other locations. A tradition of humanist hostility to science, especially to more scientistic and reductive interpretations of it, still exists. However, a separate tradition has also developed within the academic study of science, reconceptualizing 'the nature of science' in sociological terms, and has had some influence within science curriculum reform.

It is not news that the field of science studies, which lies at the intersection of philosophical, sociological, and historical analyses of science, has become the location of intensive arguments, commonly known as the 'science wars'. Although a prominent participant, Sokal (2001: 14) has sought to distance himself from the term 'science wars', and others have found the metaphor unhelpful, a reading of contributions on the field suggests that it is an all-too-accurate descriptor. The battle lines are drawn broadly between those who subscribe to a realist, rationalist, and progressivist account of science and the knowledge it offers, and those who stress the continuity between natural science and other more humanistic forms of activity and knowing. The latter perspective usually contains some combination of the following views: science (that is the ontic perspective, discourse, other representational practices and knowledge claims of 'Western' natural science) has no special claim to rationality; its practices are imbued with politics and sociology in ways that influence its substantive knowledge claims; those knowledge claims are not true, or even progressively more accurate, accounts of the world; it is not positive knowledge, but as interpretive as other forms of human intellectual activity; it is not cumulative; its instrumental success is in some measure a sleight of hand resulting from the suppression of other perspectives on the world and a systematic ignoring of its own costs and failures. Some of the more recent exchanges display a not entirely convincing effort to negotiate a peace, or at least a ceasefire (Ashman and Barringer 2001, Brown 2001, Labinger and Collins 2001).

The 'wars' have not mainly been fought on the terrain of education itself, although their echoes are detectable in arguments around the increasingly open term 'constructivism', or in the conflicts surrounding cultural diversity and science, to which I referred above. Some of the early exchanges around the US National Science Standards drew on these arguments (Holton 1996, Phillips 2000, Aikenhead 2002). Turner and Sullenger (1999) and others (Eflin *et al.* 1999, Allchin 2004) have offered a careful, and not noticeably sympathetic, account of the use made of science studies by North American science educators.

The issues I have just sketched, the arenas in which they are debated, and their influence within the science curriculum are all heavily mediated by local political and institutional circumstances. They merit an extended discussion, but that is not my purpose here. I wish mainly to suggest that the availability of what might be categorized as 'post-Kuhnian' perspectives has added to the range of potential epistemic positionings available to reformers of science education. These perspectives have been employed to address the concerns I identified earlier about the educational purposes of science.

It is relatively easy to find examples of these post-Kuhnian influences, often articulated in terms of hostility to an older, rationalistic account of science:

> [Today's] curriculum portrays science as a purely rational and objective inquiry into absolute knowledge. (Aikenhead 1994: 18)

> [S]cience is presented as the meticulous, orderly and exhaustive application of a powerfull, all-purpose, objective and reliable method for ascertaining factual knowledge … (Hodson 1998: 9)

A recent Delphi study of 'expert' opinion, although generally bland in its conclusions, displays some post-Kuhnian elements (Osborne *et al.* 2003). Occasionally there are more extreme manifestations (Bencze 2000).

It is not easy to identify with any clarity a distinctive intellectual perspective on science education being promoted within this post-Kuhnian approach. However, one important element is the introduction of more interpretive social and political analyses of the practice of science, which translate educationally into scope for pupil judgement within the science curriculum. I will argue later that these educational aims are in fact often crudely instrumental, including, for example, the aim of making science education more popular. Beyond this, as I have already indicated, perhaps their strongest characteristic is oppositional: to provide an alternative educational focus to that based on the ontic knowledge claims of science. This epistemic repositioning also draws on the third intellectual domain I identified at the beginning of this paper: that of values.

