De-Centring the 'Big Picture': "The Origins of Modern Science" and the Modern Origins of Science
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De-centring the 'big picture': *The Origins of Modern Science* and the modern origins of science

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> What had happened to him was that the ways in which it could be said had become more interesting than the idea that it could not.
>
> A. S. Byatt, *Possession*

Like it or not, a big picture of the history of science is something which we cannot avoid. Big pictures are, of course, thoroughly out of fashion at the moment; those committed to specialist research find them simplistic and insufficiently complex and nuanced, while postmodernists regard them as simply impossible. But however specialist we may be in our research, however scornful of the immaturity of grand narratives, it is not so easy to escape from dependence – acknowledged or not – on a big picture. When we define our research as part of the history of science, we implicitly invoke a big picture of that history to give identity and meaning to our specialism. When we teach the history of science, even if we do not present a big picture explicitly, our students already have a big picture of that history which they bring to our classes and into which they fit whatever we say, no matter how many complications and refinements and contradictions we put before them – unless we offer them an alternative big picture.

This paper is based on the principle that big pictures are both necessary and desirable: that if our subject is to provide not merely accumulated information or discourse without meaning, but vision, growth, understanding and liberation – as our students have a right to expect of us and as we have a right to demand of ourselves – then we need to think explicitly about the overall picture of the history of science which we present and within which we work. On this principle, the problem which we now face is not the existence of big pictures in general but the continued existence of the particular big picture on which our discipline was founded, having been established in the early years of its professionalization and embodied in textbooks such as Herbert Butterfield's *The Origins of Modern Science*. The power of this old big picture, and the difficulty with which our

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We are very grateful to Jim Secord for his invitation and encouragement to give an earlier version of this paper to the British Society for the History of Science conference 'Getting the Big Picture' in May 1991; to the respondents at that meeting, who inspired us to explain certain points more fully; to Nick Jardine and Harmke Kamminga for their expert and critical advice on several matters; and to John Christie, Ole Grell, Jonathan Hodge, Jim Secord, and an anonymous referee for various helpful suggestions. And finally we are grateful to our students, who have been our original audience and our original critics during the ten years that we have been developing this argument.

discipline is moving away from it, is revealed by the fact that *The Origins of Modern Science* is still in print, in paperback, over forty years after it first appeared, and that students continue to have their first and most formative encounter with the subject either through this book or through others that rely upon variously modified versions of the same big picture.[1]

That big picture is one which in principle covers the whole of human history in a single grand sweep; science is taken to be as old as humanity itself, so that the history of science can in principle run continuously from prehistoric megaliths and Bronze Age metallurgy to the human genome project. In practice, certain periods are selected for attention: for example, classical antiquity, the Middle Ages, and the early modern period. The 'scientific revolution' of the seventeenth century is regarded as a key event; Butterfield's title proclaimed that it represented 'the origins of modern science',[2] that is to say 'modern' as distinct from 'ancient' or 'medieval' science. It was supposed to mark the true beginning of the modern world and the abandonment of the ancient and medieval world, and for that reason Butterfield called it 'the supremely important field for the ordinary purposes of education', the one piece of the history of science which students of both the Arts and the Sciences should know. Butterfield and his followers were indeed successful in making the 'scientific revolution' 'supremely important'; today, it is almost unheard of for a History of Science course not to cover it in some way or another, and it is about the only piece of our discipline which has any currency in the general intellectual world.

This is now rather unfortunate, since over the past ten years the 'scientific revolution' concept has become increasingly difficult to sustain. In the first section of this paper, we survey the problems which have arisen with this concept since Butterfield's time. We realize that these will already be familiar to many readers. Our reason for rehearsing them here is to try to construct an account which explains why we are in our present position: an account which does not claim that Butterfield and his followers were idiots or worked with a defective historiography (as can so easily be done when attacking a former generation of historians), that is to say judging them by our lights and making them out to be failures, but one which acknowledges that they were brilliantly successful in terms of *their own aims*. Those aims we reconstruct as being the formulation and establishment of a concept encapsulating the particular big picture of the history of science which they wanted to promote: a big picture which was itself based on certain assumptions about the nature of

1 Herbert Butterfield, *The Origins of Modern Science 1300–1800*, 2nd edn, London, 1957. The chief rival as an introductory textbook in English is probably *The Scientific Revolution 1500–1800: The Formation of The Modern Scientific Attitude*, New York, 1954, by Butterfield's pupil, A. Rupert Hall, now in its second edition as *The Revolution in Science 1500–1750*, Harlow, 1983. See also Thomas S. Kuhn, *The Copernican Revolution: Planetary Astronomy in the Development of Western Thought*, Cambridge, Mass., 1957; C. C. Gillespie, *The Edge of Objectivity: An Essay in the History of Scientific Ideas*, Princeton, 1960; E. J. Dijksterhuis, *The Mechanization of the World Picture*, Oxford, 1961; Richard S. Westfall, *The Construction of Modern Science: Mechanism and Mechanics*, New York, 1971.

2 The title was also used by Koyré for a series of lectures at Johns Hopkins University in 1951. See his *From the Closed World to the Infinite Universe*, Baltimore, 1957, p. ix. Compare also the sub-title of Hall, 1954, op. cit. (1). 'The origins of modern science' was also the title of Chapter 1 of Alfred North Whitehead's *Science and the Modern World*, New York, 1925, the printed version of his Lowell lectures given the same year; he too was referring to the seventeenth century.

science which were common amongst science-supporting intellectuals in the years just before and just after the Second World War. What we are striving for here is a symmetrical account, which distances us from the legacy of a previous generation of historians, not by saying 'we're right and they're wrong', but by saying 'circumstances have changed'. In particular, what we are arguing is that the reason why the concept of the 'scientific revolution' is in trouble is, not that more or better research has been done, but that we have doubts about those beliefs about the nature of science and the big picture of the history of science which that concept encapsulated and promoted. The implication of this argument is that the concept of the 'scientific revolution' cannot be revived by tweaking, modification, or the addition of a few more 'social factors', or even a heavy dose of sociology of knowledge. And if the old big picture is going, then the 'scientific revolution' must go too. Indeed, trying to hold on to the concept may be damaging, for it will hinder us from developing a new big picture.

In so far as a new big picture is now being developed, inside and outside the profession of the History of Science, it seems to be pluralist in nature;[3] that is to say, it is based on the principle that there are many possible ways of knowing and studying the world, and that science is just the particular way-of-knowing currently dominant in our culture. Hitherto, in the old big picture, all ways-of-knowing-the-world which seemed sensible to the historian have been appropriated to a single, unitary 'history of science'. In the new big picture, a general history of ways-of-knowing-the-world across the whole of human history would have to be the history of many different things, rather than of one single thing at different stages of development. Working within this new big picture, it becomes important to understand the origin of our own culture's dominant way-of-knowing, though this is now to be seen not as the origin of modern science, by contrast with ancient or medieval science, that is the transition from one stage of science to another, but as the origin of science itself – or, as we personally prefer to call it (for reasons to be explained), the *invention* of science. A number of historians in recent years have attempted to discuss the origin of science, in the new sense, but almost without exception they have located it in the period of the old 'scientific revolution', on the assumption that these canonical events, suitably reinterpreted, correspond to the changes they are trying to identify. In principle, of course, there is no reason why science should not have originated at that time; but we believe that this happens not to be the case, and in the second section of this paper

3 Others, including other authors in this issue of the *BJHS*, would probably prefer to express this in the language of postmodernism. We are deliberately not using this language, not on the grounds of disagreement with postmodernism intellectually, but because we believe in using the minimum possible theory in an exposition, and in this case we think that all the necessary ideas can be adequately expressed in plain speech. The moral and political principle behind this stance is analogous to that behind the movement for 'intermediate technology', which seeks to develop solutions to the material problems of developing countries using only tools and materials which can be obtained locally – that is to say, without the importing of high technology which would tend to increase economic and political subordination to industrialized countries. The aim is to provide useful assistance in a form which does not lead to exploitative political relationships.

However, for those readers who want to explore how the ideas in this paper relate to postmodernism, we recommend not only the usually-cited Lyotard *The Postmodern Condition* but also Zuzana Parusnikova, 'Is a postmodern philosophy of science possible?', *Studies in History and Philosophy of Science* (1992), **23**, 21–37, which unusually for a work on postmodernism is not itself written in postmodern language.

we will argue that the period 1760–1848 is a much more convincing place to locate the invention of science.

We offer this sketch of the invention of science as a heuristic for teaching and research, and a contribution to the development of a new big picture, one which does not privilege one particular kind of knowledge. Its main significance, we think, is that it helps to demarcate more clearly the place in the big picture which our culture occupies. In the third section of this paper, we turn to the question of how we should deal with the remainder of the picture – that is to say, almost all of it. In the old big picture, science was taken to be a human universal, and so could act as a neutral framework on which to organize ways-of-knowing across the whole span of human history and human cultures. If we no longer assume that science is neutral and universal, a new big picture will require our vision to be jolted out of our culture and made aware of its contingency. We mention three forms of such 'de-centring', as we call it, the first of which is relatively close to existing practice, the second of which is more difficult to imagine but still, we think, quite feasible, and the third of which points towards a subject completely different from the History of Science as we know it now and which we ourselves can barely imagine, although some of the readers of this, starting from a more advanced baseline, may be able to do better – perhaps even eventually create it.

THE ORIGINS OF MODERN SCIENCE

Wise is the child that knows its father.
English proverb

It is now well established that our present concept of the 'scientific revolution' of the seventeenth century, whatever precedent it may have had in earlier writing, was forged by a number of scholars during the 1940s, chiefly Alexandre Koyré, whose work was then beginning to be taken up in the USA, and Herbert Butterfield, who promoted the concept in Britain, for example with his 1948 Cambridge lectures which were the basis for *The Origins of Modern Science*.[4] This first generation of those working professionally on the History of Science were generalists, not only from necessity, because there were too few of them to specialize, but because they had a big picture of the history of science which they were eager to communicate. That big picture was itself based on their view of what science was, for at this period the main reason for working on the history of science was to speak out on behalf of science itself and to explain its nature and importance.[5] To understand

4 Roy Porter, 'The scientific revolution: a spoke in the wheel?', in *Revolution in History* (ed. Roy Porter and Mikuláš Teich), Cambridge, 1986, 290–316, see 295. Precedents for the concept can be traced back to the eighteenth century; see John R. R. Christie, 'The development of the historiography of science', in *Companion to the History of Modern Science* (ed. R. C. Olby, G. N. Cantor, J. R. R. Christie and M. J. S. Hodge), London, 1990, 5–22, especially 7–9; also I. Bernard Cohen, *Revolution in Science*, Cambridge, Mass., 1985, 51–101.

