LOGIC AND METHODOLOGY OF SCIENCE: AN INTRODUCTION TO THE PHILOSOPHY OF SCIENCE

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Summary

This chapter presents some aspects of the logic and methodology of science within the framework of the philosophy of science. This, as well as the history of science, the psychology of science, the sociology of science, the anthropology of science, the politics of science, and the economics of science, is part of the so-called *metascientific studies* or *science studies* or, more precisely, *studies about science*, which have *science* as its *object of study*, with the aim of understanding both its nature and the way it functions, better. Nevertheless, since it makes a reflection on science from *philosophy*, it is also a part of it. The present chapter could be considered an introduction to certain subjects which we consider central and basic in metascientific reflection in general and philosophical reflection on science in particular. These subjects are the nature and function of philosophy of science (Section 1), the scientific concepts and the test and evaluation of hypotheses (Section 2), the notions of scientific law and explanation

(Section 3) and of scientific theory (Section 4). While we are dealing with each one of these subjects, we will persistently refer to methods, developments and authors belonging to the various phases we have identified in the history of the philosophy of science of the 20th century and of the 21st century so far. This chapter comes under the level of the *general philosophy of science* and, from there, it will provide elements which will enable us to reflect on the different particular scientific practices and theorizations. It will also make the link between these reflections and those made from other perspectives – historical, psychological, sociological, anthropological, political, economic – possible, in order to lead to a better understanding of at least one of the aspects of the exciting world around us: the world of science.

1. Introduction: Nature and Function of the Philosophy of Science

1.1. The Metascientific Studies

In spite of the high regard which societies like ours have for science (understood as *activity* or *process* or as *result* or *product*), and of all the attention devoted to it and to scientists, many questions concerning the nature of science and the way in which it functions remain unanswered.

In general, we do not find such questions explicitly formulated while we *study* one of the different scientific disciplines or while we *do* science, due to the fact that they are not questions *of* science but questions that we formulate *about* science. These are dealt with by the so-called *metascientific studies* or *science studies* or, more explicitly and precisely, *studies about science*, which have *science* as its *object of study*, which *reflect on* science.

We will call *second-order knowledge* a knowledge which has another body of knowledge as its object, and *first-order knowledge* the knowledge-object in that context. We can thus say that *metascientific studies* constitute a *second-order knowledge on* a first-order knowledge, *science*. Nevertheless, and owing to its great complexity, science is not susceptible of being approached from only one point of view: each one of the *aspects of scientific activity* opens up a perspective from which this activity can be studied. Without intending to be exhaustive, we will mention at least seven different aspects of the scientific activity object of metatheoretical reflection: *psychological*, *sociological*, *anthropological*, *political*, *economic*, *historical* and *philosophical*. These different aspects give rise, in turn, to seven *different perspectives* from which this activity can be investigated: *psychology of science*, *sociology of science*, *anthropology of science*, *politics of science*, *economics of science*, *history of science* and *philosophy of science*. The so-called *metascientific studies*, *science studies* or *studies about science* are constituted precisely by these various second-order theorizations on the (scientific) first-order theorizations. But although these different perspectives of metascientific reflection are linked in diverse and complicated ways, and not tension-free, they are different disciplines. In the following we are going to focus our attention on one of them, namely on the philosophical theorization about science.

1.2. The Philosophical Theorization about Science or Philosophy of Science

1.2.1. Its Nature and Relationship with Other Metascientific Disciplines

It could be said that what is characteristic of this metascientific discipline is the *working out of interpretative conceptual schemata of a philosophical character* – or, as we had said before, the *philosophical theorization* – with *the aim of understanding science*. Philosophy of science is, thus, not only a part of metascience but also a *part of philosophy*, that which is precisely devoted to the *analysis of science*.

In general, *philosophical* or *conceptual analysis*, or *explication* (as it is also called), consists in *transforming a given concept* which is more or less *inexact* (the *explicandum*) into a new, *exact* one (the *explicatum*) or rather in *replacing* the first one for the second one. The latter is not said to provide a *true* explication for the former, but only that it provides us with a *satisfactory* or *more satisfactory* explication than that given by other *explicata* which are presented as alternative. And an explication is satisfactory if the *explicatum* fulfills the following requirements: to be *similar* (though of course not identical) *to the explicandum*, in such a way that, in most cases in which the explicandum has so far been used, the explicatum can be used; to be *exact* (or at least *more exact* than the *explicandum*), that is, the rules of its use (for instance, in the form of a definition) are given in an exact form, so as to introduce the explicatum into a well-connected system of concepts; to be *fruitful*, that is, useful for the formulation of many universal statements or for allowing more or finer distinctions; and to be *simple*, as much as the preceding requisites – which are more important – permit.

