Sir Karl Raimund Popper (1902–1994) is considered to be one of the great philosophers of science of the 20th century (and his lifetime spanned most of the century). Among Popper’s many contributions to scientific thought are his principles of epistemology: the branch of philosophy that deals with the origin, nature, and limits of knowledge. The word “epistemology” derives from the Greek prefix epi-, meaning “upon,” and histánai, meaning “stand,” hence, to “stand upon,” as in provide a basis (for knowing), which later became epistēmē, for “knowledge,” and epistemology, for “the body of knowledge (-ology) that provides a basis for knowing.” In particular, Popper sought to resolve the question, When is science really science? He concluded that a scientific theory was only valid if:

a) a doubtful outcome predicted by the theory was at stake
b) this unlikely yet predicted outcome could be objectively tested
c) such tests (experience) verified that the theoretically predicted outcome could indeed be realized, which thus allowed the theory to
d) survive the test of falsification, and hence
e) gain credibility as being “for real,” but
f) only until (and if) the theory could survive the next test of an improbable prediction.

The operative words in the above criteria are doubtful, unlikely, and improbable, because Popper’s main contention was that the “scientific method,” as applied in practice, was subjectively structured to produce a priori predictable results, i.e., the theories formulated led to self-fulfilled prophecies. Thus, according to Popper, only if unexpected forecasts could actually be realized, which is to say, only if a theory was formulated in a way that allowed experience to falsify it, and only if it survived such tests, could the theory be considered to be “scientifically” sound. The reasoning that led Popper to postulate this Principle of Falsification, which I have condensed into what I call Popper’s Seven Basic Principles of Human Knowledge, goes something like this:

a) one can deductively (going from the general to the specific) predict what further evidence is likely to be discovered in future investigations, from which
b) more structure is accumulated, and
c) the sequence of steps in the cyclic scientific method begin again, going through an inductive process to fine-tune and/or modify the theory as necessary to account for new findings.

(See “On the Seven Elements of Knowledge,” American Laboratory News Jul 2001; 33[15]:4.) The more evidence that accumulates in a manner that is self-consistent with, and not in conflict with, an existing theory, the more confidence one has in the validity of the theory. Sounds good on paper, but not so in real life, says Popper.

First of all, contrary to popular belief, theories are not formulated by objective, logical, inductive reasoning that follows directly from generalized, pure, empirical observations, which is to say, experience gleaned in a traditional sense from objective laboratory data or sound, abstract critical thinking. Rather, most theories derive from attempts to solve specific, ill-defined problems and hence are encumbered both by an a priori “existing-theory-laden” bias and a preconceived idea of what’s happening, based on state-of-the-art thinking. Thus, from the get-go, there are problems with the frame-of-reference element of knowledge, which may explain in part why, historically speaking, so many major advances in science (like the discovery of X-rays or the more recent unexpected spin-offs from the boom in World Wide Web Internet technology) occur by accident, rather than by design. The individual(s) involved simply
wasn’t looking for or expecting them and wasn’t, in effect, blindsided. Popper’s First Principle of Human Knowledge can thus be expressed this way:

• Knowledge derives not from logical inference based on objective, theory-free observations, but from biased, subjective efforts to solve selective, ill-defined problems. The “theories” formulated are thus less “scientific” than they are “descriptive generalizations” derived to explain isolated experiences.

Second, related to the scale-of-observation and resolution elements of knowledge—not to mention the logistical constraints involved—it is impossible to evaluate all predictions of any given theory, everywhere in infinite space, continuously in infinite time, under all possible boundary and initial conditions, at all levels of observation, to any desirable detail of resolution, and under any and all circumstances. Thus, one can never be absolutely certain that the predictions of any given theory remain universally and perpetually true; we can only hope for the best based on limited experience and a reliance on various ergodic hypotheses. Because of these practical constraints, no matter how many examples we can find to confirm any given theory, there might always be lurking just around the corner another not-yet-observed case that could refute or cast serious doubt on the alleged hypothesis. After all, it only takes one exception to the rule to invalidate it as a universal concept, even though there is much evidence to support it.

Thus, claims Popper, affirming evidence can only serve to strengthen a theory, never to uniquely prove it. This is especially true when there are many hidden (perhaps undefined), confounding, conditional, circumstantial, and/or conflicting/paradoxical, independent variables involved, variables that cannot be entirely accounted for in randomized, double-blind, controlled, experimental investigations, or highly complex, nonlinear, nonhomogeneous, higher-order mathematical formulations. Popper’s Second Principle of Human Knowledge can thus be expressed as follows:

• All knowledge is conjectural and provisional, to the extent that experience can only corroborate (verify) a theory on a limited basis, never prove it absolutely. The “theories” formulated are thus less “deterministic” than they are “probabilistic.”

