Axiomathes (2021) 31:677–693
https://doi.org/10.1007/s10516-021-09568-1

ORIGINAL PAPER

The Multiple Aspects of the Philosophy of Science

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Received: 22 April 2021 / Accepted: 9 June 2021 / Published online: 23 June 2021

Abstract
Philosophy of Science, understood as a special philosophical discipline, was born only at the beginning of the twentieth century as part of the effort for overcoming the "foundational crisis" that had affected especially mathematics and physics. Therefore, it was conceived as an investigation about the features and reliability of scientific *knowledge* and for a few decades was deeply marked by the philosophical approach of logical empiricism. This cognitive point of view persisted also when, after Kuhn's work, the attention focused on the scientific *activity* in order to understand scientific change and a sociological model replaced the view that empirical adequacy and logical consistency are the factors that determine the change of scientific theories. Ethical, social and political considerations regarding science ware considered inappropriate and potentially dangerous since they violate the alleged "neutrality of science" with respect to values. Nevertheless, the strict intertwining of science and technology in contemporary "technoscience" has produced a wide debate regarding the practical aspect of technoscientific *activity* that has the intrinsic features of a philosophical debate. Therefore, it is natural and advisable that the entire wealth of the philosophical disciplines (and not just logic, ontology, epistemology and philosophy of language) be called to contribute to the specific complex discourse of the Philosophy of Science.

Keywords Ethics of science · Techoscience · Neutrality of science · Science and values · Science and society

1 Introduction

The task of specifying an adequate meaning of the term "philosophy of science" requires a preliminary distinction: whether one wishes to consider in a general sense what a philosophical reflection on science consists of, or whether one wishes to specify the nature of a particular discipline—the one called Philosophy

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of Science—which occupies a recognized place in the catalogue of the branches of philosophy. Even assuming that we share the concept of philosophy as a rational reflection that can concern the most diverse objects, we have the problem of specifying what its object is when dealing with science. In other words, a first task consists precisely in clarifying the very concept of science. To this commitment Plato and Aristotle already dedicated themselves, the first distinguishing science (*espisteme*) from opinion (*doxa*) and the second also proposing a first fundamental distinction between the sciences. This is essentially an investigation belonging to the theory of knowledge, although it has sometimes even been identified with the essence of philosophy (as in Fichte's booklet entitled *On the concept of the doctrine of science or so-called philosophy* of 1794).[1] Already in antiquity, on the other hand, particular disciplines existed that we today call sciences in the modern sense of the term, such as mathematics, physics, astronomy, life sciences, and also regarding these disciplines the ancient philosophers elaborated theories of great significance. In the following centuries this intertwining continued, not only because the most important philosophical schools, in their effort to offer interpretative frameworks of the entire field of reality, inevitably had to take into account what was known about certain sectors of reality within disciplines that we today qualify as scientific, but also because the intellectual constructs of these disciplines themselves had their roots in general philosophical doctrines, so that rather often the most important figures in the field of philosophical thought are also noted for scientific contributions and, reciprocally, many prominent scientists have supported more or less original philosophical conceptions, even after the birth of modern science in the Renaissance: it will suffice to mention the names of Galileo, Descartes, Newton, Leibniz and Kant. Concerning the latter, one can note that—in the *Critique of Pure Reason*—metaphysics (i.e. the core of every philosophical doctrine according to tradition) is subjected to a validity test in comparison with science: in fact the problem addressed in this first *Critique* is *whether* metaphysics is possible as a science, while mathematical and physical science are t*aken for granted* to be sciences, and the purpose of the work is to draw inspiration from them in order to see how they could "place themselves on the safe path of a science" and see if metaphysics can adopt this model. As is well known, Kant's answer is negative: metaphysics (understood in the classical sense of the doctrine of reality as such and, in particular, of its suprasensible dimensions) is not possible as a science. Only in appearance does the title of the Kantian *Prolegomena to any future metaphysics that wants to present itself as a science* sound contrary; in fact, this work proposes a very different meaning of metaphysics, identified with the theory of the universal and necessary conditions of all knowledge as such, consisting in that a priori synthesis with an indispensable ingredient of sensory intuitions that metaphysics in its traditional sense cannot satisfy. We took the liberty of recalling these well-known Kantian theses because they highlight how in Kant one finds a particularly significant example of the philosophy of science, both from the point of view of the characterization of scientificity as such, and from that of the application of this concept. of science to specific scientific disciplines, such as mathematics and

[1] See Fichte 1794

physics (not only in the two works just mentioned, but also in various other writings belonging to the so-called pre-critical period of his thought).

