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REGULARITIES IN THE EVOLUTION OF PARTICULAR SCIENCES

Reflections on the subject of regularities in the evolution of science are made either in reference to one selected scientific discipline, or—more often—to science as a whole, where this "science as a whole" usually represents model disciplines, constructed on the basis of one of the exact sciences: physics, chemistry, astronomy, and more rarely—biology and earth sciences. Such an approach eliminates problems of complexity and the internal differentiation of sciences as well as the connections and influences between disciplines. In searching for more general models of the development of science, one must nevertheless have knowledge of the changes occurring in particular scientific disciplines and in their groups as an effect of such influences.

I

The basic category characterizing the changeability of scientific disciplines is the concept of development factors, i.e. phenomena and events influencing the formulation and substantiation of new scientific assertions with the full or partial elimination of old ones. Development factors can be divided into internal, or cognitive, and external, or social. We take it for granted that internal factors are theoretical and empirical premises determining the meaning of successive assertions; in investigations of the history of science they appear as the logical stimulating or blocking of later assertions by earlier ones as well as the destruction or absorption of earlier assertions by later ones. External factors, on the other hand, are those aspects of reasoning and selection of theory (together with unconscious processes) which reflect the social situation of the scientist. The external factors as a whole are characterized by the culture within which given investigations are conducted.

One can presume that particular disciplines differ from each other according to their greater or lesser susceptibility to internal and external development factors. The stronger the influence of some factors, or rather—the greater their contribution to changes in science, the weaker is the contribution of the other factors and *vice versa.*

Classifying the existing, historically distinct scientific disciplines according to the degree of their dependence on both kinds of development factors, we obtain a continuum (succession), beginning with mathematics and formal logic as disciplines most strongly dependent on internal factors and going to the other extreme of the historical sciences which are most strongly influenced by external factors.[1] However, it is impossible for the development of any scientific discipline whatsoever to be dependent exclusively on factors of one kind. For example, the evolution of mathematics is influenced in a certain way also by important external factors such as philosophical trends on the one hand and the needs of the natural sciences, and even practice, on the other. Likewise the meaning of historical explanations depends not only on the cultural tradition and political circumstances in which the historian works, but also, *inter alia,* on his study of the ideas professed by earlier historians and on utilization of the methodology of other sciences.

On this continuum logic is followed by other deductive sciences (in the broad sense), *inter alia,* systems theory and cybernetics. The next place is occupied by theoretical physics, and after it come the other natural sciences more and more dependent on external factors. Investigations within these sciences are influenced more or less strongly not only by the needs of practice, but also by disputes on world views in which the scientist is entangled as well as by the so far little understood psychological and aesthetic preferences. (These sciences also develop in the course of providing answers to questions formulated on the basis of successive sciences in the continuum and practice.) Moving further in direction of the historical end, we find sciences even more than the natural ones dependent on external factors: agricultural, medical, and technological, connected with respective spheres of practical knowledge through assertions formulated on the subject of practice. These sciences are especially dependent on social conditions in which they are cultivated. Such dependence is greatest in the social sciences, however.

Classification of sciences according to their susceptibility to internal and external development factors overlaps with their classification according to a few other aspects.

The first of these criteria is the degree of changeability of the subject of research. One could briefly say that mathematics has no subject, but only methods, or more precisely—its subject is created almost exclusively through the process of investigation. Hence this subject does not exist autonomously and shows no changeability other than the changebility of its points of view in historically successive assertions. One can observe, however, that the changing

[1] See: H. Hollender, "On the Place of Science History in Historical Syntheses", *Organon,* Warszawa, No. 11, 1975, pp. 97—106.

subject of other sciences may suggest new formulations of the assertions of mathematics; this also concerns the other deductive sciences.

On the other hand, at the opposite end of the continuum, in the sciences describing quickly changing social reality without attempts to add theoretical assertions, there appears—metaphorically speaking—the annihilation of method in favor of the subject, for—leaving aside the great variety of research techniques used—the only general and fundamental method is to reconstruct the subject as faithfully as possible. In this sense, such parascientific fields of knowledge as historical narration or ethnographic description do not have autonomus research methods that could exist independently of the subject.

The natural sciences deal with investigation of an objective and changing reality. This ontological status, however, remains in suspension, as it were, owing to giving reality the form of theoretical beings, whereas changeability was and is of little or no importance to successive generations of scientists. However, this changeability can become—e.g. in social sciences cosmogony or the theory of biological evolution—the main subject of investigation. The case is different with the medical, agricultural, and especially the technological sciences, where the subject of investigations is a creation of society and changes together with it. The social sciences describe an even more rapidly changing reality, though some of them are somewhat removed from the historical end of the continuum, for they describe phenomena that change so slowly they can be regarded as constant factors of culture. Assuming the stability of these phenomena is connected to a large extent with the application of theoretical models; an example can be such disciplines as anthropology and some branches of linguistics.

