NATURAL SCIENCE

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Keywords: science, observation, fact, conceptualization (theory), induction, deduction, syllogism, valid/invalid, truth, experimentation, empiricism, positivism, Francis Bacon, Robert Boyle, Auguste Compte, William Whewell, Herbert Spencer, Karl Marx, Friedrich Engels, Karl Popper, Thomas Kuhn, social constructionism.

Contents

Summary

Based on the important distinction between rational and non-rational thought, or "ways of knowing", this chapter is devoted to the characteristics of rational thought and discusses the distinction between observation, fact and conceptualization, the principles of inductive and deductive logic and the generation of hypotheses, and testing of hypotheses.

1. Introduction

The term "science" (from the Latin *scientia*) refers to knowledge that has been accumulated and systematized to present some ordered view of the world. The natural sciences encompass all those areas of human knowledge dealing with the natural world, and include the specific areas of physics, chemistry, the life sciences, earth and planetary sciences and cosmology. Fields such as psychology are also considered by many to be part of the natural sciences today, though it has been shuffled back and forth between the natural and social sciences for a century or more. The question of whether the natural sciences have any sort of claim to a special and unique epistemological status has been much debated among philosophers, especially philosophers of science. A long-standing tradition (since the seventeenth century) in western culture has made a clear distinction between the natural sciences and the social sciences and humanities. The grounds for this distinction have rested largely on the claim that the natural sciences generate hypotheses that can be tested by experimentation or observation. In the middle of the twentieth century, philosopher of science Karl Popper narrowed the definition even further by claiming that the only areas of knowledge that could properly be called "science" were those that generated falsifiable hypotheses. Clearly, such definitions are epistemologically insufficient, since many areas long considered parts of science, such as astrophysics or historical geology, are not subject to experimentation or falsification in the usual sense; and conversely, many areas of the social sciences and humanities also generate and test hypotheses (though testing is less organized around experimentation in the laboratory sense).

In the seventeenth and eighteenth centuries what we now call "natural science" or "science" was actually referred to as "natural philosophy", and as such was considered only one branch of the larger field of philosophy. The term "science" was actually not used in its modern sense (as "natural science") until 1830 when it was introduced by William Whewell (1794-1866) to refer to the process by which we develop increasingly certain (meaning axiomatic) knowledge about the natural world. Whewell and others gave natural science a privileged position in the evolution of human knowledge. Thus, from the seventeenth century onward, "science" became increasingly identified as a qualitatively different, and superior, form of knowledge to that in the arts and letters (including history and what we today would call the social sciences). Natural science was special because it was able to establish law-like statements that applied throughout the entirety of the material world and that in the most advanced cases could be expressed mathematically.

The question of whether human social activities (including economics, politics and history) could be approached scientifically has been a much-debated issue. In the seventeenth century natural philosophy tended to exclude human history, although the intersection of psychology and philosophy was a matter of great interest. In the eighteenth and early nineteenth centuries, areas such as political economy, were claimed to be subject to scientific analysis and to the generation of universal laws (for example, the law of supply and demand) by such writers as Montesquieu (1689-1755), Adam Smith 1723-1790, and Thomas Robert Malthus (1766-1834). In the later nineteenth century, especially in the wake of Darwin's theory of evolution by natural selection, there were various attempts to argue that all of human history and social activity, like animal and plant historical evolution, are also a part of natural science, and are subject to discoverable laws. Among those advocating such views were Herbert Spencer (1820-1904) and Karl Marx(1818-1883). Spencer saw human history as merely an extension of cosmic evolution, following such general principles as the tendency to move from homogeneity to heterogeneity. Marx, on the other hand, argued that human economic, political and social practices follow specific laws (literally, those established by humans, rather than independently existing laws of nature), and that these laws can be uncovered by close analysis of human behavior in its historical context. Unlike natural laws, which according to nineteenth-century philosophers were thought to be fixed and permanent, Marx saw human laws as evolving through history in the ongoing attempt to resolve contradictions within the social, political and economic spheres. For Marx, not only do specific human practices, beliefs and institutions evolve, but the laws governing them do so as well.