According to this principle, then, attempting to “prove” a theory by amassing tons of confirming evidence is futile. First of all, the process can (and should, ideally) go on ad infinitum, with no end in sight, which is not practical. Second, amassing such evidence is really rather trivial, since, in the first place, most theories are in fact deliberately couched in ways that make them amenable to confirmation (First Principle). Thus, proving them amounts to little more than circular reasoning, which is to say, it is a straightforward process to obtain evidence to support a theory that, a priori, was formulated to predict known phenomena (those already observed)—that’s easy! What the evidence affirms is merely the self-consistency of the formulation process: It verifies the accuracy of the inductive handling of observations, to the extent that such handling is consistent with results obtained in a comfort zone of experience, but it doesn’t prove the theory.

No, the more appropriate approach to proving a theory is to look for the exceptions to the rule, since it takes fewer of those to nullify the hypothesis than it takes positive evidence to prove it. In other words, theories, to be truly “scientific” must be predictive not only in the sense of explaining things we already know, but must somehow predict “risky” outcomes in the sense of suggesting physical phenomena not previously observed or likely to have been anticipated—going out on a limb, so to speak, to dare somebody to disprove it! Popper calls this a leap of the imagination, which exposes the theory to falsification, rather than verification. Thus, the way to prove a theory is not to seek confirming evidence, but just the opposite, i.e., to see how well it holds up to ever-more-aggressive attempts to disprove it; which brings us to Popper’s Third Principle of Human Knowledge:

• To be truly scientific, theories must be formulated in ways that both explain anomalies that have plagued earlier theories and go beyond existing knowledge (requiring a leap of the imagination) to predict as-yet unobserved and unanticipated phenomena. The “theories” formulated must thus make novel predictions that can be tested in ways that make the theory more amenable to proof by surviving attempts to falsify it, rather than by accumulating evidence to verify it.

If I may be so bold, I would like to interject here my own Fourth Principle of Human Knowledge, based on my editorials, “The Physiology of Relativity” (American Biotechnology Laboratory Jan 2003; 21[1]:4) and “Can We . . . Should We . . . Measure Everything in a Purely Objective Way?” (American Laboratory News Jun 2005; 37[12]:4-6). These editorials, in line with Popper’s own logic, suggest that no single observation can ever be taken to falsify a theory because, among many considerations:

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Theories, to be truly “scientific” must be predictive not only in the sense of explaining things we already know, but must somehow predict “risky” outcomes in the sense of suggesting physical phenomena not previously observed or likely to have been anticipated.
a) Anatomical/physiological limitations and information-processing constraints prevent our being able to objectively perceive, much less experience, all possible outcomes of any theoretical predictions.

b) Technological limitations and constraints bring into question the ability of empirical observations to objectively determine which theories are false. For example, what if the observation is false or flawed, but the theory is actually true? That, of course, is part of the dilemma. By Popper's own reasoning, one can argue that no theory can ever be truly falsified because the experimentation itself is inherently imperfect and, hence, not a reliable test of the hypothesis.

c) It is impossible to prevent human frailties from biasing empirical/theoretical results and/or empirical/theoretical observations.

d) The assumptions and background knowledge under which the investigation is being carried out might be incomplete, erroneous, and/or defective.

Indeed, in order to falsify a conclusion, one has to be able to undermine one or more of the assumptions underlying the argument(s) that leads up to it (by, for example, showing the existence of non sequiturs). The difficulty in doing this is one reason (among many) that "science" does not endeavor to prove a negation of non sequiturs). The assumptions and background knowledge under which the investigation is being carried out might be incomplete, erroneous, and/or defective.

The truth-content of a theory that has a terrific ability to explain known findings, and to predict things in ways that can be reasonably tested by critical thinkers, is defined to be the total class of verified (as-yet unfalsified) explanations, propositions, and predictions that are attributable to the theory. The greater the preponderance of such positive evidence, the greater the truth-content of the theory. The false-content of that same theory is defined to be that class of propositions predicted by the theory that have either proven to be false or have consequences that have not yet been verified. Popper's Sixth Principle of Human Knowledge, then, asserts that:

- Theory X is "better" than Theory Y if it explains more things, predicts more testable outcomes, possesses a higher overall informative content (which gives it more degrees of freedom for possible falsification), and has a higher truth-content-to-false-content ratio. Such a theory is said to be "optimized" as opposed to "proven," from the point of view of falsification.

While it appears to bring us full circle, Popper's Sixth Principle does not negate the need for falsification in the sense of Principles 1, 2, and 3, but it does propose ways of determining when one theory is better than another, which brings us to his last principle. Popper's Seventh Principle of Human Knowledge summarizes the above considerations by asserting that:

- Given Principles 4 and 5, the best policy is to "believe in" (not "prove") a theory if there is an overwhelming body of reasonable evidence to support or corroborate it in the sense of Principle 6, even though the theory cannot be proved or falsified in an absolute sense as addressed by Principles 1, 2, and 3, which represent the ideal situation. Otherwise, the "innocent-until-proven-guilty" philosophy should prevail, in the sense that, absent sufficient evidence to verify it, the theory should be considered ill-founded and suspect.

One thing is for sure: If history is any guide to the future, I would stick my neck out to add one final principle to those of Popper:

- The chances are pretty good that most or all of the theories upon which current knowledge is based are wrong (i.e., will eventually be falsified!). They work in spite of, rather than because of, their explanatory and predictive powers, and they will prevail until better, more comprehensive ones come along.

Count on it!

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