The place of a given science in the continuum also determines the attitude toward the concepts of past and future. In mathematics such concepts are superfluous. In the physical sciences—as N. Kuznetzova[2] notes—there exists the concept of the flow of time, i.e. earlier and later stages of events, but there is no concept of the past, for it is more or less tacitly assumed that the laws of these sciences are unchangeable and hence that phenomena studied in the laboratory can be repeated an arbitrary number of times (leaving aside thermodynamics, which from the point of view developed here must be excluded from the physical sciences). In this sense, their subject is always the present. This does not apply to the other natural sciences, however, and especially not to the earth sciences and—since the middle of the 19th century—to the biological sciences. In ecology and to an even greater extent in the technological, agricultural, and medical sciences we have to do with irreversible social time, though even in some social sciences the restoration of quasi-presentness is sometimes possible

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[2] See: N. I. Kuznetzova, *Nauka v ee istorii. Metodologitcheskiye problemy* (*Science in its History. The Problems of Methodology*), Moskva 1982, p. 26; see also the review of this important book by E. Olszewski in *Science of Science*, Warszawa, No. 1 (13), 1984, pp. 125—129.

through experiments. On the other hand, history and ethnography on the extreme end of the continuum are not interested in the present but exclusively—though each in a different way—in the past.

A similar classification of the sciences is obtained by investigating the degree of abstractness of the assertions formulated in them. Besides mathematics and the other deductive sciences, the most abstract are physical laws. As we move toward the social end of the continuum, however, we observe a gradual trend toward autonomy of empirical data which can be the subject of investigation with less and less use of abstraction; there is hardly any at all in the historical sciences.

The position of particular sciences in the continuum also determines the range of correspondence between diachronically successive assertions. In mathematics and logic successive assertions as elements of a system aiming to take the form of a deductive system (with the limitations discovered by K. Gödel) are connected by almost complete correspondence. In physics this is made impossible by the empirical content of theory. To an even greater extent this applies to the other natural sciences in which new theories sometimes do not refer to old ones either in the concepts they use or even in the section of reality that is selected to be studied. On the borderline between the natural and agricultural sciences is ecology, which studies natural phenomena from the standpoint of their dependence on human behavior. Reconstruction of successive phases of the development of sciences of this type and also the agricultural, medical, and technological sciences is impossible without referring to the successive diachronic phases of these behaviors.

The social sciences have poorly distinguished sequences of development; newer theories to only a very small degree can be described as transformations or negations of earlier ones. On the other hand, they unquestionably correspond synchronically with non-scientific knowledge, i.e. practical and common. The continuity of the diachronic emergence of assertions is relatively most difficult to reconstruct in descriptive history, for the researcher encounters earlier assertions together with the social context in which they were formulated.

The continuum of the sciences is not strictly linear, for its criteria do not travel a completely isomorphic route. Thus some disciplines can be closer to the mathematical end in one respect and further away in another. For example, some branches of biology do not compare in abstractness with theoretical linguistics, though in turn linguistics to a greater extent considers the concept of the past. So a precise location of individual disciplines in their continuum would sometimes require separation of research trends existing within one science. The graphic model of the continuum as a system of the sciences, their relations between themselves, their place in culture, and their susceptibility to change would thus have to consider the appearance of parallel processes and branchings-off.

II

From the standpoint of science as a whole, relations between particular disciplines belong to the internal development factors, whereas from the standpoint of particular disciplines—they are an external factor. Till now the functioning of these relations has been investigated haphazardly and sporadically, though it seems that these relations play a very important role in the development of individual disciplines as well as of science as a whole. So reflections on the diachronic correspondences of successive theories of a model scientific discipline ought to be supplemented with investigations on quasi--synchronic correspondences between various disciplines.

The basic types of such correspondence can be described by a combination: asking or answering (borrowing or lending) either about methods or the substantive content. Lending methodology takes place most often in the direction from the mathematical-logical end of the continuum of disciplines to its historical end, while answers to substantive questions are given in the same direction by physics and all the successive sciences up to and including the historical sciences. Hence the disciplines close to the historical end of the continuum develop by answering questions posed from outside of science by social practice, and simultaneously use methodologies from the opposite end and answers to substantive questions given them by the natural sciences (the social sciences correspond only with the biological, medical, agricultural, and technological sciences). On the other hand, sciences at the mathematical end of the continuum develop mainly on the basis of their internal factors, but simultaneously are subject to stimulation from methodological questions given by all the other sciences.

Physics plays a specific role in synchronic correspondence. This was pointed out a quarter of a century ago by Pantin.[3] He noticed that, thanks to their abstractness, the physical sciences (physics and chemistry) can create simplified and simultaneously general models of reality by using methods taken from the deductive sciences. Such sciences as geology and biology cannot do without models of this kind in explaining the phenomena which they study. Since these sciences have to transcend their boundaries, Pantin called them "unrestricted" in distinction from "restricted" ones, i.e. physical sciences. Here it is worth noting that the boundary fixed by Pantin between the above groups of sciences more or less corresponds to the boundary fixed by Kuznetzova between groups of sciences which can be called "synchronic" (i.e. mathematics and the physical sciences) and "diachronic", i.e. using the concepts of past and present.

