Styles of Thinking and Historiography of Science

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Summary

The historiography of science is introduced in the context of the history of intellectual culture, social habits and dispositions, and physical and biological ecology. The subject is treated as a kind of comparative intellectual anthropology, the study of human behaviour in situations of habit or decision. This provides the historiographical context for the historical discussion of styles of scientific thinking as an integral part of cultural identity.

Styles of scientific thinking in Western intellectual history have been dominated and progressively diversified by the interaction of philosophical programmes, embodying antecedent conceptions of nature and of science, with the success or failure of their scientific realization in widening varieties of subject-matter. Scientific experience made explicit the organization of scientific inquiry historically round a series of overlapping types of scientific method and explanation, with characteristic modes of self-correction and criteria of acceptability. These types of science have been differentiated, out of the rational programme initiated by the Greeks, by the demands imposed by diverse subjectmatters; the conceptions of nature presupposing what was there to be discovered and so guiding inquiry and supplying its ultimate irreducible explanatory principles; the consequential procedures of research, including the crucial point at which experiment came into a scientific argument; and the theories of scientific demonstration distinguishing kinds of causal and non-causal relations and governing what to accept as having been discovered.

I. *Somes General Questions in the History of Science*

(1) *Its peculiarities within historical studies*

Plato's Pythagorean friend the mathematician Archytas of Tarentum commented on their inmediate predecessors and contemporaries in the 4th century B. C.:

Mathematicians seem to me to have an excellent discernment, and it is in no way strange that they should think correctly concerning the nature of particulars. For since they have passed excellent judgement on the nature of the whole, they were likely to have an excellent view of separate things.

This comment illustrates both the continuity and the mutations of the Western scientific tradition. It was found with other fragments of Archytas by the 15th-century Italian scholar Giorgio Valla among the Greek manuscripts said to have been brought to Italy after the capture of Constantinople by the Turks in 1453, published in a Latin translation in Valla's vast and influential *De expetendis et fugiendis rebus opus* (1501), and cited in the 16th century to exemplify the foundation of the sciences both of material things and of human perception on mathematical reasoning and quantity.

This seems to link us now with Archytas in a continuous living tradition extending from the ancient Greeks to the present. But his words invite us also to ask what he himself meant by «the nature of the whole» in this arcane and somewhat paradoxical context. They invite us to put ourselves at the viewpoins of Archytas's particular vision of existence and of the possibilities of knowledge, at the viewpoint of his interpreters in the 16th century, and in general to treat the history of science (including medicine and technology) as a kind of comparative intellectual anthropology.

Every society has a cultural ecology in which its view of nature and of man is conditioned both by its physical and biological environment and by its mental vision of existence and knowledge and their meaning. I certainly share the belief that one main reason for studying history is to understand ourselves. Today's problems can indeed alert us to formerly unnoticed counterparts in the past. The dramatic irrationalism of our time has sensitized us to the irrational in earlier societies and individuals, and likewise our contemporary experience of the relativity of beliefs and values has given emphasis to differences in expectation and action among different societies and cultures, as opposed to an enduring rational similarity of all men. Yet if each generation is predisposed to dismantle the history written by its predecessors in their image, before rewriting it in its own, our critical inheritance commits us to

distinguishing on evidence between fact and interpretation. I should argue that if we are to understand any historical culture now we must investigate the history of its mental commitments which may survive, modified in new contexts, over long periods of time. For educated understanding of ourselves as we are now, yesterday's events may be the least relevant. But of course it is not only through recognition of continuity that history can give us educated understanding. Societies and their mental ecologies may mutate radically or vanish. Cultures may differ radically. It is hardly neccessary to insist that many of the categories in which we in the West understand both man and nature now, the intellectual and moral and material satisfactions that we demand and the methods by which we get them, have never been accepted by all mankind and have become ours only through a long process of orientation and reorientation. In order to understand our contemporary culture we need then to see it in the context of both comparative anthropology and of its own intellectual and social history, which might be seen as comparative anthropology extended into the past. We could make a natural history of intellectual, moral and practical behaviour in situations presenting themselves for decision. Yet again if we treat the history of science as a kind of comparative intellectual anthropology, putting ourselves into the minds of the individuals or societies we are studying and trying to understand their questions and satisfactions and discontents, we need to control relativity both by objective scientific truth and by the objective continuity of scientific tradition.

