Introduction

The legacy of Francis Bacon

English science in the seventeenth century acknowledged a great debt to the work of Francis Bacon (1561–1626). Today we value Bacon not so much as a scientist – he made no major discovery, formulated no scientific law, performed few original experiments – but as a propagandist for science who urged that "natural philosophy" be given a new importance in human affairs and be organized on a new plan. From his early masques and "devices" of the 1590s,[1] to the *Two Bookes of Francis Bacon. Of the Proficience and Advancement of Learning, Divine and Humane* (1605), expanded in the Latin translation of 1623 (*De Dignitate et Augmentis Scientiarum, Libros IX*), and the major works of the 1620s, the *Instauratio Magna* (1620), containing his *Novum Organum* or "New Instrument" of scientific method, the *New Atlantis* (1624), and the *Sylva Sylvarum: or a Natural History. In Ten Centuries* (1626), Bacon found time in a busy career in politics and law to formulate a new programme for science.[2] Some of his ideas, such as the attack on medieval scholasticism and its purely philological practice of science, had been expressed by others in the European Renaissance, but he was the first to develop a coherent critique of outmoded science and to suggest practical remedies, while no one else expressed these ideas so forcibly and so eloquently. Yet in the seventeenth century Bacon was actually revered as one of the pioneers in the new philosophy, both as a theorist and an experimenter, his fame spreading throughout Europe.

Bacon's new plan started by freeing the scientist from a reverential attitude towards antiquity. Whereas much medieval science derived from the text of the greatest classical authority, Aristotle, and his many commentators, Bacon exposed the limitations of such reverence in a striking metaphor: "Knowledge is like a water that will never arise again higher than the level from which it fell; and therefore to go beyond Aristotle by the light of Aristotle is to think that a borrowed light can increase the original light from which it is taken" (III, 227, 290; IV, 12). Further, Aristotelian science was a verbal science, passed

down in texts and commentaries, relying on a verbal discipline, logic, which can manipulate received ideas but not find out new sciences. "The syllogism consists of propositions, propositions consist of words, words are symbols of notions. Therefore if the notions themselves (which is the root of the matter) are confused and over-hastily abstracted from the facts, there can be no firmness in the superstructure" (IV, 49). The remedy, according to Bacon, was to start from a fresh examination of reality in all its detail, not rejecting, as earlier theorists had done, certain topics as trivial or sordid, and on the basis of observation and experiment gradually build up axioms or scientific laws of increasing generality and universality. From this level one could return to works, or specific man-made transformations of nature (IV, 24ff., 92ff.).

"All depends on keeping the eye steadily fixed upon the facts of nature", Bacon wrote, "and so receiving their images simply as they are" (IV, 32). The chief obstacle to this ideal of fidelity to experience is the propensity of the human mind to be deceived by phantoms or fallacies, what he called human "idols". Drawing on the original sense of the Greek word *eidolon*, "an image in the mind, a mental fiction", Bacon distinguished four types of misconception. The "Idols of the Tribe" concern human perception, which far from being absolutely objective and reliable varies according to the measure of the individual. The "Idols of the Cave" refer to each individual's "cave or den", those factors in his personality, psyche, or education that cause him to "refract or discolour the light of nature". Human communication is through language, and the "Idols of the Market-place" are the distortions caused by "the ill and unfit choice of words", which can obstruct and deceive the understanding itself. Lastly the "Idols of the Theatre" are all extant philosophical systems, which are "but so many stage-plays, representing worlds of their own creation" in an unreal and fictitious manner (IV, 54–5). The deficiencies inherent in human perception and communication must be overcome before the mind can enter into a true relation with the universe, from which marriage "let us hope ... there may spring helps to man, and a line and race of inventions that may in some degree subdue and overcome the necessities and miseries of humanity" (IV, 27). Bacon's whole system is directed towards producing inventions and processes which will be useful to man, not in the debased modern sense of "utilitarianism" (in which material profit is pursued without concern for ethics), but in the older traditions of the *vita activa* or involvement in society for the benefit of others (an idea that goes back to Plato and Cicero), and Christian charity. In Bacon "usefulness" is equivalent to "phil-

anthropy".[3] The scientist in the *New Atlantis* is described as having "an aspect as if he pitied men" (III, 154).

