COMMITMENTS AND STYLES OF EUROPEAN SCIENTIFIC THINKING

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Received: 1995.6.20.

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BIBLID [ISSN 0495-4548 (1996) Vol. 11: No 25; p. 65-76]

Plato's Pythagorean friend, the mathematician Archytas of Tarentum, wrote of his 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". When we speak today of natural science, we mean a specific style of rationality created within European culture, a specific philosophical vision at once of knowledge and of the object of that knowledge, a vision at once of nature and of natural science, a vision explored and controlled exclusively by argument and evidence. I shall offer an analytical interpretation of the history of this European style. To understand the present, and no doubt to foresee the future, we must take a long and a comparative historical view. European rationality is a style of thinking that may be traced to the ancient Greek commitment to this mode of control and decision, as distinct from custom, edict, authority, revelation or some other practice. It was the Greek habit to make their style of rationality explicit, in the manner of Socrates, and in this manner European scientific thinking was initiated, by the ancient Greek philosophers, mathematicians and medical men, in their search for principles at once of nature, including human nature, and of argument itself. The Greeks introduced an exclusive form of rationality based on two fundamental ideas: universal, self-consistent and discoverable natural causality and, matching this, formal proof. From these two ideas came the essential style of Western philosophy, mathematics and natural science: the conception of a rational system, generated by the identification of problems as distinct from doctrines, the selective vision of the soluble, and the criteria of what counts as a solution, both in the particular and in general systems of theoretical explanation.

The Greeks invented a style of rationality not only effectively competent to solve problems, in which an essential criterion for accepting a general system was that it could incorporate the solution of the particular; each problem generated an open-ended prolification of further problems into an expanding diversity of cognate subject-matters. In this sense they invented the notion of a scientific problem as distinct from a doctrine. They invented likewise the conception of nature as a general system, entailed by their initial commitment to universal causality, organized as science. They found the methods of their Babylonian and Egyptian predecessors, for example in astronomy and medicine, defective because they lacked *physiologia*, the science of nature (cf. Adrastus reported by Theon of Smyrna, *Expositio rerum mathematicarum ad legendum Platonem utilium*, recensuit E. Hiller, Leipzig, 1878, pp. 177-8). Thus they invented the conceptions both of nature and of science. Neither is found in other ancient cultures. Both found a natural place in the philosophical monotheism developed in somewhat different forms by Plato and Aristotle, in which one divine designer or first cause of all that exists provided the stability and consistency essential for confidence in research and explanation. The decision, that among the possible worlds as envisaged in different cultures, the one world that exists is a world of exclusively self-consistent and discoverable natural causality, committed European scientific thinking exclusively to this effective direction, and closed others to it. The exclusive rationality so defined supplied the presuppositions, and came to supply the methods of reasoning and explanation, alike in formal discourse and in the experiential exploration of nature. Hence it offered rational control of subject-matters of all kinds, from mathematical to material, from ideas to things.

At the heart of Greek thinking was the principle of reasoned control. Plato and Aristotle incorporated the principle of reasoned control, through general theories, of all particular subject-matters and activities, metaphysical, scientific, technical, aesthetic, moral, legal and political, into a general conception of all rational knowledge, all science and all art. Thus Plato described architectural theory as a "directive science" (p. 110; *Statesman* 260 A-B), controlling the construction of a building by measurement and calculation. Any artist or craftsman, he wrote, in making something, "has before his mind the form or idea" (p. 110; *Republic* x, 596B) of what he is going to make, just as the divine maker modelled the world from the eternal forms. Similarly the science of rhetoric, by an analysis and classification of types of person and types of argument, could show "what type of person is susceptible to what type of argument" (p. 107; *Phaedrus* 271E), and so could provide a powerful instrument of persuasion for lawyers, politicians and denizens of the mediatic world. Plato set out in his various writings the historic fact that the rational mastery gained by logical analysis and synthesis gave a unique power to manipulate matter and mind alike, whether for truth or for effect. Rational analysis, design and control were again for Aristotle what distinguissed the human race, which "lives by art and reasonings", from other animals and enabled man alone to invent, choose, learn, and "know the cause" (p. 250; *Metaphysics* vi.1), and so to progress. For "from art proceed the things of which the form is in the soul of the artist" (p. 250; vii.7). "All art is concerned (...) with contriving or considering how something may come into being (...) whose origin is in the maker and not in the thing made" (p. 8; *Nicomachean Ethics* vi.4). "In all the arts and sciences both the end and the means should be equally within our control" (p. 251; *Politics* vii.13). Always, sound practice required sound antecedent reasoning, and sound reasoning was endorsed by practical success, whether concerning nature or human behaviour.

