FALSIFIABILITY

Karl Popper (1902–1994) made falsifiability the key to his philosophy of science. It became the most commonly invoked "criterion of demarcation" of science from nonscience.

According to the simple, hypothetico-deductive (H-D) model of scientific inquiry, a law claim, theory, or hypothesis H is falsifiable when a potentially checkable prediction O can be logically deduced from it, that is, when $H \rightarrow O$. If O is observed to be true, then H passes this predictive test (although it may fail other tests). If O tests false, then H must also be false, since no true statement can logically imply a falsehood. For example, Isaac Newton's (1642–1727) theory of gravitation predicts, among many other things, a slow rotation of the orbit of planet Mercury which is different from what astronomers have since observed. Thus Newton's theory is not only falsifiable (empirically vulnerable) but has also been falsified (shown to be false). Albert Einstein's (1879–1955) general theory of relativity is subject to the same test, so it, too, is falsifiable; but it passes the test. "All life in the universe employs the same genetic coding found on Earth" is falsifiable in principle but not in current practice, since to date we have identified no examples of extraterrestrial life. By contrast, "The universe is recreated at each instant by a divine being" yields no predictive tests at all, so it is not falsifiable even in principle.

Note that *falsifiable* does not mean "falsified" or "false" any more than *breakable* means "broken." On the simple model, even if, *per impossibile*, an empirical law could be known to be absolutely true in our universe, it would still be falsifiable in the sense that it would be empirically testable and would test false if the world were relevantly different. A falsifiable claim rules out some potentially observable situations; and the more it excludes, the greater is its empirical content, that is, the more it claims about the structure of our universe.

Popper's Emphasis on Falsifiability

Falsifiable contrasts with *verifiable.* A claim is empirically verifiable if possible observation statements logically imply the truth of the claim. If actual observation statements do imply the claim, then it is verified. "This raven is black" verifies "There are black ravens." During the 1930s the logical empiricists of the Vienna Circle proposed verifiability both as a criterion of demarcation of science from nonscience and a criterion of meaning. Their idea was that a statement is meaningful if and only if it is verifiable in principle, and its meaning is given by its method of verification. For the logical empiricists, only empirically verifiable claims make genuine assertions about the world and are, in this broad sense, scientific. All other claims (metaphysical, religious, ethical, etc.) are cognitively meaningless. In his *Logik der Forschung* (1934; *Logic of Scientific Discovery*), Popper replied by rejecting the logical empiricists' concern with language and meaning and by noting that verifiability as a criterion of demarcation excludes scientific law claims and thus the core of science itself. For since a law claim is universal in scope (in simplest form, "All A's everywhere and everywhen are B's"), it cannot possibly be verified: there are always actual or potential instances beyond those so far observed. Yet a universal claim can be falsified by a single negative instance. The first observed black swan refuted the claim "All swans are white." (Law claims of statistical-probabilistic forms are more problematic.) Based on this logical asymmetry of verification and falsification, Popper proposed falsifiability as a criterion of demarcation of science from nonscience, although not as a criterion of meaning. According to Popper, nonscience includes pseudoscience (e.g., Freudian psychology and Marxism) and metaphysics, the one fraudulent, the other sometimes providing a valuable heuristic for science. Many deep scientific problems have their roots in metaphysics, but to be scientific, a claim must take an empirical risk.

Moreover, falsifiability, as the ongoing risk of falsification in *our* world, is a permanent status for Popper. No amount of successful testing can establish a hypothesis as absolutely true or even probable: it forever remains conjectural. That all scientific theories remain falsifiable entails fallibilism, the view that our best epistemic efforts remain open to future revision. There can be no certain foundations to knowledge.

Popper's falsifiability doctrine lies at the heart of his empiricist epistemology and scientific methodology of "conjectures and refutations." The latter, he claims, shows how it is possible to learn from experience without induction from the facts. Previously, empiricism had been equated with inductivism. Popper attacked as question-begging the view that we must arrive at our ideas by induction, that is, by first gathering masses of facts and then gradually detecting regular patterns in them—letting nature speak for herself. Rather, said Popper, we first propose a conjecture to solve a problem, then test the conjecture by trying to falsify it. It is the conjecture that tells us which observations are relevant. Contrary to the inductivists, it does not matter where our ideas come from, only how we test them. There is no logic of discovery, only a logic of testing.

Since law claims can be falsified but not verified, Popper concluded that the way to truth is indirect, by elimination of falsehood. Hence error, in the sense of faulty hypotheses, is not a bad thing. On the contrary, it is necessary to scientific progress. "We learn from our mistakes." This is Popper's more extreme form of the nineteenth-century idea that science is a fallible but self-correcting enterprise. Since bold hypotheses that yield novel predictions are risky and hence easier to test, Popper urged boldness. He explicitly forbade, as a form of intellectual dishonesty, *ad hoc* tinkering to save a hypothesis from falsification. Popper spoke of degrees of falsifiability and attempted, with limited success, to measure both simplicity and the empirical content of a claim (how much it says about the world) in terms of its degree of falsifiability.

