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__Willam Harper (2005)__
__Oliver Schulte (2005)__

SCIENTIFIC REALISM

Scientific realism is a philosophical view about science that consists of three theses:

> *The metaphysical thesis*: The world has a definite and mind-independent structure.
>
> *The semantic thesis*: Scientific theories should be taken at face value. They are truth-conditioned descriptions of their intended domain, both observable and unobservable. Hence, they are capable of being true or false. The theoretical terms featured in theories have putative factual reference.
>
> *The epistemic thesis*: Mature and predictively successful scientific theories are well confirmed and (approximately) true of the world. So the entities posited by them, or entities very similar to those posited, inhabit the world.

METAPHYSICS

Let us call the first thesis of scientific realism *metaphysical realism*. What exactly is involved in the claim of mind-independence? One way to construe the opposite claim that the world is mind-dependent, along the lines of traditional idealism and phenomenalism, is to argue that the world consists of mental entities, be they ideas or actual and possible sense-data. Thus understood, mind-dependence is a thesis about the kind of stuff that makes up the world. The insistence of scientific realism on metaphysical realism might be thought of as opposing this idealist or phenomenalist doctrine. It might be seen as a declaration that there is nonmental stuff in the world and, in particular, that the entities posited by scientific theories are material. This view is certainly part of the realist construal of mind-independence, but there is more.

There is another, more complicated and interesting, way to construe the claim that the world is mind-dependent. This way centers not on what *types* of entity exist (whether they are material or mental or what have you) but rather on what is involved in claiming that they *exist*. There is a long antirealist philosophical tradition according to which it does not make sense to assert the existence (or reality) of some entities unless we understand this assertion to mean that … , where the ellipsis is filled with a suitable epistemic/conceptual condition. Much like realism, these views (call them varieties of verificationist antirealism) oppose idealism and phenomenalism. They entail the position (or at least are consistent with the claim) that material objects are real (be they the middle-sized entities of common sense or unobservable entities).

The substantive disagreement between this antirealist tradition and realism is the *sense* of existence. Verificationist antirealism makes the world (or a set of entities) mind-dependent in a more sophisticated sense: What there is in the world is determined by what can be known to exist (verified to exist, rationally accepted as existing, or the like). Hence it forges a logical-conceptual link between what there is in the world and what is affirmed as existing on the basis that it satisfies suitable epistemic conditions. Accordingly, the realist claim of mind-independence should be understood as logical or conceptual independence: What the world is like does not logically or conceptually depend on the epistemic means and conceptualizations used to get to know it. Scientific realism allows for the possibility of a *divergence* between what there is in the world and what is issued as existing by a suitable set of conceptualizations and epistemic conditions. Verificationist antirealism precludes this possibility of divergence a priori by advancing an epistemic conception of truth. No matter what the details of this conception are, the key idea is that truth is conceptually linked with epistemic conditions so tightly that a theory cannot be false even though epistemically justified (because it meets the relevant epistemic condition, for example, being under ideal circumstances theoretically justified or warrantedly assertable). Typically, realists honor the possibility of divergence by adopting a non-epistemic conception of truth (the standard candidate for which is the correspondence theory of truth).

Why should scientific realism incorporate the claim of mind-independence? Why, that is, cannot someone who accepts the reality of unobservable entities but regards them as mind-dependent (in the above sense) be a scientific realist? Ultimately at stake in the debate over scientific realism is a robust sense of objectivity, that is, a conception of the world as the arbiter of our changing and evolving conceptualizations of it. Scientific realism honors this conception by claiming that the world is mind-independent. The kernel of its metaphysical thesis is that science is in the business of discovering what a world that is not of our making is like. This thesis implies that if the natural kinds posited by theories exist at all, they exist objectively, that is, independently of our ability to be in a position to know them, verify them, recognize them, etc., and hence that natural kinds, if anything, make scientific theories true. This robust sense of objectivity contradicts verificationist antirealism. It also blocks a number of projectivist or social constructivist views about science from being realist. In the view of scientific realism, scientific theories and scientific theorizing in general, instead of projecting (or worse, socially constructing) the structure of the world, discover and map out an already structured, mind-independent world.

