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THE ARCHITECTONICS OF SCIENTIFIC KNOWLEDGE
AN ESSAY ON THE DYNAMICS OF THE SCIENCES

I. *Science, myth, magic*: three components of knowledge, in other words three types of activity in man who, in interaction with his surrounding environment seeks to accomodate himself to the constraints which this environment imposes on him while at the same time seeing to his own immediate or far-reaching needs.

In comparison to mythical beliefs and magical practices, scientific knowledge is a recent innovation in the history of humanity; its development has accompanied the emancipation of the individual. Scientific thinking has in common with myths the fact that it presumes to explain the nature of things; in common with magic is the fact that it aims to predict events in such a way as to act

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effectively on them. But unlike both of these earlier practices, science attempts to go beyond the world of appearances and constantly tries to push back its boundaries.

We might believe that all forms of knowledge derive originally from the imagination of a fertile mind. However, as soon as the products of the individual imagination appear on the market of ideas, the distinctive mark of their authors is erased and they pass into the public domain. From then on the credit is assigned to anonymous tradition, which is not entirely false, for each generation supplies its own modifications to the initial model. Nevertheless, since the dawn of historic times, man has disposed of means to determine and transmit concrete testimonies of his thinking, by the act of writing among others. And it is there, no doubt, that we must look for an explanation of the superiority of science over mythical or magic thinking. Science is more apt than its rivals to preserve its new acquisitions from anonymity and oblivion; it can overcome its own deficiencies and allows human communities to differentiate themselves from one another, to distance themselves from communities which are called "primitive" depending on whether such communities have or have not been able to equip themselves with the means of preserving scientific acquisitions.

The word "progress" is generally used to designate the combined effect of this distancing and this differentiation. But science's dominance has never been complete, and it is still possible to find traces of mythic tales or magic tricks. I do not intend to cite as proof the ravages worked upon the consciousness of our contemporaries by the number of words terminating in "ism", such as racism, elitism, machinism or messianism, and the abuse of chemotherapy in neuro-psychiatry.[2, 5, 14, 33, 28] These are all facts which militate against a too linear interpretation of progress, which for a while was in favor among certain sociologists of our times who take opposing anthropological typologies to be so many successive stages in human evolution.[26, 27]

This is not the only paradoxical aspect which emerges from the comparison of scientific thinking with its two rival mentalities. Whereas the former derives from perception, constantly subjected to the control of reason by verifying measures, the latter appeal to the imagination which unceasingly escapes the boundaries which nature imposes, if not on the desires at least on the satisfaction of

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man's needs. The method of science is slow, prudent, verifying each step. But although science proceeds by small steps, in societies which use this method, progress is real, while in those dominated by the prestige of myth and magic, it stagnates. If writing contributes significantly to determining and transmitting intact the forms of scientific thinking, it is also a powerful aid in their modification. These are no doubt the aspects of progress which can be found with the same ambivalence in every branch of knowledge.[40]

II. Scientific thinking is a mental activity which consists essentially in developing concepts whose interrelations in turn will constitute what is termed the conceptualization of experience. This is an individual operation in theory, but one which is nevertheless transmissible through the use of natural language. To weave together conceptual networks, pairs of antithetical concepts, such as day and night, life and death, right and left, high and low, movement and rest, which reflect indissociable oppositions, are found to be of remarkable fruitfulness, constantly enriching the patrimony of the sciences. Aristotle had already stressed this role[1]; but it was J.W. Goethe who was the first to clarify the place that bi-polarity occupies in scientific logic,[21] the list of authors who, before him or after him, applied the notion of polarity to their system of thinking would be long.[4, 18] From the simple methodological instrument which it was initially, che concept moved up to the rank of ontological law with Karl Heim.[23] Polarity played a determining role in the morphogenesis of science as well as in its morphostasis. It can even be said that the specific forms of scientific thinking can be analyzed from two complementary points of view. To bring out clearly the nature of this complementarity, the Kantian notion of *architectonics* can be usefully applied.

Two centuries ago Kant devised a mode of approaching the problem of scientific knowledge which aimed both at describing and legitimizing it.[24] He began by tracing a parallel between the sum of knowledge of which man and mankind disposes at a given moment in time and an architectural construction. This parallel serves to demonstrate that science is not simply an accumulation of disparate knowledge, any more than a building is simply a pile of stones, bricks, sand and mortar. Sciences and buildings are complex ensembles, composed of knowledge in the first case and building materials in the second. Each ensemble is subordinated to a key idea. The unity of a system—whether it be a scientific theory or a construction plan—is an organic entity whose parts form a whole, brought about by a process of growth, like the body of an animal or of a plant, and not by simple accretion. For Kant, "unity by idea" is similar to a genetic code which prefigures variety and order, just as the seed contains in itself the entire program of subsequent development of the plant.