5 For very clear evidence of this in the American context, see Arnold Thackray, 'The pre-history of an academic discipline: the study of the history of science in the United States, 1891–1941', in *Transformation and Tradition in the Sciences: Essays in Honor of I. Bernard Cohen* (ed. Everett Mendelsohn), Cambridge, 1984, 395–420, especially 402–5.

fully the concept of the 'scientific revolution', and the problems which we are now having with it, we need to understand the view of science that through it they were trying to promote.

Amongst the various kinds of people who were interested in promoting science at that time, we can distinguish at least three ways of characterizing its nature, which they used in various combinations. The first was philosophical, defining science as a particular method of enquiry, producing knowledge in the form of general causal laws, preferably mathematical, as in the physical sciences, or which could be reduced to this form. This characterization of science was a legacy of nineteenth-century positivism, and it was very strong in the 'logical positivist' position articulated in the 1930s by the Vienna Circle; but even those philosophers who were anti-positivist in their stance, such as, in their different ways, Emile Meyerson and Karl Popper, continued to accept it. Few doubted that the scientific method existed, or disputed the centrality of issues such as laws, explanation and prediction to the business of defining philosophically what science was.[6]

A second, less academic, way of characterizing science was to see it in essentially moral terms, as the embodiment of basic values of freedom and rationality, truth and goodness, and the motor of social and material progress. Those who characterized science in this way saw it as the disinterested pursuit of truth, undeflected by the sway of emotions, and free from personal, political or economic interest. They generally believed that rational, scientific thought, if more generally distributed amongst the population, would put an end to misunderstanding, prejudice and social conflict, and even to fascism and totalitarianism; a classic expression of this belief was Robert Thouless's *Straight and Crooked Thinking*, first published in 1930, which had the double aim of setting out the principles of 'straight thinking', exemplified by science, and of exposing dishonest rhetorical tricks and so freeing people from manipulation by politicians.[7] The promoters of science also believed that practically applied science could bring an end to suffering and want; futuristic utopias from this period tended to show happy contented people wearing plastic clothing, free from drudgery in a world of automated factories and domestic robots, their only problem being finding things to do with their time.[8]

A third way of characterizing science was as a universal human enterprise. By this, we mean that science was seen as the expression of an innate human curiosity, a general and universal desire to understand the world, that was a fundamental part of human nature and

6 Emile Meyerson, *Identity and Reality*, London, 1930; original French edition, 1908. K. R. Popper, *The Logic of Scientific Discovery*, London, 1959; original German edition, 1935.

7 Robert H. Thouless, *Straight and Crooked Thinking*, 1st edn, London, 1930. For example: 'A really educated democracy, distrustful of emotional phraseology and all the rest of the stock-in-trade of the exploiters of crooked thinking, devoid of reverence for ancient institutions and ancient ways of thinking, could take conscious control of our social development and could destroy those plagues of our civilisation – war, poverty, and crime' (244–5). A later example of the association of science and freedom (here construed as opposition to Soviet totalitarianism) is *Science and Freedom*, London, 1955, being the proceedings of a conference convened by the Congress for Cultural Freedom and held in Hamburg 23–26 July 1953.

8 See, for example, the vision of the far distant future ('Everytown 2036') in the 1936 film *Things to Come*, loosely based on H. G. Wells's *The Shape of Things to Come: The Ultimate Revolution*, London, 1933; the 1934 film *Plenty of Time for Play* (excerpted in the Open University television programme *The All-electric Home* written and presented by Gerrylynn Roberts, from the course A282 'Science, technology and everyday life 1870–1950'); the BBC television film *Time on our Hands*, first transmitted in 1963.

human thought throughout time and space. Many propagandists for science represented it in this way, deliberately challenging the older arts-based concept of humanity and humanism which prevailed in the university curriculum and in intellectual life generally;[9] thus George Sarton spoke of science as 'the *new* humanism', and Julian Huxley coined the phrase '*scientific* humanism' to represent his beliefs.[10] Others use the phrase 'science and civilization' in order to express their claim that science was central to human civilization properly understood – or according to some, that science *was* human civilization;[11] the best-known example of this phrase today is probably Joseph Needham's grand project on *Science and Civilisation in China*, which was originally conceived in the late 1930s.[12]

These were the three most usual characterizations of science amongst those seeking to promote it in the 1940s, and historians of science naturally incorporated elements of all of them as they developed the concept of 'the scientific revolution'. In the first place, the philosophical characterization of science led them to conceive 'the scientific revolution' as the seventeenth-century transformation of human thought into a form close to that of 'scientific knowledge' as defined by twentieth-century philosophers of science. Its defining events were taken to be those in which knowledge approximating to the ideal of general mathematical causal laws seemed to be achieved; since this ideal derived from the physical sciences, naturally enough the physical sciences supplied almost all the defining events – the Copernican revolution in astronomy, the Galilean revolution in mechanics, and the Newtonian synthesis, which were conceived in terms of mathematization and the 'mechanization of the world picture'.

At the same time, the moral characterization of science meant that the historians who developed the concept of 'the scientific revolution' attributed to these defining events liberal values such as freedom and independence of thought against superstition and Church dogma. They regarded the main theme of 'the scientific revolution' as being the elevation of experience above tradition and authority, or the rise of research and experiment as against the study of ancient texts; and this was supposedly exemplified in Copernicus's rejection of Ptolemy, Galileo's rejection of Aristotle and his challenge to the Catholic Church, and – a sole example from the 'life' sciences – Harvey's rejection of Galen. Because these historians conceived 'the scientific revolution' in terms of the

9 Thackray, op. cit. (5), 411.

10 George Sarton, *The History of Science and the New Humanism*, Bloomington, 1962, original edn 1930; Julian Huxley, 'Scientific humanism', in his *What Dare I Think? The Challenge of Modern Science to Human Action and Belief*, London, 1931, 149–77. C. P. Snow's *The Two Cultures and the Scientific Revolution* (Cambridge, 1959) was also an expression of this view; it is often forgotten that his reason for pointing out the cultural divide between the arts and the sciences was to complain that arts people did not sufficiently understand and respect the sciences. (Snow's 'scientific revolution', incidentally, was the change resulting from the application of science to industry, which he dated not earlier than 1920.)

11 Thackray, op. cit. (5), 401, 408. The identification of science and human thought was also common; for example, 'it was as though *science or human thought* had been held up by a barrier until this moment [i.e. until 'the scientific revolution']' (Butterfield, op. cit. (1), 7, our emphasis).

12 Cambridge, 1954– , i, 11. Jacob Bronowski's *The Ascent of Man* was commissioned by the BBC as a counterpart to a similarly epic television series on the history of art by Sir Kenneth Clark; J. Bronowski, *The Ascent of Man*, London, 1973, 13. One may surmise that it was extremely irritating to Bronowski that the title 'Civilisation' had already been commandeered by Clark for his subject; but in the event, his own title made an even stronger claim: that the history of science was the history of human *evolution* (ibid., 19–20).

advancement of free thought, they generally saw politics, religion and economic circumstances only as factors impeding its progress. But at the same time, the way in which they associated science with material advance and social harmony led them to emphasize such events as Bacon's prophecy of power over nature, and the formation of the Royal Society and the Académie Royale as instances of scientific co-operation.

Finally, the fact that these historians characterized science as a universal human enterprise meant that they conceived 'the scientific revolution' as only a revolution *within* science. Since they supposed the scientific enterprise to be a fundamental part of human nature, the history of science, for them, was in principle as long as the history of the human race itself; they counted all respectable knowledge about the natural world, wherever and whenever it was found, and however it had been produced, as some form of science. Thus despite the revolutionary nature of what they believed had happened in the seventeenth-century period, they supposed that there was still an essential continuity with the past; the ancients had engaged in essentially the same activity as the seventeenth-century heroes; they had tried to answer the same questions (such as the problem of motion), only they had not done so as well or to such an advanced level. The 'scientific revolution', despite its tremendous significance, thus consisted only of 'picking up the opposite end of the stick' or putting on 'a different kind of thinking-cap';[13] it was only a change of approach to the same, supposedly eternal, problems.

All these defining characteristics of 'the scientific revolution' now seem rather dubious. The most obvious explanation for this change is internalist (that is to say, in terms of things internal to the History of Science discipline): more recent detailed, specialized studies have undermined the general big picture of 'the scientific revolution' as it was first conceived.[14] For example, with respect to the philosophical characterization of 'the scientific revolution', it has proved very difficult to fit developments in the 'life' sciences into the mould of mathematization and mechanism; Harvey's discovery of the circulation of the blood, once seen as the exemplary case of the physiological application of mechanical ideas (e.g. the heart as a pump) is now generally accepted to have been the result of an essentially Aristotelian investigation into the 'final cause' of the heart's motion and structure, into the ways in which this organ served the purposes of the soul.[15] Even in the physical sciences, seventeenth-century mechanical philosophy has been found to have been much less close to the twentieth-century ideal than was once imagined; seventeenth-century natural

13 Butterfield, op. cit. (1), 7, 5.

14 One problem raised by more recent research, which we are not attempting to discuss here, is that the length of 'the scientific revolution' has expanded enormously, as everyone has tried to climb on the bandwagon. Now that it has been extended to the end of the eighteenth century in order to include Lavoisier (Butterfield wrote of 'The postponed scientific revolution in chemistry'; op. cit. (1), ch. 11), and back to the high medieval period to trace the origins of Galilean mechanics (as in the work of Alistair Crombie, following Pierre Duhem), we are faced with a scientific revolution which spanned maybe five centuries. As Roy Porter has nicely put it, compared with *Ten Days that Shook the World*, this is an extraordinarily leisurely revolution (op. cit. (4), 293).