As *philosophical* or *conceptual analysis* or *explication*, philosophy of science reveals, states explicitly or *explicates* the philosophical-conceptual aspects of the scientific activity, that is, the *fundamental concepts* of scientific activity, such as *hypothesis* or *law*, and reorganizes conceptually or *reconstructs* the systems of concepts (or *theories*) produced by science.

On the other hand, the scientific activity involves a series of *conventional practices*, which are carried out in accordance with certain *rules*, *norms* or *conventions*, even when there is not an explicit or conscious *knowledge* of the rules involved, but only a *tacit*, *implicit* or *unconscious* one.

In fact, in order to practise an activity or, moreover, in order to *practise* any activity (be it either a scientific or a daily activity, such as speaking) *correctly*, *it is not necessary to be able to say what practising it consists in*, formulating the rules or principles that govern it: it is enough to do it competently, according to the tacit or implicit knowledge you have of it. However, one can not only want to know a language or *know science, in the sense of practising it* according to its tacit or implicit knowledge, but also to know what *carrying it out* consists in, *knowing the rules that govern such practice*. At least part of the philosophy of science has the aim of *making the rules* that govern the various practices (such as *testing* or *explaining*) of that activity which is doing science *explicit*, making it in this way *comprehensible*.

In order to carry out these tasks, philosophy of science not only *relies* – depending on the case and relevance – on one or all of *the other metascientific disciplines*, but also on others of the so-called *branches of philosophy*, such as Ontology, Epistemology or Ethics and on *other disciplines*, mainly Logic and Mathematics, applying their analyses and results to the specific study of science, thus constituting possible branches of the philosophy of science, in turn, closely related to each other. We could speak, then, of a *logic of science* (which would do research on the logical structure of scientific theories and the logical and metalogical problems of the logic required by science); a *semantics of science* (which would systematize the concepts of sense, reference, representation, interpretation, truth and the like, and would analyze its application to science); a *pragmatics of science* (which would examine the way in which scientists use the different concepts or conceptual schemata); an *epistemology of science* (which would inquire into the specificity of scientific knowledge with respect to other kinds of knowledge); a *methodology of research* (which would do research on the general method of science – if existent – and would analyze the different procedures, devices, instruments and specific methods or techniques used in the particular sciences); an *ontology of science* (which would analyze and systematize the ontological commitments and results of science); an *axiology of science* (which would study the epistemic or non-epistemic values shared by the various scientific communities); an *ethics of science* (which would investigate the moral values and/or norms which guide, or should guide the scientific activity) and of an *aesthetics of science* (which would examine the values and aesthetic norms present in scientific research).

1.2.2. The Distinction between General and Special Philosophy of Science

The different scientific theorizations are grouped into *disciplines*: logic, mathematics, physics, chemistry, biology, psychology, economics, sociology, etc. These disciplines, in turn, are generally grouped into *bigger units*: natural sciences, social sciences and formal sciences, the first two conforming, in turn, to the so-called *empirical* (or *factual*) *sciences*. When we leave aside the specificities of the different disciplines, ignoring their peculiarities, and analyze the *common aspects* of science, the corresponding analysis moves in the field of the so-called *general philosophy of science*. At a lesser level of abstraction, where the *common aspects* found in *some disciplines* grouped into the aforementioned bigger units are analyzed we find, on the one hand, *the philosophy of formal sciences* and, on the other, the philosophy of *natural sciences* and the philosophy of *social sciences*, or more generally, the philosophy of *empirical sciences*. Finally, the philosophical reflection on the various particular disciplines, which deals with the specific problems of the theorizations belonging to each science, and where the aforementioned problematics are rethought in relation to specific sciences or theorizations, gives rise to the different *special philosophies of science*: philosophy of logic, philosophy of mathematics, philosophy of physics, philosophy of chemistry, philosophy of biology, etc.

1.2.3. The Distinction between Synchronic and Diachronic Philosophy of Science

From a temporal point of view, science and its different particular theorizations can be considered either in a certain historical moment or in its development through a given period of time. If we borrow from linguistics the terms *synchrony* and *diachrony,* we can say that if one makes a philosophical analysis considering science or its particular theorizations in a certain historical moment, that analysis is performed within the area of the so-called *synchronic philosophy of science*. If, on the other hand, the analysis comprises a certain temporal interval of science or of any of its particular theorizations, it is said that this belongs to the *diachronic philosophy of science*, which is in a natural way closely related to the historiography of science.

