Science and Scientific Method

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Abstract. *The roots of science go back to the contributions of Greek philosophers some 2,500 years ago. However, science as it is known today and its great power and remarkable influence over humanity emerged in the 16th century as a consequence of the Renaissance revolution that radically transformed the objects, methods and objectives of knowledge of nature. Objects became natural phenomena; the methods, disciplined cooperative research, and a set of objective, systematic, rational, and critical procedures that have been generically called the "scientific method"; and the objectives, the construction of a factual, verifiable and explanatory body of knowledge. What essentially characterizes science as a rationally and critically grounded body of knowledge is the method by which that knowledge is constructed. This article reviews the foundations of the scientific approach to knowledge generation and characterizes the scientific method.*

1. Introduction

The common person can acquire knowledge in different ways. The farmer, for example, is aware of the plants he cultivates, the time of sowing and planting, the way to treat the land, the means of protection against insects and pests. This knowledge comes from imitation, information transmitted by predecessors, family members and formal education, and personal experience. This person may also possess knowledge generated by research carried out by scientific institutions that is transmitted to him by means of communication and training. Scientific knowledge can also be acquired more rationally through formal higher education, and enhanced with specialization in postgraduate courses.

The discovery that nature is governed by an intelligible scheme originated in Greece. Greek theory discovered the universe of ideas and forms, ordered by the rules of geometry, and the universe of nature, consisting of logically ordered movements. All Greek theory is dedicated to the description of these two orders, embodied in Euclid's Geometry, in Aristotle's Physics and in Plato's Theory of Ideas. Only at the beginning of the 17th century did modern science originate.

Science is a logical process of investigation for solving problems and seeking answers to questions regarding natural phenomena. Through the scientific method, scientists attempt to generate a body of knowledge free from personal beliefs, perceptions, values, attitudes and emotions. This is achieved by the empirical verification of ideas and beliefs through a procedure open to public inspection. The reliability of scientific knowledge derives from its evidence base provided by objective observation.

Scientific knowledge is not absolute and definitive knowledge. On the contrary, it tends to improve itself and, as a result, lead, for example, to the creation of new more adequate and convenient methods, techniques and procedures. This progress is achieved by the permanent activity of inquiry to which researchers are dedicated. Thus, science is a source of knowledge generation that renews itself to solve problems, answer questions, and develop more effective procedures to solve problems and answer questions.

This article reviews the origins, evolution and characteristics of the scientific approach to knowledge generation. This review is based mainly in the contributions of Descartes [1], Madden [2], Lastrucci [3], Bunge [4], Heath [5], Cervo & Bervian [6], Wilson [7], Hinkelmann & Kempthorne [8], Johann [9], Christensen [10], Carey [11], Gottschall [12], Silva [13].

2. Sources of Knowledge

The search for knowledge of nature was already a characteristic of prehistoric man. Man's first contacts with nature generated eminently sensitive knowledge. Limited resources allowed the perception of phenomena only through the senses and superficial explanations. Seeking to unravel the universe, man adheres to the cult of the forces of nature as a form of knowledge. In the passage from primitive times to antiquity, man expands the limits of his knowledge, going from mythological explanations of the universe to explanations of a religious nature. The next step is interpretation by way of reason. With the rise of philosophy, the explanation of nature becomes eminently rational. The incessant search for truth leads to the passage from philosophy to science, that is, to the interaction of reasoning with the empirical approach to explaining the causal relationships between phenomena, through rigorous analytical and rational procedures.

Empirical knowledge. The most remote and ordinary way for man to create his representations and interpretations of reality is through everyday experience and common sense. The knowledge constituted by these representations arises from the need to solve immediate problems. This empirical knowledge is a spontaneous and unsystematic way of representing reality, without an appropriate method to deepen its foundations. This is the knowledge of the common person, without training, generated by his relationship with the material world. It originates from individual and collective experiences and beliefs. This knowledge is developed, used to predict future events and transmitted from one generation to the next.

Common sense implies a certain degree of abstraction. However, it proceeds to a simple junction of ideas, notions and concepts and does not reach a level of elaboration that originates the creation or use of concepts whose meanings deepen the understanding of reality. This limitation generates knowledge of facts based on their appearance, without concern for their explanation through analysis to characterize their origins. The knowledge generated is constituted by an agglomeration of elements, without unity and coherence. Besides, it is not subjected to a level of criticism necessary to understand reality beyond what is experienced. This can lead to fatalistic interpretations of the situations that present themselves, which attribute to destiny defined by a superior being responsible for the events of life.

Mythical knowledge. Without using writing, primitive man sought to explain, narrate and announce phenomena through symbols and allegories, thus creating myths. Reality then began to be interpreted based on these myths. Mythical knowledge is a product of the oral transmission of empirical knowledge from generation to generation. Myths were rooted in the culture and tradition of ancient peoples and represented much more than an attempt to explain reality. Myth constituted the historical foundation of civilizations, explaining the past and the origin of the present. It was a representation of the real world, recreated from the subjective elaboration of man's experiences. The origins of inexplicable phenomena were attributed to immanent powers and forces existing within objects, animals and people. Ancient peoples worshiped the Sun and the Moon; the Hindus, the cow; the Mayans, the Incas, the Aztecs and other peoples, the totems and amulets, monuments and objects that they built themselves. These peoples believed that these entities and objects had the strength and powers to do good and evil, and created their interpreters or interlocutors, such as witches, sorcerers, priests, shamans.

At a later stage, these mysterious forces are transferred to fictitious beings with human forms. These beings were invisible, represented by statues, to which, mainly the Greeks, Romans and Egyptians, rendered cults. The interventions of these superior beings, called gods, would be the origin of all natural phenomena. It is the phase of polytheism. The cause of a set of phenomena in a particular sector of nature was attributed to a particular god. Polytheism predominated in Greece and ancient Rome. Thus, for example, Diana was the goddess of the hunt, Eolo the god of the wind, Neptune the god of the sea, Ceres the goddess of the harvest.

Theological knowledge. Religious experience is as old as civilized man is. Religious or theological knowledge is aimed at understanding the totality of reality. Its purpose is the explanation of a unique origin and end concerning the genesis and existence of the universe. It attributes the cause of all phenomena to a single superior being: God. In the Judeo-Christian religion, God is the only creator of all that exists. The creation of the universe and natural phenomena are attributed to him, in particular the creation of man and animals, their existence, transformations and purposes.

From a theological point of view, the divine existence is evident and evidence needs no proof. Based on this principle, it seeks to find explanations for everything that has happened and happens to human beings, and seeks to study issues relating to knowledge of the deities, their attributes and relationships with the world and with men. Religion has its foundations in dogmas and rites, which are accepted by faith and cannot be proved or criticized, because it is the only source of truth. The sources of theological knowledge are the holy books – Koran for Muslims, Veda for Hindus, Talmud for Jews and Bible for Christians. The interlocutors between man and God are priests, rabbis, pastors and other interpreters.

Philosophical knowledge. Philosophical knowledge began with man's first attempts to understand the world by associating reasoning with observation. Philosophy developed in Persia, China, India, and elsewhere in the Orient. Western philosophy originated six centuries before Christ, from the teachings mainly of Greek philosophers such as Pythagoras (580-500 BC), Socrates (470-399 BC), Plato (428-348 BC) and Aristotle (384- 322 BC), and the first ones who sought to interpret nature by observation and logic, without necessarily supernatural interpretation.