The European scientific movement has been concerned with man's relations with nature and his fellow beings as perceiver, knower and agent. Its specific and explicit style of rationality defines the central European intellectual tradition, in which natural science and mathematics have been from the beginning not only an integral part, but also a model. They were an integral part also of traditional medieval and humanist education, until its disintegration by the Romantic movement against reason, starting in the 18th century, and its irrational successors. Because of the sheer bulk and complexity of contemporary science, it is obviously not possible now to restore that integration in its traditional form, but it would be possible, by means of the philosophical history of science, to restore a more educated and realistic perception of ourselves as cultural beings, and to present a true identity of the natural sciences within the whole complex history of European culture and its relation to the other cultures and civilizations sharing human history.

We must then take a long and a comparative historical view. Every society has a cultural ecology in which its view of nature and of mankind is conditioned both by its physical and biological environment, and by its mental vision of existence and knowledge and their meaning. Embodied in that vision are intellectual and moral commitments, dispositions, memories and expectations concerning conceptions of nature, of science and its modes of inquiry into nature, of the consequences both physical and moral of our actions, and of what can and should be done in living with nature and mankind. Styles of thinking and making decisions established within any society or culture habitually endure as long as these commitments and dispositions remain. Hence the structural differences among different civilizations and societies and the persistence in each, despite externally or internally generated change, of a specific identity. This is a striking phenomenon of the recent past, notably in the Islamic world and in eastern Europe, to which we in the West have too often perhaps been ignorantly insensitive. The whole historical experience of thinking about and acting towards nature, like all the rest of human thought and action, can then be treated as a kind of comparative intellectual and moral historical anthropology. To this belongs the scientific movement developed in the West and diffused throughout the world. At the same time, equally diagnostic of European intellectual culture since the Greeks, has been the matching rational style of its metaphysics and theology, of the moral causality and aesthetic geometry of its drama, music and visual art, of its technology and industry, and of its ethics, law, government and economics. The scientific movement itself has been as much a moral as an intellectual enterprise, and its commitments have been integral and essential to that intellectual competence. We can recognize in the solution of stable problems of nature and of reasoning an objective continuity that survives the relativity of culture. Nature stays put; "Nature", as Galileo wrote, "deaf and inexorable to our entreaties, will not alter or change the course of her effects" (p. 8; *Opere*, ed. naz., v, 218). Reason likewise remains consistent in its principles. We can recognize also in the acceptance of scientific argument and evidence, so dramatically insisted on by Galileo, a moral commitment to truth which survives the relativity of many other varieties of human discourse and behaviour. We cannot "cheat nature" and her "inviolable law" he wrote, however much we may cheat our fellow men, and this could be shown "by true and necessary demonstration" (p. 567; ibid. ii, 155). On all of this rests the objectivity of science and of scientists, and thereby science offers a therapeutic moral experience for mankind.