With this, however, it cannot be said that the Philosophy of Science was born as a specialized philosophical discipline and not even this term was introduced. This is not surprising: just think that denominations that have become so familiar to us that they are spontaneously considered very ancient parts of our languages have actually had relatively recent historical origins. Think of the term *aesthetics*, which means for us the doctrine of beauty, above all in works of art, but which traditionally referred to the lower level of knowledge, that is to the sensitive knowledge, and only towards the middle of the eighteenth century, in the *Aeasthetuca* of Alexander Gottlieb Baumgarten (1750), there was a transition from that traditional meaning to the modern one that we still use (in the same *Critique of Pure Reason* the "Transcendental aesthetics" is still the treatment of sensitive knowledge). Another frequently used technical term is that of *ontology*, which can be found in a couple of dictionaries from the early seventeenth century and was then defined and systematically treated by Wolff at the end of that century. Even a term as common as that of *biology* was introduced and clarified in a modern scientific meaning (after a few occasional sporadic antecedents) independently by Lamarck and Treviranus in 1802.[2]

As for the term "philosophy of science", it appears for the first time in a treatise by André Marie Ampère published in two volumes respectively in Ampère, 1838 and 1845.[3] It is therefore the work of a great scientist sensitive to philosophical issues, and cannot be counted as the birth of a specialized discipline in the field of philosophy. This transition took, place in the first decades of the twentieth century, especially as a consequence of the emergence of some "crises" in the foundations of the physical–mathematical sciences that we are going to to deal with now, abandoning the details of the historical reconstructions.

2 The Crisis of Classical Mathematics

At the beginning of the nineteenth century, also the "working mathematicians" began to feel in trouble when using without a sufficient conceptual clarification such fundamental concepts of analysis as those of infinite, infinitesimal, continuity, function, while in the domain of geometry the old problem of the "Euclidean postulate" was also knowing a significant revival of discussions. In such a way a generalized concern took shape regarding what was later called the "problem of foundations" of mathematics that fuelled during the whole century conspicuous investigations aiming at granting again to mathematical knowledge those *selfevident* and uncontroversial grounds that could justify the *certainty* that has been its traditional distinctive mark. Toward the end of the nineteenth century it seemed that set-theory could offer the ultimate ground on which it is possible to logically "construct" the whole building of mathematics, while Frege had come to a similar result following

[2] SEE Lamarck (1802) and Treviranus (1802).

[3] See Ampère (1834).

an independent path, that is, by relying on the notion of "class" (not really different from that of "set"), which he considered as purely *logical,* and claiming in such a way that it was possible to reduce mathematics to logic. But at this point the *crisis of the foundations of mathematics* exploded, because several *antinomies* (that is, insoluble contradictions) could be formulated in set-theory and the theory of classes by an unrestricted use of certain apparently "self-evident" principles.

A crisis of the mathematical evidence had also been the outcome of the critical investigations in the domain of geometry. After having abandoned the centuries-old series of frustrating efforts for proving *directly* the Euclidean postulate from the other unproblematic "evident" postulates of traditional geometry, the new strategy had been adopted to prove it *indirectly*, by showing that an internal *contradiction* affected those anti-intuitive geometrical systems obtained by admitting a *negation* of the Euclidean postulate. But such an internal contradiction could never be discovered and internal consistency was gradually taken as the only criterion of legitimacy for a mathematical theory. This process entailed a deep reconsideration of the *axiomatic method*, that had been the cornerstone of classical mathematics and of classical science in general, and required that a science be deductively constructed starting from *immediately true (or evident)* axioms. In the modern perspective, the axioms were reduced to the simple role of "primitive propositions", with no requirement of evidence or truth and, in addition, as "devoid of meaning" and, at most, susceptible of "receiving" a meaning according to different possible *interpretations*. Once this view is generalized to the conception of every mathematical theory, it follows that no such theory is concerned with the investigation of "its own" domain of objects, and that the requirement of non-contradiction (or "consistency") is the only limitation to the arbitrary construction of axiomatic systems.

All these are well-known historical facts, that show how the "foundational crisis" immediately imposed a series of *epistemological and methodological problems*, regarding the soundness of what had been considered along the whole history of Western civilization the most perfect example of solid *knowledge*, endowed with truth, certainty, absolute logical rigor. Therefore, the general conviction was that such a crisis *should* have a solution, and it is interesting to note that the diagnosis and therapies proposed for overcoming that crisis depended on different *ontological* conceptions regarding the "kind of existence" of the mathematical objects. For example, the so-called *logicists* and *platonists* (such as Frege and Russell) thought that logical and mathematical objects have an actual *existence* in themselves, and that antinomies only depend on our way of *speaking* of them; therefore, we must find the remedy in a suitable rigorization of our language (this is the spirit of the Russellian theory of logical types). *Intuitionists* (such as Brouwer), on the other hand, believed that antinomies were the consequence of having admitted the consideration of actually infinite sets, whereas in mathematics only such entities *exist* that can be constructed by means of finitely examinable operations. Other scholars believed that the root of the antinomies was the confidence in the content of seemingly"evident" intellectual intuitions, so that a strictly *formal* axiomatization of all the branches of mathematics (including set theory) should be realized, followed by the proof that no contradiction could be formally derived from such axiomatic systems. The idea that non-contradiction was the necessary and sufficient condition

for mathematical existence was at least implicit in this position (called *formalism)*, but the problem was how to prove such a consistency. Hilbert's "programme" was that of showing such a consistency by systematically investigating the *proofs* realizable in certain axiomatic systems. From a strictly formal point of view they consist in finite manipulations of finite strings of signs according to a finite set of rules, and it seemed reasonable that, through a finite exploration of these possible manipulations, one could obtain the consistency proof at least of the simplest of the mathematically interesting axiomatic systems (that of elementary arithmetic). The famous "Gödel's theorem" of 1931, however, proved the impossibility of such a result and entailed many consequences in various fields.

