“The Scientific Method” on Trial

Brian A. Woodcock

woodcoba@uwec.edu

Department of Philosophy and Religious Studies,
University of Wisconsin-Eau Claire
Eau Claire, WI 54702-4004

Abstract The targets in this essay are popular and introductory accounts of “The Scientific Method”. The aim in this essay is to articulate problems and puzzles raised by such accounts. It is concluded—in agreement with Henry H. Bauer (*Scientific Literacy and the Myth of the Scientific Method*, 1992)—that “The Scientific Method” is a myth. But myths can have important functions. After examining the functions served by presentations of “The Scientific Method”, it is argued that these functions can be separated from “The Scientific Method” and preserved in other, less-misleading ways. In its informative role, what is important to convey about the nature of science is an epistemic stance—the empirical stance.

1 Introduction

James Bryant Conant—the chemist, historian of science, and former president of Harvard University— wrote:

> To be sure, it is relatively easy to deride any definition of scientific activity as being oversimplified, and it is relatively hard to find a better substitute. But on one point I believe almost all modern historians of the natural sciences would agree...There is *no* such thing as *the* scientific method. If there were, surely an examination of the history of physics, chemistry, and biology would reveal it...[F]ew would deny that it is the progress in physics, chemistry, and experimental biology which gives everyone confidence in the procedures of the scientist. Yet, a careful examination of these subjects fails to reveal any *one* method by means of which the masters in these fields broke new ground. (Conant, 1951, p. 45)

Despite Conant's denial that such a thing exists, we continue teach *the* scientific method.

The targets in this essay are popular and introductory accounts of "The Scientific Method". These are the sorts of accounts that one finds in the popular media, in books on science for a popular audience, at the beginning of some introductory high school and college science texts, in grade school presentations of science, and in various materials on how to create a science fair project.

The reader will note that I employ scare quotes around the words 'The Scientific Method'. I do so for two reasons. First, it is to indicate that I am concerned with popular and introductory accounts as opposed to contemporary scholarly accounts. Second, the actual use of the definite article would seem to commit one to the existence of a single method of science and, in keeping with Conant's statement above, I do not wish to suggest such a commitment. It is not my aim to use these words to attempt to refer to what actual scientists do, or ought to do, but rather my concern is with what is represented in presentations about science that use this label.

2 No Canonical Statement of "The Scientific Method"

In a course I teach on philosophy of science, I have students gather statements about "The Scientific Method" from popular sources and introductory science textbooks. After looking at several such accounts, one feature that stands out is the variation one encounters. This leads to the first point:

> (1) There is wide variation in contemporary popular and introductory presentations of "The Scientific Method".

How many steps are there in "The Scientific Method"? It is sometimes summarized in as little as two or three steps. As Bill Nye the Science Guy summarized it: "watch the world, come up with things to try, and then try them. That's using the Scientific Method" (Nye, 1993, p. 2). But one can find popular statements of "The Scientific Method" with as many as eleven steps (Edmund, 2011). An internet search for 'scientific method steps' will produce related searches for five, six, seven, and eight steps. It appears that, within some range, one can choose the number of steps one wants and find some statement that will accommodate.

It might be, perhaps, that some presentations combine several steps into one. At some level of description, then, are they equivalent formulations of the same content? No. They do not all agree in the starting or ending points. Some begin with observations; some begin with a question or a problem to be solved. Some include the communication of results as their final step; some don't. One might wonder then: Is there some core that all of them have in common? In their manner of presentation, "No". Most accounts describe formulating a hypothesis and testing it; but, one can find accounts of "The Scientific Method" that do not include mention of hypotheses or tests in the statement of the method (Pilar, 1979). Since most contemporary presentations of "The Scientific Method" include the procedure of "formulate a hypothesis and then test it", let us treat this as the core of contemporary accounts of "The Scientific Method", although one should recognize that this is not universally the case.

The variation in presentations of "The Scientific Method" is an interesting phenomenon that requires some explanation. At least one part of the explanation is that

(2) There is no historically canonical statement of scientific methodology.