1.2.4. A Brief History of the Philosophy of Science

Philosophy of science has a long tradition. We can say that it was born with the reflections Plato made on mathematics in the 5th century B.C. Nevertheless, since it began to the first quarter of the 20th century, it was mainly a part of the *general theory of knowledge* (also called *gnoseology* or *epistemology in a wide sense*). In general the people who practised it were *philosophers* who had an interest in science or had been trained in it, or *scientists* interested and trained in philosophy. Although these people reflected philosophically on science, this reflection was not their main activity. When they did that, however, it was either with the intention of extending the results of such reflection to other areas and thus be able to work out a general theory of knowledge, or with the desire to defend the claims of the then contemporary science, or to identify epistemological excesses in science and indicate the way in which a reformed science could provide knowledge (in the case of philosophers); or else with clear pedagogical and professional aims, trying to draw public attention and stimulate the interest in science and guide scientific practice in a certain direction (in the case of the scientists).

Even when the first chair clearly devoted to the “inductive philosophy” was created in the University of Zürich in 1870, with the aim of establishing a bridge between the traditional epistemology and the more recent developments in the foundations of the “inductive” sciences, and in 1895, the physicist, philosopher and historian of physics Ernest Mach was appointed professor of “Philosophy, especially History and Theory of the Inductive Sciences” at the University of Vienna, it could be said that philosophy of science emerges as a discipline with its own specificity, and becomes a profession in the period between World Wars I and II. This professionalization starts with the constitution of what would officially be called after 1929 the *Vienna Circle*, and becomes consolidated after the arrival of the main Central-European philosophers of science in the United States. From then on, there are people who devote themselves systematically to reflect on science in a philosophical way, with a safe income and now able to present themselves before the world as philosophers of science without causing too much confusion in the audience, although actually generating a lot of questions about their activity.

From that time on, we can distinguish three main periods, stages or phases the philosophy of science has gone through in its development:

- a classical phase, covering from the end of the 1920s to the end of the 1960s, in which the *received view* is established;
- a historicist phase, starting in the 1960s and dominant during the 1970s and the beginning of the 1980s;
- a contemporary phase, which starts at the beginning of the 1970s and extends into the early 21st Century.

(1) Classical phase

As of 1924 Moritz Schlick, Mach's successor to the chair of "Philosophy of the Inductive Sciences" at the University of Vienna, organized a discussion circle which met regularly on Thursday afternoons. Not only Schlick's students – like Herbert Feigl and Friedrich Waismann – attended the meetings of the then called "Schlick's Circle" but also mathematicians, physicists, lawyers, historians, engineers, economists (like Otto Neurath, Rudolf Carnap, Hans Hahn, Philipp Frank, Karl Menger, Kurt Gödel, Maria Hahn-Neurath, Felix Kaufmann, Victor Kraft, Gustav Bergmann, Richard von Mises, Kurt Reidemeister and Edgar Zilsel). Neurath, Hahn, von Mises, Hahn-Neurath and Frank had already been meeting regularly with the same purpose from 1907 to 1914, in what would afterwards be called "the first Vienna Circle". In their conceptions, proposed with the background of Kantian philosophy and its later development by the neokantism, we can find the following main influences: the *German critical positivism* of the end of the 19th century (Ernst Mach, Hermann von Helmholtz and Richard Avenarius), the *French conventionalism* (Henri Poincaré and Pierre Duhem), the *Italian epistemology* (Giuseppe Peano and Federigo Enriques), the *new logic* – "mathematical", "formal", "classical" or "logistic" – (Gottlob Frege, Bertrand Russell) and *the logical analysis of language* (Gottlob Frege, Bertrand Russell and Ludwig Wittgenstein), which sprang from it.