Despite the efforts of individuals like Spencer and Marx to apply a scientific approach to human social and historical problems, the view persisted throughout most of the twentieth century that there was something special and unique about natural science that set it apart from all other human intellectual activities. Science was supposed to have its own special method, the ‘scientific method” that distinguished it from work in the social sciences and humanities. Every introductory science textbook contained a discussion of *the scientific method*, and usually included such components as: identifying the problem, making observations, developing hypotheses, setting up experiments or making further observations, collecting data, evaluating the hypotheses and drawing conclusions. It did not escape the notice of philosophers and some scientists, however, that this strict sequence of activities was hardly ever observed in practice, and that even if it were it did not significantly distinguish doing science from figuring out how to fix a piece of machinery, or baking a cake. Indeed, toward the end of the twentieth century some philosophers of science introduced the term “ways of knowing” to replace what they considered to be the artificial distinction between natural science and other forms of knowledge. Thus, for example, a paleontologist (traditionally considered to be a natural scientist) might have more in common with a historian (usually not considered a natural scientist) than with a biochemist (definitely considered to be a scientist) in the ways in which they come to learn about and reconstruct the past.

For the purposes of this chapter, then, “natural science” will not be strictly distinguished from any other human activities. Rather, the important distinction is that between rational and non-rational thought, or “ways of knowing”. Rational thought is that based on a materialist philosophy, the collection of sense data and its organization through the rules of inductive and deductive logic, the formulation and testing of hypotheses, and the recognition that all conclusions are tentative. Non-rational thought is characterized by belief systems that may be held independent of sensory experience about the world, and thus not grounded in material reality. Such non-rational belief systems are often based on adherence to authority, belief in supernatural beings or processes, do not necessarily require that ideas be tested, and often lay claims to eternal truths. In these senses, rational ways of knowing would include all the so-called sciences, including the social sciences and even the arts (which in their own way try to depict and understand real human experience); non-rational ways of knowing would include the theological aspects of most religions, secular superstitions such as astrology, and fortune telling. To the extent that religions are based on the belief in some eternal Creator or Living Spirit in the world, give credence to miraculous or supernatural events (that cannot, by definition, be investigated or understood in everyday, material terms), and hold to ideas or concepts that cannot be tested, they appeal to non-rational ways of knowing.

The next section is devoted to outlining the characteristics of rational thought, and will consist of three topics: (1) The distinction between observation, fact and conceptualization, (2) The principles of inductive and deductive logic and the generation of hypotheses, and (3) The testing of hypotheses.

2. Characteristics of Science as a Rational Way of Knowing

Science is a rational way of looking at the world. It is an attempt to understand things as they are, and how they got to be that way. A “scientific outlook” is one that does not admit non-rational, or supernatural, explanations and, as much as possible poses explanations that can be tested either by further observations or by experiment. While scientists readily admit that much of our knowledge of the universe is still largely unknown, nothing in principle is unknowable. More than anything else, science is a method of inquiry. As such, the methods of science are applicable to any topic, including those that are normally referred to as the social sciences and humanities.

2.1. Observation, Fact and Conceptualization

Like all rational attempts to understand ourselves and the world, science begins with some sort of sensory data, some input from the material world as simple as the taste of an apple that is sour and the visual observation that it is also green. Each of these items of sensory data represents an *observation*, which can be defined as a discrete item of sensory data. Observations are one-time events, however, and for them to become part of any more general formulation must be confirmed as *facts*. Facts are observations that have been repeated enough times by one observer, and then by other observers, to be agreed upon collectively, to represent some regularity of human experience. It is important to recognize that facts do not exist as some independent entity but as negotiated agreements among a community of people, whether it is concerned citizens or a network of researchers in science. Thus facts are socially negotiated agreements, and are not usually accepted on any permanent basis if they represent a one-time event. In the natural sciences, facts are established collectively by various segments of the scientific community.

Facts are grouped together in various ways to form *conceptualizations*, abstractions that go beyond the facts to establish some more general point. The term conceptualization includes such mental abstractions as theory, hypothesis, inference or explanation. Although there are differences in the meaning of these terms (and some of these will be pointed out below), philosophers of science are not in any general agreement as to exactly how they can be clearly distinguished. For that reason, the term "conceptualization" is used as a general cover-all for any abstraction that goes beyond stating a simple observation or a collectively agreed-upon fact.