Philosophy seeks knowledge of first causes or principles. It has no particular object, but assumes the guiding role of science itself in the solution of universal problems. Thus, philosophy is the expression of the universality of human knowledge, that is, the source of all areas of human knowledge. In this context, science not only depends on philosophy but also includes itself.

Philosophical knowledge developed from ideas and theories formulated by great philosophers, such as the aforementioned Greek philosophers, and Saint Thomas Aquinas (1224-1274), Francis Bacon (1561-1626), René Descartes (1596-1650) , John Locke (1632-1704), Jean Jacques Rousseau (1712-1778), Immanuel Kant (1724-1804), Georg Hegel (1770-1831), Karl Marx (1818-1883) and, in recent times, Bertrand Russell (1872-1970), Ernest Nagel (1901-1985), Karl Popper (1902-1994) and Carl Gustav Hempel (1905-1997).

Philosophy rests on reflection on experience. Reflection provides interpretation variations on impressions, images and opinions. However, philosophy is not reduced to a search for reflexive and conceptual originality. Above all, philosophy aims to understand reality and provide reflective and logical content to change and transform reality. Philosophy has the task of elaborating presuppositions and guiding principles of human actions. Philosophy is also a critical reflection of society, politics, law, education. For this reason, philosophical knowledge evolves according to the historical context.

Scientific knowledge. Science originated from philosophy. From 5,000 years before Christ, Babylonians and Egyptians developed important knowledge mainly in mathematics and astronomy. However, the Greek philosophers were the main responsible for the combination of knowledge in these two areas, which constituted the starting point of science.

The task of science is the explanation of natural processes and phenomena. No system of theoretical ideas, technical terms, and mathematical procedures can be regarded as scientific unless it relates to these empirical facts at some point and in some way, and helps to make them more intelligible. Scientific knowledge is a system of methodical knowledge about nature. It differs from other forms of knowledge in that it requires objective empirical verification of all explanations regarding phenomena, which allows an understanding of their nature and causes, free from the observer's influences, desires and prejudices. Scientists seek knowledge of the relationships between phenomena, that is, of natural laws. It relies on logical reasoning to deduce new knowledge from general laws or concepts.

The special character of science can be explained by the circumstances in which scientists work in their respective fields. These circumstances include the basic principle of knowing the natural world through demonstrative arguments. Thus, a representation or interpretation of a phenomenon or process is only scientific knowledge if it has been verified or empirically demonstrated.

The search for scientific knowledge stems from the perception that the available body of knowledge is insufficient to understand some phenomenon or natural event. Part of the available knowledge is common or ordinary knowledge, that is, non-scientific, and part is scientific knowledge, that is, knowledge derived through the method of science. This knowledge can be put back to the test, perfected or surpassed, through this same method. As the scientific process progresses, portions of the ordinary body of knowledge are corrected or rejected, and the body of scientific knowledge is increased. Thus, science grows from common knowledge and surpasses it with its growth. In fact, scientific work begins at the point where experience and common knowledge fail to provide solutions to problems related to phenomena of interest, or even to formulate them. However, scientific knowledge is not a mere refinement and extension of common knowledge. It is knowledge of a special nature. Science also deals with unobservable phenomena not considered by the common person, raises conjectures that go beyond common knowledge, and puts these conjectures to the test on the basis of its theories and with the help of special techniques. On the other hand, science is unable to develop knowledge from unnatural explanations.

Thus, scientific knowledge is radically distinguished from common knowledge in many respects, particularly in terms of method. However, these two sources of knowledge have some similarity, at least if consideration is limited to the ordinary knowledge generated by common sense. In fact, common sense, like science, aspires to be rational and objective. However, the ideal of rationality, that is, the coherent systematization of knowledge is only achieved through theories, which constitute the core of science, while common knowledge is constituted by the accumulation of unrelated pieces of information. Besides, ideal objectivity, that is, the construction of impersonal representations of reality, cannot be achieved without overcoming the narrow limits of everyday life and personal experience. It demands the formulation of conjectures about the existence of physical objects in addition to precarious sensory impressions, and the verification of such conjectures through objective experience, planned and interpreted with the aid of theories. Common sense can achieve only limited objectivity because it is closely linked to perception and action.

In short, scientific knowledge is rational and objective like that which comes from common sense, but much more rational and objective than that. The peculiarity of the scientific approach that distinguishes it from common sense is the way it operates, that is, the scientific method, and the purpose for which this method is applied.

3. The relation of Science with Philosophy

Sometimes the scientific method is contrasted with other approaches to knowledge generation and the philosophical character and logical structure of scientific knowledge are questioned. First, it should be noted that science is a method and not a philosophy. As such, it is not committed to any particular theory or philosophy of knowledge. Indeed, the scientist's action reveals certain mental preferences and consistencies of his method that are sometimes related to the views of philosophical schools known by the designations of rationalism, empiricism, positivism, pragmatism and determinism.

A brief examination of the philosophical meaning of these designations is useful to clarify the distinction of the scientist's position in relation to these views, which imply differences in perspectives concerning knowledge.

Rationalism refers to the philosophical conviction that human reason is the main instrument and ultimate authority in the search for truth. Rationalism does not deny the value of sensory experience as a source of knowledge, but holds that only the logical operation of the mind can determine the truth of any experience or idea. For his adherence to the established rules of logic, the scientist could be labeled a rationalist. However, this designation would be inappropriate, since he does not only believe in pure reason as a guide to valid knowledge. The rationale of the scientific method is grounded in the system of logic employed in scientific reasoning, but the method of scientific analysis requires much more than just faith in reason.

Empiricism is based on the conviction that sensory experience must be regarded as the most reliable source of knowledge. Certainly, science is, in part and in certain areas, an empirical method as well as a logical, that is, rational method. However, the empirical aspect of science is related to the way data are perceived and not to faith in the exclusive validity of sensory experiences. Reasoning about empirical impressions is as important as the sensations received. Empirical evidence is basic to science, but it only has meaning if interpreted by particular notions about its attributes, effects, etc. In fact, a large part of the structure of scientific knowledge is composed of abstractions, that is, ideas about phenomena and their interrelationships, not empirical evidence. Science is empirical in the sense that its last resort for establishing the credibility of any particular knowledge is empirical fact, empirical demonstration, or empirical prediction. However, to hold that science is only or basically empirical is to inadequately limit its theoretical framework.

These two philosophical schools have more than three centuries of history. A more modern school that has been related to science is **logical positivism**, which refers to the belief that statements have factual meaning only when they are confirmed by empirical evidence. In fact, logical positivism is a move by some philosophers of science towards a unification of the various branches of science by clarifying ideas and developing methodological precision through logical analysis. It is a derivation of empiricism that emphasizes the development of objective communication, especially through symbolic logic and mathematics. Some scientists have something of a logical positivist in that they constantly seek a common unity of method, basic principles, and communication. However, even among today's few “neopositivists” the original restrictive attitude regarding the credibility of certain types of knowledge has been greatly modified.

The fourth philosophical school that is sometimes related to science is **pragmatism**, which is the belief that the ultimate test of an idea's worth is its usefulness in solving practical problems. Certainly, the scientist is a practical man who seeks the solution of real problems. However, as a philosophical position, pragmatism is of little value in modern science. In fact, much scientific knowledge is purely theoretical, with no practical value in itself. This theoretical knowledge plays a vital role in the structure of science. The set of abstract theories that underlie all science, which constitute what is often called "pure science", is highly unpragmatic.