## Values

The domain of values is not sharply distinguished from the epistemic. It has, for example, been argued that the epistemic quality of science is underpinned by 'cognitive values' (Lacey 1999). This term is intended to refer to those criteria by which we judge the quality of the practices needed to establish reliable or defensible knowledge. However, when values are referred to in the context of reforming science education, it is a different understanding that is usually in play (Witz 1996): that understanding is particularly ethical, relating to the good in our treatment of other entities, but also aesthetic, relating to our judgements of beauty (Girod *et al.* 2003). Some other forms of value are potentially relevant, most obviously religious values, although they are usually seen as inimical to natural science because of their appeal to a supernatural source. Discussions on this last theme commonly generate more heat than do most value-related discussions (e.g. Bausor and Poole 2003 and subsequent correspondence).[6]

Graham (1981) characterized a default position in understandings of the relationship between science and values: the restrictionist perspective. This position can be most sharply exemplified by noting that science accepts no intrinsic ethical limitations in its treatment of merely physical entities: one may treat electrons or chemical compounds how one wishes. This may seem an uncontentious view until it is recalled that, under the scientific construal of the world, there are *only* physical entities. They display various degrees of complexity, and possibly emergent properties, of which sentience is one. Evidently this is most significant when dealing with animals. Ethical status has no scientific significance, in the sense of having no purchase on arguments about the validity of any particular findings or theoretical explanations of them. Data obtained in a manner judged to be outside accepted ethical standards would potentially be *technically* usable within scientific work and scientific argumentation. Thus we find arguments about whether the ethically unacceptable work of Nazi scientists should be used within more recent research (Cohen n.d.).

The ethical status attributed to sentient creatures within discourses and practices broader than science is often acknowledged within science and allowed to limit scientific activities. Birke and Hubbard (1995) have examined the issues this judgement raises for the character of biology. They discuss the implications of acknowledging animals as quasi-human agents, with a corresponding shift in their allowable treatment within science.[7] The limits that may be placed on the manipulation of entities recognized as living but not necessarily sentient is a further matter of debate. The most conspicuous examples of such debate at the present time are in the fields of genetically-modified organisms and human embryo research, although the attribution of ethical status to non-sentient beings is a strand of argument within environmental and cultural debates (Griffin 1988). Again, however, the extent of these ethical limitations is not grounded in scientific argumentation (which could potentially treat any entity as merely physical) but in the wider social framework.

The place of aesthetic values within science presents a different set of issues. It is sometimes claimed that scientific ideas are in some sense beautiful. It is not difficult to sustain such a claim in terms of the individual person's response to scientific ideas (Girod *et al.* 2003). However, there is a stronger argument. The most famous example is perhaps Dirac's (1963) often-quoted statement about the relative importance of beauty and empirical adequacy, in favour of the former. Dirac's point is radical and interesting, although perhaps over-interpreted if he is taken to be defending the view that beauty carries weight within scientific argumentation. It is difficult to know how to respond to this claim in the absence of a detailed analysis of such a case. I have been unable to find an extended example, even in the most sympathetic accounts (Chandrasekhar 1987). Nevertheless it seems difficult to imagine circumstances in which aesthetic appeal would take precedence over empirical adequacy, simplicity, coherence with well-established theories and so on, in coming to a judgement of scientific outcomes.

Within human cultural traditions, specific entities or places may be construed in terms of values, most visibly through the quality of being sacred. On a restrictionist view, such attributions again have no place in science. This point echoes my earlier comment when discussing the scientific engagement with forms of being: scientific practice has only limited interest in specific entities, whether sacred or otherwise, except as exemplars of types. The concept of sacredness perhaps serves to highlight this more general contrast between natural science and many other forms of human engagement.

This discussion of values can be interpreted as bringing us full circle because the attribution of value to entities stands more or less in opposition to the ontic worldview of science—with its physicalism and absence of meaning and purpose. I suggested that these ontic qualities of science have represented (along with its authoritative character) a challenge to the view that science can of itself speak of human purposes and meanings. It is, therefore, not surprising that reform agendas have sought to reposition science education in relation to the domain of values.

That effort has been dominated by an engagement with ethics. Reformers have not usually gone so far as to claim that the substance of science has a clear ethical content. Yet ethical issues are prominent, indeed central, within some curriculum development projects. Subjects such as the proper uses of genetically-modified organisms, energy policy, or vaccination practices are incorporated into the body of the science curriculum. Such issues are, most characteristically, contentious technical possibilities pertaining to personal or public decision-making within which scientific knowledge has had a significant role. Introducing children to the process of decision-making in these contexts is judged to be a legitimate aim, and sometimes a central aim, of the science curriculum (21$^{st}$ Century Science Project Team 2003).