The idea of a scientific method has a rich history. Aristotle is noted for advocating an inductive-deductive method (Losee, 1993). He thought that scientific knowledge was generated by observations that were then inductively generalized to form high level principles. With these principles in hand, one explained particular phenomena by deducing the phenomena from the principles.

Presentations of "The Scientific Method" sometimes credit figures in the period of the scientific revolution of the 16th and 17th centuries—for example, Rene Descartes, Francis Bacon, or Galileo—with its origination. However, when reading figures from this period, it is difficult to find statements about method that strongly resemble current accounts of "The Scientific Method". Bacon was largely concerned to make corrections to the inductive portions of Aristotle's methodology. He is often credited with the view known as *inductivism*. The idea is that scientific knowledge consists in general principles, or laws, that are the result of inductive generalization from a wide variety of unbiased observations. Descartes's methodology is rationalist and, thus, appears more like steps for solving mathematics problems than for doing empirical science. Galileo is remembered less for elaborate statements on scientific methodology and more for having embodied the ideals of the new experimental philosophy as it was called. Isaac Newton's methodological statements indicate that he held an inductivist view.

In the nineteenth century, there was debate over the method proper to science. Inductivism was put in contrast with a view that has become called *hypothetico-deductivism* (Medawar, 1969). The twentieth century saw Karl Popper advocate a falsificationist version of hypothetico-deductivism. On the other hand, in contrast with falsificationism, a lot of work was done attempting to explicate a logic of scientific confirmation—Carl Hempel's positive instance account of confirmation, Rudolf Carnap's work on probability, and the development of Bayesian theories of confirmation. The point is that, historically, one does not find a consensus among philosophers and scientists about how to best understand what it is that scientists do in forming and evaluating laws and theories.

In the present day, although agreement about scientific methodology may be found on some points,

(3) There is no consensus account of scientific methodology among contemporary philosophers of science.

3 The Myth of a Single Method

A method is a way (or means) of accomplishing something. Most accounts of "The Scientific Method" attempt to describe both a method for coming up with answers to questions (a method of discovery) as well as a method for evaluating those answers (a method of justification). The use of the definite article 'The' in calling some account "The Scientific Method" implies that there is one and only one—a single method. This is problematic given the lack of consensus.

Most current presentations of "The Scientific Method" bear some resemblance to inductivism or hypothetico-deductivism. Some accounts lean primarily toward inductivism; some lean primarily toward hypothetico-deductivism. However, a vast number of them consist of something that looks like a blending of both views. The term 'mashup' has become a popular slang term to describe music and videos that are the result of taking pieces or elements from disparate sources and blending them together. Many current presentations of "The Scientific Method" are mashups in this sense. They begin with something akin to an inductivist statement about how to obtain answers to questions by making observations and collecting data. They then proceed to describe in hypothetico-deductive terms how to evaluate and ultimately justify such answers with observations and experiments. That is, they present an inductivist method of discovery fused to a hypothetico-deductivist method of justification. In this way, it is possible to preserve the notion that there is a single method of science where philosophers of science would typically see a fusion of two.

4 Algorithm or Stance?

The word 'method' is problematic because the word can be associated with items of very different degrees of specificity (or conversely, generality). At a high degree of generality, a stance, strategy, approach, or vague plan can be considered a method. On the other end of the spectrum, one obtains a list of specific rules of procedure like a recipe or algorithm.

Presentations of "The Scientific Method" almost uniformly include a sequential list of steps. Such a list of steps encourages the interpretation of scientific activity as the result of following a recipe or algorithm. Consider a recipe. It is a list of steps such that if they are followed attentively then you are assured, if the recipe is good, to get the specified result. The history of science, however, is littered with the accumulation of useless data, the performance of inconclusive experiments, and the pursuit of ideas that were dead ends. If "The Scientific Method" is the recipe that scientists follow, then it is not such a good recipe since it only occasionally leads them to success. Moreover, the steps are—unlike those in a good cookbook—incredibly vague.