15 See, for example, C. Webster, 'William Harvey's conception of the heart as a pump', *Bulletin of the History of Medicine* (1965), **39**, 508–17; Andrew Cunningham, 'Fabricius and the "Aristotle project" in anatomical teaching and research at Padua', in *The Medical Renaissance of the Sixteenth Century* (ed. A. Wear, R. K. French and I. M. Lonie), Cambridge, 1985, 195–222; Andrew Cunningham, 'William Harvey: the discovery of the circulation of the blood', in *Man Masters Nature: 25 Centuries of Science* (ed. Roy Porter), London, 1987, 65–76.

philosophers have been revealed to have described the universe in terms of not only matter and motion but also spirits and powers, the whole being dependent on a metaphysics anchored in a precise and complex theology.[16]

The moral characterization of 'the scientific revolution' too has been weakened by more recent research, as new historiographies laying emphasis on the role of 'context' or 'external factors' have made it more difficult to maintain the prime role of free, independent thought. For example, the work of Robert K. Merton started a new tradition of seeing the cardinal intellectual changes of 'the scientific revolution', in England at least, as a consequence of Puritanism (or, more generally, of Reformation and Counter-Reformation theologico-politics), and hence as a consequence of the development of capitalism.[17] At the same time, studies of the rise of the mechanical arts have revealed that practical technology played an important role in those intellectual changes, and was not simply a consequence of them. In general, it is now widely recognized that religion, politics and economics to a large extent facilitated, instead of impeding, those changes which supposedly defined 'the scientific revolution': some would say they *produced* or *were constitutive of* them.

Finally, difficulties have arisen with the characterization of 'the scientific revolution' as a stage in an enterprise as universal as (supposedly) human nature itself. A greater respect for the categories, values and enterprises of historical actors has led to the appreciation that, say, when the ancient Greek philosophers made reference to the soul or the Divine in their writings on the natural world they were not making a poor effort at modern science but were succeeding brilliantly at ancient Greek philosophy, the whole point of which was the cultivation of the soul for this life and the next. In the same way, it has been realized that when the supposed heroes of 'the scientific revolution' such as Newton used theology, mysticism, alchemy and biblical chronology in their study of the natural world this was neither insanity[18] nor a failure to be properly 'scientific' but part of a coherent attempt to reach a deeper understanding of the Christian God by studying His creation. It is now being recognized that even the post-'scientific revolution' way of studying the natural world was very different from what we now call science – so different, indeed, that it has taken a great deal of effort to recover it; and there is an increased awareness of the very deep differences between the ways the natural world has been conceived and studied in ancient, medieval, Renaissance, early modern and modern times.

16 A key work here was J. E. McGuire and P. M. Rattansi, 'Newton and the "pipes of Pan"', *Notes and Records of the Royal Society* (1966), **21**, 168–43. See also Betty Jo Teeter Dobbs, *The Foundations of Newton's Alchemy: Or 'The Hunting of the Greene Lyon'*, Cambridge, 1975. For current thinking on this subject, see Simon Schaffer, 'Occultism and reason', in *Philosophy, its History and Historiography* (ed. A. J. Holland), Dordrecht, 1985, 117–43; and Simon Schaffer, 'Godly men and mechanical philosophers: souls and spirits in Restoration natural philosophy', *Science in Context* (1987), **1**, 55–85.

17 The new interest in Merton is indicated by the reprint in 1970 of *Science, Technology and Society in Seventeenth Century England*, New York, originally published in *Osiris* in 1938; and by *Puritanism and the Rise of Modern Science: The Merton Thesis* (ed. I. Bernard Cohen), New Brunswick, 1990. See also Steven Shapin, 'Discipline and bounding: the history and sociology of science as seen through the externalism–internalism debate', *History of Science* (1992), **30**, 333–69. A leading example of how the 'Merton thesis' could be reapplied is Charles Webster, *The Great Instauration: Science, Medicine, and Reform, 1626–1660*, London, 1975.

18 This was what Biot claimed in his entry on Newton in the *Biographie universelle*, 2nd edn, Paris, 1854, xxx, 366–404, especially 390 and 401.

New historiography and new research on the history of science, then, provides one kind of explanation for why the original defining characteristics of 'the scientific revolution' now seem dubious.[19] But a more profound explanation, we believe, can be made in terms of things *external* to the discipline, in particular the weakening of those assumptions about the nature of science which were incorporated into the concept of 'the scientific revolution' when it was first developed. First, the philosophical characterization of science has become progressively weaker since the 1960s, when doubts began to grow about the existence of a single logically-defined scientific method. The most direct challenge came from Paul Feyerabend, whose *Against Method* argued that the scientific method as defined by Popper and others simply did not work; he claimed that what *had* worked historically, in the sense of producing the scientific knowledge which we now had, was a whole variety of methods, which could not be reduced to a single logical procedure. Thomas Kuhn's *Structure of Scientific Revolutions* was already providing a framework for thinking about a multiplicity of methods, by arguing that all aspects of methodology, including theory evaluation, were relative to a particular scientific community's set of shared beliefs, values, techniques, and exemplary problems – their paradigm, for short.[20] There was also heavy criticism of the view that all scientific knowledge could be reduced to a single unified science in the form of general causal laws; some philosophers argued that this could not be achieved for the whole range of the physical sciences, let alone the historical sciences, such as geology, or the natural historical sciences, such as botany.[21]

In the next place, the moral characterization of science as an embodiment of the highest standards of intellectual probity and as the motor of social and material progress was also challenged by the radical, feminist and environmental movements of the 1960s, 1970s and 1980s. From a radical perspective, scientific expertise began to be seen as a form of power and control, mistrust having been prompted especially by scientists who used their authority to suppress opposition to the nuclear industry, and it began to be argued that no kind of knowledge is ever truly free of value-judgement or economic and political interest. Feminist analysis called into question the very desirability of objectivity and control over

19 As David C. Lindberg and Robert S. Westman put it in the introduction to their edited collection *Reappraisals of the Scientific Revolution*, Cambridge, 1990, the last twenty years have seen 'highly focused studies [which] took root and began subtly to undermine the wall on which Humpty Dumpty sat' (p. xviii).

20 Paul Feyerabend, *Against Method: Outline of an Anarchistic Theory of Knowledge*, London, 1975; Thomas S. Kuhn, *The Structure of Scientific Revolutions*, 2nd edn, Chicago, 1970. For an interesting exegesis of Feyerabend's much-misunderstood philosophy, see José R. Maia Neto, 'Feyerabend's scepticism', *Studies in History and Philosophy of Science* (1991), **22**, 543–55.

21 Jerry Fodor, 'Special sciences, or the disunity of science as a working hypothesis', *Synthese* (1974), **28**, 77–115; Alan Garfinkel, *Forms of Explanation: Rethinking the Questions in Social Theory*, New Haven, 1981, ch. 2. We should admit that many scientists, physicists especially, still believe in the possibility and desirability of reduction and unification. For instance Phil Allport, 'Still searching for the Holy Grail', *New Scientist*, 5 October 1991, 55–6; Allport works in the High Energy Physics Group at the Cavendish Laboratory in Cambridge. In this article, he reasserts his commitment to the philosophy of Karl Popper, by contrast with that of Nancy Cartwright, and quotes with approval Gerald Holton, a Harvard professor of physics and historian of science, speaking in 1981 of theoretical physics being engaged in a quest for a Holy Grail: nothing less than 'the mastery of the whole world of experience, by subsuming it ultimately under one unified theoretical structure'. Interestingly, in view of the religious analogy which we draw in the final section of the present paper, Allport suggests that this 'monotheorist' ambition could never have become established without a long tradition of *monotheist* belief.

nature; when seen as a masculine attempt at emotional detachment from the world, these basic scientific ideals could seem positively pathological. And as the repercussions of the attempt to control nature became better known, and new terms such as pollution, acid rain and greenhouse effect entered the language, science and technology have ceased to be regarded as forces only for good; it became clear that they could create material problems which they were unable to solve.[22]

Finally, the characterization of science as the universal and trans-cultural knowledge-producing enterprise was weakened when this general disenchantment with modern science led to a search for ways of knowing the natural world that seemed not to share in its objectionable features. Whether a better way was sought through oriental religions, feminist epistemology, or the traditional culture of native Americans, the appreciation of the worth of alternative knowledge forms has led to a growing sense that the pursuit of science is not a fundamental, universal feature of human nature or human civilization, but simply one among many actual or possible ways of knowing the world.

These changes in the assumptions about the nature of science over the last twenty-five years have led to various attempts to rewrite the history of the 'scientific revolution'. One set of attempts in the late 1970s, springing particularly from the radical, feminist and environmental critiques of science, followed the traditional characterization of the 'scientific revolution', but re-evaluated it as a bad thing rather than a good thing: the origin of modern forms of repression and exploitation, rather than progress and liberation.[23] Other attempts, freed by the dwindling authority of philosophy of science over historiography, sought to add qualifications and provisos to the 'scientific revolution' concept, first by the introduction of 'external factors' such as religion, politics and economics, and then insights derived from the methods of anthropology and sociology – most recently the sociology of knowledge.[24] But as more and more elements have been added on to the 'scientific revolution' concept in an effort to make it convincing, the problem has arisen that the concept is no longer obviously coherent – a problem now acknowledged quite generally, and poignantly expressed by David Lindberg and Robert Westman in their 1990 *Reappraisals of the Scientific Revolution*.[25]

22 For the radical challenge, see for example Jerome R. Ravetz, *Scientific Knowledge and its Social Problems*, Oxford, 1971; the *Radical Science Journal*, which started publication in January 1974. For the feminist challenge, see for example Hilary Rose, 'Hand, brain, and heart: a feminist epistemology for the natural sciences', *Signs: A Journal of Women in Culture and Society* (1983–4), **9**, 73–90; Sandra Harding, *The Science Question in Feminism*, Milton Keynes, 1986. For the environmentalist challenge, see for example *The Limits to Growth* (ed. Club of Rome), London, 1972; *Only One Earth* (ed. Barbara Ward and René Dubos), London, 1972.