Physics consists of many research trends which were not connected by great syntheses until the 20th century. A few centuries ago, however, they were

[3] See: C. F. A. Pantin, *The Relations Between the Sciences*, Cambridge 1968.

separate disciplines which by no means always corresponded with each other. For example, mathematics and geometrical optics of the 16th—18th centuries could have been included among the theoretical sciences. By adding mathematics and astronomy of those centuries, T. S. Kuhn created a group of "classical sciences" dating back to antiquity and developing on the basis of its tradition.[4] Parallel to these sciences developed the experimental, "Baconian" sciences, among which Kuhn included chemistry and the sciences of heat, magnetism, and electricity. The sciences of each group were strongly connected by intragroup ties: for the first group this was, *inter alia*, mathematical methodology and since the middle of the 17th century—also mechanistic one, while for the "Baconian" group—the methodology of experiments and basing theory of the concept of fluid. On the other hand, to the end of the 18th century, intragroup correspondence was very weak, so the "Baconian" sciences did not begin to accept the methodology used in the "classical" sciences until the end of that century.

III

When a scientific revolution takes place in one of the sciences corresponding with others, the spreading of this revolution can take place. Many disciplines can be infected by it, so that a local revolution, i.e. limited to one discipline, can even cause a global revolution, gradually encompassing a substantial majority of the sciences.

We should make two qualifications here, however. First, the deductive sciences are so little susceptible to outside influences that they are, so to say, immunized from influences of revolutions in other sciences, though within them one can also observe such crucial changes as unification of the foundations of mathematics and the foundations of logic in one discipline (metamathematics). Second, the social sciences are so closely tied with rapidly changing subjects of their investigations that the radical changes of these sciences are more the result of revolutionary social changes than a result of the influence of local or global scientific revolutions. So in speaking about global revolutions one should remember that they fully encompass only the natural sciences and partly the agricultural, medical, and technological sciences.

So with these reservations, we must accept the thesis of S. Amsterdamski[5] that the beginning of changes leading to a global scientific revolution must be sought in one of those disciplines which perform the functions of a basic science, i.e. one which corresponds quasi-synchronically with a large number of

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[4] See: T. S. Kuhn, "Mathematical vs. Experimental Traditions in the Development of Physical Science", in: *The Essential Tension. Selectioned Studies in Scientific Tradition and Change*, Chicago 1977.

[5] See: S. Amsterdamski, *Between Experience and Metaphysic. Philosophical Problems of the Evolution of Science*, Dordrecht 1975. The Polish original text was published in 1973.

other disciplines, exporting the revolution taking place in it. Hence whereas the generation of revolutions takes place here under the influence of internal factors for the most part, in other sciences it is stimulated under the influence or at least with the contribution of a factor external to that discipline.

Amsterdamski has noted that in the post-Newtonian era, the basic role was played by mechanics, which is a part of physics, and now this role is played by physics; however, he was not interested in a more general problem: which sciences can become basic ones. From Pantin's arguments, however, it follows that various natural sciences direct questions first and foremost to the "restricted" sciences, and so these sciences correspond with all of the other sciences of nature. Since chemistry makes use of physical concepts, however, it must be recognized as a less "restricted" science than physics; thus physics has special predispositions to play the role of a basic science.

Within the sphere of the natural sciences, conclusions partially similar to Amsterdamski's were reached by B. M. Kedrov, who presented the broadest outline so far of the various problems connected with scientific revolutions.[6]

According to Kedrov, the seeds of global revolutions appear in the "leading fields of the natural sciences" (i.e. in the basic sciences) which, being ahead of the other sciences, supply them with concepts, criteria, and general ideas, that is they spread their local revolutions. Besides this, Kedrov distinguished another kind of revolutions of a global nature: they do not formulate new theories but only sum up the related results obtained in some sciences, as it were importing them either to one of these sciences or to physics and transforming them into a new "vision of the world as a whole", that is starting a global revolution. An example is the Darwinian revolution which took place in biology, but introduced principles of historicism (the concept of the past) and determinism also to other natural sciences, adding up in this way revolutions that had preceded it in different areas of the natural sciences.

Kedrov sketches the system of scientific revolutions which appeared in modern science on these bases and distinguishes four types of local revolutions:

The first type, Copernican, was characterized by a rejection of the common sense belief that what is real is only what is visible. The second type, Kantian, led to the fall of the belief in the unchangeability of the world and the independence of its elements: it is these revolutions that were summed up by the Darwinian revolution. Revolutions of the third type led to the overthrow of the "mechanistic conception of the complete qualitative identity of the macro- and microworlds". The fourth type of scientific revolutions are connected with technological ones and make up the contemporary scientific-technological revolution.

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[6] B. M. Kedrov, "O revolutsyonnym puti razvitya yestestvoznaniya (k diskusiyi po povodu nautchnykh revolutsyi)." ("The Revolutionary Road of Development of the Natural Sciences. A Discussion on the Causes of Scientific Revolutions"), *Voprosy Istoriyi Yestyestvoznaniya i Tekhniki*, Moskva, No. 3, 1980, pp. 61—70.

Despite certain shortcomings, Kedrov's conception is an important step in the direction of a systemic approach to the problems of scientific revolutions, an approach which could become a very important element in the studies on the development of science.