These issues are addressed through a range of questions: What science is needed in the determination of public policy? How is such knowledge known to be reliable? What political influences are in play when science is used? How is risk judged?; and occasionally, How best should some technical end be achieved? It is significant that the last category in this list is of comparatively little interest within curricular reform unless the technical end or technique is controversial, and therefore has an ethical dimension. The types of knowledge in play within many reformed science curricula are diverse, and often include sociological and political matters. Yet, I maintain that the key point at issue in all of these contexts, if it is not epistemic and to do with the sustainability of knowledge claims, is concerned with what is good in human conduct, or contributes to the good in human affairs. In sum, it is ethical. This inclusion of ethical matters represents a key repositioning of science education.

## Conclusion

In this paper I have sought to examine the intellectual domains under which science and science education can be understood, particularly in the context of curriculum reform. The discussion has focused on three domains that seem to be central:

- the forms of being under which the world is construed;
- the basis and authority of scientific knowledge claims; and
- the ways in which science relates to the key modes of human valuing.

No account of the science curriculum and its reform, and least of all an abstract one such as this, can capture the specifics of the many initiatives that exist, or their diversity. Nevertheless I claim that a focus on the intellectual characteristics of science can help to bring diverse reforms and their motivations under a common framework.

Reforms commonly involve the following types of repositioning:

- marginalizing, and sometimes problematizing, the place of science's substantive account of the world;
- emphasizing, and sometimes problematizing, the epistemic characteristics of science so as to promote the direct engagement of students with processes of knowledge creation, justification, evaluation, and use (increasingly this element is taken to involve sociological understandings of these matters); and
- redefining the subject matter of the curriculum so as to include socially and politically significant issues at the core of which are ethical questions.

My concern about these repositionings is that in any given reform they are commonly *ad hoc*, and do not have a clear foundation within our understandings of the purposes of education. That concern is the focus of this conclusion.

I wish to discuss these reforms against the backdrop of the tradition of liberal education (Hirst 1974). That tradition identifies the essential purpose of education in the intellectual development of the individual. Each domain of human intellectual activity makes a distinctive contribution to the student's development in terms both of substantive knowledge and a mode of understanding the world. These understandings, taken together, help constitute the critical, autonomous, and informed individual in his or her dealings with the world.

Under this view, the educational place and contribution of science will be based on its distinctive intellectual qualities. The status of science as authoritative knowledge, and its narrow physicalism, have sometimes been thought to render its position problematic. In my view this is a mistaken opinion, partly because a liberal education involves complementary elements, and science, including the characteristics just mentioned, is a key element of this framework. Nevertheless, science education reform often appears to accept such a critique. Claims that science education is not 'relevant', that it is too full of 'content' (i.e. scientific knowledge), that it is insufficiently motivating, that it is dominated by professional science, and so on, seem to me to be essentially superficial arguments. They derive their underlying intellectual impetus from more deep-rooted doubts about the educational legitimacy of science.

Before taking this argument further, I ought to acknowledge that the liberal account of education can appear to have little place within modern educational policy. Instead, policy appeals to what are essentially instrumental purposes.[8] These purposes include, most visibly, the provision of a scientifically-educated workforce (Roberts 2002). Another common instrumental purpose is the creation of a 'scientifically-literate' population, able to understand scientific controversies and public and personal decision-making with a scientific aspect (Millar and Osborne 1998). In other contexts this purpose transforms into that of creating a populace which will be supportive of science (HM Treasury, DTI, and DfES 2004). In yet other contexts the emphasis appears to be to promote forms of social and political change with a connection to science (Roth and Désautels 2002). These purposes overlap, and they are as prevalent in the professional discourse of reform as in that of politicians. I call them 'instrumental' because their principal focus is not the promotion of the informed autonomy of the student. The two kinds of purpose (instrumental and liberal), of course, are not entirely distinguishable: curricula can serve both purposes. However, if the former takes undue priority, the consequences are dangerous. Education begins to serve whoever can gain control of the curriculum, whether they be politicians or 'science educators', and not the student as a growing human being.