23 Carolyn Merchant, *The Death of Nature: Women, Ecology, and the Scientific Revolution*, San Francisco, 1980. Brian Easlea, *Liberation and the Aims of Science: An Essay on the Obstacles to the Building of a Beautiful World*, London, 1973; *Witch Hunting, Magic and the New Philosophy: An Introduction to Debates of the Scientific Revolution 1450–1750*, Brighton, 1980; *Science and Sexual Oppression: Patriarchy's Confrontation with Woman and Nature*, London, 1981.

24 For example, Steven Shapin and Simon Schaffer, *Leviathan and the Air-pump: Hobbes, Boyle, and the Experimental Life*, Princeton, 1985. Even more recently, there has appeared *The Scientific Revolution in National Context* (ed. Roy Porter and Mikuláš Teich), Cambridge, 1992, which unfortunately does not explore the question of what the scientific revolution was or whether it existed at all.

25 Op. cit. (19). The deliberate aim of the collection, and the conference which preceded it, was 'to offer at least a partial remedy' for the 'distressing situation' of the complete absence of 'a [general] picture fully consistent with recent developments [in scholarship]' (pp. xix–xx). 'Does any unity emerge' from the articles?

We do not want to discuss here the last twenty years or so of (to use Lindberg and Westman's image) attempts to put Humpty Dumpty together again. Our argument here is that such attempts are doomed to failure, because the 'scientific revolution' concept was specifically created to encapsulate a particular big picture and a particular view of the nature of science which, while extremely convincing in the 1940s, now seem increasingly implausible. The problem with the 'scientific revolution', we maintain, is not that insufficient research has been done, or that an up-to-date historiography is needed, or more 'external factors', or more sociology of knowledge, or discourse analysis, or whatever the current intellectual fashion happens to be. The problem is that historians are ceasing to believe in a single scientific method which makes all knowledge like the physical sciences, or that science is synonymous with free intellectual enquiry and material prosperity, or that science is what all humans throughout time and space have been doing as competently as they were able whenever they looked at or discussed nature; so small wonder that a concept developed specifically to instantiate these assumptions ceases to satisfy. If this position is correct, then (to use Nicholas Jardine's happy phrase) the 'scientific revolution' needs to be not so much rewritten as written off.[26]

This is not to say that those historians of science who have been studying the seventeenth century have been wasting their time; clearly something of great importance happened then with respect to the investigation of nature. We are not going to make any statement here about what that something might have been. We will, however, put forward our recommendation that whatever-it-is should not be referred to as 'the scientific revolution'. People at the time spoke, either proudly or contemptuously, of 'the new philosophy', and perhaps this phrase would be a better basis for conceiving and naming what happened then; or if it is felt necessary to include the word 'revolution', then we might speak of 'the mathematical revolution', since a great change in the scope and use of mathematics was at least one of its components. But we will leave *The Origins of Modern Science* there, since we now want to turn to the question of what kind of big picture we might construct to replace the old one.

THE MODERN ORIGINS OF SCIENCE

It was like having a nightmare about a man who had got it into his head that τριήρης was the Greek for 'steamer', and when it was pointed out to him that descriptions of triremes in Greek writers were at any rate not very good descriptions of steamers, replied triumphantly, 'That is just what I say. These Greek philosophers... were terribly muddle-headed, and their theory of steamers is all wrong'. If you tried to explain that τριήρης does not mean steamer at all but something different, he would reply, 'Then what does it mean?' and in ten minutes he would show you that you didn't know; you couldn't draw a trireme, or make a model of one, or even describe exactly how it worked. And having annihilated you, he would go on for the rest of his life translating τριήρης 'steamer'.

R. G. Collingwood, *Autobiography*

they ask rhetorically, and conclude that 'the reader will have to decide' (p. xx). If two scholars of such calibre, after several years of effort, can find no unity to put forward, then there is little hope of the rest of us faring any better.

26 Nicholas Jardine, 'Writing off the scientific revolution' (a review of Lindberg and Westman's *Reappraisals*), *Journal of the History of Astronomy* (1991), **22**, 311–18.

A new big picture must take account of the changed view of the nature of science. The old big picture was based on the conception of science in the time of Butterfield and Koyré – rooted in transcendent timeless logic and embodying absolute moral values of freedom, rationality and progress: a universal human enterprise. But a new big picture must be based on the emerging re-conception of science as historically contingent and embodying the values, aims and norms of a particular social group: one amongst a plurality of ways of knowing the world. In a new big picture, what we refer to as 'science' can no longer be used as a general defining framework; it must be seen as limited, bounded in time and space and culture.

The best way of establishing such a new big picture – both of fixing it in our own minds and of teaching it to a new generation of students – is surely to focus on those boundaries: to identify the origins of science and to explain how science came into being. To describe this project as identifying the origins of science unfortunately makes it sound like the project of Butterfield and others of investigating 'the origins of modern science', so it is necessary for us to reiterate that what they claimed to have identified was the appearance of the modern form of something transcendent: the definitive and most complete realization of something which had existed in potential throughout all human history; hence their frequent use of organic metaphors such as 'birth' and 'emergence', which implied an embryonic pre-existence and the unfolding of a pre-ordained plan. By contrast, identifying the origins of science, in the revised sense, would mean finding the first appearance, the first practice, of something which is distinct and specific to our own region of time and space, rooted in the particular circumstances of our culture.

In this section we will be proposing that the origins of science in this revised sense can be located in Western Europe in the period sometimes known as the Age of Revolutions – approximately 1760–1848.[27] This proposal may be somewhat unexpected, since, as far as we are aware, all those authors to date who have discussed the origins of science in the revised sense have assumed that these coincide with 'the origins of modern science' in the old big picture; in other words, that they are to be found in the so-called 'scientific revolution'.[28] Of course the major changes in the seventeenth century, in which one may continue to believe even while abandoning the old big picture and the 'scientific revolution' with it, certainly make it, at first sight at least, a plausible location for the origins of science, in the revised sense; but the extent to which the old big picture and its underlying view of

27 This takes its cue from the usage of E. J. Hobsbawm, *The Age of Revolution, 1789–1848*, London, 1962.

28 For example, Merchant, op. cit. (23), and Easlea, op. cit. (23), aimed to rewrite the history of the 'scientific revolution' as the origin of the present politically-oppressive way of knowing the world. The recent wave of anti-scientistic writings consistently ascribe to the 'scientific revolution' the origin of the scientistic outlook which they criticize; see for example Bryan Appleyard, *Understanding the Present: Science and the Soul of Modern Man*, London, Picador, 1992, especially ch. 2, 'The birth of science'. Mary Midgley's sophisticated and accessible *Science as Salvation: A Modern Myth and its Meaning*, London, 1992, is a partial exception. While she repeats the common view that it was in the seventeenth century that 'modern science first arose' (p. 1) and that matter began to be regarded as inert and passive, all interesting properties being attributed to God alone, she also relates present-day scientism to the expulsion of God from the investigation of nature in the nineteenth century. 'It is surely extraordinary that nineteenth- and twentieth-century thinkers have supposed that they could take over this attitude to matter unaltered, while eliminating the omnipotent Creator who gave sense to it, as well as the immortal soul which took its status from him' (p. 76).

science have permeated our discipline and its key concepts, such as the 'scientific revolution', makes it necessary to treat such an automatic assumption with caution. We believe that if historians of science were to come to this question of the origins of science afresh, without reference to the lines laid down by the founders of the discipline, they would locate them elsewhere. To explain why we are locating the origins of science in the Age of Revolutions, we will begin by making explicit the historiographic principles on which we have been working – principles which are, we believe, now relatively consensual within the profession.

The first of these principles, and the one that underlies and gives force to the others, is that the basic values and norms of science (its ideology, that is) are things which need explanation, rather than things which are to be taken for granted, as being above explanation, or to be used (without question) to explain other things. To put it another way, for example, the main question we used to ask about the 'objectivity' of science used to be: 'in what does the "objectivity" of science consist?'. The new question, by contrast, might be said to be: 'how did science come to have "objectivity" ascribed to it?' This principle follows from the values and norms of science no longer being seen as defined by absolute moral criteria or timeless logic, and the pursuit of science no longer being seen as a universal characteristic of human nature; if these things do not derive from some transcendent realm, then they are susceptible to, and require, historical explanation in the usual way.

The second principle is about the relation of knowledge to society, the position being that the knowledge in any society is an integral product of that society, and embodies within it the values and social relations of that society. This assumption has been used to good effect in 'New Left' work from the 1960s, and also in the more recent approach of the sociologists of science (many of whom are not politically of the Left at all).[29]

The third principle of historical enquiry concerns actors' categories. The work of Skinner and Dunn and others[30] has led us all (at least in principle) to try to respect and seek to understand the terms and categories in which the past people we study actually thought of and performed their work – in order to appreciate its authentic meaning and identity. In the recent formulation by Martin Rudwick: 'A non-retrospective narrative of any episode in the history of science should be couched in terms that the historical actors themselves could have recognised and appreciated with only minor cultural translation [to help the modern reader understand it]'[31] – and this respecting of actors' categories should not be limited to the moment when the historian is making his or her historical exposition,

29 Robert M. Young, 'The historiographic and ideological context of the nineteenth-century debate on man's place in nature', in *Changing Perspectives in the History of Science: Essays in Honour of Joseph Needham* (ed. Mikulàš Teich and Robert M. Young), London, 1973, 344–438. Steven Shapin, 'History of science and its sociological reconstructions', *History of Science* (1982), **20**, 158–211.

30 Q. R. D. Skinner, 'Meaning and understanding in the history of ideas', *History and Theory* (1969), **8**, 3–53. John M. Dunn, 'The identity of the history of ideas', *Philosophy* (1968), **43**, 85–104. Adrian Wilson and T. G. Ashplant, 'Whig history and present-centred history', and T. G. Ashplant and Adrian Wilson, 'Present-centred history and the problem of historical knowledge', *The Historical Journal* (1988), **31**, 1–16 and 253–73 respectively.