2.2. Types of Conceptualizations: Generalizations and Explanations

Conceptualizations can take two basically different forms: generalizations and explanations.

2.2.1. Generalizations

Generalizations are conceptualizations that extend from a limited sample of a phenomenon or class of objects to make a claim for *all* samples of that phenomenon or class of objects. Generalizations establish that a particular phenomenon occurs with regularity. Generalizations allow us to establish some patterns of reliability and predictability in the world.

Generalizations are statements built up from the assembly of a given sample of repeated facts by the process of inductive logic. Inductive logic goes from a series of specific statements to a general conclusion (called a generalization). For example, suppose a person tastes a green apple and determines that it is sour (a single observation). The observer could not logically conclude (with any certainty) that all green apples will be sour. However, if that observer tastes a second, third and fourth green apple and they are all sour, he or she might venture the *generalization* that "all green apples are sour." The reasoning process is inductive, meaning that it goes from a set of specific statements to a broad general conclusion applying to a class of items (green apples), as shown:

Observation 1: This green apple is sour,
Observation 2: This green apple is sour,
Observation 3: This green apple is sour,
Conclusion: All green apples are sour

It should be obvious that the more green apples that are tasted the more likely the generalization "all green apples are sour" will hold up. Thus, the power of inductive reasoning is strengthened by increased sample size. But of course it is never possible to test all green apples in the world, meaning that an inductive conclusion is never certain. There is always the possibility that a green apple that is sweet will turn up somewhere, thus invalidating the generalization that "*all* green apples are sour."

Deductive reasoning is the opposite of inductive in several critical ways. Deduction proceeds from general statements to specific conclusions. For example, continuing the green apple case, deductive reasoning starts with the generalization "All green apples are sour," proceeds to a second statement such as "This is a green apple" and proceeds to the conclusion that "This green apple must be sour." In the formal rendering of deductive logic, known as a syllogism, the first statement ("all green apples are sour") is the *major premise (or hypothesis)*, and the second (usually a less-general statement) is the *minor premise (or hypothesis)*. Syllogisms can be written formally as:

Major Premise: All green apples are sour . . .
Minor Premise: This object is a green apple . . .
Conclusion: This green apple must be sour

Note that the conclusion ("This green apple must be sour") follows with certainty from the major and minor premise. This is another important way in which deductive reasoning differs from inductive reasoning. In inductive reasoning there is no way that all green apples can be tested, and thus there is always the possibility that the next green apple will in fact not be sour. For inductive logic, more instances serve to strengthen the hypothesis, but can never establish it with absolute certainty. With deductive logic, however, the conclusion *must* follow from the two premises. Why we are *forced* to this conclusion can be illustrated diagrammatically by a series of three circles, the largest representing "all sour objects," the next largest "all green apples," and the smallest, "this green apple" (Figure 1).

Invalid reasoning would be represented by altering the minor premise, for example, as follows:

Major premise: All green apples are sour . . .
Minor premise: This is a sour object
Conclusion: This sour object is a green apple

In this case, the circle for "this sour object" does not *have* to fall within the circle for green apples; it would be possible to place it anywhere within the circle for "sour objects." Since we are not compelled to place it within the circle for "all green apples" the conclusion would invalid.

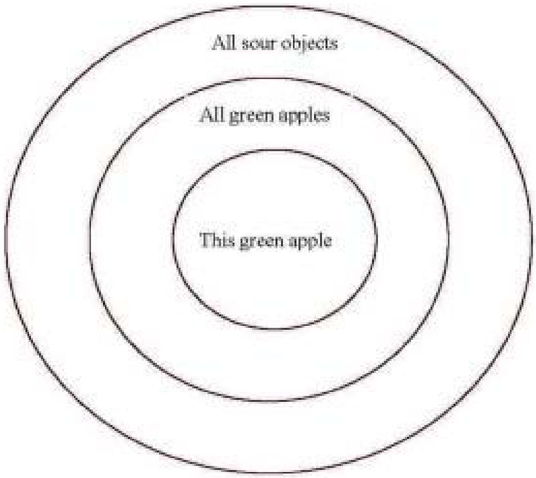

Figure 1. Nested sets of circles illustrating the necessity of conclusions based on deductive logic.