Complications of the Simple Model

Many scientists, administrators, and the legal community take falsifiability seriously as a criterion of demarcation of science from nonscience. But other scientists and science-studies experts consider falsifiability a heuristic rule of thumb at best, not a rigid requirement. Among the difficulties facing Popper's conception are these: In most scientific research, a hypothesis is tested against a competitor (often the "null hypothesis") rather than in isolation. The test typically discloses the comparative fit of the two hypotheses to the data rather than the outright falsity of one of them. The history of science discloses many cases in which a claim is not immediately falsifiable by known methods, yet the claim remained important to scientific investigation and later became testable. In the nineteenth century, August Comte (1798–1857) notoriously announced that we could never know which chemical elements were present in the sun, yet only a few years later new spectrographic techniques revealed this information, including the existence of a hitherto unknown element, dubbed helium. In 1931 Wolfgang Pauli (1900–1958) postulated the existence of the neutrino, a chargeless and presumably massless particle that scarcely interacted with ordinary matter and was hence undetectable by any known means. Yet this turned out to be one of the more fruitful ideas of twentieth-century physics, and various kinds of neutrino are now detectable. By the end of the twentieth century, science-studies disciplines were characterizing science in terms of its practices rather than simply in terms of the logical status of its claims.

Furthermore, Popper himself admitted that absolute logical falsification, and hence absolute falsifiability, are impossible in scientific practice, since the allegedly refuting observations can never be known with certainty. Since observations themselves are not statements and can have no logical relations to statements, Popper held that observation statements (roughly, data) are accepted by convention. Moreover, they are theory-laden; there is no such thing as pure observation. Although Popper never employed falsifiability as a criterion of meaningfulness, attempting to formulate the falsifiability requirement with logical precision runs afoul of the same sorts of difficulties faced by the logical empiricists with their verifiability theory of meaning.

A specific difficulty, raised already by Pierre Duhem (1861–1916) and extended by Willard Van Orman Quine (1908–2000), is that, in isolation, universal claims yield no specific predictions. By itself, the hypothesis H, "All A's are B's," implies no testable prediction, not only because of its logical form but also because A and B will be typically abstract, theoretical terms. To generate predictions from hypothesis H, we must conjoin H with one or more auxiliary premises, $A_1, \ldots, A_n$. So the simple H-D model of the testing situation must be replaced by a more complex logical model: $(H \,\&\, A_1 \,\&\, \ldots \,\&\, A_n) \rightarrow O$, where "&" means the logical "and." If prediction O is false, logic now tells us that at least one of the conjoined premises was mistaken, but not which one(s). Logic permits us to blame the failure on an auxiliary assumption rather than on H. In his influential article "Two Dogmas of Empiricism," Quine parlayed the Duhem problem into a controversial argument for holism: "our statements about the external world face the tribunal of sense experience not individually but only as a corporate body." We do not test scientific claims individually against nature but instead adjust our entire "web of belief" to fit our experience. Critics reply that deductive logic does not exhaust the distinctions licensed by scientific practice. Quineans forget that experiments are *designed* to test specific components of a theory or model, that an experiment designed to test H will rarely test the auxiliary assumptions as well (Sober). Furthermore, the relation of observation to theory is typically more complex than even the Duhem model, which remains deductive rather than probabilistic. Typically, several levels of data processing and theoretical modeling occur between theory and observation.

Thomas Kuhn (1922–1996), a leading opponent of H-D models of science, famously argued that Popper's falsificationist methodology fails to fit the history of physical science. In *The Structure of Scientific Revolutions* (1962), Kuhn advanced an alternative conception of physical science, according to which normal scientific work is highly constrained by "paradigms," the central tenets of which are immune from serious criticism and competition and hence unfalsifiable in practice. Only when a paradigm breaks down do we find the kind of critical and revolutionary ferment that Popper advocated for all scientific work. Moreover, much of normal science consists of tinkering of just the sort that the Popperians considered to be *ad hoc*. Subsequently, Popper's former student Imre Lakatos distinguished several kinds of falsificationist methodology, from simple to sophisticated. Attempting a compromise between Popper and Kuhn, he analyzed science in terms of competing research programs involving entire series of not-always-successful theories rather than individual theories in isolation. Predictive failure does not directly and immediately falsify a research program.

Finally, Larry Laudan deplores the ritual invocation of Popper's "toothless" falsifiability criterion in legal proceedings (such as the 1981–1982 creationism trial, *McLean v. Arkansas*) to distinguish good science from pseudoscience. Traditionally, the term *science* demarcated a body of established truths or scientifically warranted assertions, whereas falsifiability requires only empirical testability. For example, so-called Creation Science is false and hence falsifiable. By Popper's standard it is scientific—and so is the statement that the Earth is flat! A useful concept for certain purposes, falsifiability, by itself, fails as the hallmark of good science sought by the legal and political community.

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See: Nickles, Thomas. "Falsifiability." *New Dictionary of the History of Ideas*. 2005. *Encyclopedia.com.*