The last philosophical link to science is **determinism**, that is, the argument that nothing has a place in nature without natural causes. Determinism in science is not a “creed” but a “postulate” that is employed in the analysis of causality. Science has also been related to materialism, that is, to the philosophical doctrine that all knowledge can be derived from the study of matter. However, today science is materialist, mechanistic or deterministic only insofar as it is based on an objectively demonstrable fact base, with the aid of physical instruments of observation and measurement. Furthermore, determinism should not be confounded with “fatalism”, that is, the natural inevitability of events. Science seeks to understand the regularities of phenomena, but such regularities are not imputed to any unavoidable causal agent. A “postulate of regularity in nature” is presupposed by the scientist as a principle, with the purpose of obtaining reliable knowledge. However, this principle is not assumed as a “law of nature”. This term has no important meaning in modern scientific explanations of causality.

4. Brief History of Science

Science in antiquity. Scientific knowledge (or science) has its roots in the contributions of Greek philosophers. The first attempts to explain natural phenomena without the mythological foundation of personal agents, but based on reason and evocation of causes, originated with Thales of Miletus (624-546 BC),six centuries before Christ. However, speculative explanations of phenomena were based on common sense rather than technical arguments about artificially controlled experiences. This approach emerges with Aristotle, in the fourth century BC. Through rigorous observation and disciplined theorizing, Aristotle studied animal anatomy in detail and created a biological science. In each study, he defined the area and its problems, dialogued critically with his predecessors, and then proceeded to develop his argument through experience and reason. His explanations were grounded in terms of perceptible qualities and a series of causes.

Post-Renaissance Science. Although the Greeks created a system of thought similar to the scientific approach some 2,500 years ago, there was little progress in the following centuries. The great power of science and its marked influence have recent origins. Science as it is known today has roots in the 16th century, mainly from three sources of influence: a) the discovery of classical antiquity and the publication of Latin and Greek texts from all fields, including science, in the Renaissance; b) the invention of the printing press by Johannes Gutenberg (1390-1468) and its rapid expansion, which made books available and cheap, before the end of the 16th century, with a marked influence on learning and culture; c) the discoveries of new lands, by the Spaniards and the Portuguese, which created new demands for knowledge of astronomy, hydrographic and mathematical techniques, and introduced new plants, animals, diseases and civilizations in Europe.

At the end of the 15th century, the first experimenters appeared in Europe. Speculation is replaced by experimentation. The forerunner of this change in attitude was Leonardo da Vinci (1452-1510). In studying phenomena in nature, he sought to carry out experiments, under various conditions and circumstances, in order to reach a general rule that applied to all experiments carried out. This is how he established the rule that the weight supported by a column is proportional to the height and width of the column.

However, in the early 16th century knowledge was still rudimentary and heavily dependent on confused assimilation from ancient sources. Before the middle of that century, relevant works appeared, such as the treatise by the Polish Nicolaus Copernicus (1473-1543), published in 1543, which revolutionized cosmology with the new heliocentric idea; the new approach to research in anatomy by the Belgian Andreas Versalius (1514-1564); and the advances in algebra of the Italian Gerolano Cardano (1501-1576). Copernicus defended the idea that mathematics could be applied to research any problem involving measurable quantities. Although theoretical developments tended to be speculative, there was considerable progress in many areas. In particular, before the end of the century, mathematics was usually taught in Europe.

Science in the 17th century. At the turn of the 17th century, a man of traditional higher education, called "scholastic", still believed that the Earth was the center of the universe and that the stars and planets revolved around it, moved by some intelligent and divine being, influencing events on Earth according to their locations and aspects. He believed in a living world, created and guided by God for the benefit of man. Then, came important scientific discoveries that are still accepted today, but which were explained on the basis of the culture that was still present. Thus, in 1600, Englishman William Gilbert (1540-1603), in the course of demonstrating that the soul of the world was embodied in a magnet, explained the compass on the grounds that the earth was a very weak gigantic magnet. Shortly afterwards, in 1609, the Polish Johanes Kepler (1571-1630) discovered the elliptical orbits of the planets around the sun, but his quest for harmony in the cosmos never ceased. Later, in 1628, Englishman William Harvey (1578-1657) established the blood circulation, but explained it as a microscopic image of the world's circulations rather than a purely mechanical system.

In the 17th century, there was a radical overhaul of the objects, methods and functions of knowledge of nature. The new objects became natural phenomena in a world devoid of human and spiritual properties, and the methods, disciplined cooperative research, and the functions of combining knowledge with the power of industry. The great proponents of this revolution in science were the Englishman Francis Bacon (1561-1626), the Frenchman René Descartes (1596-1650) and the Italian Galileo Galilei (1564-1642). Bacon contested the exclusive use of logic and observation, as opposed to Aristotle's rules of logic. He advocated a new means by which man could establish control of nature, a plan for the reorganization of science, and proposed a scientific method in his most celebrated work "Novum organum". Bacon created the method of “exhaustive induction”, arguing that, ideally, the scientist should provide an exhaustive enumeration of all examples of empirical phenomena under investigation as a preliminary to identifying the natural form of which they are a manifestation. He argued that empirically observed facts are the starting points for all science and that theory must be taken into account insofar as it is derived from facts.

In contrast, Descartes focused on the problem of constructing a deductive system of consistent and coherent theory, by which the argument could proceed with the formal certainty familiar to Euclidean geometry. He advocated the idea of a unitary universal science that would bind all possible human knowledge into one comprehensive wisdom. His renowned work “Discourse on the method”, published in 1637, marked the definitive consolidation of the scientific method. In search of certainty, Descartes challenged Aristotle and scholasticism, and sought to compose a philosophy associated with mathematics, where observation and interpretation are legitimized by empirical demonstration.

Galileo is considered a founder of the experimental method. Galileo was less radical in his ideals and more comprehensive in practice. Combining experimentation with mathematics, he contributed considerable advances in physics and astronomy. He observed that the chandeliers in the tower of Pisa swayed in the currents of air and, based on the beat of his pulse, he measured the time taken for the strokes of the largest and smallest arc described by the swing of the chandelier. Thus, he discovered the property of constancy of pendulum motion. He carried out meticulous experiments on the flight trajectory of projectiles and the falling of bodies, built a telescope and with this instrument studied the Moon, the Milky Way, the rings of Saturn and, with detailed observations, proved Copernicus' heliocentric idea.

Despite their differences in ideas and contributions, Bacon, Descartes, and Galileo shared a common commitment to the natural world and its study. They saw nature as devoid of spiritual and human properties. There could be no dialogue with her, either through mystical illumination or inspired authority. Rather, it had to be investigated prudently and impersonally, through sensory experience and reason. Care and self-discipline were needed in both observation and theorizing, and cooperative work was important for the continued accumulation and testing of results.

The new ideas of science came to fruition in the 17th century and led to rapid progress in knowledge in some fields, but slow development in others. Thus, modern conceptions began in optics with Johann Kepler 1571-1630), and in electricity and magnetism with William Gilbert (1544-1603). At the end of that century, Isaac Newton (1642-1727) formulated the law of universal attraction, the law of gravity, and brought a new rigor to the methods of experimental research.

Science in the 18th century. Newton's contributions dominated science in the 18th century. Scientific developments in that century were mainly one of consolidation.