The two approaches to the purposes of science education can be related to the intellectual characteristics of science, but they invite different forms of engagement. If we are concerned with the purposes that science might serve in a liberal education, then our emphasis will be on identifying the understandings and capabilities distinctive to science, how the intellectual qualities of science condition them and the pedagogies that promote them. If, on the other hand, we are anxious that the science curriculum serves whatever instrumental purposes may be defined for it in terms of supposed social or economic needs, then the distinctive intellectual qualities of science will appear mainly as obstacles or affordances, to be defeated or exploited as necessary. In my view this latter position is not a principled stance. It is also not far, unfortunately, from that often visible in science education reform.

As well as focusing in a principled way on the intellectual qualities and contribution of science, an account of the science curriculum within the framework of liberal education has the further merit of fitting coherently within the curriculum as a whole. *Ad hoc* or instrumental purposes display no such wider coherence. One of the paradoxes of some of the current proposals for science curriculum reform is that they seek to retain science as an independent subject within a 'traditional' curriculum, while justifying it in ways which cut across the curriculum. Thus, in the repositionings identified in the previous sections it can be argued that the modes of analysis belong to sociology, philosophy, or even media studies, among other knowledge-domains. Yet the need for a cross-curricular perspective is not usually addressed, and perhaps not even apprehended, within much science curriculum reform. It is ironic, then, that the outcomes which are offered for a reformed science curriculum (e.g. the capacity to interpret media reports with a science element) would be precisely the result of a properly constituted liberal education aiming at informed critical autonomy for the student. In such an education the place of sociology, ethics, and even media studies, including their relationship to science, would need to be properly determined.

Over the last four decades, successive reform initiatives have been attempted within science education. Yet it would be a brave commentator who suggested that science education had improved significantly during that period, particularly if the judgement were to take into account the attitudes and future intentions of students. No doubt this situation has a range of causes, but I suggest that part of the difficulty stems from the lack of systematic attention given to the two dimensions of science education, its intellectual characteristics and educational purposes, that have been my principal focus in this paper. In particular, there has been a failure to acknowledge the extent to which the proper educational purposes of science should supervene on its distinctive intellectual characteristics. Those characteristics are not mere socio-political artefacts, to be adjusted at will, whatever the impression given by sociological accounts of curricular change (Young 1971, Goodson 1988).

The bulk of this paper has been concerned with exploring the key intellectual domains that need to figure in such an analysis, and the repositionings that have been attempted in relation to them within recent reform. I have not sought to offer an alternative view. It will probably be apparent that the argument I would seek to make would focus on the distinctive ontic and epistemic perspectives which science can contribute to a liberal education, and reject what I see as arbitrary attempts to appropriate ethical, political, and sociological perspectives. However, I would also acknowledge that the aims of the science curriculum can only be coherently formulated as part of the wider curriculum. Reform agendas often appear to adopt the mirror-image of this position. They forget or even denigrate what is distinctive about science, while seeking, sometimes opportunistically, to assimilate to it other forms of knowing. In the long-term this is not a sustainable position.

## Notes

1. I will use the word 'ontic' in preference to 'ontological' because, as in other settings, the suffix '-ology' is redundant, if not positively misleading. The word 'ontic' refers to the modes of being under which science (in this case) construes the world. Ontology refers to the systematic study of being. I am concerned principally with the former, and only occasionally with the latter.
2. The view that a quite different scientific account of the world would be possible if the evidence were interpreted differently.
3. Thus, for example, the US National Science Education Standards (National Research Council 1996: 201) offer the following claim, under the heading 'Nature of scientific knowledge': 'Science distinguishes itself from other ways of knowing and from other bodies of knowledge through the use of empirical standards, logical arguments, and skepticism …'. This claim seems almost perversely unwarranted on each count.
4. In England the word would be 'investigation', although even the most enthusiastic of its proponents appear now to be having second thoughts about its value, after the debacle of its statutory deployment within the National Curriculum (Roberts and Gott 2004).
5. In the UK at least, that strand has most recently resurfaced in the attempt by the President of the Royal Society to claim a distinctive place in the post-16 curriculum: 'the questioning and analytic approach—grounded on hard evidence where available and acknowledging uncertainty where appropriate—which might, for brevity, be termed "scientific reasoning"' (Royal Society 2004).
6. See Chapman (2004), Hall (2004), Monk (2004), and Spurgin (2004).
7. In this sentence I am deliberately using 'human' and 'animal' in their everyday, non-scientific sense. The scientific usage, in which human beings are indeed animals, sustains my wider point about the distinctive ethical discourse of science.
8. This is a somewhat different sense of the word 'purpose', focusing on matters extrinsic to the development of the individual student.