The existence of the group around Schlick is made public as of 1929, with the appearance of the manifesto "The Scientific Conception of the World. The Vienna Circle", from which it would also take the name by which it would enter the history of philosophy: *The Vienna Circle*. From then on, the public activities of its members multiplied in various directions, although with special emphasis on two aspects: the organization of meetings and congresses and the publication and spreading of works on philosophy of science. In connection with the second one of these aspects, we would have to highlight the publication of the first journal specialized in philosophy of science, *Erkenntnis* (*Knowledge*), published jointly with the *Society of Empirical Philosophy* in Berlin, under the direction of Rudolf Carnap and Hans Reichenbach, and the publication of eight volumes between the years 1930-1940. The Vienna Circle – as continuators of the great tradition of the French Enlightenment and opposing the irrationalistic and reactionary currents of the 20th century, as well as in their attempts at developing the most accurate philosophy of science possible through the application of the "new logic" to the analysis of science – was not alone: they were in contact with akin individuals and groups (some of them artistic) from Vienna, Prague, Germany, Poland, the Scandinavian countries, Italy, France, England, the United States and even China. After the rise of Nazism in Germany and the annexation ("Anschluß") of Austria by it, some of the members and sympathizers of the Vienna Circle started to experience working difficulties, either because of their philosophical or political positions or because of their Jewish origin, or to be directly persecuted and their works prohibited and even burnt. In 1936 Moritz Schlick was murdered at the staircase of the University of Vienna by a former student of his, who had psychological problems but was also influenced by the Nazi preachings; the murderer was promptly released by the Nazis and as of 1945 lived there as a free Austrian citizen. With Schlick's death, the Vienna Circle was finally destroyed as a group, even when it went on existing on paper and without the attendance it had had until 1938. Its members and many of the people they had been related to were forced to go into exile in order to stay alive and, eventually, to continue working in the development of philosophy of science. The philosophical movement initiated by the Vienna Circle which, in spite of the multiplicity of aspects, the differences and the variety of nuances, was first unitarily called *logical positivism* or *neopositivism* and, as of the beginning of the 1930s, *neoempiricism* or *logical empiricism*, was continued in another political and social context, mainly in the United States, by the European emigrants, giving rise to what would constitute between 1940 and 1960, the philosophy of science dominant in the Anglo-Saxon countries. Even when this phase is usually accurately called *received view*, the philosophy of science in it was marked not by only one conception but by a set of problems tackled, positions and postulates which had a family resemblance. *Positivism* or *logical empiricism* and its sympathizers (among which were Rudolf Carnap – the most notorious philosopher of science of the Vienna Circle – and together with Karl Popper the most important and influential philosopher of science of this phase, also H. Reichenbach, C.G. Hempel, P. Frank, H. Feigl, R. Braithwaite, E. Nagel, N. Goodman and so many others); Karl Popper's *critical rationalism*, the *scientific realism* of W. Sellars's, M. Bunge's or others', and the half-way *studies between pure logic* and *epistemology* (like those of A.Tarski's, K. Ajdukiewicz's, R. Montague's or J. Hintikka's), all these had a "family resemblance". This resemblance could be called "classical", in the sense that although many of its theses and methods are nowadays considered "superseded" by a great number of contemporary philosophers of science, these constitute an obligatory point of reference for later developments, and it seems impossible to imagine the contemporary philosophy of science without taking into account the contributions made during this phase. Some of the subjects tackled then were the demarcation between science and non-science, the nature of scientific concepts, the structure of scientific theories, the relationship between theory and experience, the methodology of hypotheses testing and their later evaluation and the nature of scientific explanation and prediction. Almost each one of these subjects gave rise to heated arguments and controversy: different criteria of *demarcation between science and non-science* were proposed (the latter understood as *pseudoscience* by some, especially by Popper, and as *metaphysics* by others, particularly Carnap); nearly all of them, but not all, accepted the distinction between observational concepts and theoretical concepts, though they strongly differed on the role the latter played in science, according to whether they assumed realistic, operationalist or nominalist positions. Although the *hypothetical-deductive method* was almost universally accepted as *the method by which hypotheses are tested*, there was no agreement concerning the way of evaluating the successful test of the hypotheses, be it either following Carnap's *confirmationism* or Popper's *corroborationism*. Although everybody considered *theories* as *sets of statements* or *sentences deductively* or *axiomatically organized*, not everybody agreed on the specific way in which this should be understood and specified; even when the *explication* of the concepts of scientific *explanation and prediction* made by Hempel was accepted, such explication still left room for differences in detail or even for its universality to be questioned. At the end of the 1950s, however, a series of critiques of the philosophy of science of this phase started to arise, which showed its limitations, owing mainly to: the almost exclusive application of *an excessively rigid and limited logical formalism* (the first-order logic); the concentration on the *general philosophy* of science at the expense of the special philosophies; the almost complete restriction of the analyses to the *synchronic aspects* of science, with little or no consideration for the diachronic ones; the acceptance of the distinction between what is called – as from Reichenbach's terminological proposal of 1938 – *context of discovery*, which is related to the way in which the different concepts, hypotheses, laws or theories occur to the scientist, under certain conditions or circumstances (individual, psychological, social, political, economic, etc.) and the so-called *context of justification*, related to the way in which a scientist, after something has occurred to him (be it a concept, a hypothesis, a law or a theory), and regardless of how it has occurred to him, the justification, validity, legitimacy or reliability of this discovery is determined, and the resulting restriction of the philosophy of science to the analysis of the *context of justification*, disregarding or leaving the analysis of the context of discovery to other metascientific disciplines, such as psychology of science, history of science and, especially, sociology of science.