In valid reasoning, the conclusion also serves as the basis for a *prediction* that can then be *tested*: in this case, by tasting the green apple. If the apple is sour, the hypothesis has been confirmed; if the apple is sweet, the hypothesis has been rejected, and it is no longer possible to claim that *all* green apples are sour. The hypothesis would have to be modified at least to statements such as "Most green apples are sour," or "Some green apples are sour." Again, note that the process of confirming a hypothesis is never certain while rejecting one is always certain.

It is important here to distinguish between validity and truth in the conclusions deriving from inductive and deductive reasoning. Validity refers to the *logic* inherent in the statements, that is, as derived from the reasoning process itself. Validity refers only to the rational process of induction or deduction (mostly deduction), and states nothing about the truth of the conclusions arrived at in the real world. For example, considering the following syllogism:

Major premise: All Xs are Ys
Minor premise: All Ys are Zs
Conclusion: All As are Zs

The conclusion is logically valid in that given the statements in the major and minor premise, the conclusion follows inevitably. However, as a statement about the English alphabet it is tacitly false: Xs are *most definitely not* Zs. It is important to recognize that establishing the validity of a particular conclusion is quite different from its truth in the real world. Truth or falsity must be determined by other means, such as experimental tests carried out under a controlled environment.

2.2.2. Explanations

Explanations attempt to provide a causal account of the factors that lead up to the occurrence of a phenomenon. For example, once we are satisfied with the generalization that all green apples are sour, we may want to know what *causes* green apples to be sour? To answer this question might involve a chemical analysis of green apples to isolate the component that causes sourness (for example, a particular organic acid). There are, of course, more complex examples of explanations in science: Newton's theory of gravitation provides an explanation for all forms of motion, from falling apples to the shapes of planetary orbits. In modern biology, the mechanism of DNA replication provides an explanation for both how traits are replicated faithfully and also how variations (mutations) occur. The depolarization of a nerve cell membrane provides an explanation for how nerve cells become activated and conduct an impulse.

In summary, generalizing hypotheses tell us that something happens with regularity, while explanatory hypotheses tell us how it happens.

3. Testing Hypotheses by Observation and Experiment

Establishing the truth of a conclusion based on deductive logic involves making a prediction that can be subjected to a test. That test can take the form of either additional observations, or an experiment.

3.1. Testing Hypotheses by Observation

Many hypotheses can be tested simply by making further observations. The hypothesis that all green apples are sour can be tested by tasting (an observation using the sense of taste) additional green apples. The hypothesis that the sun always rises in the east can be tested by observing the sunrise tomorrow morning. On a more sophisticated level, the hypothesis that the extinction of dinosaurs was the result of a meteoric impact can be tested by observing the mineral content and distribution of fossil remains in geologic strata both before and after the hypothesized date of impact. The hypothesis that modern birds derived from reptilian ancestors can be tested by unearthing fossils that contain both bird and reptilian characteristics (such as *Archeopteryx*, which has both modern feathers and reptilian teeth and bone structures). Testing hypotheses by observation is common, especially for cases where experimental intervention (as in historical cases) is impossible, or at least highly impractical.

3.2. Testing Hypotheses by Experimentation

Hypotheses can also be tested by designing an appropriate experiment. Experiments are interventions that force a given system to provide an answer to a specific question. For example, consider the hypothesis that plant seeds require water to start development. This hypothesis can be tested by taking two groups of seeds of the same species and planting them in two identical (or as much so as possible) plots of soil in a greenhouse. One group (called the experimental group) would be given water, while the other (called the control group) would not. In every other respect, however, the two groups would be treated identically. Experiments restructure the environment in such a way as to extract an answer from nature that would be difficult to obtain by waiting for the right conditions to occur on their own (for example, for a rainstorm). In addition, under natural conditions, a variety of other factors, called “variables” (such as light, temperature, soil conditions), could also influence the outcome. An experiment sets up the required conditions and controls all the possible variables, one at a time, that might affect the outcome.

