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Introduction

The Six Styles of Knowing

A STYLE OF SCIENTIFIC KNOWING is more than a method of scientific practice. This book differentiates between six styles: the deductive (in which science is built on first principles), the experimental, the hypothetical-analogical, the taxonomic, the statistical, and the evolutionary. Each of these styles has its own criterion for good science, the proper way of arriving at "the truth." There is no way to deduce or derive the styles of science from anything else; they form their own justification. The proposal that there are six different styles of science was first made by the historian Alistair Crombie in his magnum opus, *Styles of Scientific Thinking in the European Tradition*.[1] The assertion of six styles is the result of Crombie's taxonomic investigation, of his surveying the many forms in which the sciences have been practiced through history. The foundations of culture and the intellectual capacities of human beings have not been axiomatized to the point where we can prove that they yield these six styles and no others. Perhaps in the future new styles of science will arise, or perhaps they are already here, unnoticed. Technology may constitute an additional style; we will return to this topic later.

This view of science has various implications. In the philosophy of science, it implies that no one style can be regarded as foundational, forming a

basis for all the others. In cultural history, it implies that there is no monolith called "science" (or "natural philosophy") that has stood apart from the rest of Western culture since the ancient Greeks. The six styles identified here have their roots in different eras of cultural history and bear the marks of their origins even today. This clearly illustrates that styles are not "paradigms," one succeeding another in strict sequence in the history of science. Once a new style has emerged, it endures, retaining its distinct identity. Yet these styles are not inalterable. Each one has followed its own developmental path. They have entered into various alliances: the deductive and experimental styles, the experimental and statistical, the statistical and evolutionary, and so forth. And there is another way in which this style-based view of science bears on the history of both science and culture: namely, by opening up a wider range of historical contexts for scientific practice.

Crombie sees the stirrings of all six styles in ancient Greece, though most of them did not fully emerge until much later. The Greeks developed the deductive style, in which the only kind of knowledge that qualifies as true science is knowledge derived from first principles that are necessarily true. The view that only the deductive style can lead to genuine scientific knowledge (*scientia*) persisted until the seventeenth century, though by then other styles of science had also taken root, presenting a growing challenge to the ideal of certain and necessary knowledge.

In this respect, the High Middle Ages (1150–1400) constituted a pivotal period for science. The deductive style underwent fundamental changes and, after a long process, was eventually forced to relinquish its claims to dominance. For some time, however, the new, medieval form of deductive thinking remained the only generally accepted style of thought in the sciences. Analogy existed, but was a theological form of reasoning, rather than a scientific one. And while medieval thinkers posed questions about historical development, they couched their answers in the form of deductive systems, as the historian Johan Huizinga observed.[2]

The Middle Ages did not give rise to an experimental style, though a conceptual logic emerged that helped to pave the way for experimentation. The experimental working method did not truly take shape until the Renaissance and the seventeenth century, and even then it took two distinct forms: one associated with the Renaissance virtuoso, and the other with magicians and alchemists. The man of *virtù*, represented by Galileo Galilei, was primarily in search of insights of a general nature, preferably ones that could be expressed in a simple geometric form or as a numerical ratio. The magician, in contrast, represented by Francis Bacon and Robert Boyle, was interested in anything unusual or anomalous.

The Renaissance also produced the hypothetical-analogical style, which

was championed around 1600. The beginnings of the taxonomic style also lie in this same period. This book therefore addresses the Renaissance in some depth, though not for the same reason as histories of science that focus on the so-called Scientific Revolution. This revolution is usually said to have begun in 1543, with the publication of Copernicus's theory that the center of the universe is not Earth but the sun. It conventionally ends in 1687, when Newton proved the existence of gravity. Historical narratives based on the Scientific Revolution have well-established merits. But they also have their flaws, such as a rather one-sided emphasis on the "world picture," which is said to have undergone a profound shift, becoming mechanized or disenchanted.

Around 1800, the sciences again underwent such major conceptual changes that one might speak of a second Scientific Revolution, a revolution bound up with Romanticism. Biology established its independence as a scientific field, physics unified a range of natural forces, and history and economics took their place among the sciences. This second revolution is not one of the organizing themes of this book any more than the first one is, but it will be discussed.