(2) Historicist phase

The critiques of the *received view* came mainly from people interested in the history of science, who started to become known as the *new philosophers* of science. It is usually said that they constitute a true revolt against the philosophy of science of the classical phase, to the point of not only accusing it of being too simplistic but of insinuating that it made philosophy of "science-fiction" and not from the real science as it is or as it was practised by scientists. Nevertheless, if we take into account the multiplicity and variety of positions held by positivists or logical empiricists, greater even than all that was later on coded in the *received view*, although even here we also find ourselves with a plurality of approaches, it would be better to characterize the changes that took place in the philosophy of science during the 1960s as of *recovery* or *deepening* of the problems tackled and of previously anticipated solutions more than of a true *revolution*. However, it would be necessary to point out that the incidence of these *new philosophers* (N.R. Hanson, T.S. Kuhn, I. Lakatos, P. Feyerabend, S. Toulmin, L. Laudan, and D. Shapere, among others) was crucial in this renaissance. The consideration of the historical or historicist perspective which in general characterizes them, marks definitively the development of the later metascientific reflection. Its influence was made to be felt when questions like the importance of the historical studies and the social determinants, the questioning of the sharp distinction between the context of discovery and the context of justification, the problem of the theory-ladenness of observations and the problem of incommensurability between theories, the notions of scientific progress and rationality, the relevance and scope of the formal analyses of science and the problem of relativism, were put in the foreground. Nevertheless, a new conception about the nature and synchronic structure of the scientific theories, supposedly closer to scientific practice just as history presents it to us, underlies – although neither logically implies nor has it been systematically developed – the majority of their theses and diachronic studies. This new notion the new philosophers refer in many different terms (Kuhn's *paradigm*, Lakatos' *research program*, Laudan's *research tradition*) is, however, so extremely imprecise at times that it ends up by blurring almost completely what seem to be correct intuitions. The main motivation positivists or logical empiricists had to develop a formal philosophy of science was precisely to avoid a vague and imprecise metascientific discourse. And much of the controversy that arose after the appearance of the new philosophers was generated by the imprecision and equivocity of some of its main notions.

The majority of the philosophers of science who were sensitive to the historicist perspective concluded that the complexity and richness of the elements involved in science, escaped any attempt at formalization. It was considered that not only were the formalizations like those made in the *Received View* totally inadequate to express these entities in all their complexity, but it did not seem reasonable to expect that any other procedure of formal analysis should grasp the minimum elements of this new characterization. This is the antiformalist moral that spread in many metascientific environments after the *historicist revolt*. As a consequence, under the wing of these philosophers, a whole new branch of *science studies* (with important though specific precedents before the 1960s) develops, centered on the study of the social determinants of science and basing itself on considerable empirical investigation. During the 1980s, this line of investigation gives rise to the establishment of the sociology of science as a discipline.

(3) Contemporary phase

This `was not, however, the reaction of all the metascientific community. A part of it, made up by philosophers, has held that research in science should be carried out using methods or basing itself on results coming from the natural sciences (P. Kitcher, R. Giere, P. Thagard, P. Churchland and P. M. Churchland, among others). Both the psychologist and cognitivist approaches, and also some of the evolutionists we will refer to later belong to these proposals of analysis, grouped together under the label of "naturalized epistemologies". Another part of the metascientific community has advocated a philosophy of science which should take more into account the factors leading to the formulation of theories (use of instruments, experiments, analysis of the scientific activity in general or of the different practices in particular, etc.) and not so much the theories themselves (I. Hacking, R.J. Ackermann, P. Galison, J. Rouse, etc.). Others, mistrusting the attempts at developing a general philosophy of science, found refuge either in the analysis of the individual disciplines or in the treatment of specific philosophical problems. Within the former of the aforementioned strategies we could mention that, while the theory of relativity and quantum mechanics went on drawing philosophical attention, the ones that experienced the biggest growth were the special philosophies of biology, psychology and, to a lesser extent, of social sciences. The development reached by the philosophy of biology was so great that it could be said that this discipline started replacing physics in what refers to occupying the center of philosophical reflection, enabling some philosophers to regain hope in developing a general philosophy of science, taking biology as a model or pattern.