31 Martin J. S. Rudwick, *The Great Devonian Controversy: The Shaping of Scientific Knowledge Among Gentlemanly Specialists*, University of Chicago Press, 1985, 14.

but should apply also to the categories within which the historian conducts his or her researches as well.

Finally the fourth principle is to do with projects of enquiry: that it is necessary to identify the particular and specific 'projects of enquiry' in which people in the past were engaged in their investigations of nature. This is a particular form of the more general principle of 'Question and Answer' (as it was originally termed by Collingwood):[32] when we read texts from the past, we need to ask ourselves, 'to what *question* – both what immediate question, and what project of enquiry – in the life and world of the person who wrote it, was this text the *answer* for its author?'. For without knowing the project that a particular historical actor was engaged on, the results arrived at by that historical actor are meaningless to us; the answer is meaningless without the question. By assigning, consciously or unconsciously, the wrong project or the wrong question to the historical actors we are investigating, the results or answers that they arrived at are given the wrong meaning by us (usually a modern-day meaning). These four historiographic principles are, we believe, now relatively consensual within the profession; for example 'Whig' or 'present-centred' history would violate all four criteria, and few would now defend it.[33]

But as well as forbidding certain things, these principles can be of positive assistance in approaching the problem of the origins of science. For instance, taking the final two together, Principle 4, about projects of enquiry, suggests that we should direct our attention, not simply to statements about the natural world in past texts, but to the precise enterprises of which these thoughts and statements were part and which gave them their identity and meaning. Principle 3, actors' categories, suggests that we should take past people's own accounts of their enterprises, including their own names for them, very seriously indeed.

Following these two principles, we can start by noticing and taking seriously the fact that it was not until the beginning of the nineteenth century that the term 'science' was used for the enterprise of investigating the natural world in the way that it is used today.[34] The word 'science', deriving as it does from the Latin word *scientia*, existed prior to the nineteenth century of course. But it was not restricted to the investigation of nature, for it was used for all disciplines which dealt in terms of theory (or for the theoretical side of

32 R. G. Collingwood, *An Autobiography*, first published 1939, reprinted 1978, Oxford University Press, ch. 5, 'Question and answer'. A recent development of this philosophical argument is Nicholas Jardine, *The Scenes of Inquiry: On the Reality of Questions in the Sciences*, Oxford, 1991.

33 The term 'Whig' history derives from Herbert Butterfield, *The Whig Interpretation of History*, London, 1931. Unfortunately many people use the term as an all-purpose smear for historiography of which they disapprove, without having read *The Whig Interpretation*, and occasionally without even being aware of its existence. On this issue we recommend Wilson and Ashplant, op. cit. (30). (They propose the term 'present-centred' as a more precise and more general substitute for 'Whig'.)

34 Sadly, there have been virtually no critical discussions of the changing meaning of the word 'science'. It is probably significant that the most accessible account we know of was *not* the work of a historian of science: Raymond Williams, *Keywords: A Vocabulary of Culture and Society*, London, 1976, s.v. 'science'. There has been one good study of the word 'scientist': Sydney Ross, '"Scientist": the story of a word', *Annals of Science* (1962), **18**, 65–86. This, however, is a good deal less threatening to the discipline; the invention of the word 'scientist' can be interpreted in terms of 'professionalization' – that is, merely a change in the organization of essentially the same activity.

all disciplines), theory which was based on firm principles, and for the knowledge generated within such disciplines. Thus most of the disciplines concerned with the natural world were 'sciences', but grammar was also a science, and so was rhetoric, and so was theology. Indeed theology was often regarded as 'the Queen of the Sciences' right up until the end of the eighteenth century, whereas today it would not qualify as a science at all under our modern meaning of the term. What this difference in the application of the term 'science' should lead us to see is that for hundreds of years before this time, when western people studied the natural world they did so not as 'science' but within other disciplines, the disciplines of either 'natural history', or 'mixed mathematics' or especially 'natural philosophy'.

Yet the meaning of the most important of these, 'natural philosophy', to the historical actors themselves who actually practised it, has scarcely been investigated by historians of science. Instead it has been treated as if it was transparent: almost without exception historians of science have simply translated it as 'science' or treated it as if it meant 'science' in the modern sense, as though the two terms were interchangeable in the past;[35] or historians have thought of the term 'natural philosophy' as meaning a sort of 'general world-view', a cosmology within which the detailed, empirical investigations of science itself were performed. It is only recently that a few historians of science have regularly begun to leave the term 'natural philosophy' as it is. This has opened up the possibility of recognizing that while natural philosophy was itself indeed an investigation of the natural world which was sometimes empirical and sometimes even experimental, yet it was nevertheless one which was radically different from 'science' in the modern sense.

For the whole point of natural philosophy was to look at nature and the world *as created by God*, and as thus capable of being understood as embodying God's powers and purposes and of being used to say something about them. This is what Newton, the most famous practitioner of natural philosophy, was saying when he commented in 1692 'Et haec de Deo: de quo utique ex phaenomenis disserere, ad Philosophiam experimentalem pertinet', it is the role of experimental natural philosophy to discourse of God from the phenomena. Newton shared this view of the role and purpose of natural philosophy with all other natural philosophers, as he did his belief that the study of natural philosophy, properly conceived and pursued, was a bulwark against atheism.[36] Natural philosophy scrutinized, described, and held up to admiration the universe as the true God had created it and kept it running. To the modern ear, accustomed to the distinction between 'science' and 'religion', and to a clear-cut distinction between the 'sacred' and the 'secular', this may sound as though natural philosophy was merely an aspect of theology (and particularly that it was 'natural theology'). But this was not the case: natural philosophy was an autonomous study separate from theology and from natural theology, but whose practitioners had at the forefront of their minds, as Creator of the universe they were studying, the same God whose attributes the theologians studied from other points of view.

35 One spectacular instance we have come across is of the title of Newton's 1687 work being rendered into English as 'Mathematical Principles of Natural *Science*'.

36 See Andrew Cunningham, 'How the *Principia* got its name; or, taking natural philosophy seriously', *History of Science* (1991), **29**, 377–92.

We will probably catch the appropriate attitude of reverence toward the Creation that a natural philosopher necessarily held, if we regard natural philosophy not as a sacred study, but as a godly or pious one, which could be conducted by men both in and out of holy orders.[37] To confuse natural philosophy with science is to repeat Collingwood's nightmare about the man who had got it into his head that trireme was the Greek for 'steamer'.[38] The historical study of the trireme of natural philosophy is still at an early stage, but that does not mean that we can afford to interpret the term 'natural philosophy' as meaning the 'steamer' of science.

Thus the principles of 'projects of enquiry' and 'actors' categories' suggest that a major change in nomenclature applied by the historical actors themselves might well mark a change in the identity of the discipline under which they investigated nature. On this basis, a strong candidate for the origins of science, in the revised sense, should be the period when people stopped using the term 'natural philosophy' to refer to the identity of their project of investigating nature, and started, for the first time, to speak of 'science' or 'the sciences' referring *only* to the sciences of nature. And this period was around the beginning of the nineteenth century.[39]

Now this period is one which has already been identified as highly significant in the history of science. For one thing, it was the period when many new disciplines for the investigation of nature were created. Through Lamarck in France and Treviranus in Germany the discipline of 'biology' was created in the years around 1800 as a new discipline to replace the old study of the 'animal economy' or 'animated nature', which had dealt with the nature of those things endowed with 'soul' (*anima*, in Latin): biology now covered the same area, but now defined in terms of 'life' (*bios*, in Greek). The 'soul', the very thing which had united animals and plants as an area of study, was to be dismissed from this new discipline, and even to be regarded as something 'unscientific'. Geology, and its subsidiary sciences, was another new discipline created at this period. In the hands of Cuvier and Lyell and others, an old discipline which had been described as a '*sacred* history', and in which one had studied the earth as created and modified by God, was replaced by a *secular* history to which questions about God, Creation and Providence were deemed irrelevant and inappropriate. Radical transformations took place also in the meaning and content of other old disciplines for the investigation of nature: there was for instance a new version of physics (as Robert Fox and Maurice Crosland have shown for Laplace and the Society of Arceuil in France, and Susan Faye Cannon has shown for England). Similarly, there was a new version created of that old discipline, physiology.[40]

37 The difficulty of finding a term which conveys the sense of Christian belief typical of early modern people and which informed the natural philosopher's view of the discipline and its subject matter (nature as created by God), but which does *not* oppose such a position to notions of objectivity, secularity, and science, is itself indicative of the distance of the identity of natural philosophy from that of science.

38 Collingwood, op. cit. (32), 64.

39 The argument of this paragraph is put in more detail in Andrew Cunningham, 'Getting the game right: some plain words on the identity and invention of science', *Studies in History and Philosophy of Science* (1988), **19**, 365–89.

40 M. J. S. Hodge, 'Lamarck's science of living bodies', *BJHS* (1971), **5**, 323–52. Dorinda Outram, *Georges Cuvier: Vocation, Science and Authority in Post-Revolutionary France*, Manchester, 1984. Timothy Lenoir, *The Strategy of Life: Teleology and Mechanics in Nineteenth Century German Biology*, Dordrecht, 1982. Roy Porter,

This period has also been identified as the one in which it first became possible for people interested in investigating the natural world to do so as a career. Professional organizations, too, can be found at this period. Although Britain lagged far behind France and the German states in these matters, one can find at this time even in England the beginning of the professional career and the first professional organizations of science, such as the British Association for the Advancement of Science (copied from a German model) or the reformed Royal Society: 'professional' in the sense that the gentleman amateur was beginning to be replaced by the professional (salaried) man as the model type of person who pursued the knowledge of nature. In producing this new professional of science, a great part was played by the universities and other institutions of higher learning, especially the French ones which had been reformed as a result of the French Revolution, and the new secular University of Berlin, which was the model for other universities in Prussia and the other German states.[41]

It is now also recognized that in this period a new kind of site dedicated to the production of knowledge about nature first became common and came to be seen as basic to research in the sciences of nature: the laboratory. In chemistry the term 'laboratory' had long been used for the workplace, but now laboratories began to be created in physics, physiology, and later other new sciences such as bacteriology. Professors of the nature-sciences in the German universities were provided by their respective states with their own laboratories and were expected to use them to find out new things about nature. This was the basis of the laboratory research careers of Müller and Liebig, of Helmholz, Virchow and Koch, who were expected to (and did) establish research schools based on teaching laboratories. This pattern of state-provided laboratories was to be envied and emulated by French men of science, by the British and by Americans. In the laboratory research methods were taught in practice, and new generations of experimental researchers into nature were reared. It is now clear that between them they established the laboratory as the main locus

The Making of Geology: Earth Science in Britain 1660–1815, Cambridge, 1977. Susan Faye Cannon, *Science in Culture: The Early Victorian Period*, New York, 1978, especially the chapter on 'The invention of physics'. Maurice Crosland, *The Society of Arcueil: A View of French Science at the Time of Napoleon I*, London, 1967. Robert Fox, 'The rise and fall of Laplacean physics', *Historical Studies in the Physical Sciences* (1974), **4**, 89–136. *The Invention of Physical Science: Intersections of Mathematics, Theology and Natural Philosophy since the Seventeenth Century* (ed. Mary Jo Nye, Joan Richards and Roger Stuewer), Dordrecht, 1992. John Lesch, *Science and Medicine in France: The Emergence of Experimental Physiology, 1790–1855*, Cambridge, Mass., 1984. W. R. Albury, 'Experiment and explanation in the physiology of Bichat and Magendie', *Studies in the History of Biology* (1977), **1**, 47–131.