SEMANTICS

Let us call the second thesis of scientific realism, the view that scientific theories should be taken at face-value, *semantic realism*. This view too was motivated by problems with verificationism.

Verificationism, at least in its traditional form as defended by the logical positivists, runs together two separate issues: the evidential basis for the truth of an assertion and the semantic relation of reference or denotation. It thereby conflates the issue of what constitutes evidence for the truth of an assertion with the issue of what makes the assertion true. This conflation was the product of concerns about the meaning of theoretical terms. Some empiricists thought that since the meaning of theoretical terms is not given directly in experience, these terms are semantically suspect. Hence, empiricists (even hard-core positivists like Ernst Mach) sought to show that theoretical statements and terms are parasitic on observational statements and terms.

This line of thought led to *reductive empiricism*, which treats theoretical statements as being disguised talk about observables and their actual (and possible) behavior. Interestingly, this view is consistent with the claim that theoretical statements have truth-values, but it understands their truth-conditions reductively: Their truth-conditions can be fully captured in an observational vocabulary. Hence, theoretical statements are ontologically innocuous: They do not refer to unobservable entities, and so imply no commitments to unobservable entities. Despite the heroic efforts of many empiricists (including the early Rudolf Carnap), all attempts to translate theoretical terms into observational terms have patently failed. As a result, empiricism became liberal. It admitted that theoretical terms and statements have excess content that cannot be fully captured by anyreference to observable entities and phenomena.

If evidence-conditions and truth-conditions are kept apart, verificationism loses its bite. Semantic realism, simply put, says that there should not be two semantic standards, one for observational statements and another for theoretical ones. Observational statements, as well as theoretical statements, are true if and only if their truth-conditions obtain. Hence, theoretical terms, no less than observational terms, have putative factual reference. If theoretical statements cannot be given truth-conditions in an ontology that dispenses with theoretical entities, a full and just explication of scientific theories simply requires commitment to irreducible unobservable entities, no less than it requires commitment to observable entities.

Instrumentalism claims that theories should be seen as (useful) instruments for organizing, classifying, and predicting observable phenomena. So the "cash value" of scientific theories is fully captured by what theories say about the observable world. Faced with the semantic realist challenge that theoretical assertions are meaningful and purport to describe an unobservable reality, instrumentalism took refuge in Craig's theorem and claimed that theoretical commitments in science are dispensable: Theoretical terms can be eliminated en bloc without loss in the deductive connections between the observable consequences of the theory. If this is so, then the very question of whether theoretical terms can refer to unobservable entities evaporates. This challenge led Carl Hempel (1958) to formulate what he called "the theoretician's dilemma." If the theoretical terms and the theoretical principles of a theory do not serve their purpose of a deductive systematization of the empirical consequences of a theory, then they are dispensable (unnecessary). But by Craig's theorem, even if they do serve their purpose, they can still be dispensed with. Hence, the theoretical terms and principles of any theory are dispensable.

Is the theoretician's dilemma compelling? Note first that the very idea of this dilemma rests on a sharp distinction between theoretical terms and observational ones. This dichotomy was severely challenged in the 1960s, when Pierre Duhem's view that all observation is theory-laden resurfaced. Along with it came the view that, strictly speaking, there are no observational terms. But even if the dichotomy is accepted, instrumentalism based on Craig's theorem collapses. It is implausible to think of theories as establishing only a deductive systematization of observable phenomena. Theories also offer inductive systematizations in the sense that theories can be used to establish inductive connections among observable phenomena: They function as premises in inductive arguments and, together with other premises concerning observable phenomena, yield conclusions that refer to observable phenomena. Seen as aiming to establish inductive connections among observables, theories are indispensable. There followed a battery of indispensability arguments, fostered by Sellars (1963) and Quine (1960) among others, suggesting that theoretical terms are indispensable in any attempt to formulate a powerful and efficacious system of laws and to explain why observable entities obey the empirical laws they do.