The concept of architectonics is part of methodology, and Kant applied it to all systems of rational knowledge. Just as he defined architectonics as the theory of all that is scientific in our knowledge in general, we can say that for him architectonics is the theory of science. All systems of knowledge form a great ensemble encompassing all human knowledge, the architecture of which can be demonstrated both by an analysis of our present knowledge and by the comparative study of the fragmentary knowledge of the generations who preceded us.

As scientific theory, architectonics is first of all a theory of the forms of conceptual organization whose linguistic expressions are, in increasing order of complexity: statements, theories, science.

According to their purpose and their relative position ranging from opinions to beliefs, statements can be called: theses, hypotheses, conjectures, theorems, laws or principles.

Statements cannot and should not be presented for a long time in an unconnected form. They belong together and follow upon one another according to a key idea suggested by the common goal, in order to form ensembles of increasing complexity, the simplest of which are scientific theories. These scientific theories, again ranging from opinions to beliefs, can also be related more or less closely to other types of theories in the realms of philosophy, politics or aesthetics.

Scientific theories are in turn combined and connected together according to a dominant idea determined by a certain number of common points: fundamental concepts, methodological principles and areas of application. The complex ensembles which result from such combinations are the particular sciences which can also be grouped together by selected affinities, which are, however, less limited since they answer to less rigid criteria of selection.

Sciences are the components of the intellectual life of a human society and as such enjoy a certain stability because of the interest shown in them by society's institutions. This interest is manifested in two ways: either they are introduced into the official educational program under the name of *disciplines*; or a more particular kind of adherence is solicited in a section of the community under the name of *doctrine*. Doctrine and discipline are thus two variants of scientific knowledge, specifically developed in view of their relative degree of distribution in the social environment. Governments frequently attempt to introduce "correctives" in the substance and form of the scientific corpus, and these modifications can even go so far as to threaten the scientific integrity of the nucleus of this corpus.

To conclude this tableau of the metamorphoses of knowledge, let us say that ideologies, whose point of departure lies in official doctrine, achieve acceptance in public opinion only through a firm and persistent application of force.

We have just seen the macroscopic aspect of architectonics. There is also a microscopic aspect which deals more with the logic of sciences than the theory of sciences strictly speaking. It might seem that architectonics is timeless. However, in reality the Kantian notion does not exclude temporality and it in fact implies the idea of future since every system of knowledge is an organic whole which develops from within. It is this development which places architectonics within time and which makes it possible to speak of a dynamic of the sciences.

The concept of architectonics is based on a double metaphor: on the architecture of buildings and on living organisms. The purpose of these two comparisons is to facilitate through analogy the understanding of the particular characteristics of scientific knowledge. They make it possible to extract the properly scientific component of the system, as compared to mythic and magical components from which it differs by nature, and as compared to opinion or to faith where the difference is only one of degree. Opinion and faith are in fact forms of knowledge which represent, respectively, maximum subjective participation and minimum scientific objectivity, whereas science represents minimum subjective participation and maximum "neutrality" in the art of communicating scientific knowledge.

To return to the Kantian definition of architectonics, the art of systems operates in the world of idealities, that is abstract entities characterized by perfection, intelligibility, removal from the world of sense experiences.[8] But unlike pure ideals, such as number or size, even and uneven, equality, etc., the components of knowledge, and scientific knowledge in particular, are organized into scientific theories, the results of an intentional activity, bearing within themselves their own finality. They are simultaneously products of an activity and a productive activity, and they conduct themselves like all teleonomic structures.[29] In the world of idealities, they are the equivalent of buildings among all the products of human industry, or living organisms in nature. These three types of "objects", although belonging to three essentially different orders of reality, have a common existential principle: to maintain the integrity of the ideal, organic or physical ensemble and to resist agents of destruction for a variable but foreseeable period.