Considering the styles all together, we can see that each one opened up new domains of experience to scientific investigation. Accordingly, what this book surveys is not so much the formation of the most influential scientific theories (though they will be included) as the history of empirical scientific practice.

The organization of this book is guided mainly by Crombie's styles of science—or of scientific thinking, as he puts it. This approach has a built-in limitation—namely, that the development of engineering and technology remains largely unexamined (though the influence of these fields on the development of the sciences is discussed). Given the organization of the book, it is important to ask whether engineering and technology represent a distinct style. My provisional answer is yes; one could make a strong case for their separate status as a style characterized by visualization—the use of drawing and computer animation to obtain a concrete (rather than analogical or metaphorical) picture of whatever feat of engineering one has in mind. In our twenty-first-century world, where technological thinking and practice are ever more likely to enter into alliances with various styles of science, it is reasonable to argue that the technological style has the same autonomous conceptual status as other styles.[3] The notion that technology is merely applied science has by now been thoroughly refuted and should be regarded as obsolete.[4]

The view of scientific styles presented here is also inspired by the work of Ian Hacking. Hacking took Crombie's concept of styles of science as his

point of departure before it had even been presented to a broad public, and his own explorations of the experimental and statistical styles have pointed the way for other scholars.[5]

This study also draws on a great deal of other British and American scholarship. Historians of science have made great strides over the past thirty years—partly under the influence of the interdisciplinary field of science and technology studies—and, at the same time, strengthened their ties with general history. In the preceding period, the history of science had been plunged into turmoil by Marxist approaches, which had introduced valuable but overly reductive socioeconomic perspectives. Science and technology studies brought quite a few other "continental" perspectives into the history of science, and I hope to do justice to some of them in this book.

Recently, John Pickstone has proposed an interesting threefold distinction between natural history, analysis, and synthesis/experimentalism: three "ways of knowing," along with several "world readings" and present-day technoscience.[6] While Pickstone's natural history can be easily absorbed within the taxonomic style presented in this book, his "analysis" and "synthesis" both fall squarely within the experimental style. Pickstone's distinction between the latter two has the merit of drawing attention to the great wealth of variety within the experimental method. He moreover points to an alliance between analysis and the taxonomic style as practiced in the eighteenth century. All in all, the six styles of knowing presented here are more encompassing than Pickstone's "ways of knowing."[7]

Culture and Science

In 1969, the historian of science Robert M. Young wrote that some of his colleagues were beginning to realize that the history of science had more in common with general history than had previously been assumed.[8] This observation may seem commonplace now, but at the time it was anything but. E. J. Dijksterhuis, for example, in his masterwork *The Mechanization of the World Picture*, described the history of physics from Pythagoras to Newton as an autonomous line of development in which the scientific mind unfolded and awakened over a period of two millennia, virtually without reference to any social and cultural developments.[9] General history, for its part, did not seem to have any need for the history of science. The two subdisciplines were also separated by another factor: the history of science was usually practiced by people with a scientific background, addressing an audience of exact scientists.

When historians of science with a Marxist orientation, such as Young, began to speak out (the Dutch historians Jan and Annie Romein had, in fact, expressed similar views in the 1930s), they generally dismissed their

predecessors and opponents as "internalists." These new historians were self-styled "externalists," connecting history to society and demonstrating influences "external" to what had always been regarded as a self-enclosed system. They also imported large parts of the sociology of science into its history.

It was not just the history of science, but the field of history in general, that moved toward a sociological perspective in the 1960s. While political history had once been the norm, social and economic historical writing soon took precedence. This tendency partly reflected the progressive social engagement of a new generation of scholars, but as the historian Lynn Hunt has argued, it was quickly defended on intellectual grounds as well. The French *Annales* school had begun propagating "total history" several decades earlier, and had a growing international influence.[10]

Around 1980, as Hunt demonstrates, the discipline of history began to take what is now known as the linguistic turn. This turn took place, in various guises, within different historical schools and approaches (as well as in philosophy and some social sciences, even playing a role in the formation of new areas of research such as cultural studies). The *Annales* school also shifted its focus to language, deposing social and economic history from their throne. Roger Chartier, one of this movement's later representatives, claimed that "mental structures" are independent of their "material determinations," and further stated: "The representations of the social world themselves are the constituents of social reality."[11] Chartier and other historians of his generation show the unmistakable influence of Michel Foucault, who did not accept any historical category whatsoever as a pretheoretical given. Foucault taught us that madness, the state, and sexuality are not universal concepts that merely take different concrete forms from one historical period to another.