Semantic realism opposes both instrumentalism and reductive empiricism. It renders scientific realism an "ontologically inflationary" view. Understood realistically, theories admit of a literal interpretation, that is, an interpretation according to which the world is populated by a host of unobservable entities and processes. Semantic realism is not contested any more. All sides of the debate take theoretical discourse to be irreducible and contentful. It should be clear from the above discussion, however, that making semantic realism the object of philosophical consensus was no trivial feat.

EPISTEMOLOGY

Let us call the third thesis of scientific realism *epistemic optimism*. Its thrust is that science can and does deliver theoretical truth no less than it can and does deliver observational truth. One can grant semantic (even metaphysical) realism and yet remain epistemically skeptical or agnostic toward scientific theories. This agnostic stance has appealed to empiricists who have come to terms with the collapse of instrumentalism and reductive empiricism. An argument for the realist interpretation of scientific theories is not ipso facto an argument for *believing* in the existence of the entities those theories posit and in the truth of what they say of them.

Can the epistemic thesis be avoided? Some realists, notably Alan Musgrave (1999), think that scientific realism is an exclusively axiological thesis: Science aims for true theories. There is clear motivation for this axiological approach: Even if *all* theories scientists ever came up with were false, scientific realism would not thereby be threatened. There are, however, inevitable philosophical worries about the axiological characterization of realism. First, it seems rather vacuous. Realism is rendered immune against the serious criticism stemming from the empirical claim that science has a poor record in tracking the truth. Second, aiming at a goal (truth) whose achievability by the scientific method is left unspecified makes the supposed regulative role of the goal totally mysterious. Finally, we lose all the excitement of the realist claim that science engages in a cognitive activity that pushes back the frontiers of ignorance and error. Other realists, notably Jarrett Leplin (1997), do take the epistemic thesis to be part of scientific realism, but argue for a minimal or thin version of it: There are possible empirical conditions that would warrant attributing some measure of truth to theories. The problem with this minimal account is that, in the end, it cannot provide a rational or warranted basis for belief in the unobservable entities posited by science (and the assertions made about them).

Naturally, the scope of the epistemic thesis need not (and should not) be universal. Scientific realists need not take current science uncritically. They need not commit themselves to everything that current theories assert. They can have a differentiated attitude toward the theoretical constituents of modern science: Some of them are better supported by the evidence than others; some play an indispensable explanatory role, while others do not; some contribute to the successes of theories, while others do not. But we should not lose sight of the general philosophical issue at stake, which is this: Are there good reasons to believe that science cannot achieve theoretical truth? That is, are there good reasons to believe that, given that we understand the theoretical statements of scientific theories as genuine propositions, we can never be in a warranted position to claim that they are true (or at least, more likely true than false)? The *epistemic thesis* denies that there are such good reasons and defends the claim that the ampliative-abductive methods of science are reliable and can justify/support theoretical assertions. Hence, science has succeeded in tracking truth. To be sure, this success requires a certain amount of epistemic luck: It is not a priori true that science has been, or has to be, successful in truth tracking. If science does succeed in truth tracking, this is a radically contingent fact about how the world is and how science and its method have managed to latch onto it.

The prime argument in favor of the epistemic thesis has come to be known as "the no-miracles argument." It is an abductive argument, or inference to the best explanation. Jack Smart (1963) argued against instrumentalists that they must believe in cosmic coincidence. On the instrumentalist view of theories, a vast number of ontologically disconnected observable phenomena are "connected" only by a purely instrumental theory: These phenomena just *happen* to be related to one another in the way suggested by the theory. Scientific realism, in contrast, leaves no space for a cosmic-scale coincidence: It is *because* theories are true and *because* the unobservable entities posited by them exist that the phenomena are related to one another as they are. Smart's key point was that scientific realism (and its concomitant view of science) should be accepted because it offers the best explanation of why the observable phenomena are as scientific theories predict them to be.