41 For Britain see Jack Morell and Arnold Thackray, *Gentleman of Science: Early Years of the British Association for the Advancement of Science*, Oxford, 1981. Marie Boas Hall, *All Scientists Now: The Royal Society in the Nineteenth Century*, Cambridge, 1984. On France see for instance Dorinda Outram, 'Politics and vocation: French science 1793–1830', *BJHS* (1980), **13**, 27–43; Robert Fox, 'Science, the university, and the state in nineteenth century France', in *Professions and the French State 1700–1900* (ed. Gerald Geison), Philadelphia, 1984, 66–145; Robert Fox, 'Scientific enterprise and the patronage of research in France 1800–70', *Minerva* (1973), **11**, 442–73. On Germany see R. Steven Turner, 'The growth of professorial research in Prussia, 1818 to 1848 – causes and context', *Historical Studies in the Physical Sciences* (1971), **3**, 137–82; on Berlin, see Elinor S. Shaffer, 'Romantic philosophy and the organization of the disciplines: the founding of the Humboldt University of Berlin', in *Romanticism and the Sciences* (ed. Andrew Cunningham and Nicholas Jardine), Cambridge, 1990, 38–54.

of the creation and assessment of most natural knowledge. The laboratory was made the final arbiter of truth about nature.[42]

More controversially, the growing body of work on this period enables it to be characterized as a time when the investigation of nature was changed from a 'godly' to a secular activity. This does not mean that there was a decline in religious belief (although there probably was); the important thing is that religious beliefs became private. It is possible today for scientists to have religious beliefs, but these are supposed to be irrelevant to their science; their religion is supposed to be a matter *only* of private belief. As sociologists use the term, 'secularization' means religious institutions giving way to new social institutions in matters of politics, education, social policy and morality.[43] And this kind of change was just what happened in the Age of Revolutions as new political, legal and educational institutions were established across Europe, inspired by the *philosophes*, as with the educational systems of Prussia and Hannover, or imposed by the administrators of Napoleon's Empire. Despite the political changes following from the Bourbon Restoration, most of the new legal, educational and administrative institutions were preserved intact, and even in political terms no country returned to the *ancien régime*. What we are pointing to here is that, paralleling this creation of new secular institutions, there was the creation of new secular disciplines – or the desacralizing of old ones.[44] Epitomizing which is that wonderful if perhaps apocryphal moment when Laplace said to Napoleon – when the world's top physicist said to the world's most powerful man – that he had 'no need of the hypothesis' of God in his account of the Heavenly Mechanism, having effectively, in his *Traité de mécanique céleste* (1799–1825), taken God out of Newton's universe.[45] Coupling this with the observation about the abandoning of the term 'natural philosophy' previously used for the study of the natural world as created by the Christian God, our claim can be stated most simply: that 'science' was the new collective name of the new secular disciplines for studying the natural world as a secular object, for the discovery of abstract regularities in nature and for the exploitation of natural resources, for acquiring knowledge in a secular sense and for material and social improvement.

This is a sketch of these changes in broad brush strokes. Of course, when we come to look in detail, we find that there were local contests for the meaning of the important terms, and the term 'science' in particular was used by many who did not agree that the investigation of the natural world should be a secular activity. This was especially the case in England, which frankly is an exception to this pattern. But we believe that it is the exception which proves the rule, because it was an exception at every level. Although in

42 See the articles in *The Development of the Laboratory: Essays on the Place of Experiment in Industrial Civilization* (ed. Frank A. J. L. James), Basingstoke, 1989; in *The Investigative Enterprise: Experimental Physiology in Nineteenth-Century Medicine* (ed. William Coleman and Frederic L. Holmes), Berkeley, Calif., 1988; and in *The Laboratory Revolution in Medicine* (ed. Andrew Cunningham and Perry Williams), Cambridge, 1992.

43 See, for example, Tony Bilton *et al.*, *Introductory Sociology*, London, 1981, which defines secularization as 'the process through which religious thinking, practice, and institutions lose their social significance' (p. 531). The crucial word here is 'social'.

44 Owen Chadwick, *The Secularization of the European Mind in the Nineteenth Century*, Cambridge, 1975.

45 On the Laplace story see Roger Hahn, 'Laplace and the mechanistic universe', in *God and Nature: Historical Essays on the Encounter Between Christianity and Science* (ed. David C. Lindberg and Ronald L. Numbers), Berkeley, California, 1986, 256–76.

the eighteenth century England had been the source of inspiration for French and German intellectuals, the defensive reaction of the British to the French Revolution meant that England was slow to follow the transformations in the study of nature taking place on the Continent. In England the Church and the aristocracy stayed largely in control, and Oxford and Cambridge, the main institutions of learning, were kept avowedly Christian. Exceptional institutions of learning such as the University of London (later University College London), founded in 1826 to represent the radical, God-less and Utilitarian view, were deeply controversial. Even the attempt to found the British Association for the Advancement of Science on the German model of the Gesellschaft Deutscher Naturforscher und Ärzte was almost immediately hijacked by Cambridge dons such as William Whewell and devoted to the pursuit of a Christianized contemplative knowledge of nature.[46] Until mid-century, the most forward-looking amongst young British men went to France and the German states to study. Not until around 1860 did corresponding institutional and intellectual changes happen in England and enable it to catch up with the Continent; hence although we can find individual attempts to model English investigation of the natural world on the Continental pattern, yet still most such investigation by the English remained God-centred – that is, it remained Natural Philosophy – until then.[47]

We are proposing that the origins of science can be located as one aspect of the Age of Revolutions (with England as a partial exception, in that changes there took place later and more gradually than in Continental Europe). These revolutions, as conventionally characterized, are: (1) the French Revolution, beginning in 1789, which was a political revolution, concerned with radically transforming the political organization of society; (2) the industrial revolution, beginning in Britain in the 1770s, a revolution in the means of production, exchange and ownership of the wealth or resources of society; and (3) the post-Kantian intellectual revolution, centred on the German states, a revolution in what one should think and in who should be the intellectual masters of the future. As a result of these simultaneous and linked revolutions, a new middle class was consolidated, wielding the political power, the industrial power, and the intellectual power.

To locate the origins of science in these events nicely conforms to the second historiographic principle outlined above, that the knowledge of any society is an integral product of that society. For it is to be expected that the invention of a new form of intellectual activity should be the product of a major social change, such as the consolidation of a new social class with new power bases.

Locating the origins of science in the Age of Revolutions is also supported by the first

46 J. B. Morrell, 'Brewster and the early British Association for the Advancement of Science', in '*Martyr of Science': Sir David Brewster 1781–1868* (ed. A. D. Morrison-Low and J. R. R. Christie), Edinburgh, 1984, 25–9; Morrell and Thackray, op. cit. (41), especially 63–76, 165–75. For an argument that Whewell's entire philosophy was part of a programme to bring the investigation of the natural world back into the service of the Christian God and the established social order, see Perry Williams, 'Passing on the torch: Whewell's philosophy and the principles of English university education', in *William Whewell: A Composite Portrait* (ed. Menachem Fisch and Simon Schaffer), Oxford, 1991, 117–47.

47 Frank M. Turner, 'The Victorian conflict between science and religion: a professional dimension', *Isis* (1978), **69**, 356–76. W. H. Brock and R. M. Macleod, 'The scientists' declaration: reflexions on science and belief in the wake of *Essays and Reviews* 1864–5', *BJHS* (1976), **9**, 39–66. Ruth Barton, 'The X Club: Science, Religion, and Social Change in Victorian England', Ph.D. thesis, University of Pennsylvania, 1976.

historiographic principle, that the norms and values of science require explanation rather than being truths derived from some transcendent realm. For the emergent middle class, or to be more precise, the emergent *professional* middle class, drew its authority from all three revolutions, the intellectual, the political and the industrial. First they drew authority from the intellectual revolution, following which primacy was given to the autonomy of ideas and to the attendant concepts of 'originality' and 'genius', with intellectual achievement being considered to be above the market and something to be judged only by one's peers. Secondly the professional middle class drew authority from the political revolution, as developed into the ideology of liberalism: a philosophy not only of free trade but also of free enquiry (especially criticism of the old powers, Church and aristocracy); a philosophy arguing for the establishment of a new aristocracy of intellectual talent – a 'meritocracy', as we would say today. Thirdly the professional middle class also drew authority from the industrial revolution, for although this benefited the commercial-industrial middle class more directly, the two classes at this time saw their interests as essentially coincident and worked closely together, for example in promoting a vision of progress and prosperity, both social and material, in which the professional middle class's secular knowledge, disseminated by new secular education, would be vital. In these three revolutions can be seen the origin of values and aims – for example, genius, free enquiry, free exchange of ideas, objectivity, disinterestedness – which have been made an integral part of the identity of science.[48]

Finally, the location of the origins of science in the Age of Revolutions is supported by the observation that this period also saw the start of many of the particular stories about the history of science which were handed down to Butterfield's generation, and hence down to our own time. In the same way that long, distinguished national traditions were constructed to support the existence of the new nation states,[49] so a long, distinguished intellectual tradition was now also constructed to support the existence of the new enterprise, science.[50] Building on the twin traditions created in the eighteenth century by

48 On intellectual transformation and liberalism, see Raymond Williams, *Culture and Society, 1780–1950*, London, 1958, especially Introduction and chs. 1–2; M. H. Abrams, *The Mirror and the Lamp: Romantic Theory and the Critical Tradition*, London, 1971; Marilyn Butler, *Romantics, Rebels and Reactionaries: English Literature and its Background 1760–1830*, Oxford, 1981; R. Steven Turner, 'The growth of professorial research in Prussia, 1818 to 1848 – causes and context', *Historical Studies in the Physical Sciences* (1971), **3**, 137–82; T. W. Heyck, *The Transformation of Intellectual Life in Victorian England*, London, 1982; Christopher Harvie, *The Lights of Liberalism: University Liberals and the Challenge of Democracy 1860–86*, London, 1976; Irene Collins, 'Liberalism and the newspaper press during the French Restoration, 1814–1830', *History* (1961), **46**, 17–32; R. Hinton Thomas, *Liberalism, Nationalism and the German Intellectuals 1822–1847*, Cambridge, 1951.