Thus we find ourselves with a series of proposals of analysis of the development of knowledge in general and/or of scientific knowledge in particular (whose first formulations are found in the works of K. Lorenz, D. Campbell, K. Popper and S. Toulmin, and the most recent ones in those of D. Hull, for example), known by the name of "evolutionary epistemologies", which take as a starting point for their analysis (some specific treatment of) biological evolution. As regards the second one of the abovementioned strategies, we would have to point out that one of the questions that has undoubtedly been more discussed in this phase of the philosophy of science is that of scientific realism (starting in the 1960s with people like W. Sellars, G. Maxwell and J.J.C. Smart and its more recent defenders: R. Boyd or I. Hacking, down to its most bitter critics, like B. van Fraassen), in connection with the more general semantical problematics of realism (of the kind discussed by W.V. Quine, D. Davidson, S. Kripke or H. Putnam). Within this strategy it must be included, related to the "cultural studies" in general, the "feminist" critic of science and scientific institutions (S. Harding, P.G. Abir-Am).

Finally, we will refer to other contemporary currents in philosophy of science which show, after the retreat of the first antiformalist effects, that at least part of the new elements mentioned during the historicist phase are susceptible to formal reasonable analysis and reconstruction. During the 1970s, after having assimilated the unquestionable contributions of the historicists and expurgated their main excesses, trust in the viability of formal or semiformal analyses of science is recovered, at least in some of its areas, among them that related to the nature of theories, which continue being the basic units of what we call science, since experiments and instrumental operationalizations in science are only meaningful insofar as they form part of a theoretical context.

In this sense, at the end of the 1970s and in the 1980s, and starting with the work developed by J.C.C. McKinsey, E. Beth and J. von Neumann in the period ranging from the 1930s to the 1950s, a new characterization of scientific theories called *semantic* or *model-theoretical conception of theories* spreads and becomes established. In fact, it is not a unique conception but a *family* of them which share some general elements. The followers of the abovementioned authors belong to this family and they are P. Suppes, B. van Fraassen and F. Suppe, as well as R. Giere in the United States; M. Dalla Chiara and G. Toraldo de Francia in Italy; M. Przełecki and R. Wójcicki in Poland; G. Ludwig in Germany; N.C.A. Da Costa in Brazil; and the structuralist view of theories, initiated in the United States by one of Suppes' students, J. Sneed, and developed in Europe, mainly in Germany, by that who reintroduced analytical philosophy in general and the philosophy of science in particular in German-speaking countries and other Central-European countries after the Second World War, W. Stegmüller and his disciples C.U. Moulines and W. Balzer.

All members of this family share the "formalistic spirit" of the classical phase though not the letter: the *classical virtue of conceptual clarity and precision* is a regulative principle for them; nevertheless, they consider that the best way of approaching this ideal is *to make use of all the logico-mathematical instruments which may contribute to* the attainment of this objective. They do not restrict themselves, then, to the use of first-order logic – the favorite instrument during the classical phase – but make an increasing use of logical and mathematical concepts, methods and results of set theory and model theory, of topology and of category theory, among others. On the other hand, some of them – particularly the structuralist view – are conscious of the numerous philosophically essential aspects of science which resist to be dealt with in a purely formal way, be it either because we do not have at our disposal the suitable tools for the task (at least not at the present time), or because we encounter elements which are *irreducibly pragmatic and historically relative*, like the ones which have been mentioned in the historicist phase.

This double procedure which, on the one hand makes use of the maximum of logico-mathematical resources to analyze the structure of science and on the other, does not deny the aspects that do not let themselves be formalized completely, though it is held that they can be dealt with by a rigorous conceptual analysis; this "double strategy" – which intends to recover the best of each of the preceding phases – constitutes one of the fundamental characteristics of this approach. So the semantic conception teaches us that, besides *synchronic* studies in philosophy of science, there is room for a systematic *diachronic* approach, thus getting over the sterile antagonism between the metatheories centered on the analysis of the structure of scientific theories and those of a historicist kind, of the type of Kuhn's or Lakatos's.