The short survey outlined here indicates what were the origins of a specialized *philosophy of mathematics* that flourished along the twentieth century and whose themes regarded the ontology of mathematical objects, the purport of the cognitive methods used in mathematics, the relations between consistency ad existence in mathematics, the meaning of the notion of mathematical truth, the relations between provability and truth, even the difference between human thinking and computer algorithmic functioning. These philosophical discussions have continued, around other topics, also when the impulse coming from the original "foundational schools" became exhausted, and philosophy of mathematics is a well-established sector of philosophy of science in its modern sense.

3 The Crisis of Classical Physics

In physics a foundational role similar to that of set-theory in mathematics had been attributed to mechanics, and a theoretical effort was displayed in the nineteenth century by several scientists in order to *reduce* to mechanics all the branches of physics, in the sense of showing that their fundamental concepts could be defined in terms of mechanical magnitudes, and their empirical laws could be deduced from mechanical laws and principles. The extreme difficulty (and finally the recognized incapability) of proposing correct mechanical interpretations and explanations of the second principle of thermodynamics, on the one hand, and of the electromagnetic field, on the other hand, already toward the end of that century started that "foundational crisis" in physics that was going to know its most dramatic manifestations at the beginning of the twentieth century with the birth of quantum mechanics and relativity theory. Without entering the (rather well-known) details of this crisis, we simply want to point out that the debates among scientists revealed from the start on a clear philosophical (especially epistemological) flavour: physical theories were considered as intellectual constructions intending to be "representations" of the material world but, while in the past they had been easily credited with this capacity, several doubts began to be advanced on this point, and certain authors, such as Mach, for instance, explicitly denied the cognitive purport of scientific theories giving them the simple role of "economically" useful schematizations for the organization of empirical data and for making some predictions. This anti-realist and instrumentalist conception of science was based on a clear *philosophical presupposition*, that is, *radical empiricism* that gives to the said crisis its more precise sense of the "crisis of

visualizability" of the physical objects, that emerges when these objects appear to be *unobservable* entities that we try to understand through *intuitive* models.

Not only sensitive intuition, however, was challenged by the advancements of physics. Also that which we could call intellectual intuition (i.e. the clarity not of the *images* but of the *concepts*) has been put in trouble by relativity and quantum physics. Let us simply mention the difficulty of coupling continuity and discontinuity in the interpretation of the microworld, the double representation as a particle and as a wave of one and the same microobject, the indeterminacy in the simultaneous attribution of values to conjugate magnitudes at the microlevel, the necessity of considering the mass and the spatial dimensions of a physical body not as its most inalterable intrinsic properties but as variables depending on its velocity, not to speak of the interdependence among two conceptually very distinct "entities" such as space and time and, finally, of the turn from a "deterministic" to a "probabilistic" conception of natural laws with the implicit reconsideration of the principle of causality.

These very well known facts have nourished in the first decades of the twentieth century ample and deep philosophical debates regarding physics in which not only the most prominent scientists of the time have participated, but also several philosophers with a sufficient knowledge of science. Debates that concerned themes of epistemology, ontology, metaphysics, philosophy of nature, methodology of science, and in which the most diverse philosophical positions have appeared. All this is a confirmation that a *philosophy of physics* has strongly developed out of the crisis of the foundations of physics and has powerfully contributed to the constitution of philosophy of science as a specialized branch of philosophy.

4 The Predominance of Logical Empiricism

The subsequent developments of this new branch of philosophy soon acquired a particular direction, due to the fact that philosophy of science became almost monopolized by logical empiricism and the philosophical trends inspired by this movement. The members of the Vienna (and Berlin) Circles had in common the consideration of science as the only genuine form of knowledge and shared with the old positivism a clear antimetaphysical programme reinforced by the adoption of a radical empiricism. In addition they had received the influence of the "linguistic turn" that had characterized a large part of philosophy at the beginning of the century and reduced philosophy to analysis of language. As a consequence of these factors, those scholars conceived philosophy of science as an analysis of the language of science and, in particular, as a *logical* analysis, logic being understood by them in its most recent sense of mathematical logic with the strictly formalistic interpretation bound to this discipline. Especially the systematic use of such techniques gave to the writings of those people the appearance of a very rigorous and "scientific" exercise and of a kind of philosophical "neutrality" that facilitated the confluence in this stream of many scholars coming from several different countries and cultural traditions. When many of the most prominent representatives of this school went to the United States as a consequence of the nazi racial persecutions, they encountered there a favourable milieu for the expansion of their cultural programme and philosophy of science

received that form of an "analytical philosophy of science" that has remained standard for several decades and has been practically considered as the only serious paradigm of this philosophy, to the extent that, after the end of the second world war, this model imposed itself also in Europe, where philosophy of science had found its cradle at the beginning of the century. A not negligible effect of this cultural phenomenon was the following: several important traditions in the philosophy of science that had developed outside the logical-empiricist and analytical line were thrown into the shade, up to the point that in the standard handbooks of philosophy of science (including those written by not English-speaking authors) one does not find the names not only of those great scientists who in the first decades of the twentieth century wrote not trivial things regarding philosophical problems of science, but also names such as those of Duhem, Poincaré, Meyerson, Bachelard, Gonseth, Dingler, Enriques, that is, of authors who explicitly wrote works of philosophy of science not limited to a logical–linguistic analysis of the discourse of science.

