Philosophy of Science – Routledge Encyclopaedia of Philosophy

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1. Historical background and introduction

Science grew out of philosophy; and, even after recognizable, if flexible, interdisciplinary boundaries developed, the most fruitful philosophical investigations have often been made in close connection with science and scientific advance. The major modern innovators – Bacon, Descartes, Leibniz and Locke among them – were all centrally influenced by, and in some cases significantly contributed to, the science of their day. Kant's fundamental epistemological problem was generated by the success of science: we have obtained certain knowledge, both in mathematics and – principally due to Newton – in science, how was this possible? Unsurprisingly, many thinkers who are principally regarded as great scientists, had exciting and insightful views on the aims of science and the methods of obtaining scientific knowledge. One can only wonder why the epistemological views of Galileo and of Newton, for example, are not taught along with those of Bacon and Locke, say, in courses on the history of modern philosophy. Certainly it can be argued very convincingly that the former two had at least as much insight into the aims and methods of science, and into how scientific knowledge is gained and accredited as the latter two (see Galilei, G. §3; Newton, I. §§2–3; also see Boyle, R.; Copernicus, N.; Kepler, J.).

In the nineteenth century, Maxwell, Hertz and Helmholz all had interesting views about explanation and the foundations of science, while Poincaré who was undoubtedly one of the greatest mathematicians and mathematical physicists, was arguably also one of the greatest philosophers of science – developing important and influential views about, amongst other things, the nature of theories and hypotheses, explanation, and the role of probability theory both within science and as an account of scientific reasoning (also see Duhem, P.M.M.; French philosophy of science; Le Roy, É.; Meyerson, É.; Science, 19th century philosophy of).

The period from the 1920s to 1950s is sometimes seen as involving a movement towards more formal issues to the exclusion of detailed concern with the scientific process itself (see Logical positivism). While this has been over-exaggerated – Carnap, Hempel, Popper and especially Reichenbach for example all show sophisticated awareness of a range of issues from contemporary science (also see Bridgman, P.W.; Operationalism) – there is no doubt that general attention in philosophy of science has been redirected back to the details of science, and in particular of its *historical* development, by 'post-positivist' philosophers such as Hanson, Feyerabend, Kuhn, Lakatos and others.

Current philosophy of science has developed this great tradition, addressing many of the now standard philosophical issues – about knowledge, the nature of reality, determinism and indeterminism and so on – but by paying very close attention to science both as an exemplar of knowledge and as a source of (likely) information about the world. This means that there is inevitably much overlap with other areas of philosophy – notably epistemology (the theory of scientific knowledge is of course a central concern of philosophy of science) and metaphysics (which philosophers of science often shun as an attempted a priori discipline but welcome when it is approached as an investigation of what current scientific theories and practices seem to be telling us about the likely structure of the universe). Indeed one way of usefully dividing up the subject would see scientific epistemology and what might be called scientific metaphysics as two of the main branches of the subject (these two together in turn forming what might be called general philosophy of science), with the third branch consisting of more detailed, specific investigations into foundational issues concerned with particular scientific fields or particular scientific theories (especial, though by no means exclusive, attention having been paid of late to foundational and interpretative issues in quantum theory and the Darwinian theory of evolution). Again not surprisingly, important contributions have been made in this third sub-field by scientists themselves who have reflected carefully and challengingly on their own work and its foundations (see Bohr, N.; Darwin, C.R.; Einstein, A.; Heisenberg, W.; Planck, M.), as well as by those who are more usually considered philosophers.

2. Contemporary philosophy of science: the theory of scientific knowledge

Scientists propose theories and assess those theories in the light of observational and experimental evidence; what distinguishes science is the careful and systematic way in which its claims are based on evidence (see Scientific method). These simple claims, which I suppose would win fairly universal agreement, hide any number of complex issues.