Why present scientific activity as algorithmic? Subjectivity is often thought to result from the imposition of personal differences and biases. By contrast, the conception of a mechanical procedure is one in which the particular idiosyncracies of the agents involved are not essential to the outcome so long as the agents follow the procedure. So, mechanical procedures have often been viewed as paradigms of objectivity. Secondly, a procedure that can be performed by anyone ensures inclusivity. Many presentations of the scientific method are aimed at young children. If all it takes is "turning the crank", then science is inclusive and anyone can be a scientist.

At the other end of the spectrum of generality, a stance, strategy, approach, or vague plan can be called a 'method'. The nineteenth century philosopher Charles S. Peirce in a well-known paper, "The Fixation of Belief" (1877), compared different general methods, or strategies, for answering questions so as to turn doubt into belief in the individual as well as to settle opinion and produce fixed agreement in the community. Peirce locates the essence of "the method of science" in the interaction of our senses with a reality that is independent from us and is intersubjectively accessible. That is, the scientific method, according to Peirce, is the general strategy of trying to align our beliefs with the facts via our senses. This is to use the word 'method' in a very general way—as a strategy or epistemic stance—and clearly not as a kind of algorithm or recipe. For Peirce, the significance of "the method of science" as a strategy for settling doubts is apparent by comparison with other epistemic stances such as the appeal to authority (the method of authority) and the appeal to intuitions about what reason dictates (the *a priori* method).

When "The Scientific Method" is conveyed as a particular algorithm or recipe, it inevitably raises questions about the accuracy and usefulness of such descriptions to actual scientific practice. The importance of "The Scientific Method", however, for truly understanding and conveying the nature of science is not to be found in a particular algorithm but in the communication of a kind of epistemic stance. One might call it the *empirical stance*. This is a commitment to hold our conceptual schemes about the world responsible to observation and experiment. As Peirce recognized, the significance of "the method of science" becomes apparent by comparison with other epistemic stances.

5 Retraction Statements

After presenting the steps of "The Scientific Method", some presentations add "good science isn't always done this way" (Hewitt, 2002, p. 9). There seems to be a growing recognition in introductory accounts of "The Scientific Method" that the presentation given drastically oversimplifies scientific practice and that the particular sequence of steps presented is not an adequate description of scientific activity. Qualifications or retraction statements like these get added. But they make such presentations of "The Scientific Method" seem puzzling. Why call it 'the scientific method' if it is not the method that scientists uniformly follow? When it is claimed that "Science is a special way of finding the answers to questions" (Glass, 2006, p. 8) and that this way is "The Scientific Method" but that scientists "do not always exactly follow this method" (Glass, 2006, p. 9), the presentation can even appear to be logically incoherent. There is an apparent inconsistency in the following two claims:

(A) Science is essentially the use of "The Scientific Method".
(B) Scientists do not always follow "The Scientific Method".

Differentiating the empirical stance from a particular algorithm for doing science alleviates the apparent tension between (A) and (B). If the notions of 'method' in (A) and (B) fall at different ends of the spectrum of generality previously described, then there need be no contradiction.

Moreover, this explains how retraction statements like (B) can get incorporated into presentations of "The Scientific Method" without the author recognizing the seeming inconsistency of doing so. By adding such retraction statements, the author is rather clumsily attempting to convey the idea that what is fundamental to empirical science is something more general than a particular algorithmic presentation of scientific activity—it is something on the order of the empirical stance.