If the goal of historical scholarship is to reconstruct the living past, the only past available for reconstruction is that which we can know in the present. Historiography is a dialogue between an interrogating present and an interrogated past. The questions may change. The nature of science as an analytical discipline, involved at one and the same time in the uncertainties of discovery and explanation and in the accumulation of a body of objective knowledge, raises some special problems of historical reconstruction. Looking back from the present we can see scientific inquiry as an activity yielding a progressively growing body of universally communicable knowledge, any part of which we, latest heirs of the tradition, can test by stable criteria of logical consistency and comparison with observation. Knowing the whole history of the tradition to its latest point of success, we are in a position to judge the relative importance and influence in that history of different ideas, techniques and discoveries whose potentialities and limitations the development of the tradition itself has revealed. Thus the analytical reconstruction of the science of a particular period must as the same time involve an analysis and interpretation of the scientific tradition, of which the later history throws light upon the earlier simply by that development. Our superior

knowledge enables us to see tre problems and intellectual manoeuvres, the achievements and limitations, of Aristotle or Archimedes or Robert Grosseteste or William Harvey or Galileo or Faraday or Charles Darwin in a field of conceptual and technical possibilities vastly more extensive than was visible to them. In this sense we can know more about their situation than those at the actual frontiers of discovery hnew themselves. This does not of course mean yielding to the unsophisticated temptation to read history backwards in terms of the standards and problems of the present; that would not be reconstruction but distortion by evaluation. It means that the advance of knowledge, both in science itself and in related disciplines of logic and philosophy and the social sciences, provides us with instrument of analysis with which we can make comparisons across different periods and situations. We are dealing with contants of scientific thought and social behaviour as well as with scientific and social change. We put ourselves into a position to see particular episodes in scientific history as examples of more general logical types or social phenomena.

Conversely, historical knowledge of the scientific tradition enriches these instruments of rational analysis. It displays the varieties of scientific methods and intellectual manoeuvres on which any properly inductive analysis of scientific thinking must be based; it exposes us to the surprise that effective scientific thinking could be based on assumptions and have aims so various and often so different from our own; and it enables us to distinguish the historically accidental from the logically essential elements in the succession of scientific systems. Thus the reconstructed past throws light both upon its own later consequences and upon historically independent comparable situations.

The nature of the inquiry is then an invitation to look, beneath the surface of inmediate and particular scientific results and theories, for the antecedent and concomitant intellectual and social and material conditions that made them possible (and others perhaps impossible), and also for the logical structure that may be common to scientific situations arising in different fields and periods. If we make the essence of historical investigation the reconstruction of events as lived within the mental and technical and social horizons of the persons whose thinking and actions we are analyzing, we get a view of the future lacking the logical appearance of events as seen in reverse. They did not know for sure where science was going until they had taken it there. Science has been generated within the characteristically rational Western tradition as an aproach to nature effectively competent to solve problems. But before the general direction towards scientific knowledge had been decided, either in ancient or in modern societies, two essential general questions remained open. It was an open question what kind of world men found themselves inha-

biting, and so it was also an open question what methods they should use to explorand explain and control it. The characteristically Western tradition of rational science and philosophy may be traced to the ancient Greek commitment to the decision of questions by argument and evidence, as distinct from custom, edict, authority, revelation, rule-of-thumb, or some other principle or practice. They developed thereby the notion of a problem as distinct from a doctrine, and the consequent habit of envisaging thought and action in all fields as the setting and solving of problems. They introduced at the same time also the fundamental conception of a rational scientific system, separately for each category of thought and of nature and collectively for every category.