III. In order to explain how this principle applies to teleonomic idealities, we must invoke the concept of "normality", used since time immemorial in both architecture and medicine. A brief digression concerning the origins and the extension of this concept, derived from the concept of norm, is perhaps not out of place here. It is a certainty that the greatest portion of human energy is devoted to satisfying certain fundamental needs, such as food, clothing and housing. Where food is perishable and consequently must be frequently renewed, dwellings are destined to house not only the head of the family, his offspring and his goods but also his descendents and therefore are meant to be longer lasting. The choice of its location, its strength to resist the weather and the destructive action of a hostile environment make housing the image of man's overriding power over the Earth and the symbol of his civilizing action. Granted every species of animal has its den, its hole, its nest or its territory, adapted to the needs of reproduction and subsistence of the species and more or less in conformity with the morphology of its body. The boar's wallow has a circular form, like the hollow rock where snakes coil up and the nest where birds lay their eggs and hatch them. Because of his vertical posture, man has been led to construct his shelter in a form dominated by orthogonal lines. The mason's square is called in Latin, "*norma*", and it is used to ascertain the perpendicularity of walls which bear the roof beams

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and which consequently ensure the stability and solidity of the structure. If the wall collapses, this means it has lost its normality.

Like man's upright posture, normality in construction is rooted in an objective reality and cannot be simply relegated to the status of a useful but arbitrary convention. In reference to such conventions, we would speak rather of *"normativity"*, if such a term existed, to designate the rules and precepts which are subjected to an arbitrary will. The concept of normality applies first of all to the quality of products produced by man, beginning with his public and private structures; this concept makes it possible to evaluate its chances of resisting the ravages of time. But it applies equally well to the resistance of living organisms, which are products of natural evolution. In both cases, normality serves to measure life expectancy or the capacity to resist adverse forces in the surrounding environment. The pair of concepts *normal/pathological* can be applied just as correctly in the realm of medicine as in that of architecture. However, in the realm of architectonics of knowledge, we would speak instead of *progress* (scientific, technical and even moral) and *regression*; of *order* and *disorder*; *stability* and *revolution*. But these binary oppositions are not universally accepted, partly because they lack sufficiently defined criteria for their application and especially because they are extrinsic to the specific area to which they apply. However, the opposition of *normal/pathological* is intrinsic to the realm of scientific knowledge and is based in objective criteria which are universally recognized as such.

IV. Vitruvius, in the first century A.D., summarized in three words the criteria for normality in the art of constructing buildings: *firmitas* (solidity), *utilitas* (functional utility), and *venustas* (beauty).[38] More recently the French biochemist Jacques Monod defined an organism as a functional, coherent and integrated unit, and showed that in addition to the properties of autonomous morphogenesis and reproductive invariance, a living organism also has the property of teleonomy, characterized by three criteria which define its activity as being constructive, oriented and coherent. It can be easily seen that the concept of teleonomy coincides with the definition of organism.

If we compare the architectural criteria of Vitruvius with Jacques Monod's teleonomic criteria, we discover an astonishing term by

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term analogy: *firmitas* corresponds to the integrity which results from a constructive activity conducted according to the rules; *utilitas* is comparable to the functionality which results from an oriented activity; and *venustas* is equal to the end product of a coherent activity.

We can then use this triad of characteristics to examine the "normality" of teleonomic idealities, or in other words, the validity of scientific theories. We thereby renounce any type of relativism which might lead to skepticism or even nihilism. Pascal's famous formula, "Truth lies on this side of the Pyrenees, error on the other", an equivalent of which can be found in similar terms in Montaigne, can perhaps be applied to political, philosophical or aesthetic principles, but in no way to scientific theories, to which Pascal himself greatly contributed.

Anti-relativism does not mean intolerance, any more than it does a refusal to admit that scientific theories can change or can move aside in favor of new theories. It does not exclude an examination of questions which might become embarrassing, such as when and how to apply the criteria of normality to one or another current theory, and particularly who will be responsible for applying them to accepted scientific theories. It is impossible to formulate an immediate answer to such crucial questions, for the "normality" of a scientific theory is not determined simply by the intentions of its author, nor by the good will of its partisans, nor even by the antagonism of its adversaries, any more than it depends on the consensus of the scientific community. For such a community does not exist. Even less does it depend on the arbitrary decisions of an "administration" which would attempt to have its law prevail through the use of its agents. Often a government can ask teaching institutions and research groups to work on a specific program, but this in no way determines the normality of the results of the work.

Some people speak of scientific theories as if they were discussing some sort of food product which is subject to market rules determined by the laws of supply and demand. This mercantile conception would seem to be inspired by a kind of social Darwinism. It confuses the interests of scientific researchers with the aims of science, committing the same type of error as those who confuse religion with the church or, even worse, the faith with certain priests.

In order to attempt to provide a positive response to the questions raised above, we can suppose for an instant that tradition manages the selection of scientific theories, according to criteria of normality which allow it to decide sovereignly which theories deserve to be retained and which are deemed to be unsalvageable. The application of the criteria of normality is thus a problem of a diachronic perspective.