First, concerning theories: how exactly are these best represented? Is Newton's theory of gravitation, or the neo-Darwinian theory of evolution, or the general theory of relativity, best represented – as logical empiricists such as Carnap supposed – as sets of (at least potentially) formally axiomatized sentences, linked to their observational bases by some sort of correspondence rules? Or are they best represented, as various recent ‘semantic theorists’ have argued, as sets of models (see Models; Theories, scientific)? Is this simply a representational matter or does the difference between the two sorts of approach matter scientifically and philosophically? This issue ties in with the increasingly recognized role of idealizations in science and of the role of models as intermediates between fundamental theory and empirical laws (see Campbell, N.R.; Idealizations). It also relates to an important issue about how best to think of the state of a scientific field at a given time: is a scientist best thought of as accepting (in some sense or other) a single theory or set of such theories or rather as accepting some sort of more general and hierarchically-organized set of assumptions and techniques in the manner of Kuhnian paradigms or Lakatosian research programmes? It seems likely that arriving at the correct account of scientific development and in particular of theory-change in science will depend on identifying the ‘right’ account of theories.

Next concerning the *evidence*: it has long been recognized that many of the statements that scientists are happy to regard as ‘observation sentences’ in fact presuppose a certain amount of theory, and that *all* observation sentences, short perhaps of purely subjective reports of current introspection, depend on some sort of minimal theory (even ‘the needle points to around 5 on the scale’ presupposes that the needle and the scale exist independently of the observer and that the observer’s perception of them is not systematically deluded by a Cartesian demon). Does this mean that there is no real epistemic distinction between observational and theoretical claims? Does it mean that there is no secure basis or foundation for science in the form of observational and experimental results (see Observation)? If so, what becomes of the whole empiricist idea of basing scientific theories on the evidence? It can be argued that those who have drawn dire consequences from these considerations have confused fallibility with (serious) corrigibility: that there are observation statements, such as reports of meter readings and the like, of a sufficiently low level as to be, once independently and intersubjectively verified, not seriously corrigible despite being trivially strictly fallible (see Measurement, theory of). Aside from this issue, experiment was for a long time regarded as raising barely any independent, philosophical or methodological concern – experiments being thought of as very largely simply means for testing theories (see Experiment). More recently, there has been better appreciation of the extent to which experimental science has a life of its own, independent of fundamental theory, and of the extent to which philosophical issues concerning testing, realism, underdetermination and so on can be illuminated by studying experiments.

Suppose that we have characterized scientific theories and drawn a line between theoretical and observational statements, what exactly is involved in ‘basing’ theoretical claims ‘systematically and carefully' on the evidence? This question has of course been perhaps *the* central question of general philosophy of science in this century. We have known at least since David Hume that the answer cannot be that the correct theories are *deducible* from observation results. Indeed not only do our theories universally generalize the (inevitably finite) data as Hume pointed out, they also generally 'transcend' the data by explaining that data in terms of underlying, but non-observable, theoretical entities. This means that there must always in principle be (indefinitely) many theories that clash with one another at the theoretical level but yet entail all the same observational results (see Underdetermination). What extra factors then are involved over and beyond simply having the right observational consequences? What roles do such factors as simplicity (see Simplicity (in scientific theories)), and explanatory power (see Explanation), play in accrediting theories on the basis of evidence? Moreover what status do these factors have – are they purely pragmatic (the sorts of features *we* like theories to have) or are they truth-indicating, and if so why? Some have argued that the whole process can be codified in probabilistic terms – the theories that we see as accredited by the evidence being the ones that are at any rate *more probable* in the light of that evidence than any of their rivals (see Confirmation theory; Inductive inference; Probability theory and epistemology).

