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Editor's Page

Daniel J.
Schneck

On The "Scientific" Method

One of the strongest of basic human drives is the search for knowledge, and through it, truth. But there are often many obstacles standing in the way of pure, absolute, totally objective inquiry, among them:

- Strong personal beliefs (including religious beliefs)
- Unavoidable human bias (subjective orientation)
- Circular reasoning
- Ulterior motives
- The self-fulfilling prophecy trap
- Anatomic/physiologic information-processing constraints.

In an effort to minimize the effect of these limitations on the search for knowledge, and to optimize the process, the Scientific Method was devised by well-meaning investigators. Some historians trace various aspects of this method back to antiquity, but "officially," the Italian physicist/astronomer Galileo Galilei (1564–1642) is generally given credit for formalizing it into a rigorous procedure. For convenience, I think of this "procedure" as consisting essentially of 12 discrete steps:

Bias and human error are unavoidable pitfalls of the scientific process.

Step 1: *Observe*. The procedure begins by:

- *Explicitly* defining, precisely, a specific problem to be solved, or
- Becoming aware, *implicitly*, of an issue that may derive from the puzzling features of events in common experience, or
- Observing curious phenomena that need to be explained. This leads one to:

Step 2: *Collect data*. Search, explore, and accumulate evidence. In this step, all pertinent observations and pieces of significant testimonials related to the explicit problem or implicit issue are carefully gathered:

- In a particular (often observer-dependent) frame of reference
- At a specific scale of perception (within a doubly infinite domain of realization), and
- Constrained by a precise window and accuracy of resolution.

Data gathering can be deliberate, based on well-defined evidence-seeking paradigms that are planned, in advance, with specific goals in mind, or the information can be serendipitous, being derived from unforeseen (or unanticipated), fortunate discoveries that are come upon entirely by accident. In either case, one now proceeds to:

Step 3: *Confirm the data*. Repeated observations yielding similar or identical results validate the data, converting them into legitimate evidence, which is now classified as facts—structure—the attributes that characterize a particular manifestation of reality, be it the explicitly defined problem being considered, the implicit issue that has emerged, or the phenomena in need of an explanation. Careful evaluation of the structure leads one to:

Step 4: *Generate information*. Structure becomes "information" when the confirmed data are reduced to reasonable common denominators, from which there emerges an abstract interpretation of observations and experiences: a working hypothesis. In turn, this leads to the formulation of creative and logical alternative solutions to the problem, or plausible explanations of the evidence (best "educated guesses" of what is going on).

Step 5: *Inductive reasoning*. Critical thinking is now employed to work backwards, attempting to discern patterns in the common denominators, and see how well these can be explained by the working hypothesis. The investigator seeks to derive some order to the plethora of information thus-far gathered, and thereby gain some sense of temporal sequencing and spatial arranging of structure.

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Step 6: *Search for relationships*. Within this ordered structure, one now seeks intimate associations that are embedded in the accumulated information, associations that can help to further elaborate and strengthen the evolving working hypothesis by:

- Clarifying ambiguities and minimizing confusion
- Identifying similarities, looking for affiliations, and seeking even more connections and common denominators
- Avoiding chaos
- Creating the most likely, stable, consistent, and meaningful interpretation (explanation) of what is being observed. Such interpretation allows the investigator to go to:

Step 7: *Generalize, with good judgment and as little bias as reasonable*. This may require further "tweaking" (fine-tuning) of the working hypothesis. Step 7 culminates in the synthesis of relationships into a tentative, plausible theory that addresses the who, what, where, why, when, and how aspects of the problem or issue under investigation. Now it's time to take action!

Step 8: *Deductive reasoning*. We now work forward. The tentative, plausible theory is used to predict likely, testable outcomes in various situations claimed to be governed by the alleged formulation. This is the "Let's see what (and how well) the theory predicts. . ." step in the scientific method, designed to challenge it by:

Step 9: *Testing predictions*. This is done by accurately designing and properly executing carefully controlled, double-blind, randomized experiments/studies that allow the investigator to collect relevant and meaningful, quantified results. "Accurately designed and properly executed" includes:

- Clearly defining (in an unambiguous, operational sense) all relevant (especially confounding) variables, which is essential for both proper interpretation and replication of the investigations
- Ensuring that the experimental protocol quantifies these variables in accordance with appropriate analytical theories, procedural principles, technical methods, and reference values.

Step 10: *Validating the proposed theory*. Results obtained in the supporting and operating Steps 7–9, when objectively analyzed, interpreted, and properly evaluated, are used to test the strength of the tentative, plausible theory, and the conclusions reached therefrom. Indeed, faith in the utility of a proposed theory ultimately derives from validating its deductive predictions. Thus,

Step 11: *The "proposed" theory becomes a working theory!* When:

- Reasonable conclusions can be drawn that follow directly and logically from a meaningful, objective, unbiased discussion of results obtained as above
- Enough credible (reliable), substantiated (reproducible) evidence (more observations) accumulates to support the predictions of a proposed theory, and
- Seemingly contradictory observations offered to refute the working hypothesis can be satisfactorily explained in a manner that shows coherency (logical connections) and self-consistency (total agreement), then:

the working hypothesis is considered to be verified (note: not proven!), and the proposed theory is assumed to be corroborated by a preponderance of the evidence. Thus, "proposed" is replaced by "confirmed," "working," or, simply, a *theory*: the "rule."

Step 12: *Theory becomes law.* A theory (rule) that:

- Stands the test of time
- Consistently predicts repeatable/reproducible results that occur invariably under identical conditions
- Survives all valid attempts to falsify it, without succumbing to viable alternative hypotheses, and withstanding exposure to "exceptions to the rule"
- Maintains self-consistency, coherency, and the ability to be fine-tuned without major alterations, and
- Can be independently confirmed

becomes a law, beyond a reasonable doubt, *but still only corroborated, not proven.* It is both feasible and acceptable as long as it remains verified, and the accumulating evidence continues to attest to its validity. Moreover, the entire process described above applies equally well to a theoretical/analytical formulation or to an experimental investigation. However, as nice as it sounds on paper, several caution flags need to be recognized, among them:

- The "Method" is a hypothetical idealization of a process that is seriously and unavoidably constrained. Our ability to "know" is severely limited by factors over which we have little or no control, including:
- Technological constraints (not the least of which often include time, money, and practical considerations) that limit our ability to measure *everything*—in a totally unbiased, objective way—with the highest accuracy and finest resolution
- Anatomical/physiological sensory limitations that prevent us from experiencing, altogether, more than a miniscule fraction of the multifarious manifestations of "reality"
- In order to avoid clutter and information overload, anatomical/physiological information-processing constraints that filter out and modulate ("censor") the sensory stimuli to which we *are* responsive, and,
- Anatomical/physiological perceptual limitations that limit our ability to objectively interpret the information that does eventually make its way to conscious, cognitive cerebral levels. Indeed, bias and human error are unavoidable pitfalls of the scientific process. Thus, it is not uncommon for it to succeed in spite of rather than because of its inherent attributes, so we must never become complacent. Thus, finally,

Step 13, if you will, should always be *skepticism*, lest we fall victim to what I call "The Emperor's New Clothes Syndrome" in science; that is, being bullied by misguided authoritarianism.

Dr. Schneck is W.S. White Distinguished Professor Emeritus of Engineering Science and Mechanics, Virginia Tech, P.O. Box 396, Christiansburg, VA 24068-0396, U.S.A.; tel.: 540-382-6496; e-mail: adanielj@vt.edu.