6 A Generic Problem-Solving Method

As James Bryant Conant remarked,

> Indeed, if one attempts to present the alleged scientific method in any such way to a group of discerning young people they may well come back with the statement that they have been scientists all their lives! The layman confronted with some such description of science is in a similar situation to that of the famous character in Molière's comedy who had been speaking prose all his life without knowing it. (Conant, 1951, p. 50)

One cannot help but notice the resemblance between popular and introductory statements of "The Scientific Method" and descriptions of generic problem-solving: "Identify the problem, propose a solution, and then check that the proposed solution works. If need be, revise the proposed solution." At this high level of description, the method applies as well to a non-empirical area of inquiry like mathematics as it does to the empirical sciences. The difference is that in the empirical sciences, checking one's solution involves observation and experiment—namely, the application of the empirical stance. But even after adding the empirical ingredient, important as it is, one only seems to obtain a generic *empirical* problem-solving method.

Some writers on "The Scientific Method" have thought that this is a virtue in its favor: "The importance of the scientific method is based on it being a general problem solving and decision making process or method" (Edmund, 2011). And: "The scientific method is only a formalized description of what people do every day. Even when described technically, the scientific method is just systematized common sense" (Cline, 2013).

There is a common sense logic to the ordering of the steps in statements of "The Scientific Method". The proximity to common sense suggests why authors of presentations of "The Scientific Method" feel free to craft their own version of the method—along with its differences from other versions—without any apparent regard to consult specialists or to check whether it is an accurate description of what scientists do. If "The Scientific Method" is just systematized common sense, then the authority for reporting "The Scientific Method" resides in common sense.

Now, this seems to present another kind of puzzle. If it is true that

(A) Science is essentially the use of "The Scientific Method" and, if it is true that

> (C) "The Scientific Method" is a generic problem-solving method used in everyday life and good for solving problems in all domains

then it would seem to follow that everyone is a scientist and that every domain of inquiry is potentially a science. This runs contrary to the demarcative function that is one aim of many presentations of "The Scientific Method". Domains not usually considered sciences surely engage in empirical problem-solving involving observation and experimentation. For example, musicians, cooks, and religious devotees are sometimes experimental in a rudimentary sort of way—trying out ideas to see what works. If one hopes to demarcate the activities of physicists, chemists, and biologists from those of musicians, cooks, and religious devotees, the basis for doing so cannot reside in whether they ever use a generic empirical problem-solving method like that found in popular accounts of "The Scientific Method". What separates physics, chemistry, and biology from these other kinds of inquiry is not a generic empirical method but rather a host of domain and discipline specific methods and techniques—e.g., the use of double blind experiments, random sampling, etc. And surely what separates scientists from non-scientists has something to do with specialized knowledge and training. The sciences contain numerous local methods accrued over centuries and devised to address problems in domain-specific ways—e.g., mathematical methods, measurement methods, experimental methods, etc. Surely it is the use of these more local methodological commitments that must factor into differentiating the scientific from the non-scientific and from the pseudoscientific.

7 A Useful Myth?

There are at least five functions served by presentations of "The Scientific Method": informative, prescriptive, participative, demarcative, and elevative functions.

The Informative Function. Presentations of "The Scientific Method" are often provided to teach students of science how science works. But the presentation of a single method composed of a list of steps for how to do science encourages certain misunderstandings about the nature of science.

- It communicates a particular presentation as canonical when there has been no canonical presentation historically and there continues to be controversy about how best to understand scientific methodology.
- It presents a monolithic view of scientific methodology (encouraging mashups to create the impression of a single method) and thereby tends to neglect differences in the generation of scientific ideas, in the kinds of problems scientists consider (e.g., descriptive versus explanatory, conceptual versus empirical), in modes of scientific reasoning (e.g., inductive versus hypothetico-deductive), and in the evaluation of theories.
- It encourages a view of scientific activity as beholden to a kind of recipe or algorithm.

In *Scientific Literacy and the Myth of the Scientific Method* (1992), Henry H. Bauer claimed that "The Scientific Method" is a myth. Being not only oversimplified, but also misleading, justifies calling it a myth. At the same time, myths often convey important truths and serve important functions. In its informative role, "The Scientific Method" teaches the empirical stance as well as some important lessons about scientific reasoning.