2. Scientific Concepts and Hypotheses

2.1. The Language of Science

In order to be able to carry out their activities, as well as to present their results, scientists make use, among other things, of *language*. The *vocabulary* of the language used by the scientists belonging to the empirical sciences consists, in general, of three parts: 1) the words or terms of some natural language (for example, English); 2) a standard store of expressions or terms coming from the formal sciences (logic and mathematics); and 3) a generally small set of technical expressions or terms, which only acquire proper meaning in the context of particular empirical scientific theorizations. Owing to the fact that the study of natural languages in general is not a specific task of the philosophy of science, we will not devote much attention to them. As regards the expressions belonging to the formal sciences, these include expressions coming from logic – such as variables for objects of various kinds, connectives, quantifiers, rules for the construction of statements from terms or of complex statements from simpler statements – and from mathematics (set theory included) – such as sets of numbers and expressions for spaces, relations, functions and mathematical terms. Logic and mathematics constitute something like a supradisciplinary general background, presupposed – to a greater or lesser extent – by the scientists of all empirical sciences. Nevertheless, formal sciences are not the object of our study. Thus the subject left to be commented on then, is that of the technical terms of the language of science. These are a fundamental object of analysis of the philosophy of empirical sciences. In this section we will, in the first place, deal with some of its more general aspects. However, in order to go forward with our analysis, it will be useful to focus our attention not on the words or, in general, on the expressions of a given language themselves, but on the concepts expressed by them.

2.2. Scientific Concepts

Echoing Kant's philosophy, we could say that knowledge does not depend only on the world but also on our *sensory system* and on our *conceptual system.*

On the one hand, our sensory system processes and selects the series of stimuli we perceive. Our perception of the world is thus conditioned by our sensory system, which determines the guidelines by which this is possible. In fact, if our sensory system were different from what it actually is, we would perceive the world in a different way.

On the other hand and similarly, our conceptual system selects and determines the aspects of the world we take into account, those which we think and talk about. Hence what we think and say about the world does not depend only on the world itself but also on our conceptual system. Concepts enable us to identify, compare, differentiate, relate, etc., the objects of our experience. And the more articulate and complex our conceptual system is, the more articulate and effective our knowledge will be.

But even when at present there is quite wide – though not total – agreement on the Kantian idea of the fundamental role concepts in all forms of knowledge – including scientific knowledge – play, there is no agreement on *what concepts are*. In fact, this is one of the most difficult subjects in philosophy, which has been very much discussed – at least since Plato's time, and in general, related to the so-called *problem of universals* –, and which is still being discussed, with the contribution of other disciplines, like linguistics and psychology. The variety of theories about concepts is amazing, including those positions which plainly and simply *deny* the existence of concepts.

However, we will neither present the different theories here nor attempt at mediating in the discussion among them; we will simply assume that *there are concepts*, and that since they are *different* from the *words* and *things* they designate or refer to, they closely relate to both of them: while words *express* concepts, objects *fall under* them or, as it is also said inversely, concepts *are applied* to objects or *subsume* objects. We will also say that the *extension* of a concept is the set of objects that come under it and that consequently, the concept *determines* such set.

2.2.1. Kinds of Concepts

In science we can distinguish three kinds of conceptual forms which organize knowledge:

- classificatory (or qualitative) concepts,
- comparative (or topological) concepts,
- metric (or quantitative) concepts.

2.2.1.1. Classificatory (or Qualitative) Concepts

The simplest conceptual form is constituted by the *classificatory* concepts, also called *qualitative* concepts. Classificatory concepts are those which are more familiar to us, besides being those that are learned first. Classifying is the simplest and most direct way of subsuming multiple and diverse objects under the same concept. A classificatory concept is simply a concept that *places an object within a certain class*. Examples of classificatory objects are *man*, *woman*, *red*, *blue*, *dog*, *cat*, *house*, *tree*, *cold*, *hot*, *spoon*, *fork*.

The terms which express classificatory concepts are, from the point of view of their *logical form*, very simple: they are *monadic predicates* (a predicate is monadic when it expresses a property, i.e. when it has place for one argument), while from the point of view of the *theory of sets*, the extension of a classificatory concept is a *simple set*, without internal structure.

In science it is not common to introduce classificatory concepts in an isolated way but in sets or systems of concepts called *classifications*. A classification of a certain area or domain of objects consists in putting the objects of this domain into groups, classes or sets, according to certain systematic criteria, in such a way that none of these sets is empty, that none of the objects of the domain belongs to more than one set and that each object of the domain belongs to some set.