Historically, the scientific movement has come to be a series of interactions among a variety of cultures, each bringing its own commitments, expectations, memories, techniques and styles. In other ancient civilizations, whether Babylonian, Egyptian, Chinese, Indian or Mayan, these were all essentially different, and in none does one find the fundamental Greek conceptions of causality and proof, and hence explicitly of system, argument and decision. These civilizations in their own diverse ways developed independently highly sophisticated abilities to discover observable regularities in events, and to express them in abstract regularities of numbers and of taxonomy. The Babylonians, with their mastery of numbers, introduced into astronomy the fundamental conception of an abstract mathematical scale of time extending indefinitely into the past and future (pp. 95-7). But the numerical skills of the ancient Babylonians and Indians seem to have involved no central conception of mathematical proof, and neither their cosmological and medical speculations, nor those of the ancient Egyptians or Chinese or Maya, seem to have been controlled by any general theory of natural causation embodying a logic of exclusion. It is evident that the styles of different major civilizations may be difficult to compare, and impossible without violence to reduce to one another. Arabic-Islamic science, like that of the Latin West, was an heir to the Greeks, the unique source of the science that is now universal. The Greeks committed European intellectual culture to a conception of nature and to a conception of science. All other cultures and societies have acquired science in the Western sense and style by diffusion, during successive historical periods, from the West. That has generated all the problems of relating a science that is the product of Western mentality, commitments and expectations, to the often very different mentalities, commitments and expectations of other traditions, as embodied in their languages and beliefs.

The selective scientific vision of the soluble, focused at once upon particular details and universal principles which it must relate to each other in exact and measured correspondence, is a specific product of European intellectual culture. Equally a product of that culture is the search for meaning in time and history, leading to cosmogonic and cosmological speculation and historical scholarship which save from the Greeks accompanied scientific thought. The historiography of science has since Aristotle been an integral part of the scientific movement. For Aristotle, the advances made by the arts and sciences in each civilization were the fulfilment of the potentialities of their natural form beyond which they could not so. This was a structural rather than temporal view of history, on which he imposed the same structural teleological conception of causation as he used in organizing his biology and cosmology.

The Western search for meaning in time and history was transformed by the entry into philosophical debate of the Hebrew and Christian theology of creation. The first systematic confrontation of Greek philosophy with that theology came in the 1st century B.C. with Philo Judaeus of Alexandria, the last great thinker of a line of Hellenized Jews in Alexandria (pp. 294-304; *De opificio mundi*, with an English translation by F.H. Colson and G.H. Whitaker, i, London and Cambridge, Mass., 1929). Philo came both directly and through St. Augustine of Hippo and other routes to bring about a radical revision of later Christian, Jewish and Moslem thinking about the relation of God to the world, to time and to mankind. Plato had proposed in the *Timaeus* that the order of nature had been imposed on pre-existing material chaos by God acting with rationally provident goodness following necessarily from his own perfection.

Aristotle had argued that the world was a necessary and eternal emanation from the First Cause, in which man could discover by reasoning the necessary reasons why the world must be so, was best so, and could not be otherwise. The Stoics had conceived God as a material, eternally active principle which had created the world and remained within it as the cause of the immutable order of its endless cyclical returns, a succession of periodic catastrophes and regenerations of the world and the human race repeating each other forever. Philo followed by St. Augustine readily accepted the Greek conception of immutable causality which determined the order of the world, but looked elsewhere for the true source of that order. This they argued was not the Greek divine rational necessary principle operating within nature and fully knowable to man, but the inscrutable, omnipotent God of Abraham, the Creator utterly distinct from his creation, which he had made freely according to his own reasons. Those reasons were knowable to man only in so far as they could be discovered by an exegesis of what God had himself revealed to us, both in the Book of Holy Scripture and in the Book of Nature. God could not be limited within any human definition. Causality came to be incorporated into a theology of laws of nature laid down by the Creator. "The most customary course of all this nature", wrote Augustine, "has certain natural laws (*naturales leges*) of its own" (pp. 299-304; *De Genesi ad litteram* ix.17). The laws of nature were the laws of numbers, exemplified to the senses in time and space in motion, "obeying God in all things" (*De musica* vi.58), "by the unfolding of their proper measures and numbers and weights" (*De Trinitate* iii.9.16). Created laws re-established the stable predictability of nature within Hebrew-Christian doctrine. The separation of God from nature opened the boundaries of scientific discovery closed by the Aristotelian conception of a completed apodeictic science of all that existed and could exist, even though conflicting exegeses of the two Books brought other troubles.