The Prescriptive Function. In many cases, the primary function of the presentation of "The Scientific Method" is to provide a procedure for performing, documenting, and reporting a science fair project. The items in the procedure are viewed as the "steps" for doing science. It is often stated or implied that this prescriptive function is justified by the informative function: "This is how scientists do it; so, you should too." For pedagogical purposes a list of steps may be necessary. But, this can be separated from the claim that such a list represents the way science is uniformly done.

The Participative Function. Grade school presentations sometimes claim that by following the steps of "The Scientific Method" one can be a scientist: "Anyone who is inquisitive can be a scientist. All you have to do is answer questions by following a simple, logical and straightforward prescription that's called the scientific method" (Cowens, 2006).

Trying on the scientific mindset is important for encouraging participation in science. At the same time, we all distinguish "playing doctor" from being a real physician, and we all distinguish "playing scientist" from being a professional scientist. Professional scientists are distinguished by their knowledge and extensive education in their respective discipline.

The Demarcative Function. Some presentations of "The Scientific Method" are concerned to demarcate science from non-sciences and so-called pseudosciences. But, at the level of generality "The Scientific Method" is often presented, it does not distinguish scientific problem-solving from common sense, everyday empirical problem-solving. So, it is difficult to see how it could demarcate science from non-science.

The Elevative Function. Many presentations of "The Scientific Method" aim to elevate science as a means of answering questions about the world. Scientific answers, while fallible, are distinguished from others in being "rational" and "objective", where the rationality and objectivity of scientific answers is purported to result from following a "logical" method—namely, "The Scientific Method".

How the list of steps contained in "The Scientific Method" avoids subjectivity is obscure, however. Although a presentation might suggest that one ought not to let personal biases in, it is difficult to see how individual differences in imagination, experience, presuppositions, logical thinking, and motivation are unimportant to the practice of the steps in presentations of "The Scientific Method". Moreover, although the conscious attempt to be unbiased in doing science would address sources of explicit bias, implicit biases are perhaps just as dangerous. Rather than trying to locate the objectivity of science in "The Scientific Method", perhaps a better place to locate a sense of objectivity is in the nature of the scientific community and its institutions. Science is objective (in at least one sense of the term) not because human emotions, presuppositions, and biases are absent in the process, but because acceptance by the community requires claims to be checked and requires ideas that are too idiosyncratic to be revised in order to win the allegiance of the group. The community and its institutions act as a filter. On this view, objectivity is to be found in the process of obtaining intersubjective agreement. (This still leaves group biases as an issue of real concern, however.)

In conclusion, the prescriptive and participative functions can be separated from "The Scientific Method" if we have good reasons to question its informative adequacy. And as for the demarcative and elevative functions, there are good reasons to think that "The Scientific Method" by itself is not correctly viewed as the means of demarcation or the source of the objectivity of science.

8 The Stance and the Toolbox

In their informative role, presentations of "The Scientific Method" function to communicate some important lessons about science, but they also mislead. The empirical stance or "scientific spirit" (Hewitt, 2002, p. 9) can be communicated without the extra baggage. The word 'method' has shown itself to become too easily associated with a particular recipe-like list of steps that requires retraction statements to more accurately convey that something so specific is not really what is intended. The word 'stance' is a more accurate description of what is often intended.

Scientific methodology is very important to science. But, in discussing scientific methodology, one can do so without using the label "The Scientific Method". If one would like a catchy metaphor for such discussions, some have suggested the *Scientists' Toolbox* (Wivagg and Allchin, 2002). The toolbox metaphor suggests that we view scientists as workers who select tools they view as appropriate to solving their problems. This avoids suggesting that scientists follow a canonical recipe. And, since toolboxes typically contain tools specialized for certain tasks, it encourages the recognition of differences. There are different kinds of problems—conceptual and empirical. There are differences in reasoning—inductive and hypothetico-deductive. There are differences in mathematical techniques used for representing and analyzing data. There are different techniques for measuring and experimenting. Methodology is important to science, but a lot of what is interesting about methodology is more local to domains and disciplines.

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