This philosophy of science, that we can call "analytical-empiricist" has produced an abundant harvest of publications and also a conspicuous amount of "results", among which the most significant are probably those obtained through a formal-logical analysis of certain metatheoretical properties regarding scientific theories (especially in the domain of mathematics, but also in that of the empirical sciences), such as the reducibility among theories, their mutual relations of consistency, the nature and power of the logical calculi most suitable for their formal treatment, the development of logical calculi for the formalization of the methodologies of empirical confirmation and so on. Less significant, however, seem to be several other results which, though being "correct", appear essentially as a proliferation of cases and subproblems more or less artificially extracted from more important publications, according to a practice common in the domain of the sciences and which corresponds rather well to what Kuhn calls the status of "normal science". Since we have mentioned Kuhn, we can add that, according to his view (that we share at least partially here) normal science is that which grows up as a development of a given *paradigm*. In our case we can say that the analytical-empiricist philosophy of science developed under the shelter of the already mentioned paradigm, whose salient features were: the reduction of the sciences to linguistic constructions, radical empiricism as an epistemological presupposition, use of the methods and results of formal logic and philosophy of language as tools for the philosophical analysis. Under this very general umbrella we can encompass several positions characterized by not insignificant differences, such as, for instance, the whole line of the Popperian philosophy of science.

5 The Crisis of the Analytical-Empiricist Philosophy of Science

Kuhn's book *The Structure of Scientific Revolutions* (1962) is usually considered the work that inaugurated the post-empiricist philosophy of science, and this is to a certain extent true. One cannot overlook, however, that the decline of the preceding paradigm had been produced by internal reasons. The tenet of radical empiricism (i.e., the refusal of a cognitive value of the intellectual intuition) had imposed to the philosophers of

science the task of logically "reducing" all *theoretical* components of the scientific language to an *observational* basis, but this enterprise (apart from its great technical difficulties) had been blocked by the doctrine of *semantic holism* defended by Quine, that maintained that all terms in science are "theory-laden" and in this sense theoretical. This thesis is typical of a *philosophy of language* that, wanting to skip the *intellectual nature* of *meaning*, had reduced it to the *linguistic context*, and was proving detrimental rather than useful for a satisfactory understanding of science. But also the "semantics" elaborated by *mathematical logic* proved equally inadequate. In fact such a semantics was also inspired by the desire of dispensing with the intellectual "meaning" and, therefore, proposed that the *meaning* of symbols be obtained by linking them (by means of an *interpretation*) with certain *referents* or sets of referents. This is the core of *model theory* which is a conspicuous part of mathematical logic. Precisely within this theory, however, it appeared that the methods proposed were unable to secure to any empirical theory its "intended model", that is, to justify the fact that it intends to speak about certain specific objects. In conclusion, all the fundamental components of the logical-analytic philosophy of science appeared inadequate for justifying the *cognitive purport* of science, and this was obviously frustrating for a philosophical school that has considered science as the most genuine and reliable form of knowledge.

But the most serious drawback was still another. The logical and methodological machinery elaborated within that paradigm—that showed serious flaws already regarding the correct understanding of the *static structure* of science—was absolutely inadequate for understanding the *dynamics* of science, that is, the transition from a theory to another one, the idea of scientific change and scientific progress, and this especially because the doctrine of the "theory-ladenness" of every scientific concept made impossible to adopt experiments as criteria for discriminating between rival theories. This explains the fortune and the cultural impact of Kuhn's book, that constituted a clear signal of a shifting of interest within philosophy of science from the study of the structure to the study of the dynamics of science, a shifting that, in particular, implied an overcoming of those investigations that, proposing themselves as a "logical reconstruction" of the cognitive structure of science in general, did in fact refer themselves to an extremely idealized and vague model that resembled more or less the presentation of classical physics that we find in schoolbooks. Instead of this vague model, the investigation of the dynamics of science must rely on the study of the concrete *history* of science, and see what are the real *conditions* that determine scientific change. In such a way a *sociological* approach to the understanding of science was emerging and was considered *at variance* with the logical and analytical approach. As a matter of fact, one could maintain that the two approaches can and should cooperate, once certain tenets of the "received view" are abandoned, but we cannot enter this discourse here.

6 The Sociological Turn

There is certainly no need to summarize here the well known view of science that Kuhn proposes as the outcome of a disenchanted consideration of its history. Scientific *knowledge* is no longer considered as the (possibly fallible) representation

of the status of the physical world, acquired by the scrupulous adhesion from the side of scientists to the fundamental criteria of faithfulness to *empirical evidence* and *logical consistency*. Scientists are rather faithful to a *paradigm*, consisting of a variegated combination of general worldviews, accepted principles, methodological rules, conceptual frameworks, received theories of different sorts. It is within this paradigm that they apply the usual criteria of empirical testing and logical construction in what he calls "normal science", trying to solve the "puzzles" that can emerge from the empirical investigation. When difficulties along this practice appear too frequent and insurmountable, the paradigm enters a status of crisis and can be abandoned if a new paradigm emerges whose initial force may be offered by the capability of solving the most serious insoluble anomalies of the old paradigm, but whose acceptance is a global phenomenon concerning the whole of the scientific community working in a given domain, according to a psycho-sociological process very similar to the ideological or religious conversions, and almost entirely indifferent to empirical and logical constraints. This conception made scientific knowledge entirely dependent on the *contingent* micro-social context of the scientific communities, almost totally downplaying the criteria for securing a minimal degree of *objectivity* to such a knowledge. As a consequence, scientific theories became *incommensurable* and *incomparable*, and the very notion of scientific progress vanished. Even more, no objective criteria could be defended in order to distinguish science from non-science, to estimate astronomy better than astrology, scientifically based medicine better than witchcraft (as Paul Feyerabend maintained[4]).