Many times scientists are not only interested in classifying the objects of a domain but in building classifications of decreasing refinement in the same domain, intertwined and forming *hierarchies with different levels of generality*. These classifications are called *taxonomic hierarchies* (since classes established by a classification are called *taxons*).

2.2.1.2. Comparative (or Topological) Concepts

The following conceptual form, that of *comparative* concepts (also called *topological* concepts), offers more information than classificatory concepts. From a methodological point of view, comparative concepts play a sort of intermediary role between classificatory and metric concepts. This conceptual form not only enables us to classify a given domain, but also to *order* it, by "more or less" comparisons. Some examples of comparative concepts are *taller*, *darker*, *older*, *better*, *faster*, *hotter*, *sharper*, *better adapted*, *harder*, *sourer*.

Comparative concepts are, from the point of view of their *logical form*, of a *relational* character. The terms that express them are made up of two closely related dyadic predicates (a predicate is dyadic when it expresses a relationship between two objects, i.e. when it has place for two arguments): '*K*', which expresses a relation of *coincidence* – "*x coincides with y*" or "*x is so like y*" – and '*P*' which expresses a relation of *precedence* – "*x precedes y*" or "*x is less than y*" –, both defined over the same domain of objects *D*. The first of the relations '*K*' enables us to *classify* the domain of objects *D*, while the second '*P*' (together with the first one), enables us to *order it*. The *extension* of a comparative concept is the *union of the relations of coincidence and precedence*.

2.2.1.3. Metric (or Quantitative) Concepts

The third conceptual form is that of *metric* concepts, also called *quantitative* (besides *numerical*, *numerical functions* or *quantities*). These concepts – unlike qualitative and comparative ones – do not have correspondence in ordinary language but constitute an original contribution of the scientific languages and their most effective instruments: they allow for finer and more precise differentiations, to formulate more general empirical laws and to make more exact and controllable explanations and predictions. Metric concepts are closely connected with the idea of measuring things or processes or some of their features. In order to do that, they assign numbers (i.e. numerical values and not just numerals) to the objects of a given domain to represent certain specific properties of the objects called *magnitudes*. This *assignment* facilitates the use of mathematical operations (addition, multiplication, derivation, integration, etc.) in an empirically meaningful way among the numerical values assigned, i.e. it allows us to operate with numbers "as if" we operated with the objects themselves.

From the point of view of its *logical form*, a metric concept is a *numerical function* (or better, and as we will clarify later on, a set of such functions), i.e. a function (set of functions) which assigns a numerical value to each object of the domain D, namely the value of the quantity for that object. The value assigned can be a single number or a set of several numbers (vectors, matrixes, tensors, etc.).

The specific functions f which assign real numbers to each one of the objects of domain D are called *scales*. These specific numerical functions measure the same magnitude but assign different numbers to the same objects. Each one of these functions constitutes different equally valid scales – equivalent – for the same magnitude.

Due to the existence of equivalent scales, it is not correct to identify the extension of a metric concept with only one of the metric functions, i.e. with only one scale: this should be done with the set of all the possible numerical functions which represent the magnitude, i.e. with the set of all the possible scales for the magnitude corresponding to the concept under discussion. The *extension* of the quantitative concept is thus the *set of numerical functions* $\{f_1, f_2, f_3,...\}$.

2.3. Scientific Statements: Hypotheses and Their Testing

It could be said that concepts, which enable us to articulate knowledge, are the smallest meaningful units. However, both in science and in daily discourse, language is used primarily to make *assertions* (statements or claims), i.e. to say that certain things are in a certain way. Concepts are essential for this use, but it is not enough to consider them in isolation, since they do not constitute assertoric units on their own. The smallest assertoric units are the so-called *propositions* or, in linguistic terms, *statements* or *sentences*.

Hypotheses, i.e. claims which are simple or complex, singular or general and are susceptible to testing, constitute a special kind of statements. Below we will present the elements and the structure involved in hypotheses testing, as well as the conditions which are to be fulfilled in the test process. In this presentation we will not consider the approximative character all claims in science (be they either hypotheses or observations by means of which the former are tested) have; neither shall we deal with the specific aspects of hypotheses testing whose predictions are essentially statistical or probabilistic.

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Biographical Sketch

Pablo Lorenzano was born in Buenos Aires, 1962. Degree in Philosophy from the National University of Mexico, 1986. Ph.D. in Philosophy from the Free University of Berlin, 1995.

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