49 See for example Eric Hobsbawm and Terence Ranger (eds.), *The Invention of Tradition*, Cambridge, 1984.

50 Apparently some people find this claim difficult to countenance; but an argument of this kind was being made as long ago as 1970, by Thomas Kuhn in *The Structure of Scientific Revolutions*, in the chapter on 'The invisibility of revolutions':

> Characteristically, textbooks of science contain just a bit of history, either in an introductory chapter or, more often, in scattered references to the great heroes of an earlier age. From such references both students and professionals come to feel like participants in a long-standing historical tradition. *Yet the textbook-derived tradition in which scientists come to sense their participation is one that, in fact, never existed.* For reasons that are both obvious and highly functional, science textbooks (and too many of the older histories of science) refer only to that part of the work of past scientists that can easily be viewed as contributions to the statement and solution of the texts' paradigm problems [op. cit. (20), 138, our emphasis.]

the French *philosophes* and the German Romantics, early nineteenth-century men of science located science's origin at one or the other of the periods in which these two groups had located the origin of their own forms of philosophy, namely the seventeenth century and ancient Greece respectively.[51] As they co-opted the people of these two periods to serve their own political and social ambitions, the new men of science naturally recast them in a contemporary mould: the ancient Greeks were represented as having established free enquiry into the natural world, appealing only to natural principles and not to gods, while Galileo, Bacon, Descartes, and Newton were represented as having led the way back to this Greek way of thinking and then gone beyond it by establishing a physicalist, mechanist science, free from the constraints and superstitions of religion.[52] This period, in other words, saw not only the beginning of the history of science, but also the origin of the specific 'Whiggish' or 'present-centred' traditions of the history of science which our own generation of historians have inherited, and from which we have been trying to move away for some twenty-five years. It was also this period which saw the origin of that tradition of political history which Herbert Butterfield first called 'the Whig interpretation'; this was created by Whigs or liberals writing constitutional histories, in which all the causes for which they were currently fighting were presented as having been anticipated long ago and fought for for centuries, so that their values seemed transcendent and eternal, their own victory historically-ordained.[53] Here, surely, is the reason why it has been so natural to adopt critically for the history of science a term originally coined in the context of political history: the triumphalist progressivist 'Whig' traditions in the history of politics and the history of science are twin traditions: they were constructed at the same time, by some of the same people, in the service of the same political interests.[54]

To sum up, historical scholarships over the last twenty years enables us to identify the Age of Revolutions as the period which saw the origin of pretty well every feature which is regarded as essential and definitional of the enterprise of science: its name, its aim (secular as distinct from godly knowledge of the natural world), its values (the 'liberal' values of free enquiry, meritocratic expert government and material progress), and its history.

For some concrete examples of how revolutionary changes have been made invisible by newly-constructed histories, we recommend *Functions and Uses of Disciplinary Histories* (ed. Loren Graham, Wolf Lepenies and Peter Weingart), Dordrecht, 1983.

51 On the *philosophes* see Christie, op. cit. (4), 7–8; I. Bernard Cohen, 'The eighteenth-century origins of the concept of scientific revolution', *Journal of the History of Ideas* (1976), **37**, 257–88. For the classic expression of the Romantic view of the Greeks, and of the supposed 'rediscovery' and emulation of the Greek approach in the Renaissance, see Jacob Burckhardt, *History of Greek Culture*, originally published as *Griechische Kultur*, 1898–1902; and his *Civilization of the Renaissance in Italy*, originally published as *Kultur der Renaissance*, 1860. On the historical roots of this image of the Greeks see Martin Bernal, *Black Athena: The Afroasiatic Roots of Classical Civilisation*, Vol. 1, *The Fabrication of Ancient Greece 1785–1985*, London, Free Association Press, 1987; Wallace K. Ferguson, *The Renaissance in Historical Thought*, Cambridge, Mass., 1948.

52 For an example of 'Whig' history of science being deployed for political ends, see John Tyndall, 'The Belfast address', in *Fragments of Science*, 6th edn, 2 vols., London, 1879, ii, 137–203.

53 See Butterfield, op. cit. (33). See also Peter J. Bowler, *The Invention of Progress: The Victorians and the Past*, Oxford, 1989.

54 For a perfect example of a Whig politician and historian creating a 'Whig' view of the history of the investigation of the natural world, see Lord Macaulay's famous essay on Francis Bacon.

It is on the strength of this scholarship that we propose that the origins of science should be regarded as being in this period, rather than in the seventeenth century. We must emphasize that we are not arguing for Butterfield's 'origins of modern science' or 'the scientific revolution of the seventeenth century' to be simply moved forward 150 years. Most historians who claim to have identified a fundamental change around 1800 have seen it as akin to the old 'scientific revolution'; indeed, some of them have even called it a 'second scientific revolution'.[55] But to see the change in this way is to stay within the old big picture, based on the old assumptions about the nature of science; thus the change is presented as just a further development in the supposedly universal and eternal human enterprise of investigating nature, just a matter of the same thing ('science') being suddenly done much better, with greater intensity, and being better organized. By contrast, what we are proposing in this paper is something more fundamental: that this period saw the origins of science, in the revised sense: that it saw the *creation* of science's particular and definitive aims, values and practice, not by derivation from some transcendent realm, but as a result of particular human activity in response to the local conditions of material life: an event not of *emergence* but more of *invention.* This term 'invention', which is our preferred term, helps to fix the revised view of science as a contingent, time-specific and culture-specific activity, as only one amongst the many ways-of-knowing which have existed, currently exist, or might exist; and for this reason the phrase which we propose for the fundamental changes which took place in this period is 'the invention of science'.[56] And we can of course now drop the qualifier 'modern', since the term 'science' can only be properly applied in our own time, the modern era.[57] What we are speaking of is therefore not the origins of modern science, but the modern origins of science.

This radical way of interpreting these changes may, we hope, be found useful for teaching and as a heuristic for future research. For the purposes of this paper it enables us to identify the boundaries of science in time and space and culture: to map out the

55 As far as Cohen (op. cit. (4), 97) could find, the term was first used by Thomas S. Kuhn ('The function of measurement in modern physical science', *Isis* (1961), **52**, 161–93, 190). However, the term is now also used in other ways; for example, Stephen G. Brush, *The History of Modern Science: A Guide to the Second Scientific Revolution, 1800–1950*, Ames, Iowa, 1988, uses it to refer to a *late*-nineteenth, early-twentieth century revolution, associated with the breakdown of classical physics. One author who as long ago as 1974 saw the change around 1800 as having been something like as fundamental as we are proposing was Arnold Thackray. He pointed out that in the 1750s,

> not only was the very name and function of the scientist not yet invented, but *science in the sense we know and use the term was unfamiliar to the English-speaking world of the mid-eighteenth century.* Natural knowledge certainly existed, and... the period's philosophers or men 'deep in knowledge' certainly included many... 'well-versed in natural philosophy'. But the professional norms, occupational structures, values, goals and rewards associated with the scientist were as unknown as the word. [Our emphasis. 'The industrial revolution and the image of science' in *Science and Values* (ed. Arnold Thackray and Everett Mendelsohn), New York, 1974, 3.]

56 There is further discussion of the term 'invention' in Cunningham, op. cit. (39).

57 We think it necessary to make this point explicitly, because the report (in the *Newsletter* of the British Society for the History of Science) of our original conference paper, on which this present paper is based, suggested that we were attempting 'to seek transcendent criteria of "modernity"'. We were not. As we hope is now clear, we are not attempting to seek transcendent criteria of *anything*. In fact, that is exactly what we are arguing against.

boundaries of that part of the big picture which we occupy. And as the advocates of the 'scientific revolution' believed their story conformed to the historical evidence and accurately represented what had happened in the past, so we believe 'the invention of science' tells the true story about the origins of science: that those origins are modern.

DE-CENTRING THE 'BIG PICTURE'

History may be servitude,
History may be freedom. See, now they vanish,
The faces and places, with the self which, as it could, loved them,
To become renewed, transfigured, in another pattern.
T. S. Eliot, *Little Gidding*[58]

On this view, the history of science becomes a relatively short and local matter: extending back less than 250 years, and largely confined to western Europe and America. What are we to say of the rest, of analogous knowledge before this time or in other cultures? In the old big picture, other forms of knowledge appeared as early and more primitive versions of science; thus big picture histories which had chapters on Indian and Chinese 'science' tended to place them after the chapters on tribal societies but before the chapters on ancient Greece. This evolutionary view (in accordance, that is, with evolution as popularly understood rather than as in neo-Darwinian theory),[59] showing growth and progress taking place along a single line, was possible only on the assumption that the pursuit of science was a fundamental part of human nature, a universal enterprise transcendentally derived. For a new big picture, in which science is just one amongst a plurality of ways of knowing the world, other forms of knowledge must be allowed to appear on their own terms, instead of being measured against a scientific framework. Science will appear only as the native knowledge-form of our own culture, not in a central or special place. What is required, we might say, is a kind of 'de-centring'.