It is rather obvious that this turn in philosophy of science has greatly contributed to that disinterest with regard to this discipline that we can ascertain today among working scientists, at variance with the rather generalized interest they had at the time of logical-empiricist philosophy of science which, in spite of its limitations, had the merit of taking science seriously and trying to account for its cognitive endeavours.

Even more radical became these characteristics with the transition from the micro-sociological approach of Kuhn (in which the *epistemic conditions* of science were made dependent on the scientific community) to a fully fledged *sociological view of science* that rapidly developed shortly afterwards, according to which science is a "social product" in a literal sense, that is, an activity that is totally conditioned by the dynamics of power that steers society, and produces those contents of knowledge and those applications that are requested by the different powers, independently on any criterion of objective value. This sociologic trend has met with a considerable success in the English-speaking world, where it had been prepared by the academic prestige acquired by sociology of knowledge, but it also had significant resonances in the new-Marxist doctrines (such as those of the Frankfurt school) that maintained the strict dependence of science from the social structure in which it takes place, For all the said reasons this sociological epistemology of science has contributed in a considerable measure to the shaping of that attitude of

[4] See Feyerabend (1975).

"anti-science" that was already spreading as a consequence of certain dynamics of a different nature.

7 From Science to Technoscience

The sociological turn, both in its Kuhnian initial stage and in its subsequent more radical formulations, can be considered, at least in a certain sense, as the outcome of a "crisis" of the traditional concept of science, a crisis that has ripened slowly and which can be characterized as an overcoming of the purely *speculative* nature of science in favour of a more integrated *speculative-pragmatic* view of it. This transition was already more than implicit in the "Galilean revolution" that is usually considered as the most crucial moment of the birth of modern natural science. Galileo's natural science is indeed explicitly grounded on *instrumental* observation and manipulation of the physical world, and depends in a substantial measure on the technologically accurate realization of instruments. This characteristic has remained fundamental in the whole tradition of modern natural science: scientific *knowledge* strictly depends on a specific and highly sophisticated *doing*, and the actual *objects* of scientific inquiry are those aspects of nature that can be "clipped out" by means of suitable *operational* procedures. Therefore not only it is true, obvious and well known that modern technology is to a large extent "applied science", but it is also no less true that modern science heavily depends on the advancements of high technology. This interrelation could be seen somehow as a "mutual aid" for a couple of centuries, but it appeared as a real *symbiosis* when natural science became (as we have already noted) almost entirely a science of the *unobservable*. As a matter of fact these unobservables were such only with regard to the unaided human sense organs, but a lot of "unobservable" objects could be "observed" in a different (and scientifically more exact) sense thanks to several instrumental apparatuses. For this reason it is correct to qualify contemporary science as *technoscience*, according to a neologism that has been introduced for different reasons a few decades ago, but that corresponds very well to the specific nature of contemporary science. We shall consider later certain important consequences of this pragmatic dimension of technoscience, and shall pay attention now to another aspect.

A peculiar feature of contemporary science (which was prepared by the developments of nineteenth-century science) consists in the fact that its *immediate* object is no longer Nature, but the thick layer of mediations science itself has little by little set up through the construction of models and the elaboration of complex theories, with the assistance of ever more refined and "artificial" technologies. If ancient science considered itself inspired by the ideal of *observation*, and modern science by the ideal of *discovery*, present-day science is rightly presented as *research.* It is, in other words, an *activity* grafted onto what science has already constructed, not as a surely held patrimony, but as an ensemble of constructions that can be revised, criticized, or abandoned. Science feeds on science itself; it corrects itself. In the exchange between one branch and another it discovers instruments, suggestions, and models for advancing, or for radically altering its perspective. New problems arise from the solutions to old ones, and their solutions in turn can come from unexpected

sources, provided even by disciplines considered distant. The scientist who is initiated into his research is not "put in contact with Nature," but is placed in a branch which then becomes his *field of research.* In other words, science no longer feels the pull to go outside of itself to continue to thrive and develop. Even the problems of its "foundation" are increasingly approached and treated from within itself. It is occupied with changes in its own concepts, the definition of their extension, and the creation of new concepts, heedless of the scandals to common sense and the perplexity of philosophers. All this amounts to recognizing that contemporary science has set itself up as an *autonomous system*, in that it fashions its field of objects by itself. While we have just spoken about natural science, a wholly analogous account could be given with regard to the human sciences.