Finally, suppose we have characterized the correct scientific way of reasoning to theories from evidence, what exactly does this tell us about the theories that have been thus 'accredited' by the evidence? And what does it tell us about the entities – such as electrons, quarks, and the rest – apparently postulated by such theories? Is it reasonable to believe that these accredited theories are *true* descriptions of an underlying reality, that their theoretical terms refer to real, though unobservable entities? (Or at least to believe that they are *probably* true? or *approximately* true? or perhaps probably approximately true?) More strongly still, is any one of these beliefs the *uniquely* rational one? Or is it instead more, or at least equally, reasonable – at least equally explanatory of the way that science operates – to hold that these 'accredited' theories are no more than empirically adequate, even that they are simply instruments for prediction, the theoretical 'entities' they involve being no more than convenient fictions (see Conventionalism; Fictionalism; Incommensurability; Putnam, H.; Scientific realism and antirealism)? One major problem faced by realists is to develop a plausible response to once accepted theories that are now rejected either by arguing that they were in some sense immature – not 'fully scientific' – or that, despite having been rejected, they nonetheless somehow live on as 'limiting cases' of current theories (see Alchemy; Chemistry, philosophical aspects of §2; Field theory, classical; Mechanics, Aristotelian; Mechanics, classical; Optics; Vitalism).

Clearly an antirealist view of theories would be indicated *if* it could convincingly be argued that the accreditation of theories in science is not simply a function of evidential and other truth-related factors or even of epistemic pragmatic factors, but *also* of broader cultural and social matters. Although such arguments are heard increasingly often, many remain unconvinced – seeing those arguments as based *either* on confusion of discovery with validational issues *or* on fairly naïve views of evidential support (see Constructivism; Discovery, logic of; Gender and science; Marxist philosophy of science).

3. Contemporary philosophy of science: 'scientific metaphysics'

Suppose that we take a vaguely realist view of current science, what does it tell us about the general structure of reality? Does a sensible interpretation of science require the postulation, for example, of natural kinds (see Natural kinds) or universals? Does it require the postulation of a notion of physical necessity to distinguish natural laws from 'mere' regularities (see Laws, natural)? What is the nature of probability (see Probability, interpretations of) – is a probabilistic claim invariably an expression of (partial) ignorance or are there real, irreducible 'objective chances' in the world? What exactly is involved in the claim that a particular theory (or a particular system described by such a theory) is deterministic (see Determinism and indeterminism), and what would it mean for the world as a whole to be deterministic? Does even 'deterministic' science eschew the notion of *cause* (as Russell argued)? Does this notion come into its own in more 'mundane' contexts, involving what might be called 'causal factors' and probabilistic causation? What exactly is the relationship between causal claims – such as 'smoking causes heart disease' – and statistical data (see Causation)? How should spacetime be interpreted (see Spacetime): as substantive or as 'merely' relational? Does current science plus whatever ideas of causality are associated with it unambiguously rule out the possibility of time travel (see Time travel), or does this remain at least logically possible given current science? Finally, and most generally, what is science (or, perhaps more significantly, the *direction* of scientific development) telling us about the overall structure of the universe – that it is one simple system governed at the fundamental level by one unified set of general laws, or rather that it is a 'patchwork' of interconnected but separate, mutually irreducible principles (see Unity of science; Reduction, problems of)? Although it is of course true – despite some exaggerated claims on behalf of 'theories of everything' – that science is very far from reducing everything to a common fundamental basis, and although it is of course true that, even in cases where reduction is generally agreed to have been achieved, such as that of chemistry to physics, the reduction is *ontological* (that is, chemistry has been shown to need no essential, non-physical primitive notions) rather than *epistemological* (no one would dream of trying actually to *derive* a full description of any chemical reaction from the principles of quantum mechanics), some would nonetheless still argue that the overall *tendency* of science is in the reductionist direction (see Chemistry, philosophical aspects of §5).

These are examples of the more or less general, and impressively varied, 'metaphysical' issues informed by science that have attracted recent philosophical attention.