'De-centring' is a psychologists' term, deriving from the theories of Mead and Piaget, according to which very young children's understanding of the world is at first entirely 'centred' on themselves; 'de-centring' thus describes the process by which children come to realize that external objects have permanence, that other people can have different visual perceptions of the same scene, and that other people can have different knowledge, interests, feelings and so on.[60] In a more general sense, de-centring is something which we continue to do repeatedly throughout our adult lives, as we identify yet another aspect of our own egotism, and realize that something which we thought was universal is actually

58 Excerpt from 'Little Gidding' in *Four Quartets*, copyright 1943 by T. S. Eliot and renewed 1971 by Esme Valerie Eliot, reprinted by permission of Harcourt Brace & Company, and Faber and Faber Ltd.

59 Strict neo-Darwinian theory, based on natural selection, implies that evolutionary lines branch like the twigs of a bush: a non-linear and non-hierarchical view of evolution (see, for example, Stephen Jay Gould, *Wonderful Life: The Burgess Shale and the Nature of History*, London, 1989, 27–45). Nevertheless, the popular view of evolution is one of a linear, progressive ascent. Peter Bowler has pointed out that it was *this* view of evolution which prevailed following the publication of the *Origin of Species*, not the non-teleological view which Darwin's theory of natural selection implied (*The Non-Darwinian Revolution: Reinterpreting a Historical Myth*, Baltimore and London, 1988).

60 See, for example, George Herbert Mead, *Mind, Self, and Society* (ed. Charles W. Morris), Chicago, 1934; Jean Piaget, *The Child's Conception of Reality* (tr. Margaret Cook), London, 1955.

peculiar to ourselves, or our group, our class, our nation, or our culture. To see science as a contingent and recently-invented activity is to make such a de-centring, and to acknowledge that things about our primary way-of-knowing which we once thought were universal are actually specific to our modern capitalist, industrial world.

This kind of de-centring is already beginning to be made in the history of religion, which until recently, in western European countries, was firmly centred on Christianity. This was quite explicitly and unapologetically the case in traditional providential Church History, in which other religions figured only in relation to Christianity; most spectacularly, Judaism was relegated to the status of a precursor. But even in the more liberal viewpoint, in which different faiths are thought of as moving towards the same end, or as being different parts of the same truth, the Christian-centredness remains, because that element of sameness is conceived in Christian terms; features of Christianity, such as monotheism or belief in the existence of an immortal soul, are taken to be constitutive of religion in general.[61] But during the course of the last two decades, a few writers, mainly working in comparative religion or (in Britain) the teaching of Religious Education, have begun to build a view of religion and its history that is not centred on Christianity but which tries to treat at the very least all the major world faiths symmetrically.[62]

The problem which we face in the History of Science is essentially the same. We too have the legacy of a big picture in which historical events have been interpreted as leading towards our own culture, providentially guided from a transcendent realm – in this case the transcendent element being objective truth, goodness or human nature, rather than the Christian God. There are parallels between the way in which the first practitioners of Christianity attempted to erase the separate identity of Judaism and the way in which the first practitioners of science attempted to erase the separate identity of natural philosophy; in both cases, the older texts were taken over by the new practice and reinterpreted as marking early stages in its development: a reinterpretation that was validated only by assuming the transcendent, eternal and universal nature of Christianity, in the one case, and of objective scientific knowledge, in the other. Just as we need a big picture of religion which does justice to the separate identity of Judaism and other non-Christian faiths, so we need a big picture of the history of science which does justice to the separate identity of natural philosophy and other past and present ways of knowing the natural world.

It is not too difficult to imagine a new big picture which is de-centred from our own position along the axis of time, which grants a separate identity to, for example, ancient

61 This Christian-centredness is revealed, for example, in the common statement that 'different religions are worshipping God in different ways'.

62 Ninian Smart, *The Religious Experience of Mankind*, New York, 1969, London, 1971; Don Cupitt, *Taking Leave of God*, London, 1980; Wilfred Cantwell Smith, *Towards a World Theology: Faith and the Comparative History of Religion*, London, 1981; Keith Ward, *A Vision to Pursue: Beyond the Crisis in Christianity*, London, 1991; Jean Holm, *The Study of Religions*, London, 1977. For both Christian priests and teachers of Religious Education, the practical political problems of living in a liberal multi-cultural (hence multi-faith) society have been an important stimulus to the development of this view. Interesting possibilities for an account of the invention of religion, paralleling our account of the invention of science, are raised by Wilfred Cantwell Smith, *The Meaning and End of Religion*, New York, 1962, London, 1978; as John Hick says in his foreword to the 1978 edition, 'he shows with full historical evidence that the concept of religions, as contraposed ideological communities, is a modern invention which the West, during the last two hundred years or so, has exported to the rest of the world' (p. xi).

Greek philosophy, medieval natural philosophy, and the modified forms of natural philosophy developed in the early modern period; historiography for these periods already exists which points clearly in this direction. De-centring from our own position in space, however, is a more difficult step to take; we are much less aware of the existence, let alone the separate identity, of ways of knowing the natural world outside our own culture, or even of those which we claim as ancestors. One way of seeing the necessity for such a de-centring is to look at a map of the world, preferably in the Peters projection,[63] and consider that almost all the material with which the History of Science discipline has been concerned comes from a tiny geographical area, about the same size as Zaire or the Sudan, and considerably smaller than Brazil. The only thing that is unusual about the countries in this area, apart from the fact that they are where we live, is that it was these countries which rose to world-domination during the nineteenth century, through the formation of overseas empires. It was only this historical accident that has meant that what began as their own native culture – by that time including that recent invention, science – has now become world-culture.[64] A spatially or rather geographically de-centred big picture would treat all native knowledge-forms with perfect symmetry.

But even de-centred temporally and spatially in this way, our big picture might still retain its present almost exclusive focus on cognitive knowledge, following our culture's peculiar elevation of theoretical knowledge to a higher status than practical knowledge. To de-centre further, then, we would need a big picture which dealt not only with cognitive knowledge, the knowledge of fact, but also with practical knowledge, the knowledge of skill: not only with *know-of*, but also with *know-how*. To some extent, this de-centring is already being made, particularly with the work on skills now being done in the Sociology of Scientific Knowledge, and with the growth of the History of Technology as a discipline. But even this new work retains a very strong centre, being concerned with subjects such as measurement and calculation, power sources and industrial processes: those things that have importance principally in industrial societies, and principally for men within industrial societies. Feminist and environmentalist analysis points to some further de-centring which is needed: away from the rather specialized technical achievements, such as travelling very fast, and building tall buildings, and killing people in large numbers; and towards more basic and more generally-appreciated technical achievements, such as making sure that people have enough to eat, and clothing to keep them warm, and a place

63 The Peters projection is claimed to provide a more accurate representation of the relative size of the Earth's major land areas than the more-familiar Mercator projection, which exaggerates the area of countries further away from the Equator (e.g. Europe). See Arno Peters, *Der Europa-zentrische Charakter unseres geographischen Weltbildes und seine Überwindung*, Dortmund, 1976.

64 Much of the literature on the exporting of Western knowledge is based on the assumption that the process has been more-or-less successful; for example, Peter Buck, *American Science and Modern China, 1876–1936*, Cambridge, 1980; James R. Bartholomew, *The Formation of Science in Japan*, New Haven and London, 1989. But interestingly, some recent works have emphasized the *difference* of the non-Western traditions, hence questioning how completely Western science retained its identity when transplanted. See for example Arnab Rai Choudhuri, 'Practising Western science outside the West: personal observations on the Indian scene', *Social Studies of Science* (1985), **15**, 475–505; *Science, Hegemony and Violence: A Requiem for Modernity* (ed. Ashis Nandy), Oxford, 1988; Masao Watanabe, *The Japanese and Western Science* (tr. Otto Theodor Benfey), Philadelphia, 1991, original Japanese edn 1976.

to sleep, and comfort and healing when they get sick. To incorporate such know-how within a big picture should surely be a feasible goal.[65]

De-centring could be taken still further. Cognitive knowledge – the knowledge of fact, and technical knowledge – the knowledge of skill, are only two aspects of the knowledge which each one of us possesses. There is also what we might call relational knowledge: the knowledge of acquaintance, the knowledge by which each of us relates to another, person to person, and in small groups, and in larger social and political units. There is also moral knowledge: the knowledge of value, by which each of us judges what is right and wrong. Would it be possible to write a history of human knowledge which, instead of following the positivist legacy of elevating cognitive knowledge (and only one kind of cognitive knowledge, at that) above all the rest, would treat fact, skill, human relations and morals with perfect symmetry?[66]

We do not apologize for raising such questions, even if we cannot yet see how they might be followed out. A big picture, as we understand it, is not just a summary of research results or a general theory of history, but a vision of the world and our place in it; and if such a vision is to remain alive, to grow and to change, then it is necessary for its limits to be constantly pushed beyond what is currently imaginable. Of course, all of us will probably continue to remain specialists, more or less; even when teaching general courses, for some considerable time to come we are likely to continue to specialize in the dominant Western traditions of knowledge – philosophy, natural philosophy, and science. But since these specialisms derive their meaning and identity from the big picture in which, explicitly or implicitly, they are placed, we should do our best to ensure that the big picture we use is one in which we believe and which is appropriate to our time and place and culture. We owe this to our students, to our public, and to ourselves.

65 This paragraph was inspired by Ursula K. Le Guin, 'The carrier bag theory of fiction', in her *Dancing at the Edge of the World: Thoughts on Words, Women, Places*, London, 1989, 165–70. See also Joan Rothschild (ed.), *Machina ex Dea: Feminist Perspectives on Technology*, New York, 1983. An interesting recent attempt at a 'big picture' history from an ecological perspective – i.e. of humanity's changing relationship to its environment, through the development of agriculture and industry – is Clive Ponting, *A Green History of the World*, London, 1991.

66 This paragraph was inspired by Hilary Rose, op. cit. (22).