The above remarks open up easy suggestions in favour of an anti-realist conception of science, but we are not going to discuss this problem here. We want rather to point out that science, especially as far as it is considered as technoscience, appears the product of a specific *activity*, namely the complex, articulated collective activity of the *scientific community.* We can continue to call this "product" *knowledge*, provided that we are not too much interested in specifying "of what" this is knowledge: yes, in the last analysis and indirectly this is, for example, "knowledge of Nature", but Nature in turn appears more and more the many-faceted "referent" of the scientific discourse. Therefore, the *cognitive* dependence of science on the scientific community is not just a provocative invention of Kuhn (possibly anticipated by other less famous authors) but is a matter of fact that cannot be reduced to the abstractly idealized work of people sticking to a compatibility between empirical evidence and logical consistency. The *acceptance* of scientific statements and theories within a scientific community depends on a variety of intellectual, cultural, technological factors that justify a considerable part of the Kuhnian "micro-sociological" epistemology of science. Only in part, however, because the fact that technoscience is an "autonomous" system does not entail that it is a "closed" system; in particular, it is open toward some "external world" that it tries to know and to modify (science is not *selfreferential*). This remark allows one not to derive from the Kuhnian view a position of *total relativism* regarding scientific knowledge. The mention of the "external world", however, cannot be restricted to the consideration of nature, but must also include, in particular, the *social context* that is "external" to the scientific community, but entertains with this community a dense web of interplays. In such a way we are led to expand the micro-sociological perspective of Kuhn to the macro-sociological perspective of the so-called "social philosophy of science".

8 From the Social Community to the Global Society

Kuhn's position can be seen, in a certain sense, as a restriction to the domain of the scientific community of the general perspective of sociology of knowledge, according to which the intellectual categories, the cognitive frameworks and the tools of human knowledge are not something inborn and universal, inscribed in something like the "human nature" or the "human mind", but are featured by the social context of every particular culture. Kuhn maintains that also in the case of science we

cannot believe in the existence of a unique and universal model of what is science, but that the very conception of scientific knowledge and of the ways of attaining it are featured in the form of changing paradigms by the historically variable scientific communities. The importance of this step resides in the fact that it eliminated an exception still existing in the original perspective of sociology of knowledge proposed by Karl Mannheim. He had asserted that historical and social environment determines both the content and forms of our knowledge, but had admitted an exception to this epistemological rule and said that mathematics and the natural sciences are exempt from what he calls "existential determination". It is clear that this exception was suggested by the deep conviction that science constitutes a form of *objective* knowledge and, as such, independent on personal and collective idiosyncrasies, but Kuhn had precisely eroded this conviction. A kind of rebound occurred quickly and consisted in a "dilatation" of the micro-sociological view of Kuhn to the macro-sociological perspective of those authors who maintained that scientific knowledge is a *social product* not just of a delimited collectivity, but of society in general.

The consequences of maintaining far too great a dependence of science on the social context soon emerged in the debate over epistemologies: radical relativism, antirealism, the disappearance of the notion of truth and even of scientific objectivity, the dissolution of the criteria capable of justifying the preference not only of one scientific theory over another, but also of scientific forms of knowledge over those of pseudo-sciences. These theses, which may seem paradoxical in the openly iconoclastic and provocative writings of a Feyerabend, have received systematic treatment since the 1960s, and make up a solid block of a well known metascientific literature. Of course, there is no reason to give this a negative cast, but certain implications must be taken into account. It is certainly a positive thing in itself to introduce historical and social consciousness into the understanding of science. It is also useful to submit the scientific enterprise to sociological study: the information gained thereby is always interesting and illuminating. It is something completely different, however, to claim to *reduce* scientific knowledge to *nothing but* a social product. Herein lies the mistake of a good portion of sociological epistemology, a mistake that can be seen as a consequence of not having *distinguished* (though without separating) the cognitive dimension of science from other not strictly cognitive ones; in such a way certain negative facts (pertaining mostly to the domain of technology), that have rightly contributed to reshuffle the "received" overoptimistic view of technoscience have produced a generalized negative appreciation of the whole of technoscience, including also its strictly cognitive dimension.

9 The Crisis of Confidence in Technoscience

A wide display of fears, criticisms, and reflections of ethical and social nature have begun to attack technology and, indirectly, science after the end of the second world war. The start was given by the psychological impact produced on public opinion and also on several scientists by the explosion of the first atomic bomb, followed by the fears of a nuclear war that could be the outcome of the arms race opposing the two super-powers, soon expanded into the fears regarding possible disasters

accidentally produced by the peaceful use of nuclear energy, and from there to the concerns regarding the contamination of the environment deriving from the acceleration of the industrial development. All these are very well known facts that need no additional explanation. They were accompanied by a deep change in the global evaluation of science. Whereas, in the Western tradition, science had been almost always considered as intrinsically positive and as an essential factor of the progress of humankind, it begun to be considered with suspicion and rather seen as a negative element susceptible of threatening the very survival of humankind.. It is certainly possible to point out that the really occurred damages and the hypothetical dangers derived from certain *technological* realizations and not from *scientific* knowledge. However, owing to the already stressed unity of *techno-science* it is undeniable that it is at most possible to *distinguish* conceptually science from technology, but not to *separate* them and, in the common perception, they are easily identified. Therefore, the negative judgment on technology (expressed in general in the name of ethical or social values) has been extended also to science, impairing that which had previously appeared as a fundamental principle of Western culture, that is, the *axiological neutrality* of science, that was considered the strong point of its *objectivity*. A rather confusing superposition of such factors of mistrust in the *practical usefulness* of science, on the one hand, with the mistrust in its *cognitive reliability* on the other hand, have led to a widespread attitude of hostility against science and technology that makes an appeal to philosophy of science for a necessary clarification. Once more, we are confronted with a *crisis*, that now is primarily a *crisis of confidence* in science, but whose solution seems to reside in a new way of conceiving philosophy of science itself.