## References

21st Century Science Project Team (2003) *21st Century Science*—a new flexible model for GCSE science. *School Science Review,* 85(310), 27–34.

Abrams, D. (1996) *The Spell of the Sensuous: Perception and Language in a More-than-human World* (New York: Pantheon).
Aikenhead, G. (1994) The social contract of science: implications for teaching science. In J. Solomon and G. Aikenhead (eds), *STS Education: International Perspectives on Reform* (New York: Teachers College Press), 11–20.
Aikenhead, G. S. (2002) The educo-politics of curriculum development. *Canadian Journal of Science, Mathematics and Technology Education,* 2(1), 49–57.
Allchin, D. (2004) Should the sociology of science be rated X? *Science Education,* 88(6), 934–946.
Aronson, J. L., Harré, R. and Way, E. C. (1994) *Realism Rescued: How Scientific Progress is Possible* (London: Duckworth).
Ashman, K. M. and Barringer, P. S. (eds) (2001) *After the Science Wars* (London: Routledge).
Atkins, P. W. (1995) The limitless power of science. In J. Cornwell (ed.), *Nature's Imagination: The Frontiers of Scientific Vision* (Oxford: Oxford University Press), 122–132.
Bartholomew, H., Osborne, J. and Ratcliffe, M. (2004) Teaching students 'ideas-about-science': five dimensions of effective practice. *Science Education,* 88(5), 655–682.
Bausor, J. and Poole, M. (2003) Science education and religious education: possible links? *School Science Review,* 85(311), 117–124.
Bencze, J. L. (2000) Democratic constructivist science education: enabling egalitarian literacy and self-actualization. *Journal of Curriculum Studies,* 32(6), 847–865.
Birke, L. and Hubbard, R. (eds) (1995) *Reinventing Biology: Respect for Life and the Creation of Knowledge* (Bloomington, IN: Indiana University Press).
Black, P. and Atkin, J. M. (eds) (1996) *Changing the Subject: Innovations in Science, Mathematics and Technology Education* (London: Routledge, in association with OECD).
Brown, J. R. (2001) *Who Rules in Science? An Opinionated Guide to the Wars* (Cambridge, MA: Harvard University Press).
Cartwright, N. (1999) *The Dappled World: A Study of the Boundaries of Science* (Cambridge: Cambridge University Press).
Chandrasekhar, S. (1987) *Truth and Beauty: Aesthetics and Motivation in Science* (Chicago: University of Chicago Press).
Chapman, B. (2004) Opinion: 4.5 billion versus 4.5 thousand—no contest? *School Science Review,* 85(313), 8–10.
Clarendon Commission (1864) *Report of Her Majesty's Commissioners Appointed to Inquire into the Revenues and Management of Certain Colleges and Schools,* vols. xx, xxi [contain minutes of evidence] (London: Her Majesty's Stationery Office).
Cobern, W. W. and Loving, C. C. (2004) Defining science in a multicultural world: implications for science education. In E. Scanlon, P. Murphy, J. Thomas and E. Whitelegg (eds), *Reconsidering Science Learning* (London: RoutledgeFalmer), 195–214.
Cohen, B. C. (n.d.) The ethics of using medical data from Nazi experiments. *Jewish Law.* Available online at: http://www.jlaw.com/Articles/NaziMedEx.html, accessed 11 December 2005.
Collins, H. M. (1985) *Changing Order: Replication and Induction in Scientific Practice* (London: Sage).
Cooper, D. E. (2003) *Meaning* (London: Acumen).
Cross, R. T. (1997) Ideology and science teaching: teachers' discourse. *International Journal of Science Education,* 19(5), 607–616.
Department for Education and Skills (DfES) (2005) *14–19 Education and Skills—White Paper* (London: Her Majesty's Stationery Office). Available online at: http://www.dfes.gov.uk/publications/14-19educationandskills/, accessed 11 December 2005.
Devitt, M. (1984) *Realism and Truth* (Oxford: Blackwell).
Dirac, P. A. M. (1963) The evolution of the physicist's picture of nature. *Scientific American,* 208(5), 45–53.
Donnelly, J. (1999) Interpreting differences: the educational aims of teachers of science and history, and their implications. *Journal of Curriculum Studies,* 31(1), 17–41.
Donnelly, J. (2001a) Contested terrain: the nature of science in the National Curriculum for England and Wales. *International Journal of Science Education,* 23(2), 181–196.
Donnelly, J. (2001b) Instrumentality, hermeneutics and the place of science in the school curriculum. In F. Bevilacqua, E. Giannetto and M. R. Matthews (eds), *Science Education*