4. Contemporary philosophy of science: foundational issues from current science

Many of the most interesting issues in current philosophy of science are closely tied to foundational or methodological concerns about current scientific theory. One fertile source of such concerns is quantum theory. How much of a revolutionary change in our general metaphysical view of the world does it require? Is the theory irreducibly indeterministic or do 'hidden variable' interpretations of some sort remain possible despite the negative results? What does quantum mechanics tell us about the notion of cause? Does quantum mechanics imply a drastic breakdown of 'locality', telling us that the properties of even vastly spatially separated systems are fundamentally interconnected – so that we can no longer think of, for example 'two' spatially separated electrons as separate, independent 'particles'? More directly, is there, in view of the 'measurement problem' a coherent interpretation of quantum mechanics at all? (It has been argued that when the theory is interpreted universally so that *all* systems, including 'macroscopic' ones, such as measuring apparatuses, are assigned a quantum state then the two fundamental principles of quantum theory – the Schrödinger equation and the projection postulate – come into direct contradiction (see Bell's theorem; Field theory, quantum; Quantum measurement problem; Quantum mechanics, interpretation of; also see Randomness; Statistics).)

Although perhaps attracting relatively less attention than quantum theory, the other two great theories that form the triumvirate at the heart of contemporary physics – relativity (both special and general) and thermodynamics – pose similarly fascinating problems. In the case of relativity theory, philosophers have raised both ontological issues (for example, concerning the nature of spacetime) and epistemological issues (concerning for example the real role played in Einstein's development of the theory by Machian empiricism, the role of allegedly crucial experiments such as that of Michelson and Morley (see Crucial experiments), and the evidential impact on the general theory of the Eddington star-shift experiment). There are also important issues about the consistency of relativity and quantum theory – issues that in turn feed into the more general questions concerning the unity of science and realism (see General relativity, philosophical responses to; Relativity theory, philosophical significance of).

Thermodynamics raises issues about, amongst other things, probability and the testing of probabilistic theories, about determinism and indeterminism, and about the direction of time (see Thermodynamics; Determinism and indeterminism; Duhem, P.M.M. §2; Time). Other current areas of physics, too, raise significant foundational issues (see Chaos theory, Cosmology). For a long time, philosophy of science meant in effect philosophy of *physics*. A welcome broadening-out has occurred recently – especially in the direction of philosophy of biology. The central concern here has been with foundational issues in the Darwinian theory of evolution (or more accurately the neo-Darwinian synthesis of natural selection and genetics). Questions have been raised about the testability and, more generally, the empirical credentials of that theory, about the scope of the theory (in particular what it can tell us about humans and human societies), about the appropriate 'unit of selection' (individual, gene, group), about what exactly are genes and what exactly are species, and about whether evolutionary biology involves distinctive – perhaps even in *some* sense 'teleological' – modes of explanation (see Darwin, C.R.; Ecology; Evolution, theory of; Functional explanation; Genetics; Huxley, T.H.; Life, origin of; Linnaeus, C. von; Sociobiology; Species; Taxonomy; Wallace, A.R.). More recently philosophy of biology has started to widen its own scope by considering issues outside of evolutionary theory (see Molecular biology; Medicine, philosophy of), where, however, issues of reductionism and of the possibility of distinctive modes of explanation still loom large.

Further reading:

- Kitcher, P. (1993) The Advancement of Science: Science without Legend, Objectivity without Illusions, New York, and Oxford: Oxford University Press. (Thorough and illuminating account of the general issues surrounding theory-change in science; also useful as an introduction to the methodological issues raised by Darwinian theory.)
- Maudlin, T. (1994) Quantum Non-Locality and Relativity, Oxford, and Cambridge, MA: Blackwell. (Given its subject matter, an exceptionally clear, accessible account of some of the foundational issues in quantum theory, especially concerning its reconcilability with relativity theory.)
- Papineau, D. (1996) The Philosophy of Science, Oxford Readings in Philosophy, Oxford: Oxford University Press. (Recent collection of articles, especially on the realism/antirealism issue, but also on issues of empirical support.)

- Salmon, M.H. et al. (1992) Introduction to the Philosophy of Science, Englewood Cliffs, NJ: Prentice Hall. (A text written by members of the internationally celebrated History and Philosophy of Science Department at the University of Pittsburgh and covering general philosophy of science, as well as philosophy of physics, of biology, and of the behavioural and social sciences.)