But for a true historical anthropology of science, a true history of the experience of nature mediated through the specific vision and commitments of a particular society, we need to remind ourselves again that successful scientific programmes are only part of the cultural ecology. Their historical data must be matched from visions of nature that solved no problems and from theories proved by scientific experience to have been misguided. The dominant element in Western culture remained theology well beyond the 17th century, and science shared its growing but still subsidiary position wih other intellectual activities ranging from philosophy and literary scholarship to the visual arts and music. These might entail an attitude to nature or, like philosophical responses to scepticism, an attitude to science, but they were seldom strictly scientific. Many individuals and sections of society found their intellectual and moral satisfactions in categories of thought and explanation not at all concerned with natural science but expressing some quite different purpose. The historical problem is to see how these various interests and categories affected and were affected by the science of nature found in the same culture.

At the present time, when, whether in welcome or reluctance, Western science is being appropriated by even the remotest peoples on the globe, and when East and West have indeed met in competition for industrial and political power and in experience of its social consequences, as well as in more benign mutual knowledge, there are many reasons for looking for mutual understanding through the comparative history of intellectual orientation and reorientation. Of inmediate relevance is the comparison of Western with different Eastern and other conceptions of nature and of man's relation to nature as knower and agent, of the potentialities and limitations of languages for expressing scientific reasoning, and of the consequential positions of natural science in different intellectual cultures. I offer here towards this inquiry simply a suggestion of the

process by which natural science acquired and identity in the intellectual culture of Europe. I shall sketch also an historiographical approach which could be used for any historical culture.

(2) *Scientific style*

We may begin in the most general terms with man, nature and science. In every culture at any time men have experienced existence through the mediation of a particular vision of existence and of knowledge presupposed in their cultural style. Their styles of thinking and of solving problems within this vision and experience, not only in natural science and mathematics but also in the aesthetic arts and sciences and in those of personal and public government, in morality, law, commerce, industry and so on, have usually all had the marks of a recognizably common ambience. In any culture then men's relations to nature as perceivers, knowers, and agents have been regulated, as knowledge, by conceptions of human nature and its intellectual capacities within a total scheme of knowledge and existence. This has entailed conceptions of both man and nature, of both perceiver and perceived, knower and known, and of man's place in nature, time and history, of his origins and his destiny. Relations as action have been regulated by practical needs, habits and motivations and by conceptions of man's practical capacities, freedoms and limitations.

The scientific thinking found in a particular period or society or individual has got its style from different but closely related kinds of intellectual commitment or disposition. We may distinguish three. First there have been conceptions of nature within the general scheme of existence and of its knowability to man. These in turn have been conditioned by language. In the succession competing for dominance in subsequent Western thougth, nature has been conceived as a product of divine economy or art with appropriate characteristics of simplicity and harmony, as a consequence of atomic chance, as a causal continuum, as a workshop of active substantial powers, as a passive system of mechanisms, as an evolutionary generation of novelty, as a manifestation of probabilities. Sources of such conceptions have ranged from cosmological myths to theology and philosophy, and to analogies with human artifacts changing with the artifacts in use. Associated with these different conceptions of nature's modes of operation have been distinct conceptions of how they could be known. Modes of knowing have ranged from revelation or the interpretation of occult symbolism, to a variety of scientific methods assuming an exclusive natural causality. These in turn have been validated by a corresponding range of interpretations of the history of thought

in man's search for the true sources and forms of dependable knowledge.

Competing scientific conceptions of nature have entailed competing conceptions of causaiy which likewise have dominated periods of scientific thought, each conditioned by logic embodied in language. Aristotle's syllogistic logic imposed for many centuries on Western science a form of demonstration, relating cause to effect as premiss to conclusión, expressing the logic of subject-predicate, substance-attribute embodied in all Western languages. Not until the 17th century did the great enlargement of mathematical thinking show clearly that mathematical demonstrations had a different logical form. This then became associated with a causality relating physical events as sequences in time, brought about whether by contact or throught a medium. This causality itself incorporated a theology of laws of nature laid down by a divine creator. Only later again was the logic of mathematics explicitly liberated from physics and from all questions of actual existence, with radical consequences for all scientific thinking. In physics reexamination follower of the whole question of causation.