In his great work the *City of God* (xii. 10, 12, 14, 20-22, xxii. 24) Augustine utterly rejected the Stoic theory of cyclical returns and replaced it by a fundamentally new conception of linear time. God had created the world and the human race uniquely with a definite beginning, progressing through linear time towards a definite end at the Last Judgement. Thus in the ordered course of God's providential government every event was unique, every human decision responsible, and every action both of individuals and in the succession of ages at once a genuine novelty and the fulfilment of a purpose. Within this scheme of Creation, Fall and Redemption, of the unique passage through linear time of responsible individuals moving towards eternity, which Christianity gave to the Western vision of history, Augustine left no doubt that progress in the human sciences and arts was definitely secondary. Yet in the last book of the *City of God* he gave an attractive account of the inventions and discoveries which God's mercy had allowed even sinful man to make in the course of history through his genius and industry. Some were useful and necessary, some dangerous and harmful, and all had to be seen within the complete picture of man's spiritual destiny. Within that destiny scientific investigations were a proper offering to the Creator in return for his gift of intelligence. The simplicity of Christian certainty about the origin, purpose and end of the world and of man provided a powerful, though not of course sufficient, disposition towards the development of scientific thought. It offered hope, both morally, and scientifically in that stable laws of nature could be securely investigated.

The conception of the natural world as the product of a rational and benevolent Creator and of man as made in his image was an invitation to use the gifts of reason and the senses to follow his thoughts. Kepler was to say just that (p. 308; Kepler to Herwart von Hohenburg, 9/10 April 1599, *Gesammelte Werke*, xiii, hrsg. M. Caspar, München, 1945, p. 309). At any rate, this view both of history and of nature was projected by Augustine on to the Latin West where natural science did eventually rise to become a major element of intellectual and practical culture, despite the ups and downs of theological and institutional controversy. It was the medieval institution of the universities that provided a further essential condition for the stable and organized pursuit of intellectual curiosity. Western science developed from the 12th century as a series of responses to Greek thought recovered through translations into Latin. With them came fresh apprehensions of continuity or discontinuity with the past and fresh programmes projected therefrom. Bernard of Chartres compared his contemporaries to "dwarfs perched on the shoulders of giants", able to see more and farther than them "because we can raise ourselves up thanks to their giant stature" (p. 25; John of Salisbury, *Metalogicon libri iii*, iii.4, ed. C.C.J. Webb, Oxford, 1929).

Of the essence of the European scientific movement following its ancient Greek origins have been its genuine continuity, with even long breaks bridged by the recovery of texts; its genuine progress both in knowledge and in argument; and its recurrent critique of both its logical foundations and its moral justification, varying in different historical contexts. The recovery of Greek thinking, after the collapse of the Roman empire, in the different society, economy and theology of medieval and early modern Europe, took place in three stages of response to ancient intellectual examples. First came a primary intellectual achievement: the renewed grasp and critical elaboration in the 12th and 13th centuries, by the philosophical community of the medieval schools and universities, of the conception of a demonstrative rational system on the model of Euclid and Aristotle, and of logical precision in the control of argument and evidence for the decision of a diversity of questions ranging from theology and law to quantitative and experimental science, notably in optics, magnetism and medicine.

With this organized capacity to act with rational intent in the control of argument and calculation, the new intellectual orientation of Western Europe generated at the same time, secondly, an organized capacity to control a variety of materials and practices. Working essentially outside the academic philosophical community, but with a rising level of education, the practitioners of arts ranging from painting, architecture and cartography to music, mechanics and commercial arithmetic devised their success by rational and, where possible, quantitative design anticipating material construction or action. These were the rational artists, proceeding in the same style as the rational philosophers but in different subject-matters and with different ends, practical construction rather than theoretical explanation. They were the Renaissance men of *virtù*, men with active intellectual power to command any situation, including themselves. Echoing Plato's image two thousand years later, Marsilio Ficino in the 15th century envisaged how "human arts construct by themselves whatever nature herself constructs, as if we were not slaves of nature but rivals". Thus they "imitate God the artificer of nature", and "who will deny that man has a genius (so to speak) almost the same as that of the creator of the heavens" (pp. 469-70; *Theologica Platonica*, xiii.3).