The proper design of experiments involves the setting up two groups, a control group and an experimental group. By convention, the experimental group is the one subject to particular manipulations – in the example of seeds above, the group that receives water, while the other group receives no water, and thus serves as a comparison. Water is considered the variable, that is, the factor whose effect is being tested. The control group is subjected to all the same conditions as the experimental group *except for* the factor whose effect is being tested, in this case water. If the group of seedlings exposed to water grows and those in the control group do not, it would be reasonable to conclude that water is necessary for the growth of seedlings. If the seedlings grew equally well in both the experimental and control groups, then it would be logical to reject the hypothesis that water is necessary for seed growth. Because they involve direct and highly controlled intervention into a natural system, experiments can yield rigorous answers – that is, answers that are unambiguous because all the various alternative hypotheses have been eliminated.

Experimentation is clearly not limited to the natural sciences. In everyday life people carry out experiments all the time. Much of the time these are rather informal, but they have the main characteristics of the more formal scientific experiment nonetheless. For example, many ingredients (factors) are involved in baking a cake: amount of milk, flour, sugar, eggs, mixing procedures, temperature of the oven, duration of baking time, and the like. If a particular cake turns out badly, the baker might try altering one factor at a time until he or she found which variable was responsible for the problem. This would clearly be problem-solving in an everyday context using the experimental method.

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Biographical Sketch

Garland E. Allen earned his B.A. at the University of Louisville, and his M.A. and his Ph.D. at Harvard University.

He is *Professor of Biology* at the Department of Biology of the Washington University in St. Louis.

His main research interests lie in the areas of the history, philosophy and sociology of biology. The major focus of his present research is on the history of genetics and its relationship to eugenics and agriculture in the United States between 1900 and 1950. In addition to an interest in Mendelian genetics, agriculturists and eugenicists also believed that the principles of animal and plant breeding could be applied to managing human evolution. He is exploring the funding and institutional base for eugenics (defined in the early part of the century as “the science of human improvement through better breeding”): who paid for it, what were their motives, and what was the sort of scientific (genetic) basis for eugenic arguments. The major goal of this work is to place eugenics in its historical context, and to explore its implications for society today (raising many issues of ethical, legal, and social importance that are surfacing today in the midst of the Human Genome Project). He is currently investigating the relationship between eugenics and the conservation movement in the first half of the twentieth century. He is interested also in the history of dialectical materialism in the works of Charles Darwin (natural science), Karl Marx (social science) and Richard Wagner (humanities) in the mid- and later 19th century. Some of his publications are: *Life Science in the Twentieth Century*, New York: John Wiley & Sons, 1975; “Genetics, Eugenics and Society: Internalists and Externalists in Contemporary History of Science”, *Social Studies of Science* 6, 105-122; *Thomas Hunt Morgan. The Man and His Science*, Princeton, N.J.: Princeton University Press, 1978; The Eugenics Record Office at Cold Spring Harbor, 1910-1940: An Essay in Institutional History, *Osiris* 2nd Series 2 (1986): 225-264; The social and economic origins of genetic determinism: A case study of the American eugenics movement, 1900-1940, and its lessons for today. *Genetica* 99 (1997): 77—88; Essays on Science and Society: Is a New Eugenics Afoot? *Science* 294 (October 5, 2001): 59-61; (with M.B. Adams and S. Weiss) Human heredity and politics: a comparative institutional study of the Eugenics Record Office at Cold Spring Harbor (United States), the Kaiser Wilhelm Institute for Anthropology, Human Heredity and Eugenics (Germany) and the Maxim Gorky Medical Genetics Institute (USSR). *Osiris* 20 (2005): 232-262. He also retains an interest in introductory biology and have co-authored several texts, including *Matter, Energy and Life* (4 eds., 1965-82) and *The Study of Biology* (4 eds., 1967-84), and, most recently, with J. Baker, *Biology: Scientific Process and Social Issues* (April, 2001).

Prof. Allen was Editor of the *Journal of the History of Biology* and is a Member, among others, of the History of Science Society (HSS) and the International Society for History, Philosophy and Social Studies of Biology, which he served as President (2005-2007).