Must science in different linguistic cultures always acquire differences of logical form, and must the grammatical structure of a language always impose its ontological presuppositions on the science developing within it? The technical language of science has often been developed partly to escape from just such impositions. Nevertheless philology can be an accurate guide to implicit or explicit intellectual commitments of this kind and to their changes. Conceptions of nature and of the form of its knowability held at any time can be precisely reflected in the current and sometimes various technical meanings of general terms such as nature, science, cause, law, demonstration, explanation. Likewise more particular terms: for example motion, matter, element, power, organ, instrument, measure, experiment. It would be useful to compare systematically the problems and their consequences encountered in translating Western scientific thought at its various stages into the linguistic and ontological commitments of, say, the Arabic, Chinese and Japanese languages and cultures. The traslation of ancient Greek thought into the Christian context of medieval Latin offers another point of comparison. The whole question might throw an interesting light in our philosophical anthropology upon a question central to the whole Western debate: that of distinguishing the argument giving rational control of subject-matter from an implication of the existence of entities appearing in the language used, or, more, generally, that of distinguishing a rational structure of nature from that of the organizing human mind.

A second kind of intellectual commitment affecting scientific style has been to a conception of science and of the organization of scientific inquiry. Two different traditions of scientific organization and method

began in antiquity. The dominant Greek mathematicians saw as their goal the reduction of every scientific field to the axiomatic model of their most powerful intellectual invention, geometry. At once alternative and complementary to this was the much older medical and technological practice of exploring and recording by piecemeal observation, measurement and trial. We might say that the subsequent history of scientific styles or scientific methods was generated by the fruitful tension between these alternatives, each trying to draw new subject-matter towards its way of thinking. In that persistent drive of Western thinking, at once to define acceptable norms of rational thought and to explore ever-widening varieties of subject-matter, scientific methods have become both logically and chronologically diversified by the diversity and interactions on the one hand of general commitments, and on the other of particular subject-matters of varying complexity. I shall discuss this further at the end of my paper.

The commitments of a period or group or individual to general beliefs about nature and about science, combined with the technical possibilities available, have regulated the problems seen, the questions put to nature, and the acceptability of both questions and answers. Such commitments have directed research towards certain types of problem and towards certain types of discovery and explanation but away from others. They have both guided inquiry and supplied its ultimate irreducible explanatory principles. By taking us beneath the surface of immediate scientific results, they help us to identify the conceptual and technical conditions, frontiers and horizons making certain discoveries possible and explanations acceptable to a particular generation or group, but others not, and the same not to others. Dominant intellectual commitments have made certain kinds of question appear cogent and given certain kinds of explanation their power to convince, and excluded others, because they established, in anticipation of any particular research, the kind of world that was supposed to exist and the appropriate methods of inquiry. They established in advance the kind of explanation that would give satisfaction when the supposedly discoverable had been discovered.. In this process the cogency of such worlds might change from generation to generation as each nevertheless added to enduringly valid scientific knowledge.

A third kind of intellectual commitment has been to a disposition generating an habitual response to events: a disposition to expect to master or to be mastered by events, to change or to resist change, to anticipate innovation or conservation, to be ready or not to reject theories and to rethink accepted beliefs and to alter habits. Such dispositions have been both psychological and social. They may be specified by habitual styles and methods both of opposition and of acceptance. They may characterize a society over the whole range of its intellectual and

moral behaviour, of which its natural science is simply a part. Change has obviously come more easily in some scientific situations, periods and societies than in others. It has been easier to reject particular theories within an accepted system of general doctrine than to take the drastic step of rejecting the whole doctrine. The disposition to change, which has been so marked a characteristic of the whole modern history of the West, became within the same culture an essential part of the early modern scientific movement over a period when innovation and improvement were also becoming the intellectual habit in art, theology, philosophy and many other activities. It was a matter of individual as well as collective behaviour: Kepler for example contrasts notably with some of his contemporaries and opponents in controversy by his readiness to sacrifice a favourite theory to contrary evidence. The conscious cultivation and reward of a disposition towards innovation began in Western society perhaps first in the arts and philosophy, but it has been transmitted elsewhere mainly with Western science. Comparative historical studies of the intellectual and social commitments, dispositions and habits, and of the material conditions, that might make scientific activity and its practical applications intellectually or socially or materially easy for one society, but difficult or impossible for another, have an immediate relevance for the diverse cultures brought into contact with the science, medicine and technology of our contemporary world.