The confident establishment in the 16th and 17th centuries of the rational experimenter and observer as the rational artist of scientific inquiry, designed first in the mind and proceeding by antecedent theoretical analysis leading to execution with the hands, marked the culmination of European orientation in response to ancient scientific sources in its third stage. Artist and philosopher alike could achieve their goal only, as Galileo put it, "according to the necessary constitution of nature" (p. 567; *Opere*, ed. naz., ii, 188-9). Galileo himself marks the connection and transition between two great European intellectual movements: from the world of the rational constructive artist to that of the rational experimental philosopher. The leading architects of this new scientific experimental philosophy saw it as the deliberate combination of a theoretical search for common forms of explanation with a practical demand for accurately reproducible results. Thus they could develop a general theory of discovery and explanation in which their particular solutions were embodied, and they could establish a specific identity both for nature among the diverse possibilities long entertained, and for natural science as a mode of inquiry and decision in specific distinction from other diverse modes of thinking within contemporary culture, such as in the search for theological consensus or for legal or commercial convenience (pp. 598-9; Galileo, *Opere*, ed. naz., v, 319, 326-30). In all this, and in the whole scientific movement considered in the context of society and of communication, persuasion has been as important as proof. Scientific ideas, discoveries and modes of argument have had to be made convincing and relevant to the thought and life of their audience not only within the scientific community, but also in the society at large. The essence of scientific thinking has been the advancement of knowledge through the identification of soluble problems, but assent to solutions offered has depended heavily on expectations arising from antecedent commitments concerning both the nature of things and the style of argument.

The whole subject offers an invitation to look beneath the surface of immediate scientific results for deeper, continuing structures. In our comparative historical anthropology of thinking we must look not only with, but also into, the eye of the beholder. I use for my analysis of the European scientific movement two basic concepts: that of commitments or dispositions, and that of styles of thinking. We may distinguish three related kinds of intellectual and moral commitments or dispositions. First there have been commitments to conceptions of nature, as perceived within general schemes of existence and its knowability to man. Nature as a general system, as invented by the Greeks, remained the constant element through its various competing forms: nature as a product of divine art, emanating or distinct from its creator, of atomic chance, of probabilities, of the emergence of evolutionary novelties, etc. Secondly there have been commitments to conceptions of science, and of the organization of scientific inquiry, argument and explanation according to different styles. Together these two commitments establish, in advance of any particular research, the kinds of argument, evidence and explanation that will give satisfaction, because the supposedly discoverable has been discovered in conformity with the acceptable criteria. Argument throughout the scientific movement has been conducted at two levels: that of general conceptions of both nature and science, and that of the solution of particular problems. Both are profoundly affected by, and come to affect, language. Equally essential to the scientific style, an element of it made explicit in early modern Europe, has been the acknowledgement of error, of mistakes and their reasons, an art of the soluble based as much on how rationally to differ as on how to agree. The scientific movement was integrated during the 17th and 18th centuries largely through the establishment of generally accepted forms of argument, evidence and language.

Historically, language is an indispensable guide both to theoretical scientific ideas and to real actions. Any language embodies a theory of meaning, a logic, a classification of experience, a conception of perceiver, knower and agent and their objects, and an apprehension of existence in space and time. We need to ask how language conditioned scientific thinking and was in turn altered by it. We may distinguish three levels: those of the structure of a language itself, of general conceptions of the nature of things expressed in it, and of particular theories. The language of causality for example is closely related to conceptions of causality. It is hard to say which came first, but there is an obvious structural conformity between the grammar of subject and predicate found in all European languages, and the ontology of substance and attribute developed most systematically by Aristotle. Aristotle's logic imposed on Western science for many centuries a form of demonstration, relating cause to effect as premise to conclusion, expressing this grammar and ontology of subject-predicate, substance-attribute. His conception of causality was structural and non-temporal and was focused on the definition. This became the object of an essentially taxonomic style of science, which explained both the behaviour and the existence of something by its defining attributes. Parallel to this the Greek mathematicians exploited the speculative power of geometry by imposing upon the phenomena at once its deductive logic and an appropriate geometrical model delineating for each its form in space. The geometrical conception of causality was again structural and non-temporal, focused on space and place, not on the sequence of events in time.