Bacon's system was designed to unite "the empirical and the rational faculty" (IV, 19), that is, the powers of observation and theory. Once the mind has become a *tabula abrasa* (IV, 27), it could begin to classify the sciences, find where research is needed, and then evolve "Directions concerning the Interpretation of Nature", the new logic worked out in most detail in the *Novum Organum*. Where traditional logic operated deductively, from first principles down to ever more minute distinctions, Bacon would reverse the process by using induction, ascending from a host of specific instances to general propositions. At this stage experiments would be used, but not in a hasty way, nor designed for a swift material application. The scientist must use "experiments of light" to induce new axioms, but he must also proceed deductively to generate "experiments of fruit" that will produce new works (IV, 71, 95). Experimentation must not be random, rather, experiments must be "skilfully and artificially devised for the express purpose of determining the point in question" (IV, 26). In order to prevent an over-development of the theoretical phase recourse must be constantly made to "the Phenomena of the Universe; or a Natural and Experimental History for the foundation of Philosophy" (IV, 22). Bacon proposed the compilation of a "History" – in the sense of a systematic analysis, not necessarily diachronic – of all the phenomena of nature, adding a list of over a hundred suggested titles to his *Preparative* (IV, 265–71). In the frantically busy last years of his life he produced a specimen *Historia Naturalis et Experimentalis*, with histories of the winds (II, 7–78), of life and death (II, 101–226), and of the dense and rare (II, 241–305).

Yet Bacon was not a mere fact-collector. This amassing of concrete observation and experimental results was to form the basis of the last three stages of his *Great Instauration*, his restoration or renewal of science. Next would come the "Ladder of the Intellect", moving from specific phenomena up the ladder of axioms to the "summary law of nature" (IV, 31). This would be followed by "Anticipations of the New Philosophy" (IV, 31–2), tentative generalizations – in effect, hypotheses – to be tested by further observation and analysis. Finally, the Baconian scientist would reach "the New Philosophy or Active Science", the complete system ascending through axioms to natural laws and descending to works (IV, 32–3). Since Bacon only completed fragments of the whole scheme, mostly the earlier parts concerned with the collection of data, he has been wrongly accused of advocating a random amassing of facts: but his plan involved theory and

hypothesis as an organic part of the enterprise. The whole system would be a work of many years and of many hands, for Bacon foresaw that large scientific enterprises would only be possible given collaboration and co-ordination. In his Utopian fable, *New Atlantis* (written *c.*1624) he outlined a whole scientific research institute, with a fully worked out division of responsibilities. He also saw that at many levels science would depend not on geniuses but on people of ordinary ability, trained to perform specific but limited tasks. Unlike the great individualists of the scientific revolution – Galileo, Kepler, Descartes, Newton – Bacon was thinking in terms of institutions that would channel scientific research and then apply it to the benefit of society at large. His achievement was lesser than theirs, of course, but he did redirect attention to several important aspects of science.

The next generations certainly gave him all credit for his programme and for the vision of ultimate success that he so memorably formulated. As a master of rhetoric Bacon used his skills of persuasion to stimulate his readers to the practice of science in the conviction of its value to humanity.[4] Although it has been claimed that Bacon only influenced minor and eccentric figures,[5] in fact many of the leading English scientists between 1630 and 1680 acknowledged the inspiration they had drawn from him.[6] William Petty described Bacon as "the Master-builder" of the revival of science, praising his "most excellent specimen" of a history of nature, and his "exact and judicious Catalogue" of particulars.[7] Petty's plan to compile a History of Trades (that is, Crafts) – a project that occupied many writers, from Boyle to Defoe – owed its inspiration to Bacon, as did his project to found a "mechanical and medical college". Sir Thomas Browne's *Pseudodoxia Epidemica* (1646) offered a catalogue of "vulgar errors" as proposed by Bacon (III, 221; IV, 169, 295). Robert Hooke's *General Scheme, or Idea of the Present State of Natural Philosophy, and how its defects may be Remedied by a Methodical Proceeding in the making Experiments and collecting Observations. Whereby to Compile a Natural History as the Solid Basis for the Superstructure of True Philosophy*,[8] is a fantasia on Baconian themes, a digest of the *Novum Organum*. Henry Power, one of the pioneers in microscopy, described Bacon as "that Patriark of Experimental Philosophy".[9] Thomas Sydenham, one of the outstanding doctors of the period, who laid the foundation of the practice of clinical medicine in England, described Bacon as "that great genius of rational nature".[10] Robert Boyle, second only to Newton as a scientist, collected material for a continuation of Bacon's *Sylva Sylvarum*,[11] unstintingly praised "the illustrious Lord *Verulam*, one of the most judicious naturalists