Hilary Putnam (1975) and Richard Boyd (1973) argued that inference to the best explanation is the very method scientists use to form and justify their beliefs in unobservable entities, and that realism should be seen as an overarching empirical hypothesis deriving support from the fact that it offers the best explanation of the success of science. The no-miracles argument found pithy expression in Putnam's encapsulation: "The positive argument for realism is that it is the only philosophy that does not make the success of science a miracle" (1975, p. 73). A key element of the realists' epistemic optimism comes from the fact that some theories, because they yield novel predictions, can serve as "prophets for us," as Duhem put it. Only on a realist understanding do novel predictions about phenomena come as no surprise.

How exactly does the no-miracles argument support the epistemic thesis? Though this issue has been extensively debated, the role of the no-miracles argument in the realism debate is quite complex. To a good approximation, the argument should be seen as a grand inference to the best explanation. It is a philosophical argument that aims to defend the reliability of scientific methodology in producing approximately true theories. The argument proceeds in two steps. The first is that we accept as approximately true the theories that are implicated in the (best) explanation of the *instrumental* reliability of first-order scientific methodology. The second step is that since these theories have typically been arrived at by means of inference to the best explanation, such inference is reliable. The main strength of the no-miracles argument rests on the first part of the argument. Coming after more concrete types of explanatory reasoning that occur all the time in science, the argument suggests that it is reasonable to accept certain theories as approximately true, at least as concerns their components that guided predictions. These successful instances of explanatory reasoning in science provide the basis for the grand abductive argument. However, the no-miracles argument is not just a generalization over the scientists' abductive inferences. Although itself an instance of the method that scientists employ, it aims at a much broader target, specifically, to defend the thesis that inference to the best explanation (a *type* of inferential method) is reliable. This relates to the second step of the argument. What makes the no-miracles argument distinctive as an argument for realism is that it defends the claim that theoretical truth is achievable. The second step of the argument seeks to secure this claim. It is reasonable to believe that abductive reasoning is reliable, since it tends to generate approximately true theories.

There are two challenges to scientific realism. The first relies on the claim that the evidence underdetermines theories and is discussed in a separate entry. The second argument is the so-called pessimistic induction. As Larry Laudan (1984) pointed out in developing this argument, the history of science is replete with theories that were once considered empirically successful and fruitful but that turned out to be false and were abandoned. If the history of science is a wasteland of aborted best theoretical explanations of the evidence, then it might well be that current best explanatory theories will travel the route to this wasteland in due course. The best defense of realism against the pessimistic induction has been to try to reconcile the historical record with some form of realism. To do this, realists need to be more selective in what they are realists about.

A claim that emerged with some force in the 1990s is that theory-change is not as radical and discontinuous as the opponents of scientific realism have suggested. Realists such as Philip Kitcher (1993) and Stathis Psillos (1999) have sought to ferret out the theoretical components of abandoned scientific theories that essentially contributed to their successes, separate them from other idle components, and demonstrate that the components making essential contributions to the empirical success of the theories were retained in subsequent theories of the same domain. In such a scenario, the fact that our current best theories may be replaced by others does not necessarily undermine scientific realism. All that such evolution shows is that we cannot get at the truth all at once, and that our judgments from empirical support to approximate truth should be more refined and cautious in that they should commit us only to the theoretical components that enjoy evidential support and contribute to the empirical successes of the theory. Realists ground their epistemic optimism on the fact that newer theories incorporate many theoretical components of their superseded predecessors, especially those components that have led to empirical successes. The substantive continuity in theory-change suggests that a rather stable network of theoretical principles and explanatory hypotheses has emerged, survived revolutionary changes, and become part and parcel of our evolving scientific image of the world.

Faced with the challenge of the pessimistic induction, other realists have sought to weaken realism. There have been two prominent strategies for weakening realism. The first is to opt for structural realism, and the second is to opt for entity realism. Structural realism, defended by John Worrall (1989), capitalizes on the fact that despite the radical changes at the theoretical level, successor theories have tended to retain the *mathematical structure* of their predecessors. It argues that theories can successfully represent the structure of the world even when they are wrong about the entities they posit. Despite its initial appeal, it turns out that this particular position is very difficult to defend. For one, the distinction between the mathematical structure of the theory and its theoretical content is not as clear-cut as it initially seems. For another, even if a sharp distinction is granted, it turns out that structural realism collapses the difference between the claim that a theory is true and the claim that it is empirically adequate.