The linguistic turn also led to an anthropological turn, inspired by Clifford Geertz and others, in which the search for historical essences made way for the reconstruction of contemporary systems of meaning.[12] Hunt has pointed out the difficulties resulting from the anthropological turn, particularly its overriding emphasis on shared systems of symbolic forms, which are supposedly organized, within any given culture, into a unified, homogeneous field. This touches on the tension, well-known in the social sciences, between structure and agency, or between structure and event. A historian, like an anthropologist, must have an eye for the differences and inequalities that present cultures and societies with opportunities for change.

Finally, there was also a literary turn, though it encountered more resistance than the other two. Dominick LaCapra used the work of the liter-

ary theorist Mikhail Bakhtin to identify multiple voices in a historical text by means of their stylistic features. Hayden White carried on the work of another literary theorist, Northrop Frye, in a book about historical writing itself. White presented compelling evidence that a small set of archetypal literary genres is also identifiable in historical texts, and that each of those genres has a certain rhetorical thrust derived from its narrative mode (its plot structure).[13]

These developments formed a substrate that also absorbed several older cultural traditions of historical writing, such as the art-historical tradition of the Warburg School (whose members included Ernst Gombrich and Frances Yates) and R. G. Collingwood's hermeneutic approach, which had previously been viewed as something of an oddity.

The cultural turn (the product of the linguistic, anthropological, and literary turns) opened up new opportunities for historians, from which I hope to benefit in this book. Essentially, what we now recognize is that science is a form of culture, produced by culture, and linked to other forms of culture. It should be added that science is by no means exclusively a form of "high" culture. There are many episodes in the history of science in which "low" culture was influential. In any case, Chartier notes that in "micro-situations" this dichotomy is often irrelevant.[14]

The Term "Style"

Crombie uses the term "style" mainly to refer to the "cultural ecology" of a society: its views, convictions, and sacred cows, as well as its methods of problem solving. In science, he identifies three clusters of convictions. One consists of views about nature and its knowability. Another relates to science itself, specifically the organization of inquiry, argument, and explanation. The third has to do with social conceptions of what is desirable and possible: the moral, scientific, and technical dimensions of human intervention in nature, and the tension between conservation and innovation.[15]

Crombie says nothing about the origins of the term "style" as he uses it. It seems likely, however, that there is a connection with the term "style of thought," coined by the sociologist of knowledge Karl Mannheim.[16] In the 1920s, Mannheim was just about the only scholar to use the term "style" in connection with anything but periods of art history. He was in search of something more fundamental than schools of thought. Schools of thought differ from each other because that they make use of different theories, but the differences between styles of thought have to do with what Mannheim called the *Weltanschauungstotalität* (internal unity of a worldview).[17] Furthermore, each style of thought is associated with a different *seinsmäßige Beziehung* (existential relationship) to the objects of knowledge. Mannheim

also used the compound word *Weltwollen* (will to the world) to make this point.[18]

In art history, such styles—Gothic and Baroque, for instance—are a collective matter. Individual artists share a background that provides them with similar "habit-forming forces," as the art historian Erwin Panofsky has argued.[19] A certain style (distinguished from other styles by its conventions) is the result. Individual representatives of that style have internalized the conventions in question. The French sociologist Pierre Bourdieu called a style of this kind a "habitus."[20]

Yet it is highly unconventional to apply the same perspective to the great scientists of the past. Galileo and Newton, for instance, are often described as timeless geniuses for whom the limitations of their age were so much ballast, mere social obstacles rather than intellectual ones. I aim to present scientific achievements such as those of Galileo and Newton as innovations within a style or as combinations of styles. My hope is that this approach accords great scientists the recognition they richly deserve for their trailblazing achievements, while placing them firmly in their historical context.

However, the conception of a style as the embodiment of a collectivity is not free from the usual pitfalls. The art historian Ernst Gombrich was one critic of excessively holistic views that turn a style into an imaginary superartist as a way of attempting to gain insight into the mentality of a period.[21] Looked at in this way, style and *Zeitgeist* are one and the same.