10 Beyond Epistemology of Science

We have already explained that science has always meant, within Western culture, the most perfect form of *knowledge* and that, at a certain historical moment, natural science was considered to have realized the best model of science so that, especially with Kant, the study of the cognitive structure of that model was practically playing the role of a general theory of knowledge, or epistemology. In order to deserve such a privileged status, the "exact sciences" had developed during the nineteenth century that complex quest for rigor and foundation that can be qualified as an "internal" epistemological enterprise but this, as we have seen, ended up with a very serious situation of foundational *crisis*. Philosophy of science in its modern disciplinary sense was born then in order to come to term with this crisis and, for this reason, was almost entirely concerned with epistemological issues, it was in practice an *epistemology of science*. The different schools and trends that have been present within philosophy of science were only the expression of different approaches to this epistemological problem, repeating in this case the variety of positions that has been usual along the whole history of general epistemology: the problems were the same, but the philosophical presuppositions and the methodological tools adopted could be very different and produced accordingly different interpretations of the *cognitive purport* of science. This remains true also in the case of the Kuhnian epistemology

of science and even in the case of the social epistemology of science whose most explicit goal was that of pulling down that idealized portrayal of science that pretended it to be the most solid actualization of *knowledge.* But precisely this was the weakest point of such philosophy of science. Certainly, one cannot minimize the pertinence of many remarks that sociology of knowledge in general and sociology of science in particular have put forth regarding certain conditionings of human knowledge deriving from the social context; neveretheless one cannot deny at the same time that the generalizations and amplifications defended by this school are far from convincing and are not able to impair the substantial objectivity and reliability of scientific knowledge.

The sociological approach, however, while did not produce a sound epistemology of science, has its strong points elsewhere and, perhaps, on issues that it has overlooked. We want to refer to those multifaceted dimensions of science that become patent as soon as we consider science also as a *human activity*, an activity that has the acquisition of sound knowledge as its primary and *specific* goal but that, at the same time, is involved in that web of different factors and conditionings that surround every human activity. This, as we have already stressed, is particularly clear if we recognize that contemporary science is actually technoscience and, especially, if we are aware that the great majority (if not the totality) of those problematic situations that have fueled the criticisms of anti-science or inspired the destructive reasoning of a certain social philosophy of science have to do with technoscientific *activity* and not with scientific *knowledge*. But if this is the situation, and if we recognize that the present crisis of the public image of science fundamentally depends on this kind of issues, we must conclude that a philosophy of science capable to correspond to its role must cross the limits of an *epistemology of science* and develop a serious reflection on those dimensions of science that are implicit in its being also a human activity: epistemology of science keeps its legitimacy intact, but it must be incorporated into a philosophical approach that takes much more into account.

The awareness of this fact has not been an easy process and has entailed a real change of paradigm in the way of conceiving philosophy of science, This was especially visible when discussions of ethical, political and social nature regarding science and technology started to become frequent and popular (let us say, at the end of the 1970's). On the one hand, many professional philosophers of science continued to think that this should limit itself to develop those logical–linguistic and methodological analyses that had characterized the empiricist-analytical approach, and considered a lack of "seriousness" the fact of accepting that philosophy of science should give room to such vague considerations and sterile discussions as those of ethical or social nature. At best, they could be the concern of other branches of philosophy. In this attitude, on the other hand, they found themselves in agreement with a certain number of university teachers of ethics, political and social philosophy, who wanted to keep for themselves the treatment of such questions and considered almost as an intrusion in their own domain if a professor of philosophy of science lectured on ethics of science. These were not just manifestations of academic jealousy, but rather the consequence of a *crisis* of science that pulled a rethinking of philosophy of science. As we have said, this crisis consisted in the emergence of the conception that science is not, essentially, a cognitive enterprise: the inextricable

interlacing of science with technology, the thick web of relations of technology with industrial production, the considerable social impacts of this production, and the political and ethical consequences that all this entails represented such a complex situation that necessarily had to reflect itself on science, so that continuing to consider it as a system of "knowledge" appeared at least too partial, if not even misleading. Since making a philosophy of something means essentially to *think* it, to understand it by means of thought, it easily follows that, to the extent that the complex nature of science in the present world has become patent, also philosophy of science must concentrate its reflection on the nature and consequences of this complexity.