*and Culture: The Contribution of History and Philosophy of Science* (Dordrecht, The Netherlands: Kluwer), 109–127.

Donnelly, J. (2002) The 'humanist' critique of the place of science in the curriculum in the nineteenth century, and its continuing legacy. *History of Education,* 31(6), 535–555.

Donnelly, J. (2004) Humanizing science education. *Science Education,* 88(5), 762–784.

Donnelly, J., Buchan, A., Jenkins, E. W., Laws, P. and Welford, G. (1996) *Investigations by Order: Policy, Curriculum and Science Teachers' Work Under the Education Reform Act* (Nafferton, UK: Studies in Education).

Eflin, J. T., Glennan, S. and Reisch, G. (1999) The nature of science: a perspective from the philosophy of science. *Journal of Research in Science Teaching,* 36(1), 107–116.

Girod, M., Rau, C. and Schepige, A. (2003) Appreciating the beauty of science ideas: teaching for aesthetic understanding. *Science Education,* 87(4), 574–587.

Goodson, I. F. (1988) *The Making of Curriculum: Collected Essays* (London: Falmer).

Graham, L. R. (1981) *Between Science and Values* (New York: Columbia University Press).

Griffin, D. R. (1988) *The Reenchantment of Science: Postmodern Proposals* (Albany, NY: State University of New York Press).

Habermas, J. (1972) *Knowledge and Human Interests,* trans J. J. Shapiro (London: Heinemann).

Hacking, I. (1999) *The Social Construction of What?* (Cambridge, MA: Harvard University Press).

Hall, E. G. (2004) Rational or illiberal? [Letter to the Editor]. *School Science Review,* 86(314), 11–13.

Harding, S. (1998) *Is Science Multi-cultural? Postcolonialisms, Feminisms and Epistemologies* (Bloomington, IN: Indiana University Press).

Hepburn, R. W. (2001) Truth, subjectivity and the aesthetic. In R. W. Hepburn (ed.), *The Reach of the Aesthetic: Collected Essays on Art and Nature* (Burlington, VT: Ashgate), 16–37.

Hirst, P. H. (1974) Liberal education and the nature of knowledge. In P. H. Hirst (ed.), *Knowledge and the Curriculum: A Collection of Philosophic Papers* (London: Routledge & Kegan Paul), 30–53.

HM Treasury, DTI, AND DfES (2004) *Science & Innovation Investment Framework 2004–14* (London: Her Majesty's Stationery Office). Available online at: http://www.hm-treasury.gov.uk/spending_review/spend_sr04/associated_documents/spending_sr04_science.cfm, accessed 11 December 2005.

Hodson, D. (1998) *Teaching and Learning Science: Towards a Personalized Approach* (Buckingham, UK: Open University Press).

Holton, G. (1996) Science education and the sense of self. In P. R. Gross, N. Levitt and M. W. Lewis (eds), *The Flight from Science and Reason* (New York: New York Academy of Sciences), 550–560.

House of Commons Science and Technology Committee (2002) *Science Education from 14 to 19,* Third Report of Session 2001–02, Vol. I: Report and Proceedings of the Committee, HC 508-I (London: The Stationery Office). Available online at: http://www.publications.parliament.uk/pa/cm200102/cmselect/cmsctech/508/50802.htm, accessed 24 December 2005.

Hurd, P. D. (1997) *Inventing Science Education for the New Millennium* (New York: Teachers College Press).

Kant, I. (1926) *Fundamental Principles of the Metaphysics of Ethics,* 3rd edn, trans T. K. Abbott (London: Longmans).