Entity realism, defended by Nancy Cartwright (1983) and Ian Hacking (1983), accepts the existence of all sorts of unobservable entities but denies the truth of the theories in which descriptions of these entities are embedded. A major motivation for entity realism comes from laboratory life. Experimenters have good reasons to believe in specific unobservable entities, not because they accept the relevant theories, it is claimed, but rather because they *do* things with these entities. If these entities did not exist, the phenomena of the laboratory would be inexplicable. But can one be a realist about theoretical entities without also being a realist about the theories? In a sense, one can. For posited entities survive theory-change. For instance, scientists accept the existence of electrons even though their theoretical views about what electrons are have changed. So it appears that we can know *that* the electron is, even though we may not know *what* it is. But this cannot be fully right. We cannot assert that electrons are real, that is, that electrons are part and parcel of the furniture of the world, without also asserting that they have *some* of the properties attributed to them by our best scientific theories. So entity realism cannot be fully divorced from theory realism. In any case, the very same inferential process (inference to the best explanation) is involved in accepting the reality of an entity and in accepting the approximate correctness of some theoretical description of it.

SCIENTIFIC REALISM AND EMPIRICISM

Bas van Fraassen (1980) fostered a rivalry between scientific realism and empiricism with his influential doctrine of constructive empiricism. According to this view about science, (a) science aims at empirically adequate theories, and (b) acceptance of scientific theories involves belief only in their empirical adequacy (though acceptance involves more than just belief; it also involves commitment to the theory). Van Fraassen took realism to be, by and large, an *axiological* thesis: The aim of science is true theories. He supplemented it with a *doxastic* thesis:

Acceptance of theories implies belief in their truth. Seen in this way, realism and constructive empiricism *are* rivals. But, of course, a lot depends on whether an empiricist ought to be a *constructive* empiricist. There is no logical obstacle impeding an empiricist (who thinks that all knowledge ultimately stems from experience) from fostering methods that warrant belief in the truth of theories in a way that goes beyond belief in their empirical adequacy, and hence from being a scientific realist. Similarly, there is no logical obstacle impeding an empiricist from being stricter than constructive empiricism, for instance, by claiming that (a') the aim of science is unrefuted theories and (b') acceptance of a theory involves the belief only that it is unrefuted.

Constructive empiricism does set the boundaries of experience much farther afield than strict empiricism, and since what empiricism is, is not carved in stone, there is no logical obstacle to setting the boundaries of experience (that is, the reach of legitimate applications of scientific method) even farther afield, as realists demand. Indeed, as Hans Reichenbach (1938) noted, the key question is what kinds of methods are compatible with empiricism. Even if we grant, as we should, that all factual knowledge starts with experience, the boundaries of experience depend on the warrants of the methods employed. It is perfectly compatible with empiricism to accept ampliative methods and to accept the existence of unobservable entities on their basis. So there is no incompatibility between being an empiricist and being a scientific realist.

Van Fraassen tied empiricism to a sharp distinction between observable and unobservable *entities*. This, to be sure, is a step forward from the more traditional empiricist distinction between observational and theoretical terms and predicates. Drawing the distinction in terms of entities allows the description of observable entities to be fully theory-laden. Yet, van Fraassen insisted, even theoretically described, an entity does not cease to be observable if a suitably placed observer *could* perceive it with the naked eye.

Long before van Fraassen, Grover Maxwell (1962) denied this entity-based distinction, arguing that observability is a vague notion and that, in essence, *all* entities are observable under suitable circumstances. He based this view on the claim that "observability" is best understood as detectability by some means. If observability is thus understood, there are continuous degrees of observability, and hence there is no natural and nonarbitrary way to draw a line between observable and unobservable *entities*. Rebutting Maxwell's argument requires that naked-eye observations (which are required to tell us which entities are *strictly* observable) form a special kind of detection qualitatively set apart from any other way of detecting the presence of an entity (for example, with a microscope). Be that as it may, the issue is not whether the distinction between observable and unobservable entities can be drawn but what its epistemic relevance is: Why should the observable/unobservable distinction define the border between what is epistemically accessible and what is not?