These conceptions, and specifically Aristotle's logic of subject and predicate, were to become a major obstacle to the medieval and early modern natural philosophers and mathematicians of Latin Christendom who, in a different intellectual context, came to develop a new conception of causality based not on static structure but on rates of change. They came to express causality in the language not of subject and predicate but of algebraic functions, and they devised a new Latin terminology to express such fundamental quantities as velocity, acceleration, instantaneous velocity, and so on. These quantities were defined in the 14th century by mathematicians in Paris and Oxford, and their terminology was to be used by Galileo and Newton. This new functional causality of classical physics related events as sequences in time brought about only by contact or through a medium or field; the disputed choice between these was based on wider ontological beliefs. With Roger Bacon, scientific causality came to be incorporated into a theology of laws of nature laid down by the Creator: for as Dante put it "dove Dio senza mezzo governa, la legge natural nulla rileva (where God governs without intermediate, the natural law has no relevance)" (*Paradiso* xxx.122-3). Newton was to combine this theology with Euclid in calling his fundamental dynamical principles "axioms, or laws of motion" (*Principia mathematica*, 1687). Such language clearly arises not from the interior of natural science but from its intellectual context.

Must science in different linguistic cultures always acquire differences of logical form, and must 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, and to detach a specific scientific meaning from misleading analogies coming from its source in common vocabulary. From the 14th century radically new technical languages were gradually built up, precisely symbolized first for mathematics and music. Both were universal numerical languages, transcending all national boundaries and transparently comprehensible within their explicit limits. Their message was precision and economy.

A third kind of commitment, giving people their vision and style, has been to conceptions of what is desirable and possible, in view of their evaluations of the nature, purpose and circumstances of human life. Such commitments provide the motivations of research and action, or alternatively hostility or indifference. They concern right human action, what should and can be done, both morally, and scientifically and technically in the sense of being capable of achieving their ends. To this kind of commitment are linked dispositions, both of individuals and of societies, generating habitual responses to events: dispositions to expect to master or to be mastered by events, to change or to resist change both in ideas and in practices, to accept or to reject the possibility of truth within supposed error and hence to integrate within reasoned argument both agreement and disagreement. Here education and experience can furnish options for the choice of a different future. Integration and choice may be open in some societies and circumstances, but difficult or closed in others. They became open in medieval and early modern Latin Christendom, but remained evidently closed in Islam. It seems that in Islam there was no rational theology that could relate to rational science like that developed in Christianity by exegetical and philosophical evidence and argument. This and the lack of stable institutions to support philosophical inquiry may account for the failure of Arabic science after the 13th century. All three of these commitments or dispositions clearly affect the possibility of scientific innovation and change. There is also a fourth, different kind of commitment, to the physical and biological environment in which men find themselves. They may try to control or change it, but first it is given by nature indifferent to man.

Within these general commitments scientific thinking became diversified into a number of different styles of inquiry, demonstration and explanation, of which I have identified a taxonomy of six. The novelty was in the style. It is illuminating to focus on the critical occasions of intellectual orientation, leading to the maturity of each style. There is a logical and chronological sequence, in which each arose in a cultural context where an assembly of different but cognate subject-matters, scientific, artistic, economic and so on, was united under a common form of argument. Styles became diversified by the diverse subject-matters addressed, by general conceptions of nature and of science and the expectations they entail, and by scientific experience of the interactions of programmes with realizations. A scientific style, with its commitments, identified certain regularities in nature, which became the object of its inquiry, and defined its questions, methods and kinds of evidence appropriate to acceptable answers within that style. Three styles were developed in the subject-matters of individual regularities, and three in the subject-matters of regularities of populations ordered in space and time.

