1.2: Scientific Method – The Practice of Science

For an amusing look at how scientists think, check out The Pleasure of Finding Things Out: The Best Short Works of Richard Feynman (1999, New York, Harper Collins). Here we focus on the essentials of the scientific method originally inspired by Robert Boyle, and then look at how science is practiced today. Scientific method refers to a standardized protocol for observing, asking questions about, and investigating natural phenomena. Simply put, it says look/listen, infer a cause and test your inference. As captured by the Oxford English Dictionary, the essential inviolable commonality of all scientific practice is that it relies on “systematic observation, measurement, and experiment, and the formulation, testing and modification of hypotheses.”

A. The Method

Adherence to the method is not strict, and may sometimes breach adherence to protocol! In the end, scientific method in actual practice recognizes human biases and prejudices and allows deviations from the protocol. Nevertheless, an understanding of scientific method will guides the prudent investigator to balance personal bias against the leaps of intuition that successful science requires. The practice of scientific method by most scientists would indeed be considered a success by almost any measure. Science “as a way of knowing” the world around us constantly tests, confirms, rejects and ultimately reveals new knowledge, integrating that knowledge into our worldview.

Here in the usual order are the key elements of the scientific method:

1. Observe natural phenomena (includes reading the science of others).
2. Infer and propose an hypothesis (explanation) based on objectivity and reason. Hypotheses are declarative sentences that sound like a fact, but aren’t! Good hypotheses are testable, easily turned into if/then (predictive) yes-or-no questions.
3. Design an experiment to test the hypothesis: results must be measurable evidence for or against the hypothesis.
4. Perform the experiment and then observe, measure, collect data and test for statistical validity (where applicable). Then, repeat the experiment.

5. Consider how your data supports or does not support your hypothesis and then integrate your experimental results with earlier hypotheses and prior knowledge.

But, how do theories and laws fit into the scientific method?

A scientific theory, contrary to what many people think, is not a guess. Rather, a theory is a statement well supported by experimental evidence and widely accepted by the scientific community. One of the most enduring, tested theories is of course the theory of evolution. Among scientists, theories might be thought of as ‘fact’ in common parlance, but we recognize that they are still subject to testing and, modification, and may even be overturned. While some of Darwin’s notions have been modified over time, in this case, those modifications have only strengthened our understanding that species diversity is the result of natural selection. You can check out some of Darwin’s own work (1859, 1860; The Origin of Species) at Origin of Species. For more recent commentary on the evolutionary underpinnings of science, check out Dobzhansky T (1973, Nothing in biology makes sense except in the light of evolution. Am. Biol. Teach. 35:125-129) and Gould, S.J. (2002, The Structure of Evolutionary Theory. Boston, Harvard University Press).

A scientific law is thought of as universal and even closer to ‘fact’ than a theory! Scientific laws are most common in math and physics. In life sciences, we recognize Mendel’s Law of Segregation and Law of Independent Assortment as much in his honor as for their universal and enduring explanation of genetic inheritance in living things. But Laws are not facts! Laws too, are always subject to experimental test.

Astrophysicists are actively testing universally accepted laws of physics. Strictly speaking, even Mendel’s Law of Independent Assortment should not be called a law. Indeed, it is not true as he stated it! Check the Mendelian Genetics section of an introductory textbook to see how chromosomal crossing over violates this law.

In describing how we do science, the Wikipedia entry states: “the goal of a scientific inquiry is to obtain knowledge in the form of testable explanations (hypotheses) that can predict the results of future experiments. This allows scientists to gain an understanding of reality, and later use that understanding to intervene in its causal mechanisms (such as to cure disease).” The better an hypothesis is at making predictions, the more useful it is, and the more likely it is to be correct. In the last analysis, think of Hypotheses as educated guesses and think of Theories and/or Laws as one or more experimentally supported hypothesis that everyone agrees should serve as guideposts to help us evaluate new observations and hypotheses.

A good hypothesis is a rational guess that explains scientific observations or experimental measurements. Therefore by definition, hypotheses are testable based on predictions based on logic. Additional observation can refine or change the original hypothesis, and/or lead to new hypothesis whose predictive value can also be tested. If you get the impression that scientific discovery is a cyclic process, that’s the point! Exploring scientific questions reveals more questions than answers!

We now recognize that a key component of the scientific method is the requirement that the work of the scientist be disseminated by publication! In this way, shared data and experimental methods can be repeated and evaluated by other scientists.
B. Origins of the Scientific Method

Long before the word *scientist* began to define someone who investigated natural phenomena beyond simple observation (i.e., by doing experiments), philosophers developed formal rules of *deductive* and *inferential logic* to try to understand nature, humanity’s relationship to nature, and the relationship of humans to each other. In fact, Boyle was not alone in doing experimental science. We therefore owe the logical underpinnings of science to philosophers who came up with systems of *deductive* and *inductive logic* so integral to the scientific method. The scientific method grew from those beginnings, along with increasing empirical observation and experimentation. We recognize these origins when we award the Ph.D. (*Doctor of Philosophy*), our highest academic degree! We are about to learn about the life of cells, their structure and function, and their classification, or grouping based on those structures and functions. Everything we know about life comes from applying the principles of scientific method.