At the beginning of this period, scientific activity was carried out on a small scale, mainly by wealthy men and well-trained professionals, such as physicists and engineers, in their spare time. The mathematical sciences (mathematics, astronomy, mechanics and optics) were well developed, but physics was still a set of isolated experiments with qualitative and mostly speculative theories, chemistry was almost entirely empirical, and biology paid attention mainly to collecting activities. Before the end of the period, successful examples of well-organized scientific work already existed, and the foundations for coherent and efficient theories in almost every area of science had been laid. Force technology was the first to be influenced by the application of earlier scientific developments. The steam and vacuum engine (1717), invented by the Englishman Thomas Newcomen (1663-1729), originated from 17th century pneumatics.

At the end of the 18th century, the industrial revolution began that transformed Europe from an agrarian to an urban society. At the same time, the French Revolution introduced the modern policies of freedom and democracy. Scientific activities underwent similar changes: at that time, the social and institutional foundations for the maturation of science in the 19th century were established.

The dominant style of science at the time of the French Revolution was mathematics. At that time, some French mathematicians stood out, such as Pierre-Simon Laplace (1749-1827), Joseph Louis Lagrange (1736-1813), Gaspar Monge (1746-1818), Jean Baptiste Fourier (1768-1830), Siméon Denis Poisson (1781-1840) and Augustin Louis Cauchy (1789-1857). The great Swiss mathematicians Jacques Bernoulli (1654-1705), Daniel Bernoulli (1700-1782) and Leonard Euler (1707-1783) developed the differential and integral calculus, invented by the German Gottfried Leibnitz (1646-1716). Even in chemistry, the nomenclature reform achieved by Antoine Laurent Lavoiser (1743-1794) and his collaborators was mathematical and abstract in style.

Science in the 19th century.

Science in the 20th century. Some 19th-century trends became more salient in the early 20th century. At that time, science became increasingly professional in its social organization. Almost all research was carried out by highly trained specialists, employed exclusively or primarily for this work in specialized institutions. Scientific communities, organized by discipline, enjoyed a high degree of autonomy in setting research goals and standards, and in certifying, employing, and awarding their members. Forced by competition, scientists tend to become highly specialized researchers. The dominant style of this period was reductionist: research was mainly concentrated on artificially pure, stable and controllable processes obtained in the laboratory, and the favored theories were those involving the simplest physical causes, using mathematical arguments. Scientific developments at that time were modeled after the standards of theoretical physics.

The positive spirit of this science was shown by its increasing separation from philosophical reflection. The theories of relativity (1905 and 1916) by Albert Einstein (1879-1955) and the uncertainty principle in quantum theory (1927) by the German physicist Werner Heisenberg (1901-1976) raised vigorous philosophical discussions.

The scientific achievements of the early 20th century are too immense to be enumerated. However, a common pattern of advancement can be highlighted. In each of the most important fields, progress was based on the successful descriptive work of the 19th century. Scientific activity was initially directed towards a more refined analysis of the constituents and their mechanisms and then towards syntheses that gave rise to the names of hybrid disciplines such as biochemistry and biophysics. In physics, classical theories of the main physical forces (heat, electricity, and magnetism) have been unified by thermodynamics; and at the beginning of the century, completely new discoveries appeared (X-rays and radioactivity, for example) and penetration into the structure of matter (atomic theory and isotopy). These discoveries required a review of the fundamental laws of physics and some of its metaphysical presuppositions (relativity and quantum theory). Chemical methods became necessary for much of this work in physics. On the other hand, the new physical theories were powerful enough to provide effective explanations for a wide variety of chemical phenomena. Based on these discoveries, the chemical industry produced a wide variety of synthetic substances (fibers and plastics, for example).

In the biological sciences, physical and chemical methods have contributed to discoveries and explanations of ingenious agents (vitamins, hormones) and the reconstruction of complex cycles of chemical transformations through which matter lives. Medical science was able to develop bacteriology and, through the discovery of specific and general drugs, it markedly reduced the classic epidemic diseases and the cruel diseases of childhood.

Until the end of that century, scientific advances continued to grow in all areas, so dizzying that it becomes impossible to catalog them. Just for illustration: in transport, culminated with the trip to the Moon and launching of satellites and probes for space exploration; in health, with the control of many diseases and increased longevity; in communications, with the large-scale use of the Internet.

5. Scientific Method

Science is often defined as an accumulation of systematic knowledge . This definition includes three basic terms for the characterization of science. Yet it is inadequate, like other definitions that emphasize the content of science rather than its fundamental characteristic: its method of operation. This is inconvenient as the content of science is constantly changing, given that knowledge considered scientific today may become unscientific tomorrow. Furthermore, the demarcation between science and non-science is not obvious. Indeed, it is not a sharp line, but a mobile and debated area.

Science aims at understanding the world in which man lives, knowledge of reality. Thus, it is fundamentally a method of approaching the empirical world, that is, the world susceptible of experience by man. The consensus regarding the essential attributes and processes of the method of science allows for a functional conceptualization of science through its method, as follows:

- *Science is an objective, logical and systematic method of analyzing phenomena created to allow the accumulation of trustworthy knowledge.*

For a better understanding of this definition of science, it is convenient to explain its key terms:

Method. A controversy often arises over the uniqueness of the scientific method. It can be argued that this is not a conceptual issue, but a mainly semantic problem that arises from the various meanings attributed to the word “method”. Indeed, although the various fields of science differ in content and techniques, an examination of all highly developed science reveals a common basis of inquiry procedures, which constitutes the general method of science. The implementation of this method in particular areas of science usually requires specific techniques and procedures, which constitute the particular methods of science.

Objectve. Objectivity in science refers to attitudes devoid of personal whim, bias, and prejudgment, to methods for discovering publicly demonstrable qualities of a phenomenon, and to the principle that the last resort of a speculative argument is the objective phenomenon, that is, an observation or experience that can be publicly verified by trained observers. Evidence in science is factual, not conjectural, and the “truth” is obtained by empirical demonstration. Although science is practiced by individuals, the scientific method inspires a rigorous and impersonal way of proceeding, dictated by the demands of logical and objective procedures. Scientists constantly seek this way of proceeding through training and the use of objectification instruments that allow them to look at their data with as little bias as possible.

Logical. To say that science is a logical method means that the scientist is constantly guided by acceptable rules of reasoning standardized by reputable logicians. Competence in science requires competence in logical analysis. Rules of definition, forms of deductive and inductive inference, probability theory, calculus, etc., are fundamental to any reputable science. Science is a systematic arrangement of facts, theories, instruments and processes, interrelated by reasoning principles. While one can act in applied areas by apprehending and applying formulas, acting as a scientist requires a thorough grounding in logical analysis as well as specific factual proficiency and knowledge.

Systematic. Science is a systematic form of analysis. Science proceeds in an orderly manner, both in the organization of a problem and in the methods of operation. This is one of the essential features that distinguishes the scientific approach. The systematic procedure inherent in the scientific approach takes the form of a sequence of tightly interconnected and logically arranged steps that allows for few deviations. Verification in science is a systematic process of logical inference that requires that premises, facts, and conclusions be neatly arranged.

The systematic character of science also implies internal consistency. In a well-developed science, the various theories and laws are interrelated and corroborative. They are mutually supportive or at least not contradicting each other. An immature science is characterized by internal disagreements between theories, laws, propositions, principles and even methods. It should be noted, however, that complete and final consistency is never achieved, even in the most advanced sciences. New discoveries suggest new laws, principles and theories, which, in turn, require the modification of established notions of reality.