V. A diachronic perspective is always referred to in order to explain the passage of a scientific theory from a normal to a pathological status. The transition is not always a brutal one. In the development of a scientific theory, there is nothing comparable to such "catastrophes" as earthquakes, bombings or fires, at least up until now. Nor does a scientific theory succumb to an internal disease, as organisms do, nor "collapse" because of an error in calculations, like a building.

The causes for the weakness or even the loss of normality in a scientific theory can be found in three categories: a) "crises"; b) internal pathogenic agents; c) external pathogenic factors.

a) The word *"crisis"* in classical Greek means *"decision"*, but the modern meaning of the term was not unknown to medicine in Antiquity. It designates an unexpected change in health, whose evolution remains uncertain, suspended between life and death for an undetermined period of time, at the end of which the patient either recovers health or dies. Throughout the time the crisis endures, a *decision* is awaited between improvement or an irreversible degradation in the normal health status. The history of science is full of examples of theories which have undergone this type of crisis.

The cosmogonic theories of the solar system are a primary example of this. To explain the movements of the heavenly bodies, Ptolemy constructed a system by imagining cycles and epicycles "in order to preserve the phenomena". For centuries his theory provided a generally accepted model of the universe up until the day when phenomena were discovered which his theory could not explain. The theory then entered a long period of crisis which lasted virtually until the Copernican revolution. The new theory featured several innovations, such as the abandon of the hypothesis of geocentrism in favor of heliocentrism, but then it in turn entered a period of crisis when its inability to explain the movement of the planet Mars was discovered. This was resolved only with Kepler's theory which rejected the notion of uniform and circular movement. Kepler's empirically established laws still lacked a theoretical basis which Newton then provided by formulating the law of universal attraction. Certain disturbances in the movement of the planet Mercury brought about questioning of Newton's theory and prepared the way for the appearance of Einstein's theory of relativity at the beginning of the twentieth century. From this brief outline of the evolution of theories explaining the solar system in the West, we can conclude that crises announce the appearance of new theories rather than the disappearance of outdated ones.

The set theory faced another type of crisis from its very inception. In the second half of the last century, in the Weierstrass circle, which had achieved the arithmetisation of infinitesimal analysis. G. Cantor began his research on infinite sets of numbers and points, basing his work on actual infinity. He imagined a hierarchical system of infinite sets which was to represent an extension of the concept of real numbers. He thought it would be possible with the set theory to create a foundation for analysis and even for all mathematics. Unfortunately, Cantor's theory of transfinite numbers immediately met with a mass of objections, first because of the unpredictability of its statements and then because of the internal contradictions it contained. Consequently the set theory, from its first appearance, had to go through an infinite series of crises. Zermelo attempted to resolve the discrepancies found in the theory by axiomatising it. But Cantor was unable to prove the hypothesis of the continuous, and disputes concerning the axiom of choice brought on a long period of crisis. It seemed that the fate of the set theory was completely associated with the gigantic efforts to axiomatize arithmetic and infinitesimal analysis, efforts which proved to be vain as a result of the discovery of propositions which could not be decided according to Gödel's theorems. It is tempting to conclude from this that crises are inherent in the theory of transfinite numbers.[19] Given this impossible situation it is not surprising that a non-Cantorian set theory has been recently proposed.[10]

In each of the preceding examples we were dealing with types of real crises; but we also know of "pseudo-crises", the most

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famous of which belongs to the history of geometry. This was the problem of parallel lines which, since the time of Euclid, had remained without an irrefutable proof. As long as a solution was being sought, it was possible to consider certain demonstrations as false without bringing about a collapse of Euclidian geometry. After the introduction of new postulates, geometry entered a new phase in its evolution, characterized by an enlargement of its bases and a generalization in its methods. Under these circumstances, we can hardly speak of crisis, in the sense defined above; at the most we can talk of a "growth crisis", meaning a development and in no way a real problem in geometry.