11 Some New Features of Philosophy of Science

This means, first, that philosophy of science must become strictly allied with a philosophy of technology, and bring to light those feedback loops that exist between scientific knowledge and technological realizations. It could also not ignore or overlook the impacts and conditionings that "doing science" implies today with regard to the social and political context, and also investigate the ethical, anthropological and cultural issues that emerge from the new situations produced by the increasing of scientific knowledge and of technological development. We could summarize these last issues by saying that an *axiology of science* is emerging as an important and serious aspect of philosophy of science, and this terminology makes reference in a very general way to the wide spectrum of *values* that are implied in making science, that is, not simply the typical moral, social and political values, but the rich display of goals and ends that inspire human actions and are considered "worthy" of being pursued. This approach conflicts, at a first sight, with the well known maxim that science must be *value-free*, but this is not really the case, if one considers the issue more closely. First of all, one must at least recognize that science, even according to its traditional conception, was considered as a search for *truth* and this was the *specific value* that ought to characterize scientific activity. In order to pursue this goal, certain criteria have been elaborated by the traditional epistemology of science, such as empirical adequacy and logical rigor but, when it appeared that in several cases they were insufficient for discriminating between rival theories, other criteria were pointed out, such as simplicity, elegance, causal connection, fruitfulness in prediction, and these were also recognized as "values", so that many scholars believed to have already manifested a sufficient open-mindedness toward the presence of values in science by recognizing the role of such values. This alleged open-mindedness, however, was very limited because one could call these *epistemic or cognitive values*, remaining inside the approach that reduces science to cognition and, in such a way, continuing to subscribe to the real meaning of the thesis that science must be value-free, which means that science must remain unaffected by non-cognitive values of whatever sort. This thesis has also been expressed on various occasions as the affirmation of the *neutrality of science,* and has a hardly deniable sense, if it is understood as the affirmation that the *truth-value* or *cognitive validity* of a scientific statement or theory must be "judged" or evaluated only according to criteria depending on strictly cognitive values. But as soon as we consider scientific *activity*,

and that of technoscience in particular, we must recognize that its ways of being performed, its conditions, motivations, consequences are relevant to many aspects of human life that are oriented by a lot of non-cognitive values, and that it is correct, therefore, to submit the technoscientific *doing* and its concrete products and consequences to *value-judgments* of many kinds, from which indications regarding the best way of "doing science" should result. The delicate point is that of assuring the respect of the cognitive autonomy of technoscience and at the same time its capability of satisfying other non-cognitive values. A suitable solution consists in the adoption of a systems-theoretic approach on which, however, we cannot enter here.[5]

In order for all this to remain a task of philosophy of science it is necessary that this admits a broadening of the categories and instruments it makes use of:: for the understanding of that complex reality that is present technoscience, it is necessary to make use of all the instruments available in philosophy, not only of those of epistemology, formal logic and philosophy of language, but also, in particular, of those of ethics, social and political philosophy, axiology.

12 Safeguarding the Cognitive Value of Science Within a Responsible Performance of the Technoscientific Enterprise

The proposals outlined above could meet with a certain diffidence by several people who might see in them a concession made to the sociological trends of the "new philosophy of science" whose effect (if not even the explicit proposal) has been that of discrediting the traditional image of science as objective knowledge, of absorbing science as well into the stream of the present widespread cultural relativism, of portraying the endeavor of science to look for truth (though a partial and fallible truth) as a kind of hypocrisy aiming at masking the actual situation of scientific research as a servant of the interests of the economic and political powers. These negative effects are undeniable but, as we have already noted, depend to a great extent on the fact that these new tendencies have had the pretension of moving on the stage of *epistemology*, that is, with the intention of breaking the myth of the objectivity of scientific knowledge. But this was, as we have tried to explain, a deplorable equivocation, deplorable because it spoiled precisely the most significant gain implicit in those new approaches, namely the awareness that science is a complex reality that does not *reduce* itself to the only cognitive dimension. For, while on the one hand it can be considered as a great *system of knowledge*, it constitutes on the other hand an intricate *system of activities* that, as such, interacts with all the material, institutional, ideological, ethical, social, religious factors that move and influence the life of society. Instead of taking advantage of this awareness for enriching the understanding of science, too many authors have believed that they were of a direct epistemological character, that they conflicted with the cognitive pretensions of science and were able, in the end, to refute them.

On the contrary we need to recover the sense of the *complexity* of science that, when it is considered as *knowledge*, constitutes one of the highest products of human

[5] See Agazzi (1987) for details.

civilization and can be the object of several philosophical investigations. The task of a philosophy of science adequate to this new situation of crisis is precisely that of maintaining and justifying the consideration of science as an objective and rigorous knowledge (though fallible and limited as far as its purport and its research instruments are concerned), capable of making us know more and more aspects of the various realities that surround us; and this without offering us that *absolute certainty* that is out of reach of humans in every domain, but providing us with certainties that stand "beyond any reasonable doubt". In order to realize this task the traditional analyses of a logical–linguistic kind are still useful, provided that they are not vitiated by prejudices of radical empiricism and remain open to recognize the cognitive capabilities also of the intellect; provided that they are not afraid to use the concept of truth and to admit the ontological purport of knowledge. This correct conception of science as *knowledge* must then be able to become *compatible* with all the legitimate considerations that emerge from the ascertainment of the conditions and conditionings that come to the scientific *activity* from the largely understood social context, and this because the *value* "knowledge" typically pursued by science is not the only one, and perhaps not even the supreme, that inspires human activity. Therefore, the problem is that of satisfying in the best possible measure the different values at play, without obliging science to renounce its specific end of providing us with objective, rigorous and partially"true" knowledge. And this is compatible with the fact of requiring that science cooperates to the promotion of many "non-cognitive" values that steer the march of civilization; moreover, technoscience should try to offer means for the most efficacious realizations of such values. In this consists that *responsibility of science* that can no longer be considered a subject matter alien to philosophy of science and to be left to ethicists, but that requires the convergence of a many-sided reflection in which, in particular, philosophy of science make use of categories and principles found in ethics and political philosophy, but tailored to those situations that only through a scientific investigation can be adequately known.

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