But this puts us in danger of throwing out the baby with the bathwater. Carlo Ginzburg has rightly noted that the belief in a "spirit of the age" is a naive solution to a real problem, namely, how to interpret the connection between different aspects of historical reality.[22] We will return to this point in a moment, but first, note that Gombrich's own conception of style was more modest than Panofsky's. Gombrich analyzed style as a notational system, thus emphasizing the activity of the artist as a maker of visual images.[23] He approvingly quoted the art historian Heinrich Wölflinn, who called art history the "history of seeing."[24]

This view draws a link between style and an important aspect of Thomas Kuhn's notion of a paradigm, which has proved to be the most successful way of conceptualizing changes in science.[25] Kuhn convincingly showed how, for instance, the transition from a Ptolemaic astronomical system to a Copernican one can be seen as a change in worldview. A new theory leads to a new image of reality. In this example, that not only meant that the sun replaced Earth as the center of the cosmos, but also that the Copernicans were open to seeing changes in the heavens, whereas their predecessors and opponents in the field of astronomy believed they saw only an ancient and unchanging universe. Kuhn related such changes in worldview to an

emphasis on observations that were problematic for the old theory, even though the supporters of the old theory saw every reason to believe that these problems could be solved. The similarity to style, in Gombrich's representational sense, is striking. Theories are, as it were, different notational systems for reality, just as Impressionists and Cubists represent trees in a landscape in different ways. In both cases, the "truth" of the notation is bracketed.

There is nothing wrong with Kuhn's analysis. But it is possible to expand on it. At the same time that the new experimental style emerged, for instance, the status of scientific knowledge changed substantially. Copernicans had not only a new scientific worldview, but also new aspirations for the cultural significance of that worldview. Even if we assume that science, culture, and society are not a monolithic whole, they are clearly interrelated in countless ways. In fact, they are dynamically interrelated: a change in one component can place pressure on the internal structure of another, and bring about changes there as well. At the very least, we can conclude from this that a style involves more than just a mode of representation.

Crombie brings us closer to resolving this issue through the metaphor of a style as an ecology.[26] He probably did not have in mind the holistic approach of systems ecology, which would not have taken him very far. Crombie was an ecologist before he began his career as a historian of science, and he belonged to what is sometimes called the dynamic school of ecology.[27] An "ecological" view of style in science can help historians studying scientific change to avoid a one-sided emphasis on the representational nature of scientific activity. According to the ecological view, a style is a whole composed of many heterogeneous parts. Art historian Michael Baxandall's concept of "cognitive style" embraces more than just modes of representation. To interpret an image, he says, you need categories, model patterns, and "habits of inference and analogy."[28] A corresponding example from science is that different styles involve different ways of inductive reasoning. But if we return to Mannheim's conceptual model, we can see that the heterogeneity of scientific styles goes even further. Styles draw connections between the criteria for calling things true, rational, possible, desirable, acceptable, and plausible.[29]

The essence of Mannheim's contribution can be captured by the word "ethics."[30] Mannheim contested the "positivist prejudice" that we can free ourselves of metaphysical presuppositions and distinguish between facts and values. Every style of thought has its own way of connecting methodological and metaphysical assumptions. Mannheim drew inspiration for this more comprehensive notion of style from the work of the art historian

Aloïs Riegl, and this makes it noteworthy (though understandable) that Gombrich kept some intellectual distance between Riegl and himself.

Mannheim did not apply his postulate of the cultural relativity of a period's relationship to reality (*Seinsrelativität*) to the natural sciences. He was later criticized for this omission, but according to the sociologist Dick Pels, we must understand that Mannheim's first priority was to free the humanities from the objectivist claims of the logical positivists. He simply never got around to the natural sciences. The job was done later, however, by Mannheim's contemporary Ludwik Fleck.[31]

My analysis of the six styles of science shows that each one involves certain metaphysical assumptions. Purely deductive thinking, for instance, involves optimism about the knowability of the cosmos, which stems from an assumed affinity between the cosmos and the human mind. Such optimism is entirely absent from the hypothetical-analogical style. Though deduction plays a central role in this style as well, the expectations about what it can accomplish are very different. Another example is the experimental style, which could not have developed without the "ethics" of *virtù* and the *vita active* (active life).

A Western History of Science?