In order to avoid confusing real crises with chance delays or periodic setbacks in the demonstration of certain theorems, we must be careful not to use the word "crisis" incorrectly. A deductive theory enters a critical phase when it is no longer possible to determine whether the validity of the theory depends on the demonstration of a certain proposition. We should not interpret passing difficulties in such demostrations as proofs of the incapacity of the human mind in its pursuit of science. Consolation can be found in Pascal's *Pensées*: "Contradiction is not the mark of falsity, nor is noncontradiction the mark of truth". Closer to our own times, André Weil, one of the original Bourbakistes, expressed an almost fatalist opinion on the matter: "God exists because mathematics are consistent; and if the devil exists, it is because we cannot prove the consistency".[39]

b) *Endopathogenesis*: The internal flaws of a system lead to the abandoning of theories long held as valid. These flaws can be called "internal pathogenic agents". Some ancestors of modern science were victims of this, such as astrology and alchemy, which in their time enjoyed a good reputation, but which were subsequently discredited by the arrival of new forms of knowledge. What in part explains this disfavor is their lack of *"firmitas"*; an abyss opened up between practical knowledge based on observation and the utopian pretensions of the diviner or the alchemist. A lack of *"firmitas"* also led to the ruin of other ancient scientific theories, such as those of the augurs and the auspices, who read the future in the flight of birds or the entrails of victims, without mentioning chiromancy, oneiromancy, cartomancy, physiognomy, phrenology, graphology and other divinatory sciences which suffered the same paralysis, even though their *"utilitas"* cannot be denied, attested by the plethora of meteorological bulletins, horoscopes and lotteries.

In dedicating his work to Pope Paul III, Copernicus listed the reasons which led him to create a new heliocentric theory.[36] He cites the disturbing complexity of cycles and orbits in the Ptolemaic system which signified a violation of *"venustas"*. Other alleged reasons can be interpreted as offending against *"utilitas"* or *"firmitas"*.

Phlogistics, the 18th century theory which was meant to explain the heat of fire and its effects, posited the presence of an invisible element, the phlogiston, which emanated from every burning object. However, phlogistics could not explain certain phenomena which are inherent in combustion, such as the direction of the flames or the increase in weight of certain objects during combustion. Phlogistics, therefore, succumbed due to a lack of solidity and internal coherence. The discovery of gases provided the *coup de grace* and brought about the demise of the chemistry of principles.[36]

It is not unusual for theories to have to be abandoned as a result of some new discovery or because of their own internal development. Once the theory has fallen into disfavor, it must be demolished along with its system to make room for a more solid theory and, especially, one that is more useful. This is not only the case with the experimental sciences, but also in abstract disciplines such as mathematics where the limited field of application, the uselessness, and even the futility of the research are often cited as primary reasons for the defeat or the marginalization of certain theories which can only be rescued through their relationship with other more meaningful theories.[12]

c) *Exopathogenesis*: As illustration of an exogenous factor which can cause the ruin of scientific theories, let us examine the case cited by J. Dieudonné. The arbitrary modification of a single axiom in an axiomatic theory is sufficient to create a series of new theorems. The extension of the theory is thereby limited without in any way enriching its mathematical truth. The process just described leads to an inflation of mathematical "literature" without adding to its contents, at the risk of violating the criteria of *"normality"* and especially of *"utility"*, even if ultimately it serves the often too human interests of certain authors in need of publications.

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More serious are the consequences brought about by interference on the part of institutions and governments in the normality of scientific theories. The criterion of utility especially is violated when they attempt to raise a particular theory to the rank of a dogma. Scientific activity is thus doubly betrayed. There is a rapid stagnation and immobilization of the favored doctrine, and rival theories are squelched by being banished or degraded. Without leaving the Middle Ages, let us recall the privileged status given to Aristotelian physics and to the Ptolemaic geocentric system. Stagnation occurs as soon as it is decided, even without wishing to favor a certain theory, to condemn a rival theory and to prohibit its being taught. Punitive measures did not stop there. The author and partisans of a theory were condemned to silence, or worse were forced to recant. The procedure can also be reversed: an author can be rehabilitated, as for example Galileo or Darwin, and a theory can be reaccepted, such as cybernetics or genetics after World War II.

Much has been said recently of the manipulation of scientific theories for non-scientific ends. Even leaving aside the ethical aspects of the problem, it is still necessary to determine if the application of one or another scientific theory can be turned and used against science's final goals, or even against the welfare of mankind as a whole. And if the answer is yes, what can be done to protect ourselves against such a danger? The legend of *The Sorcerer's Apprentice* serves as a solemn warning against the spectre of the self-destruction of the human race. Norbert Wiener and Ludwig von Bertalanffy have expressed their anguish caused by the prospect of humanity being threatened by the destructive power of the most recent scientific and technological conquests.[41] A. Grothendieck launched a similar warning when he denounced the institutionalization of science as the source of a new religion, scientism.

Fortunately the apocalyptic vision of a universal catastrophe which seems to haunt the consciousness of illustrious scholars still remains a hypothetical one, although it can be listed as a type of virtual pathology, modeled on the predator-prey relationship, both members of which are congeneric.