II. *Levels of Historiographical Investigation*

A comprehensive historical view of the sciences and arts mediating man's experience of nature as perceiver, knower and agent would then include questions at different levels, in part given by nature, in part made by man. Specific historical investigations must usually be made at more than one level:

1. Historical ecology: the reconstruction of the physical and biomedical environment and of what men made of it. Fernand Braudel has illuminated this level far beyond economic history by his great study *The Mediterranean and the Mediterranean World in the Age of Philip II*, with its suitably quantified account of the geology, physical and biological geography, climate, foods, populations, migrations, transport and so on forming the basis of the economic life of the Mediterranean world in the late 16th century. The total extent of historical ecology is of course vast and requires matching expertise.

The geographical and economic history of agriculture must be related to soil, climate, pests and prevailing diseases as well as to social conditions and influences. Any adequate history of biomedical thinking must

aim to reconstruct as well the historical biomedical environment and experience of a society. The history of medical diagnosis and therapy, as a critical study of changing concepts of disease and the healthy norm, could scarcely be undertaken without medical competence to identify diseases and assess treatment. Demographic history and epidemics, the biological and social ecology of disease or nutrition or drugs in relation to biomedical theory and practice, for example the effects of introducing rice or maize or potatoes into European cultivation or of importing quinine or vaccination, are all biological as well as social phenomena and require scientific and historical expertise in both.

But it is not only through scientific knowledge that we can control the view of any present recorded through the eyes and language of those who saw it. The view is seen and recorded by any scientific individual or group through the style and expectations of thinking imposed by their intellectual commitments. Biomedical scientists record their observations in language inevitably conditioned by their taxonomic, physiological or pathological theories. The intellectual and artistic vision must likewise affect, to some extent determine, and sometimes distort the information recorded. The images of nature both particular and general projected in the selective vision of art: in medieval and renaissance landscape painting and garden design, in European depictions of the plants and animals and human life of China, Japan, Mexico or the South Pacific, run in any period parallel to the analogous projections selecting the vision of science. We can estimate and compensate for this cultural effect by comparison with other contemporary or presently available scientific evidence, but also by relating it to contemporary expectations and styles.

2. Cultural dispositions, habits, motives, opportunities and responses. How have science, medicine and technology been related to the individual and the social context of these terms? A central question must always be the conditions for scientific and technical change or conservation. We can make a comparative historical study of the antecedent and continuing mental and social conditions, expectations and habits of behaviour promoting or discouraging scientific activities and their practical applications, promoting or discouraging innovation or conservatism within a group and acceptance of or resistance to innovations brought from outside. Where scientific and analogous inquieres have interested only a scattered minority, what opportunities have existed for establishing agreement on principles and methods, or even continuity between generations? How, for example, was such agreement and continuity maintained in the ancient Mediterranean, or in China or India? In comparison, what intellectual or moral or practical commitments motivated the teaching and learned institutions of medieval Islam and of medieval and early modern

Christendom, and came in the last to establish effective conditions of education and research for an explicit scientific community? Likewise what external pressures and internal dispositions have operated in the intellectual and practical responses of once culture to another, of Islam to Greek thought, of medieval Western Christendom to Islam and to farther Asia, of early modern Europe to China, Japan, India and the New World, of Japan in its early history to China and in the 17th and the 19th centuries to the West, of China throughout its history to any other culture, of the 'developing' countries now to the industrially 'developed'.

3. Scientific thinking: conceptions of the discoverable in nature and of scientific inquiry and explanation in relation to intellectual commitments, scientific context and experience, and available technical possibilities. Clearly neither ecological challenges nor cultural dispositions or motivations can produce science without finding methods that solve problems and forward inquiry and systems of explanation supported by these scientific methods. Historical investigation enters this level through the study of perceptions of the problematic in nature and of the soluble, of traditions of acceptable questions to put and answers to receive, of procedures in scientific inquiry and of the varieties of scientific methods, of conceptions of scientific demonstration and its capabilities, of an adequate result and a satisfactory explanation, and of changes at all these levels of scientific thinking with changes in scientific knowledge and experience. The essence of effective scientific thinking has been the advance of knowledge through the identification of soluble problems. What have been the sources of new intellectual perceptions?