Phenomena. The scientific method is applicable to any phenomenon, that is, to any event or behavior that has objectively demonstrable attributes or consequences. If an event is presumed to be inherently subjective (for example, an idea, a feeling, a dream), then it is not treatable by scientific analysis unless its presence can be demonstrated through objective attributes or consequences. Although the phenomena studied by science are publicly verifiable, it should not be understood that such research objects are the only interest of science. The scientific method is built on a foundation of ideal abstractions (for example, notions, ideas, theories, laws, principles, etc.) designed to relate and explain observable objects and events. Much of the content of science consists of intellectual notions about things and events. However, the object of all such thoughts is the particular phenomenon under study.

Created. Science is a system made up of diverse factual knowledge synthesized in an interrelated and logical set created by human ingenuity. In turn, the scientific method is a creation to serve a particular purpose: the development and orderly arrangement of that knowledge and ideas concerning reality in the form that seems most fruitful for the ends to be served. It should be noted that man arranges his thinking concerning the world in which he lives according to various preferences, and the scientific method is the arrangement that has so far proved most fruitful for the explanation of objective phenomena..

Accumulation. Science is an accumulative and integrated system, built in an orderly way, where every fact, law, theory, principle, etc. support other facts, laws, theories, etc. However, science is not a mere accumulation of knowledge. Scientific knowledge is dynamic. Science always looks for additional knowledge, in the belief that knowledge is never complete. The "truth" in science is always relative and temporal, never absolute and final. In contrast to many closed philosophical and ideological systems, science is characterized as an open system of ideas. Therefore, it is constantly growing, discarding erroneous or useless notions and replacing them with more correct and useful ones in the light of new evidence.

The accumulative attribute of science must not mean that it grows by simple addition. The history of science shows that complex explanations and designations are constantly being replaced by scientifically simpler and more accurate explanations and terminology. This principle of parsimony of science determines that the scientist must constantly strive to obtain explanations that involve as few terms, attributes, concepts and formulas as possible. The accumulative attribute and the principle of parsimony are closely intertwined. Indeed, science constantly strives to predict the behavior of as-yet-unobserved phenomena on the basis of the commonly known qualities they possess as members of a class of phenomena. Together, accumulation, ordering and parsimony allow a large number of specific predictions to be made from a few basic and general laws.

The term "reductionism" has been used in discussions of this broad principle of parsimony. Reductionism refers to the general practice of seeking to encompass as many sub-theories as possible in broader and more inclusive categories of "grand theories". Although much of the scientific knowledge at any given time is temporarily unrelated or uncoordinated, the scientist constantly strives to relate isolated facts into meaningful sets or models. The history of science shows that over time such models become integrated into broader systems of facts and ideas ("theories") that allow for a greater range of explanations than would be possible if segmented facts were used in isolation.

Trustworthy knowledge. In the current context, it is referred to trustworthy knowledge for prediction. In this sense, trustworthy knowledge means correct knowledge. Science constantly strives for precision and accuracy. In fact, science progresses as its measurements and calculations become more refined. Note, however, that precision and accuracy is not an end in itself. They are only related to the purposes they serve, that is, the promotion of more specific descriptions that allow for reliable prediction or control.

The function of the scientific method is to understand phenomena in such a way that the reason and range of accurate predictions can be constantly increased. Presumably, it is only through a valid and organized system of knowledge, such as science, that predictions can be effectively extended beyond the limited experience of a particular and simple group of individuals.

Through the scientific method, scientists attempt to generate a body of reliable knowledge. This is achieved by empirical verification of ideas and beliefs through objective observation.

6. Science: Strategy and Tactics

The scientific method is the general procedure of science applied in the knowledge acquisition process, regardless of the topic under study. However, each class of knowledge problems requires the development and application of special techniques and procedures suitable for the various stages of problem treatment, from the enunciation of these to the control of the proposed solutions. Examples of these special procedures or techniques are colorimetric analysis to determine the physicochemical characteristics of a substance and vigor analysis to determine the physiological quality of the seed.

6.1. Scientific strategy

The scientific method comprises an ordered set of operations for the characterization and solution of problems, which is common to all areas of science. Thus, the scientific method constitutes the strategy of science for the generation of knowledge. Example 1 illustrates this strategy.

Example 1. Assume the following question: Why is wheat productivity in a particular region low? A simple answer to this question could be derived from the empirical observation that the environmental conditions in this state are unfavorable for the cultivation of wheat. Scientific researchers of this problem would not be satisfied with simple and generic explanations like this one, and would start by critically examining the problem itself, before trying to find a solution to it. In fact, that question implies an empirical generalization that can be refined by breaking it down into less general questions, such as the following two: Under what environmental circumstances (concerning soil, climate, disease and pest incidence, etc.) has productivity been low? Under these circumstances, what are the relevant characteristics of the wheat cultivation techniques (cultivars used, phytosanitary treatments, fertilization and soil correction, etc.) that may have implications for productivity? The questions posed in this way are still too vague and can be further refined by asking more specific questions, such as: Has yield been lower in years of high temperature and relative humidity during the growing season of wheat? At what stages of plant development are these conditions most adverse? At what stages of its development is the plant more susceptible to these climatic conditions? Do these weather conditions favor the development of fungal wheat diseases? What fungal diseases? Are the cultivars in use susceptible to these weather conditions? Are they susceptible to these diseases?

Thus, an analysis of the overly generic and vague initial problem - low wheat productivity in the region - leads to a set of more specific problems that have negative implications for wheat productivity in that region; for example, susceptibility of wheat cultivars to high temperature and relative humidity; incidence of fungal diseases; incidence of rust; susceptibility of cultivars to fungal diseases. Every simple and precise problem or question that can be solved or answered with current scientific knowledge and available resources constitutes a **scientific problem** or research problem.

Each scientific problem will raise one or more conjectures for a solution or an answer. Consider, for example, the following problem: damage to wheat productivity due to the incidence of rust. This problem can raise several conjectures, such as: a) high temperature and relative humidity favor the incidence of rust; b) the occurrence of rust can be controlled with the use of fungicides; and c) the incidence of rust can be avoided with the use of resistant cultivars. Each of these conjectures that can be verified empirically constitutes a **scientific hypothesis** or research hypothesis.

Then, each of these conjectures can be empirically verified through its consequences. For example, a) if high temperature and relative humidity are determinants of the incidence of rust and the consequent decrease in productivity, then wheat crops that differ in those characteristics must present different degrees of incidence of rust and different levels of productivity; b) if fungicides control the incidence of rust, then crops with effective fungicides should be more productive than crops without these fungicides or with ineffective fungicides; c) if rust susceptibility is an important determinant of low productivity, then crops that differ in terms of cultivars with different levels of susceptibility (or resistance) and are similar in terms of other characteristics must have different levels of productivity.

The verification of each scientific hypothesis may be carried out by **scientific research** that will include the observation and collection or gathering of data by scientific means. For example, in this illustration, through: a) a research carried out on crops, in different locations and over several years, with natural variation in temperature and relative humidity; b) a survey of available fungicides and a control (without fungicide); c) a survey of available cultivars with different levels of susceptibility (or resistance) to rust.