The same holds true, although at a less terrifying level, for a science which attempts to dominate and even suppress the auton-

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omy of other neighboring sciences. Here we must distinguish between the legitimate, irresistible and therefore normal tendency to move into the realm of another, and the morbid and consequently intolerable tendency to eliminate the independence of other disciplines, which would be an unbearable "ecological" danger. This is reported for the first time toward the end of the 17th century under the label of "mathematism". The undeniable success of Galilean science brought on a contagious enthusiasm in certain circles for the mathematisation not only of natural sciences but also of ethics, of political economics and even of philosophy![17] Without the prudent moderation of true scholars, this led from the grandiose projects of Descartes and Leibniz to the tedious "applications" of epigones. The rationalism of the Enlightenment attempted to define the status of each science by carefully fixing the boundaries of its sphere of influence. *La Grande Encyclopédie, ou Dictionnaire raisonné des Sciences, des Arts et des Métiers* is sufficient proof of this. We might think that mathematisation was finally dead. But toward the middle of our own century, after two centuries of remission, we have seen its return to the offensive, all the more aggressive in that it is better armed to give the illusion of being an imperialism of science.[31] A recent attempt was made to produce an analysis of the status of mathematism in a sincere effort to determine its limits.[37] We can hope that this severe but justified criticism will not derange mathematicians but will serve to temper the zeal of neophytes.

VI. *Updating*: A scientific theory exists as soon as it has been made public in the form of an authentic declaration, but subject to critical examination. The stages prior to publication of the text are of interest to scientific historians and biographers more than scholars and researchers. From the moment it appears, a scientific theory becomes an ideal entity, whose normality can be tested by practical applications. Scientific theory is not a subject for contemplation, like a work of art, nor a subject of thought, like philosophical theories. Nor does a scientific theory wear itself out by being used, like tools do.

In short, a scientific theory is valid to the extent that it is normal. The person who uses it for practical ends is the only judge of the normality of the theory, for there is no *a priori* nor *a posteriori* in

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this realm; only the present operation, for the time that it lasts, and the results obtained therefrom can determine whether the theory behind the operation is normal or pathological.

Since the use of scientific theories forms the very essence of the researcher's activity, several possible situations can be distinguished:

– integral use of the theory for an application which confirms it in every respect;

– partial use, without modifications of details;

– total or partial use but with slight modifications;

– partial use, with essential modifications and abandonment of the rest;

– updating of the theory, certain details of which are retained;

– abandonment of the theory because of manifest errors, and replacement by another existing or new theory.

In each of these cases, the man of science is an active performer, breaking down the theory in question in order to eliminate defective parts and retaining those which prove to be healthy. All of these operations are meant to perfect an efficient conceptual instrument which represents a synthesis between what remains useful in tradition and new contributions developed under the influence of current scientific and technological events. This entire process constitutes the updating of the theory.

Much has been said recently of "verification", "falsification", "re-enactment of experiments" and "testing", as if the validity of a scientific theory was comparable to a coin whose value a money changer assays. This is not the case at all, however. Updating is not some special expertise. It is simply the method used by every scientific researcher in his work, even if his activity is apparently primarily pedagogical. We can think of Dedekind who tells how he achieved the creation of a new theory of real numbers when preparing his course of infinitesimal analysis for students in technical institutes.[11]

The updating of scientific theories is an activity which is conscious of its ends and which consequently retains an individual character. This does not exclude the possibility of working together on the same research topic, for the resulting theory would bear the stamp of the collective mind which inspired it. As witness to this is the mathematical work of Bourbaki, where the author openly declares his intentions to update.[7]

The fertile strength of such updating can be illustrated a thousand times in the history of science. In the Middle Ages the Ptolemaic system reigned uncontested in the minds of all, and it was still being used just as it had been formulated in the Almagest. Copernicus retained certain elements of this theory and rejected others which he replaced by his own inventions. The Copernican theory was in turn updated by Kepler and Tycho Brahé, among others. Tycho Brahé's theory soon was forgotten whereas Kepler's, updated by Newton, was subject to successive updatings. We can say that scientific creation has no other significance than this constant updating.

Naturally updating knowledge is a cultural activity *par excellence.* It is found not only in the realm of teleonomic idealities such as scientific theories, but also in the practical realm of construction equipment and techniques. In the arts, however, retouching is fully undesirable. A work of art has value only if it is authentic, meaning that it retains its initial form; any subsequent modification signified an alteration of its original purity.