A few words of justification are in order. The narratives in this book relate to Western science. The Arab sciences in the Middle Ages are dealt with at some length because of the great influence they had on Western science in that period, but we tend to adopt the perspective of those who receive influence rather than those who offer it. Western science has also absorbed knowledge from many other cultures, in large part as a result of the Portuguese, Dutch, French, and English voyages of discovery in the fifteenth through the eighteenth centuries; this subject is addressed briefly.

The histories of Chinese and Arabic science are independent narratives that unfortunately do not fit within the scope of this book. Science in Orthodox Christian Europe also goes unexamined. I emphasize the relative autonomy of these scientific cultures because, in my view, there is little to be gained by attempting to tie them closely to the history of Western science.

Incidentally, the same exceptions can be made in relation to Greek and Roman antiquity. Between the fall of the Roman Empire and the intellectual reawakening of the West lay a yawning chasm of seven centuries, a long enough period to raise doubts about whether there was any real cultural continuity. Furthermore, our term "science" is much too modern to be attributed to the Greeks.[32] Almost by necessity, the chapter on science in

ancient Greece is therefore split between two worlds: on one hand, it emphasizes the aspects of the deductive style that remained highly influential throughout the later history of science; on the other hand, it attempts to reconstruct the deductive style of the Greeks in its original, practical context, and to demonstrate the difference between what the Greeks meant by deduction and the understanding of the term from the Middle Ages onward.

Quite a few attempts have been made to compare Western and non-Western science. For example, Joseph Needham proposed that the absence of a concept of natural law undermined Chinese science (though the Greeks had no such concept either), and that the division of social authority between a variety of ecclesiastical and temporal powers worked in favor of the West. As the argument goes, the fact that the West had no one dominant power center created a scope for science that was lacking in China. Finally, Needham claimed, Europe developed a mercantile class at an early stage, and its merchants became major "consumers" of scientific ideas, whereas their Chinese counterparts only managed to play a minor social role.[33]

In the case of Eastern Europe, it has been suggested that the mystical orientation of the Greek and Russian Orthodox faiths hindered them from developing the practical engagement with the world found in Western science.[34] If this is true, then mysticism was a much greater obstacle in Eastern Europe than in the Western tradition, which includes some mystical movements—Franciscan religious orders in the Catholic Church, for instance, or the Neoplatonic school in the Italian Renaissance—that had profound and constructive impacts on the history of science.

The unsatisfying thing about many histories of non-Western science is that they mainly attempt to explain why such-and-such a place did not give rise to what Western Europe did: science and technology as we have known them over the past few centuries. These "negative" accounts generally tell us more about Western science, and the intellectual and social factors that promoted its development, than about the non-Western systems of science or knowledge that are their nominal subjects. The current tendency in the historiography of Chinese and Arabic science is to emphasize the view "from the inside out," rather than assuming *a priori* that Western science is a universal standard.[35]

Another problem that surfaces when we compare Western and non-Western science is that it is not always clear precisely what achievement is being explained. Is it the birth of Western science as an overarching rational system for understanding and controlling nature? The aim of this book is to plausibly demonstrate that there is not just one form of Western scientific rationality; there are at least six. Although this book gives various examples of the intellectual links between science and technology,

the systematic exploitation of science for the purpose of technological advancement did not begin in earnest until the second half of the nineteenth century.[36] And it was not until after the Second World War that science and technology grew so tightly intertwined that "technoscience," a term many recent authors have used, emerged.

Yet the connection between science and power goes back much further. The link between power and knowledge is so close that it might almost be called intrinsic, yet this does not make the two identical. Might it not therefore be preferable to view the relationship between science and power as having a history of its own? Given the distinctions drawn here between styles of science, it even seems probable that each style bears a substantially different relationship to political and social authority.

The idea that scientific progress has led to the constant expansion of our power over nature is a romantic myth. Of course, the development of science and technology has tremendously enhanced our capacity to intervene in the natural and social worlds. But in this context, it is unhelpful to regard "nature" as singular. There is a particular historical period in which this tendency was strongest: the 1950s and 1960s, when the singular was used not only for "nature" but also for "science," and it was said that science should be approached through its (again singular) "method." As Jean-François Lyotard might say, that was a grand story—too grand, in fact. This book aims to tell stories of different natures.