Finally, in each particular research, the merits of the alternatives of the hypothesis will be evaluated, which may lead to the refutation or non-refutation of that hypothesis. If the observations collected or gathered by the research do not agree with the consequences derived from the hypothesis, the hypothesis will be refuted. Otherwise, that is, if these observations are in line with the hypothesis, the hypothesis will not be refuted. In the latter case, it will be said that the observations corroborated the hypothesis. Note, however, that a hypothesis is never proved, as it will always be subject to being refuted by future observation.

Then, the derived scientific knowledge will be incorporated into the previous body of knowledge.

If a hypothesis has been refuted, it will be necessary to formulate another hypothesis and restart the procedure; if it has been corroborated, its expansion or improvement will be desirable.

In general, if research is thoughtful and imaginative, solving the problem that gave rise to it will raise a new set of problems. The most important and fertile researches are those capable of triggering new questions and not those tending to stagnate knowledge. In fact, the importance of scientific research is evaluated by the changes it produces in the body of knowledge and the new problems it raises.

Example 1 illustrates the general science procedure for acquiring knowledge. In this process, the following ordered sequence of operations can be distinguished:

1) Enunciation of well-formulated and fertile questions – **scientific problems**.

2) Formulation of well-founded conjectures that can be tested through experience to answer the questions – **scientific hypotheses**.

3) Derivation of logical consequences from conjectures.

4) Empirical verification of conjectures – **scientific research**.

5) Analysis and interpretation of the results of the verification of the conjectures – evaluation of the pretense of truth of the conjectures.

6) Determining the domains for which the conjectures are valid, incorporating new scientific knowledge into the available body of knowledge, and formulating new problems arising from research.

This process of the scientific method is outlined in Figure 1.

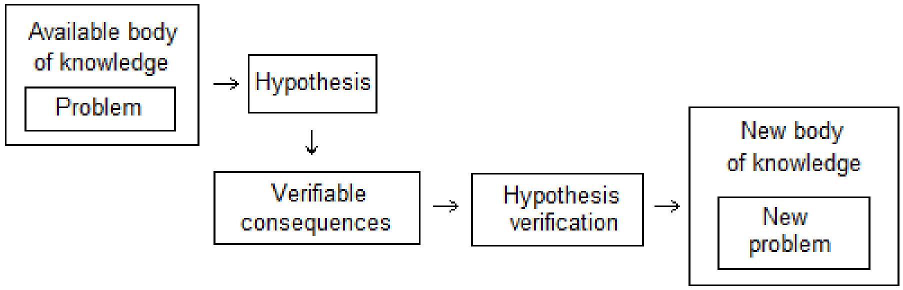

Figure 1. Schematic representation of the scientific method process.

In short, the scientific method starts with examining existing knowledge and identifying one or more problems of interest. For each of these problems, one or more hypotheses are formulated. Then, each of these hypotheses is examined for the logical prediction derivation of consequences that can be objectively verified. The next step is the objective verification of each of these hypotheses through new observations. If this objective empirical verification confirms the prediction concerning a particular hypothesis, evidence accumulates in favor of that hypothesis and it is accepted as fact and incorporated into the existing body of knowledge. Its subsequent life can be short or long, as constantly new deductions can be drawn and proved, or not, through objective empirical observation. This circular property of the scientific method is illustrated in Figure 2.

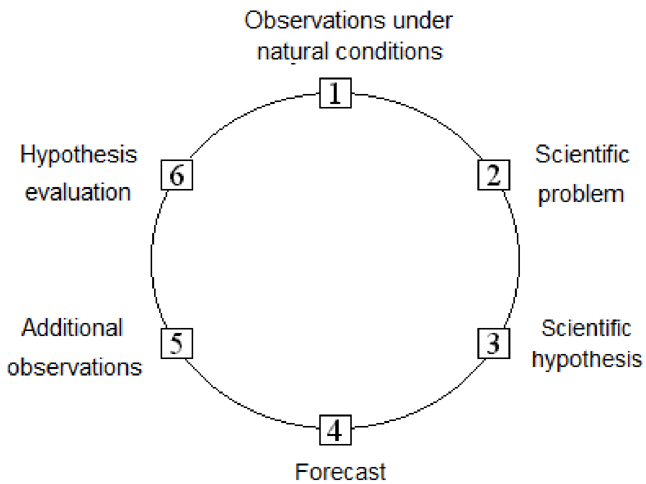

Figure 2. Diagram illustrating the circular property of the scientific method.

The fundamental process of the scientific method can be summarized as a cyclical repetition of stages of synthesis, analysis and synthesis. The scientific method for solving a generic problem related to a phenomenon starts with a global view of that phenomenon (**synthesis**). However, even the most restricted parts of the universe are too complex to be understood globally and completely by human effort. It becomes necessary to ignore many of the aspects of the phenomenon and abstract an idealized version of it, with the expectation that it will be a useful approximation. Often, certain features of these idealizations are changed for simplification. This idealization is then broken down into a number of relatively simple parts into which specific problems for separate treatment can be identified (**analysis**). This decomposition aims to identify independent or interacting parts in a simple way. When the problems relating to these parts are resolved, the new knowledge is integrated into the existing body of knowledge (**synthesis**).

6.2. Scientific tactics

The scientific method is the common strategy of science. However, the concrete execution of each of the operations of the scientific method in a research requires a particular tactic that comprises a set of techniques that depend on the topic and the state of knowledge regarding this topic. These specific techniques change much more quickly than the general method of science. Furthermore, very often they are only usable in particular fields of science. Thus, for example, the determination of nutritional deficiency symptoms of rice plants requires techniques essentially different from those necessary to obtain plants resistant to infection with a virus. The effective resolution of the first problem will depend on the state of the plant nutrition theory, while the second one will depend on the state of the disease resistance theory.

Scientific techniques can be classified into conceptual and empirical.

***Conceptual techniques** are based on definitions, axioms, postulates, laws and theories. **Empirical techniques** are related to the observation and evaluation of characteristics of natural phenomena, through observation and measurement.*

Conceptual techniques make it possible to formulate problems precisely, state the corresponding conjectures or hypotheses, establish procedures to deduce consequences from the hypotheses, and check whether the proposed hypotheses solve the corresponding problems. Mathematics offers the richest and most powerful set of these techniques. These techniques are also powerful in scientific research into natural phenomena. However, its application requires that scientific knowledge be sufficiently consolidated to be susceptible to translation and mathematical treatment. On the other hand, mastery of most empirical techniques depends only on training. However, a talent is needed for its application to new problems, for the critique of known techniques, and particularly for the development of new and better techniques.

7. Objectives and Scope of Science

Science has two fundamental goals. First, the increase in knowledge - intrinsic, or cognitive, objective; secondly, the increase of man's well-being and his dominion over Nature - an extrinsic or derivative objective.

*Science with a purely cognitive aim is called **pure science**. **Applied science** or **technology** uses the same general method as science and several of its special methods, but applies them for practical purposes.*

Examples of pure science are physics, chemistry, biology and psychology; of applied science, electrical engineering, biochemistry, agronomy, human and veterinary medicine and pedagogy.

This division of science is often challenged, arguing that science is ultimately aimed at satisfying needs of some kind. However, it is related to the objectives of the various areas of science and explains the differences in attitude and motivation between the scientist who seeks to understand better reality and the scientist who seeks to improve his grip on it.