We cannot insist too much on the role played by updating in the development and particularly in the genesis of sciences. This role is generally little known due to a lack of distinguishing sufficiently within the contents of scientific knowledge between the steps in scientific creation and the steps in the distribution of acquired knowledge. Formulas involving either verification or corroboration have been proposed.[32] But even in these concepts confusion evidently persists between the dynamics in the conception of scientific theory and the dynamics of its distribution. The range of updating of a scientific theory is vast, from a simple recopying to confirmation of existing theories, with many intermediate steps possible, including adaptation, reduction, generalization, analysis or synthesis.

Moving from the dynamics of scientific creation to that of distribution of the product and its reception, we must recognize the diversity in the categories of users and consumers of scientific knowledge. There are first of all teachers, who often are difficult to distinguish from researchers. Then there are popularizers who use articles, publications and any other means of information provided by the media to serve as mediator between the general public and specialized scientific circles. There are professional categories of all types which are interested not so much in scientific theories as in their pratical applications in industry, commerce, sports and recreation. And then there is the mass of the simply curious and amateurs, who are fascinated by scientific achievements. The diversity of these categories is so great that it is impossible to speak here of a scientific communtiy.

The reception given science is clearly an uncertain one, and its distribution is always accompanied by certain distortions which intellectual honesty and logical rigor attempt to minimise. It is at this stage sometimes that the shapeless mass of consumers, users and simple amateurs of scientific knowledge is polarized around a theory which then takes on an emblematic character. Its reputation is incontestable and it even serves as a sovereign (although not coercive) model for scientific research itself. The term used in such a case is "paradigm", a word which evokes a standard form based on normal contents. It becomes in a sense a kind of popular referendum, contrasting with the dogma imposed by authoritarian decision. Paradigms are normal theories which are distinctive because of the unanimity which they are able to sustain around themselves, ensuring them of stability and longevity. Their being updated is limited to reissuing a relatively faithful reproduction of the model. Like public monuments, they embody the spirit of their times and defiantly look to the future.

By a quirk of language, the adjective "enormous" coined by St. Bernard is synonymous with "monumental" and "colossal", literally designating "something which exceeds the norm": abnormal and consequently fragile. And this brings us to the most controversial aspect of the dynamics of sciences, the problem of scientific revolution.[25]

Just as for a great number of other concepts, a semantic analysis of the word can give us an initial approximation of the signifying contents which it holds. The term "revolution" owes its extraordinary career to the title of a major work by Copernicus, *"De revolutionibus orbium coelestium"*, where "revolution" is taken in the sense of circular movement, as in the Ptolemaic system. But since Copernican heliocentrism is opposed to Ptolemaic geocentrism, Copernicus employs this capital innovation to attack the theory of Ptolemy which he hopes to disprove. Here is a struggle between two scientific paradigms ending in the victory of the one which includes the term *"revolutio"* in its title. At the same time the word *"revolution"* became the key term for designating vaguely similar situations, from the political arena to the philosophical or economic spheres, in such hallowed phrases as the "French Revolution", the "American Revolution", the "Industrial Revolution", etc. Kant returned to the original meaning by talking symbolically of the "Copernican revolution" to designate the opposition between dogmatic idealism and his own transcendental idealism, even though Kantian epistemology rather resembles a return to geocentrism! In the 19th century, Claude Bernard upheld the idea of scientific revolution.[3] At that time the word "revolution" was frequently coupled with the word "reform" to explain the mechanisms of social life. In choosing the first term, Claude Bernard proposed to develop the thesis that science, unlike nature, advanced by successive leaps punctuated by changes in theories.

It is evident that the term has been enriched with new meanings in recent times, denoting not only past events but aspirations to changes yet to come. The concept of revolution is in the process of losing its initial identity in favor of this mixture of dream and reality. And so it is necessary to disencumber it of all the overtones with which public rhetoric has burdened it down.

As for the dynamics of scientific discovery, we must begin by eliminating the false opposition between traditional science and revolutionary science and retain only the real opposition between a normal condition and a pathological condition in scientific research in light of certain criteria. As the interaction of man and his social environment brings out the need for a revision, which must be considered an updating of a normal theory, scientific tradition is created, which must be seen not as an inventory of acquired wealth but as a sort of master plan in an urban region which contains all kinds of public buildings and services intended to facilitate the life of the human community.[30, 6] Tradition represents a slow but sure evolution, moving ahead step by step. The appearance of new paradigms within tradition is itself a normal phenomenon also, tempering the innovative role of updating but not excluding it. If updating is interrupted due to the effects of pathogenic agents, which bring about a rupture with tradition, a

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revolutionary situation arises quite quickly, one which ends only when a new theory, radically different from the other ones, re-establishes links with tradition. There is no trace of violence in this change, which is only revolutionary because it is not the product of standard updating action. Updating becomes operative once more as soon as the new theory becomes part of tradition, supposing several reciprocal concessions, and when the mechanisms of updating begin functioning again. Revolutionary acquisitions are subject to trial over a tentative period of assimilation whose length and extent vary depending on the importance of the break with tradition caused by the interruption in the updating process.

