Pearson

1.3: The Scientific Approach to Knowledge

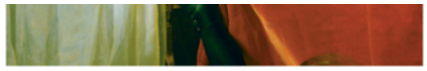
The particulate model of matter introduced in Section 1.1 is not obvious to a casual observer of matter. In fact, early influential thinkers rejected it. Nonetheless, it came to be accepted because *scientists were driven to it by the data*. When thinkers applied the *scientific approach to knowledge* to understanding matter, the only explanation consistent with their observations was that matter is particulate.

The scientific approach to knowledge is a fairly recent phenomenon, only finding broad acceptance in the last 400 years or so. Greek thinkers (over 2000 years ago) were heavily influenced by the Greek philosopher Plato (427–347 B.C.E.), who thought that the best way to learn about reality was not through the senses but through reason. Plato believed that the physical world was an imperfect representation of a perfect and transcendent world (a world beyond space and time). For him, true knowledge came, not through observing the real physical world, but through reasoning and thinking about the ideal one.

> Although some Greek philosophers, such as Aristotle (384–322 B.C.E.), did use observation to attain knowledge, they did not emphasize experiment and measurement to the extent that modern science does.

The *scientific* approach to knowledge is exactly the opposite of Plato's approach. Scientific knowledge is empirical—it is based on *observation* and *experiment*. Scientists observe and perform experiments on the physical world to learn about it. Some observations and experiments are qualitative (noting or describing how a process happens), but many are quantitative (measuring or quantifying something about the process). For example, Antoine Lavoisier (1743–1794), a French chemist who studied combustion (burning), made careful measurements of the mass of objects before and after burning them in closed containers. He noticed that there was no change in the total mass of material within the container after combustion. In doing so, Lavoisier made an important *observation* about the physical world.

Observations often lead a scientist to formulate a **hypothesis**, a tentative interpretation or explanation of the observations. For example, Lavoisier explained his observations on combustion by hypothesizing that when a substance burns, it combines with a component of air. A good hypothesis is *falsifiable*, which means that it makes predictions that can be confirmed or refuted by further observations. Scientists test hypotheses by **experiments**, highly controlled procedures designed to generate observations that can confirm or refute a hypothesis. The results of an experiment may support a hypothesis or prove it wrong, in which case the scientist must modify or discard the hypothesis. In some cases, a series of similar observations can lead to the development of a **scientific law**, a brief statement that summarizes past observations and predicts future ones. Lavoisier summarized his observations on combustion with the **law of conservation of mass**, which states, "In a chemical reaction, matter is neither created nor destroyed." This statement summarized his observations on chemical reactions and predicted the outcome of future observations on reactions. Laws, like hypotheses, are also subject to experiments, which can support them or prove them wrong.



A painting of the French chemist Antoine Lavoisier with his wife, Marie, who helped him in his work by illustrating his experiments and translating scientific articles from English. Lavoisier, who also made significant contributions to agriculture, industry, education, and government administration, was executed during the French Revolution. (The Metropolitan Museum of Art)

Scientific laws are not *laws* in the same sense as civil or governmental laws. Nature does not follow laws in the way that we obey the laws against speeding or running a stop sign. Rather, scientific laws *describe* how nature behaves—they are generalizations about what nature does. For that reason, some people find it more appropriate to refer to them as *principles* rather than *laws*.

One or more well-established hypotheses may form the basis for a scientific **theory**. A scientific theory is a model for the way nature is and tries to explain not merely *what* nature does but *why*. As such, well-established theories are the pinnacle of scientific knowledge, often predicting behavior far beyond the observations or laws from which they were developed. The particulate view of matter grows out of the atomic theory proposed by English chemist John Dalton (1766–1844). Dalton explained the law of conservation of mass, as well as other laws and observations of the time, by proposing that matter is composed of small, indestructible particles called atoms. Since these particles are merely rearranged in chemical reactions (and not created or destroyed), the total amount of mass remains the same. Dalton's theory is a model for the physical world—it gives us insight into how nature works, and therefore *explains* our laws and observations.

> In Dalton's time, people thought atoms were indestructible. Today, because of nuclear reactions, we know that atoms can be broken apart into their smaller components.

The scientific approach always returns to observation to test theories. For example, scientists have tested the atomic theory by isolating single atoms and even imaging them, providing strong validation for the theory. Nonetheless, theories are never proven because some new observation or experiment always has the potential to reveal a flaw.

Established theories with strong experimental support are the most powerful kind of scientific knowledge. You may have heard the phrase, "That is just a theory," as if theories are easily dismissible. Such a statement reveals a deep misunderstanding of the nature of a scientific theory. Well-established theories are as close to truth as we get in science. The idea that all matter is made of atoms is "just a theory," but it has over 200 years of experimental evidence to support it. It is a powerful piece of scientific knowledge on which many other scientific ideas have been built.

Conceptual Connection 1.2 Laws and Theories

Creativity and Subjectivity in Science

Interactive

As we have discussed, empiricism is the hallmark of science. However, that does not mean that creativity, subjectivity, and even a bit of luck do not also play important roles. Novices imagine science to be a strict set of rules and procedures that automatically lead to inarguable, objective facts. But this is not the case. Even our discussion of the scientific approach to knowledge is only an idealization of real science, useful to help us see the key distinctions of science. Real science requires creativity and hard work. Scientific theories do not just arise out of data—men and women of great genius and creativity craft theories. A great theory is not unlike a master painting, and many see a similar kind of beauty in both.

The Structure of Scientific Revolutions, a book by Thomas Kuhn (1922–1996), published in 1962, details the history of science and highlights the creative and subjective aspects of the scientific approach to knowledge. In the book, Kuhn argues that scientific history does not support the idea that science progresses in the smooth cumulative way one might expect of a wholly objective linear enterprise. Instead, Kuhn shows how science goes through fairly quiet periods that he calls *normal science.* In these periods, scientists make their data fit the reigning theory. Small inconsistencies are swept aside during periods of normal science. However, when too many inconsistencies and anomalies develop, a crisis emerges. The crisis brings about a *revolution* and a new reigning theory. According to Kuhn, the new theory is usually quite different from the old one; it not only helps us to make sense of new or anomalous information, but also enables us to see accumulated data from the past in a dramatically new way.

Kuhn further contends that theories are held for reasons that are not always logical or unbiased and that theories are not *true* models—in the sense of a one-to-one mapping—of the physical world. Because new theories are often so different from the ones they replace, he argues, and because old theories always make good sense to those holding them, they must not be "True" with a capital *T*; otherwise "truth" would be constantly changing.

Kuhn's ideas created a controversy among scientists and science historians that continues to this day. Some, especially postmodern philosophers of science, have taken Kuhn's ideas one step further. They argue that scientific knowledge is *completely* biased and lacks any objectivity. Most scientists, including Kuhn, would disagree. Although Kuhn pointed out that scientific knowledge has *arbitrary elements*, he also said that "Observation … can and must drastically restrict the range of admissible scientific belief else there would be no science." In other words, saying that science has arbitrary elements is quite different from saying that science is arbitrary.