Science is fundamentally a method of acquiring trustworthy knowledge. In pursuit of this goal, what it achieves - scientific knowledge - is theoretical knowledge, that is, an interpretation of reality, not reality itself. This theoretical interpretation is often expressed in terms of ideal or perfect conditions or forms; for example, a perfect synthesis of two or more chemical substances, called "solution", a space absolutely without matter, called "vacuum", and an absolutely round figure, called "circle". These conceivably ideal forms are called **models**. These models are only approximations and therefore tentative interpretations of reality. The function of science is the constant effort to refine and improve such models so that they can continually approximate reality in terms of growing and more refined empirical evidence.

Science is based on facts. A **scientific fact** is a proposition referring to properties or characteristics of a phenomenon that has been verified empirically and objectively by the scientific method. However, facts in science are not interpreted and used in isolation. Rather, they are significantly interrelated by **scientific theories** to suggest causal relationships, such as the Mendelian theory of inheritance and the Newtonian theory of motion. Scientific facts can be used to: a) suggest new theories; b) suggest revision or rejection of existing theories; and c) redefine or clarify theories. Thus, scientific facts are the basic elements that constitute the foundation of reliable knowledge and scientific theory the superstructure of that knowledge.

The relationship between theory and fact may not be straightforward. An interrelated set of facts can constitute an empirical regularity and be formulated as a **scientific law**, like the law of inertia and the law of gravity. However, a scientific theory is a generalized synthetic explanatory statement of the cause of a phenomenon or the interrelationship between classes of phenomena. In addition to systematically explaining or taking into account the relationships between facts and laws, scientific theory also has the function of serving as a unifying explanation for the possible deduction of hypotheses. Thus, hypotheses deducible from theory are intermediaries between facts and theories, as are scientific laws that interrelate verified facts (Figure 3).

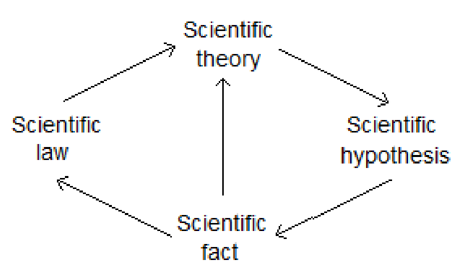

Figure 3. Relationships between theory, hypothesis, law and fact.

The ambition of science is to develop fruitful theories that cover the widest possible range of phenomena. In fact, the basic objective of science is the creation of theories that make it possible to explain or predict phenomena. Theory creation is developed by scientific research with the following functions:

a) guide the research – it reduces the range of facts to be used and at the same time determines what kinds of facts are relevant for the research purposes;

b) serve as both a conceptualization and a classification system – it allows the creation of concepts referring to important processes, the classification of relevant objects (taxonomy) and the creation of structures of concepts;

c) allow a summary of what is already known about a phenomenon, making possible an empirical generalization statement or the creation of systems of relations between propositions (laws, principles, axioms);

d) suggest the prediction of facts; and

e) highlight gaps in existing knowledge.

The idea is common that science deals only with "facts" and that its basic function is to research and reveal the "truth". This view underestimates the role of science. The notion of truth has preoccupied epistemologists and philosophers for many centuries. The difficulty of defining the term "truth" stems from the assumption that something is inherently or necessarily true, or it is not. However, the history of human experience has shown very clearly that what is at one time held to be unquestionably true may later turn out to be unquestionably false (e.g., the sun revolves around the earth). Furthermore, at any given time, different groups can define the same (or apparently, the same) phenomenon very differently. For example, for some people it is unquestionably true that criminals are born bad, or that Orientals are naturally skilled, while for others such notions have no substantial evidence to support them. This difficulty in defining "truth", due to the inherent notion of truth or falsehood, is avoided in science.

A scientific fact is a reliable statement or proposition of truth because it is supported by objective empirical evidence. Not a certain truth statement or proposition. Truth in science is never final or absolute. The reliability of a scientific fact is related to the amount and type of evidence that substantiates it. The reason why all factual knowledge in science is relative rather than absolute is a consequence of its experiential character. Facts derived from experience lead to probable truths, never to certain truths, because experience is infinite, and future experience may require a new interpretation of a phenomenon. Thus, the reliability of a scientific fact depends on the acceptability of the evidence offered. Some scientific facts are supported by undisputed objective and empirical evidence, while others are supported by less convincing evidence.

Science seeks to establish conceptual reconstructions of reality through facts. A scientific law is a conceptual reconstruction of an objective structure; a scientific theory is a system of such statements. More than that, science aims at a conceptual reconstruction of the objective structures of phenomena, both current and possible, which allows for their exact understanding and, therefore, their technological control. At every step, science performs partial reconstructions, which are problematic and not demonstrable. With the progress of science, these partial reconstructions are getting closer to reality.

This process of rebuilding the world through ideas and checking every partial reconstruction is infinite. proposes a definite and final objective, such as the complete construction of knowledge without failure. The aim of science is rather the continuous improvement of its main products - the theories, and means - the techniques.

Thus, scientific knowledge is not a simple accumulation of facts, but a permanent conceptual revision. Its progress is due to a process of continuous correction. Scientific activity can be considered as a permanent attempt to decrease the degree of empiricism and increase the scope of theory. Science is not satisfied with superficial criteria. It demands the detailed examination of a phenomenon. A phenomenon is considered known only when it is described and explained with high accuracy, so that it can be predicted and, if possible, controlled. In improving knowledge, science pursues four successive objectives: description, explanation, prediction and control.

The first objective of science is description, that is, the representation of the phenomenon in order to identify its essential characteristics. Scientific knowledge begins with description. Only after acquiring knowledge of the relevant characteristics of the phenomenon does the explanation of its origins begin. The second objective is explanation, that is, the characterization of the reason for the existence of the phenomenon or its cause. Explanation requires identifying the conditions that result in the phenomenon occurring. The scientist is cautious and conservative. He recognizes that most phenomena have many causes and that new evidence may require replacing an older explanation with a more appropriate one. As the scientific research process evolves, knowledge regarding the causes of phenomena grows and improves. With this growing knowledge comes the ability to predict and possibly control phenomena.

The third objective of science is prediction, that is, the anticipation of knowledge of the phenomenon before its occurrence. The establishment of predictions requires knowledge of the antecedent conditions of the phenomenon. Weather forecasting, for example, requires knowledge of the weather conditions that influence it, such as wind direction, temperature, humidity and atmospheric pressure. The advance in knowledge of the relationship of meteorological events allows that, nowadays, predictions of meteorological occurrences can be made with high accuracy. The impossibility of accurately predicting a phenomenon is indicative of a failure in its understanding. The fourth and most advanced objective of science is control, that is, the manipulation of the conditions that produce a phenomenon. Control, in this sense, means knowledge of the antecedent causes or conditions of the phenomenon. If the antecedent conditions are known, they can be manipulated to produce the phenomenon as desired.

8. Role of Logic in Science

Scientific facts are the essential elements that build science. However, they must be arranged and organized into useful interrelated structures. The most essential tool of science, along with the verified fact, is the system of valid logical reasoning about scientific facts that allows the derivation of reliable conclusions from them. These conclusions are propositions about interrelationships of facts that explain a given phenomenon, which constitute scientific principles, theories and laws.

At the heart of logical reasoning about facts is a system of rules and prescriptions that have been established over the course of twenty-five centuries. The correct use of these rules is fundamental to every scientific effort. The rules of deductive and inductive reasoning, the correct use of definitions, sampling procedures, etc. are essential parts of any scientist's intellectual tools.