1. Postulation was the primary and continuing style, invented by the Greeks in two different forms. The former exploited the demonstrative power of geometry and arithmetic in the simpler regularities of nature, uniting all the mechanics and music, under a common form of proof. The latter exploited the demonstrative power of logic as established by Aristotle in all the natural sciences as well as in other subject-matters of philosophy. The Greek mathematicians scored their most striking successes by their brilliant insight into a subject-matter of soluble problems of simple relations. Thus they reduced the phenomena of astronomy to the properties of the sphere, of visual perspective to the properties of the straight line and the angle, of mechanics to the relations of weights determined by the properties of the straight line and the circle, and of music to the properties and proportions of numbers. They could then develop their immediate research purely theoretically within these mathematical terms. Evidently guided by Plato and Aristotle, the elaboration of this style was the supreme achievement of Euclid, Archimedes and Ptolemy. It was Archimede who became Galileo's scientific ideal. Similarly in the 17th century Descartes exploited the demonstrative power of algebra, and Newton that of the infinitesimal calculus.

2. The experimental argument, both to control postulation and to explore nature by designed observation and measurement, was developed as a strategy of searching for principles in more complex subject-matters, proceeding by an antecedent theoretical analysis. It is exemplified in a sophisticated Greek form by Pythagorean acoustics, by Ptolemy's Optics, and by Galen's physiology, which William Harvey took as a guide. It was logically designed in medieval and early modern Europe as a form of reasoning by analysis and synthesis in which experiment, with the necessary quantification and instrumentation, was brought into an argument at the relevant points of decision. Moves towards quantification in all sciences came with the general European growth both of mathematics and of the habits and techniques of measurement, recording and calculation arising from need in some special sciences, as in astronomy, and in the practical and commercial arts. The scientific experimental method derived from the union of these practical habits with the logic of controls, with further quantification through new techniques of instrumentation and mathematical calculation, so that in the 16th and 17th centuries it became the foundation of the classical scientific movement. It was applied to every possible subject matter by Gilbert, Galileo, Harvey, Kepler, Descartes, Newton and many others, and notably by Mersenne to the science of music.

3. Hypothetical modelling, proceeding likewise by an antecedent theoretical analysis, was developed as a method of elucidating the unknown properties of a natural phenomenon by simulating the phenomenon with the known properties of a theoretical or physical artifact. The first and greatest example was Eudoxus's geometrical model of the universe, from which followed the whole of geometrical astronomy down to Newton. From the medieval formal modelling of the heavens with astronomical spheres and timekeepers, and the Renaissance modelling described by L.B. Alberti of natural perceptual clues with perspective painting, the style was systematically transposed from art into science and philosophy during the 17th century. The recognition that in the constructive arts theoretical design must precede material realization anticipated

the scientific hypothetical model. Each proceeding to a different end, artist and scientist shared a common style. The imitation of nature by art then became an art of inquisition; rational design for construction became rational modelling for inquisitorial trial. It is exemplified by the modelling of the eye with a camera obscura by Kepler, of general physiology by Descartes, of language by Mersenne, and of political society by Hobbes.

4. Taxonomy emerged as an explicit logic of classification, developed first by Plato and Aristotle. In many ways it is the foundation of all natural science, establishing fundamental similarities and differences. The argument proceeded by the analysis of a phenomenon into its elements, its location in a subject-matter with cognate phenomena, then its synthesis from those elements, thus providing an explanation of its occurrence. Analysis and synthesis of every kind of phenomenon and field yielded a taxonomy of subject-matters and of styles of argument appropriate to each of them. It was elaborated during the 17th to the 19th century as a search for natural affinities and systems, with a polarization of realism versus nominalism classically represented by Linnaeus and Buffon. The search raised the question of their origin, whether in the mind of God or through evolutionary descent, as proposed by Charles Darwin.