III. *The Variety and Historical and Logical Commitments of Scientific Methods*

Methods capable of yielding accurately reproducible results were a requirement of any practical control of material, whether in assaying, navigation, building, painting, music, medicine, chemistry or mechanics. Such methods were required equally by the practical commitments of technology and the dominat theoretical commitments of science to establishing causal connections. A variety of intellectual moves combined to establish the variety of effective scientific methods found in medieval and early modern Europe. An historian needs to ask both what methodology contributed to science, and what methodology was used by scientists. Moves towards quantification in all sciences may be traced to the general European growth both of mathematics and of the habits of mea-

surement and recording and calculation arising from need in some special sciences, as in astronomy, and in the practical and commercial arts, where new systems of weights and measures and of arithmetical calculation were first developed. The scientific experimental method may be derived from the union of these practical habits with the logic of controls, with further quantification through new techniques of instrumentation and mathematical calculation. The recognition that in the constructive arts theoretical design must precede material realization offers an antecedent to the scientific method of the hypothetical model. The imitation of nature by art became an art of inquisition; rational design for construction became rational modelling for inquisitorial trial. The elaboration of taxonomic methods and of their theoretical foundations may be attributed to the need to accommodate the vast expansion of known varieties of plants and animals and diseases following European exploration overseas, with attempts to relate diagnostic signs and symptoms to their causes. In general scientific experience had shown by the 17th century that the sciences followed an historical order in which, for example, advances in the physical sciences must precede the solution of many physiological problems and at the same time supplied physicochemical models for the analysis of physiological processes. Experience had also made explicit the organization of the sciences round a variety of overlapping, self-correcting scientific methods diversified by general commitments and particular subject-matters. These methods were specified by the demands imposed by the subject-matter; the presupposed concept of discoverable nature guiding inquiry and supplying its ultimate irreducible explanatory principles; the consequential procedures of research, including the crucial point at which experiment came into a scientific argument; and the theory of scientific demonstration distinguishing types of causal and non-causal relation and governing what to accept as having been discovered.

The active promotion and diversification of the scientific methods of medieval and early modern Europe reflected the general growth of a research mentality in European society, a mentality conditioned and increasingly committed by its circumstances to expect and to look actively for problems to formulate and solve, rather than an accepted consensus without argument. The varieties of scientific methods so brought into play may be distinguished as the simple postulation established by geometry, the experimental exploration and measurement of observable relations, the hypothetical construction of analogical models, the ordering of variety by comparison and taxonomy, the statistical analysis of the regularities of populations and the calculation of probabilities, and the historical derivation of genetic development. The first three of these methods concern essentially the science of individual regularities, and

the second three the science of the regularities of populations ordered in space and in time. My argument may ther be summamized under the following headings:

I. Intellectual commitments affecting scientific style:

1. Conception of nature: the discoverable to be discovered.
2. Conception of science: varieties of scientific methods.
3. Cultural and individual dispositions to change.

II. Levels of historiography:

1. Historical ecology.
2. Cultural dispositions and opportunities.
3. Scientific thinking.

III. Diversification of scientific methods or styles were brought about and specified by subject-matters, conceptions of nature, research procedures, and conceptions of satisfactory demonstration and explanation. From this came the varieties of scientific methods embodied in the historical development of European scientific styles:

1. The postulational method of the Greek mathematical sciences.
2. The exploratory experimental method: ancient, medieval, early modern.
3. The method of hypothetical modelling, transposed from rational Renaissance art to rational experimental science.
4. The taxonomic method, developed in ancient and early modern biology and medicine.
5. The statistical method, and the calculus of probabilities, developed in the 17th and 18th centuries: applied from the social to the natural sciences.
6. The method of historical derivation, both diagnostic and demonstrative: applied to the history both of nature and of mankind.