One of the biggest logical problems involved in scientific reasoning is the distinction between veracity and validity. This issue is addressed here to illustrate the very significant interrelationship between scientific facts (that is, statements of truth) and the logical arrangement between those facts (that is, valid reasoning) that comprise the theoretical core of the scientific framework.

Most reasoning errors stem from the common tendency to confound truthfulness with validity. A scientific fact is a certain or probable truth because there is substantial objective evidence to support it. On the other hand, an argument is valid when the conclusion necessarily follows from initial propositions or premises, that is, from presuppositions or assumptions. A person can derive a wrong conclusion from verified facts if he reasons incorrectly. He can also derive an incorrect conclusion by correct reasoning if he employs incorrect propositions as premises. The solution to this problem of logical inference is the valid argument's mode of operation. There is only one form of argument accepted in logic as correct (“strong”): one in which the presuppositions or premises are (certainly or probably) true facts and the inferences drawn from them are valid. However, there are three forms of incorrect (“weak”) argument.

This may explain why so many people draw incorrect conclusions from scientific facts, and why trustworthy knowledge grows so slowly in so many fields. The four argument forms, one correct and three incorrect, are illustrated below.

Correct argument: the presuppositions or premises are (certainly or probably) true facts and the inferences (conclusions) drawn from them are valid;

Incorrect argument: 1) the conclusion is valid, but the premises are false, 2) the premises are correct (scientific facts), but the conclusion is not valid, and 3) the premises are false and the conclusion is not valid.

Many examples could be used to illustrate the fundamental role of scientific facts and reliable reasoning in the structure of science. In physics prior to Galileo it was held that heavy objects fall faster than light objects. This statement is a false fact and is invalid in form. Heavy objects fall faster than light objects only when they have a higher density, that is, a lower ratio of resistance to the medium per unit of volume. A 1 kg lead ball falls faster than a 10 kg pack of uncompressed feathers because its density is greater. In this argument not only is one of the assumptions a false fact (density rather than absolute weight determines the rate of fall), but also the shape is invalid because it does not necessarily follow that just because it is lighter an object must fall faster.

9. Bases of Science

Interpretations (descriptions or explanations) of phenomena are usually based on some presumed prior knowledge. Since some facts are required to prove other facts, all knowledge systems are compelled to prove basic facts. As these basic facts cannot be proved, they must be admitted as fundamental conventions, necessary to any logical or epistemological system. These fundamental facts are often accepted as indisputable (dogmas) or self-evident. This kind of evidence is, however, a dubious and often unrealistic basis for establishing valid knowledge. Science rests on basic assumptions supported by logical consistency with experience, which scientists employ to interpret the evidence needed to produce verified facts, that is, to derive scientific knowledge.

These basic assumptions are the postulates of science. These postulates should not be confused with scientific discoveries.. They are just functional tools useful for their purposes, while scientific discoveries are confirmed by objective empirical evidence. The postulates can be changed over time, if the evolution of scientific knowledge demands new forms of reference, as new knowledge frequently changes the state of previous scientific discoveries.

An examination of the literature reveals that there is no agreement regarding the number and designation of postulates, as there is still no uniform or typical treatment of the scientific method. The list of eight postulates that follows is just an attempt to concretize and add what seems to be generally accepted by competent authorities as essential presuppositions of the scientific method.

1) **Every event has a natural antecedent** ("cause"). Explanations of events must be sought in natural causes or antecedents, that is, objectively and empirically demonstrable phenomena. This postulate is employed in science in the analysis of causality. Its main function is to direct the search to explain phenomena to the regularities they apparently obey.

2) **Nature is orderly, regular and uniform**. The belief that the universe operates according to certain rules of regularity ("natural laws") is inherent in the scientific analysis of natural phenomena. In practice this belief takes the form of explanations expressed in terms of inferred probabilities from the particular to the general, or from past experience to the present and hence to the future.

According to this postulate, every phenomenon has an antecedent, and while many phenomena may appear to be unique (for example, no two storms have identical characteristics), underlying such unique or inexplicable events are certain models of forces that, when understood, will allow for better prediction than would be possible by mere guesswork. Therefore, direct attention must be given to the search for qualitative and quantitative relationships that apparently exist between natural phenomena.

This postulate also expresses the apparent fact that nature is not infinitely complex. Thus, the ordering of scientific knowledge allows the scientist to develop theories regarding the interrelationships of phenomena and then proceed to a broader analysis of the universe as a whole.

The implications of this postulate form the basis of scientific logic applied to natural phenomena. It allows for generalizations and classifications regarding phenomena and supports the probabilistic basis of inference in science; particularly it is indispensable for sampling. It also suggests the possibility of ever-increasing scope for a more highly integrated general theory, which is the main aim of all scientific endeavor.

3) **Nature is permanent**. Although apparently everything changes over time, many phenomena change slowly enough to allow a reliable body of knowledge to build up. This postulate supports the cumulative attribute of science. It implies the belief that an event studied today, though perhaps indeterminately altered tomorrow, will nevertheless be sufficiently similar to allow valid generalizations to be derived about it that remain reliable for a period of time.

4) **Every objective phenomenon is knowable**. That is, given enough time and effort, no objective problem is unsolvable. This postulate stems from two related convictions: a) man's intelligence is capable of unraveling the mysteries of the universe; b) man's search in the mysteries of objective phenomena has been so fruitful that apparently no door to knowledge is immutably closed to the continued efforts of scientific research.

5) **Nothing is self-evident**. That is, reality must be objectively demonstrated. This postulate asserts that no reliance should be placed on so-called "common sense", on tradition, on popular authority, or on any of the customary interpretations of phenomena. Historical examples reveal that apparent veracity is often very different from objective empirical verification.

6) **Truth is relative** (to the existing state of knowledge). Evidence in science is always relative - to the state of scientific knowledge, to the data, to the methods, to the instruments used, to the frames of reference and, therefore, to interpretation. Therefore, the "truth" in science is simply an expression of the best demonstrable professional judgments at any given time. This postulate does not imply that stable knowledge cannot be acquired; but it recognizes that knowledge is dynamic and that, as knowledge grows in quality (that is, it becomes more highly verified) and in quantity, reinterpretations and new conclusions about phenomena become imperative. This attribute has encouraged the constant re-evaluation of ideas both old and new and has allowed for the extraordinary growth of science.

7) **All perceptions are acquired by the senses**. That is, all knowledge is acquired from sensory impressions. The elements and instruments of reasoning (that is, ideas, concepts, constructions, images, etc.) are shaped by the impressions received by the senses. This postulate also ensures that the only reliable knowledge is that which is objectively and empirically verifiable.

This postulate originated from the influence of Galileo regarding the demonstrability of theoretical predictions. The empirical demonstration became the essential test of the validity of all theoretical speculation concerning phenomena and resulting predictions.

8) **Man can believe in his perceptions, memory and reason as a means of acquiring facts**. This postulate supports the entire rational and empirical basis of scientific knowledge. It does not imply that any or all perceptions, memories and reasons are trustworthy. What this postulate asserts is that the final resolution of any dispute over phenomena must be based on accepted rules of reasoning and on sense-perceived data; not about mere notions and ideas. The ultimate belief in the analysis of phenomena must be based on empirical evidence interpreted according to rules of logical reasoning.

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