Kuipers, T. A. F. (2000) *From Instrumentalism to Constructive Realism: On Some Relations Between Confirmation, Empirical Progress, and Truth Approximation* (Dordrecht, The Netherlands: Kluwer).

Labinger, J. A. and Collins, H. (eds) (2001) *The One Culture?: A Conversation about Science* (Chicago: University of Chicago Press).

Lacey, H. (1999) *Is Science Value Free?: Values and Scientific Understanding* (London: Routledge).

McComas, W. F. (1998) The principal elements of the nature of science: dispelling the myths. In W. F. Mc Comas (ed.), *The Nature of Science in Science Education: Rationales and Strategies* (Dordrecht, The Netherlands: Kluwer), 53–70.

McCulloch, G., Jenkins, E. W. and Layton, D. (1985) *Technological Revolution? The Politics of School Science and Technology in England and Wales Since 1945* (London: Falmer).

Millar, R. and Osborne, J. (eds) (1998) *Beyond 2000: Science Education for the Future: A Report with Ten Recommendations* (London: School of Education, King's College).

Monk, M. (2004) Science education and religious education [Letter to the Editor]. *School Science Review,* 85(312), 8–9.

Nanda, M. (2003) *Prophets Facing Backwards: Postmodern Critiques of Science and Hindu Nationalism in India* (New Brunswick, NJ: Rutgers University Press).

National Research Council (1996) *National Science Education Standards: Observe, Interact, Change, Learn* (Washington, DC: National Academy Press).

National Research Council (2000) *Inquiry and the National Science Education Standards: A Guide for Teaching and Learning* (Washington, DC: National Academy Press).

Osborne, J. and Collins, S. (2000) *Pupils' and Parents' Views of Science in the School Curriculum: A Study Funded by the Wellcome Trust* (London: King's College).

Osborne, J., Collins, S., Ratcliffe, M., Millar, R. and Duschl, R. (2003) What 'ideas-about-science' should be taught in school science? A Delphi study of the expert community. *Journal of Research in Science Teaching,* 40(7), 692–720.

Phillips, D. C. (ed.) (2000) *Constructivism in Education: Opinions and Second Opinions on Controversial Issues.* 99th Yearbook, Part 1, of the National Society for the Study of Education (Chicago: National Society for the Study of Education).

Roberts, G. (2002) *SET for Success: The Supply of People with Science, Technology, Engineering and Mathematics Skills* (London: HM Treasury). Available online at: http://www.hm-treasury.gov.uk/Documents/Enterprise_and_Productivity/Research_and_Enterprise/ent_res_roberts.cfm, accessed 11 December 2005.

Roberts, R. and Gott, R. (2004) Assessment of Sc1: alternatives to coursework. *School Science Review,* 85(313), 103–108.

Roth, W.-M. and Désautels, J. (eds) (2002) *Science Education as/for Sociopolitical Action* (New York: Peter Lang).

Royal Society (2004) Students should not turn their backs on science before 19, says Lord May. Press release, 26 October. Available online at: http://www.royalsoc.ac.uk/news.asp?year=&id=2660, accessed 11 December 2005.

Rudolph, J. L. (2002) *Scientists in the Classroom: The Cold War Reconstruction of American Science Education* (New York: Palgrave).

Sokal, A. D. (2001) What the *Social Text* affair does and does not prove: a critical look at 'science studies'. In K. M. Ashman and P. S. Barringer (eds), *After the Science Wars* (London: Routledge), 14–29.

Spurgin, B. (2004) Science teachers and religion [Letter to the Editor]. *School Science Review*, 85(312), 9–10.

Stevens, P. (1978) On the Nuffield philosophy of science. *Journal of Philosophy of Education,* 12, 99–111.

Tobin, K. and McRobbie, C. J. (1996) Cultural myths as constraints to the enacted science curriculum. *Science Education,* 80(2), 223–241.

Turner, S. and Sullenger, K. (1999) Kuhn in the classroom, Lakatos in the lab: science educators confront the nature-of-science debate. *Science, Technology and Human Values,* 24(1), 5–30.

Witz, K. G. (1996) Science with values and values for science education. *Journal of Curriculum Studies*, 28(5), 597–612.

Young, M. F. D. (ed.) (1971) *Knowledge and Control: New Directions for the Sociology of Education* (London: Collier-Macmillan).