In this analysis of the concept of scientific revolution, we have deliberately left aside any consideration of a possible rivalry between "traditional" theories and "revolutionary" theories. Such antagonism, if it exists, may be of interest to the social history of sciences, but it has little bearing on epistemology.

VII. *The dynamics of sciences and historical perspective*: To conclude our analysis, we must separate synchronous aspects of the dynamics of sciences from historical perspective.

When analyzing the articulation of a normal scientific theory, that is one which is in a functional state and of practical use, we must distinguish between its *core* of fundamental concepts and specific methods and its *sphere* of possible applications.[35] Here we come back across the Aristotelian notions of the comprehension and the extension of a concept. By way of illustration, let us look at the present state of cybernetic theories, the core of which is made up of three concepts: *control, feedback, information*; and whose sphere of application involves three distinct domains: the living world, artificial intelligence and the physical universe.[20]

We saw earlier that every normal theory results from either the updating of previous theories transmitted by tradition or from the progressive assimilation of a theory issuing from a revolutionary situation. In the course of these operations, the core and the sphere referred to above undergo modifications whose importance is brought out by the diachronical study of scientific theories. This study is not limited to the updating of normal theories; it seeks to determine the causes and circumstances which led to their being abandoned or to their replacement. And in order to combine these two aspects, synchronic and diachronic, into a single concept, the term *style* was borrowed from art history. The architectural origins of the word are quite clear. Pierre Duhem in 1906 was the first to use the word in reference to theories in physics.[13] In 1935 Claude Chevalley employed it to attack the "algebraic-analytic" style of the Weierstrass school.[9] Several recent studies of "scientific style" emphasize the breadth of the concept for explaining the structure and evolution of science.[22]

In certain respects styles are related to scientific paradigms; however, unlike the latter in general they enjoy a longer life expectancy and are able to accommodate themselves to coexistence with different styles. In addition they do not always have their origin exclusively in a particular scientific theory, whether paradigmatic or not, for some are determined by geographic, ethnic, cultural or other factors.

Apparently a scientific style is a schematic and thus quite general description of the dynamic of the sciences. It is an effective instrument for characterizing and classifying scientific theories, but also for elucidating their origin, the reasons for their success or for their disappearance into oblivion. The same concept can also be used to determine past trends in scientific thinking and to formulate predictions with regard to its future. Although only recently introduced and still used only hesitatingly, the concept of style has proven to be essential for the study of the dynamics of the sciences.

VIII. *Conclusion*: We have attempted to show in this essay that man's cognitive activity is the exact counterpart in the ideal realm of his constructive activity, and that because of this fundamental symmetry it is possible to discover an *architectonics* of knowledge which is to scientific thinking what a plan is to a completed structure, with all the successive options in the course of the advancement of the work. The development of science was accomplished on two complementary levels. On the social level, it gradually separated itself from myth and magic; on the individual level it was consolidated into a system of autonomous knowledge distinct from opinion and from faith.

Apart from its descriptive role, the concept of architectonics has an operational value. It is thanks to it that we can measure the degree of *normality* in every system of knowledge. As soon as it is made public, a scientific theory finds itself confronted with internal or external factors which either threaten its validity or corroborate it. The succession or alternation of normal and pathological conditions in all scientific theories establishes the diachronic dimension of knowledge which is expressed in the variable relationship between tradition and innovation.

The transition from tradition to innovation is called *updating* when it takes place in one direction and *assimilation* in the opposite direction. The combined effects of this twofold movement form an impossible labyrinth whose Ariadne's thread is the concept of style.

We cannot end these considerations of the architectonics of knowledge without pointing out a singular feature. One of the intrinsic properties of idealities is perfection. Consequently every scientific theory is presented as complete and asks to be considered as such. However, because of the successive updatings and assimilations which they undergo, scientific theories are subject to modifications which in turn lay claim to the same property of perfection. To justify this strange situation which is inherent in the dynamics of the sciences, it is tempting to have recourse to the myth of Janus. Scientific theories are similar in nature, with one face turned toward perfection and the other toward perfectibility.

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