5. Probabilistic and statistical analysis arose, first in Greek medicine and Roman law, out of the need for a precise logic of decision in practical situations of contingent expectation and uncertain choice, and later the explicit discovery in the 17th century of statistical regularities as a new form of regularity found in adequately numerous populations of eventh. From earlier Italian work notably on insurance, the style was brought to elegant quantitative maturity in the 17th century when, as Pascal put it, uncertainty was mastered by reason and stabilized in a calculus of probability (p. 1325). An essential concept was that of the instantaneous value of any item at a given moment in an ongoing human enterprise or natural process. It took the same form whether applied to the value of a stake in a game of chance or a commercial enterprise, of a legal or philosophical opinion, or of a living species in natural selection. Out of this analysis came the statistical conception of nature exploited in the theory of natural selection in the 18th century formally by Maupertuis and then empirically by Darwin, the foundation of physics on probability, and a probabilistic conception of science.

6. Historical derivation, the analysis and synthesis of genetic development, was introduced by the Greeks in their search for the origins of human civilization and within it of language. Thus Diodorus Siculus and Lucretius envisaged a causal historical process of nature and mankind in which the past could be inferred from observation of present regularities, and the present could be explained as a development of that past brought about by natural laws. It was elaborated systematically in early modern Europe, notably by Leibniz, as a method of taxonomic and causal analysis and synthesis first in application to languages and more generally to human cultures, then to geological history, and later conclusively by Darwin to the evolution of living organisms. The subject-matter of historical derivation was defined by the diagnosis, from the common characteristics of diverse existing things, of a common source

earlier in time, followed by the postulation of causes to account for the diversification from that source. The argument went in both directions.

The natural sciences did not develop then as a monolithic system, even though all developed within the original Greek commitments in searching for principles, at once of nature and of reasoning, in all their matching diversity. These six styles and their objects are all different, sometimes incommensurable, assuming fundamentally different physical worlds, but frequently they are combined in any particular research. By identifying the regularities that become its object of inquiry, and by defining its questions and acceptable evidence and answers, a style both creates its own subject-matter and is created by it. A change of style introduces not only new subject-matter, but also new questions about the same subject-matter, as in the change in the treatment of motion from Aristotelian qualitative taxonomy to Galilean kinematic postulation. Different styles introduce new questions also about the existence of their theoretical objects: are these real or products of methods of measurement or sampling, or even of language? Scientific progress is thus not linear, but takes the form of branches growing at different levels in a variety of directions. Moreover scientific propositions are of different kinds. All science is not tested in the same way. Propositions asserting factual regularities can be tested by direct observation and are usually stable. Those asserting abstract explanations involving theoretical entities must be tested indirectly by their consequences, and they tend to be replaced with the development of theory by others more adequate, either in precision or in generality. In a different relation to any scientific system are propositions not explicitly offered for testing but nevertheless fundamental. These are changed by re-thinking. They include the axioms assumed in logic and mathematics, general principles of nature such as economy and sufficient reason, and more particularly reductive programmes such as those of mechanism, teleology and fields. All of these presuppose the kind of world to be discovered by science, and so regulate the expectations both of questions and of answers. When they change there is a scientific revolution. Progress may occur then at different levels and in different forms. Factual knowledge progressively accumulates. Theoretical change may increase the power and generality of explanations, and it may open new horizons of inquiry and new questions to put to nature. It may involve a change of commitments and styles, as when design gave way to statistics in the argument for natural selection. At another level there may be changes in commitments, entailed by general beliefs and expectations concerning human existence, to the value and purpose of scientific knowledge and its applications. These may count as progressive or the reverse. But nature stays put, and thought consistent in its principles. Hence the objectivity of science, like it or not. Science has liberated us from a raw dependence on nature. We may then celebrate the uniqueness of European scientific thinking among the great intellectual feats of mankind: a celebration of its beauty and elegant economy, of its combination of creative imagination with precise reasoning, of its enigmatic matching of nature with mathematics and of mathematics by nature, and, despite the hazards, of its power for good.

Source: Alistair C. Crombie: 1994, *Styles of Scientific Thinking in the European Tradition*, 3 vols., London, G. Duckworth & Co. Ltd., to which pages in the text refer.