In the end, scientific realism is better than constructive empiricism because (1) it does nor rely on a distinction of dubious epistemic significance, specifically, the observable/unobservable distinction, (2) it offers a better explanation of the empirical successes of science, and (3) it tallies better with actual scientific practice.

See also Realism; Underdetermination Thesis, Duhem-Quine Thesis.

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Stathis Psillos (2005)

SCIENTIFIC REVOLUTIONS

Largely as the result of Thomas Kuhn's work, the concept of scientific revolution gains an importance in post-positivist philosophy of science that it lacks in the dominant logical empiricist tradition of the twentieth century. Kuhn's notion of scientific revolution becomes wedded to a historical relativism concerning scientific knowledge that many have sought to refute, or overcome with new accounts of knowledge that go beyond positivism and relativism.

THE CONCEPTION OF SCIENTIFIC REVOLUTION IN TRADITIONAL PHILOSOPHY OF SCIENCE

To set the context for these debates, it is useful to begin with the ordinary concept of scientific revolution and understand why it lacks fundamental epistemological significance in traditional philosophy of science. In ordinary parlance, a scientific revolution is a large-scale change in the fundamental concepts, theories, or methods that scientists in some area of inquiry emply to understand the course of nature (e.g., the Copernican revolution in astronomy). Such a change is also thought to be revolutionary in so far as it provokes similarly dramatic alterations in the way laypeople see the world. As such, the notion is obviously important to historians of science and popular culture. On the other hand, scientific revolution is not a central topic for the tradition of logical positivism (more broadly, logical empiricism) that generates the key figures, problems, and models of philosophy of science for most of the twentieth century.

In this tradition, the aim of philosophy of science is to provide analyses of the standards most vital to science as the best exemplar of empirical knowledge: the standards of scientific method, confirmation, prediction, falsification, explanation, truth, progress, observation, law, and theory. The philosopher's analyses are supposed to be timeless, normative, universal, non-historical, and non-empirical. To this end, logical empiricists employed the tools of logic and semantics to illuminate the a priori formal structure of all genuine scientific knowledge (such as explanation and confirmation). Science is identified with its most successful theories, which in turn are represented as finished bodies of propositions linked by logical and inferential relations connecting sense experience to the higher reaches of law and theory.

From this perspective, scientific revolutions alter the content of successful theories, but not the logic of scientific rationality and knowledge. Indeed, the empiricist's logical standards (e.g., Carl Gustav Hempel's deductive-nomological model of explanation, prediction and confirmation) provide the grounds for evaluating the scientific revolutions of Copernicus, Galileo, Johannes Kepler, Sir Isaac Newton, and Albert Einstein. This entire development could be reasonably represented as a logical, cumulative progress. On the philosopher's standards, this progress is one in which, for example, better confirmed theories of wider explanatory scope replace lesser predecessors, whose errors are corrected, and whose sound results are preserved and extended by their successors. The history of the best science(s) illustrates but does not alter the logic of scientific knowledge. So understood, the rationality of science makes it possible for humankind's best theories to converge on the truth concerning lawlike regularities in the world of observed phenomena and, perhaps, the underlying, unobservable entities and mechanisms causally responsible for these regularities.

These achievements of logical empiricism gain one of their last, most lucid and systematic reformulations in Hempel's *The Philosophy of Natural Science*. This work appeared in 1966 four years after Kuhn's *The Structure of Scientific Revolution (SSR)*. Of course many philosophers besides Kuhn challenge one or more of the presuppositions of traditional philosophy of science and reshape the debates in the post-positivist period (e.g. William Van Orman Quine, Wilfred Sellars, Norwood Hanson, Stephen Toulmin, Michael Scriven, Nelson Goodman, Paul Feyerabend, Mary Hesse, etc.). But Kuhn's challenge in *SSR* is probably unique in the avalanche of criticisms, rebuttals, and new approaches to the history and philosophy of science that it has provoked for decades. Much of this response focuses on Kuhn's notion of scientific revo-