that our age can boast", "that great and solid philosopher", "one of the first and greatest experimental philosophers of our age",[12] and produced an influential work in the Baconian tradition of philanthropy, *Some Considerations touching the Usefulness of Experimental Natural Philosophy* (part I: Oxford, 1663; part II: Oxford, 1671).[13] Bacon remained a figure of inspiration and emulation.

The Royal Society

When the Royal Society was officially founded in 1662, it united several strands of scientific activity. One group of scientists had started meeting in London in 1645, including John Wallis (1616–1703), the mathematician; John Wilkins (1614–1672), and Jonathan Goddard (?1617–1675). They sometimes met in Gresham College, a centre for practical education in the vernacular founded in 1597, which was later to be the home of the Royal Society for many years. Independent of this group were the scientists (especially Boyle and Petty) connected with Samuel Hartlib, the indefatigable Puritan educational reformer, who poured out an unceasing flow of ideas and projects. Robert Boyle wrote in 1646–7 of the "*invisible* ... *philosophical college*" surrounding Hartlib, its "midwife and nurse", and described his own studies in "natural philosophy, the mechanics, and husbandry, according to the principles of our new philosophical college, that values no knowledge, but as it hath a tendency to use".[14] The Baconian influence on Hartlib's circle was enormous. His son Clodius, a chemist, wanted to establish, with Sir Kenelm Digby, "an universal laboratory ... as may redound, not only to the good of this island, but also to the health and wealth of all mankind", and in May 1654 Hartlib wrote to Boyle about a visit he had made to Lambeth Marsh "to see part of that foundation or building, which is designed for the execution of my lord *Verulam*'s *New Atlantis*".[15] This project, never realized, was one of a number of contemporary schemes for setting up scientific research institutes, by Hartlib, Evelyn, Cowley, and the continuator (probably Robert Hooke) of Bacon's *New Atlantis* in 1660.[16]

A third group, including some of those who had met in London, gathered in Oxford following the appointment of Wilkins as Warden of Wadham College in 1648. They attracted a distinguished group of younger men: Boyle, Petty, Seth Ward (1617–1689), Thomas Willis (1621–1675), Richard Lower (1631–1691), and Robert Hooke (1635–1702). This group joined forces with those scientists who had

continued to meet in London, and on 28 November 1660, in the rooms of Lawrence Rooke, professor of geometry at Gresham College, following a lecture by Christopher Wren, professor of astronomy, they formally constituted themselves into an academy "for the advancement of various parts of learning". Charles II awarded them their charter in 1662, and in the frontispiece to Thomas Sprat's *History of the Royal-Society* (1667) the King shares the honours with the first president, William, Viscount Brouncker, and Francis Bacon, "*Artium Instaurator*". A key figure in the early years was Henry Oldenburg, Secretary from 1662 until his death in 1677, who carried on Hartlib's tradition of collecting and disseminating information. Bacon, as Paolo Rossi has shown,[17] had made a decisive break with the magical and occult traditions, which kept knowledge secret among the initiated, urging that it was a common good, to be shared by all. (In the *New Atlantis*, however, he recognizes that some scientific discoveries must be restricted, in the national interest: p. 43 below.) The ethos of free circulation of knowledge, so important in the *respublica litterarum* of the seventeenth century, was widely applied to science, as in Sprat's vigorous advocacy of its advantages (pp. 165–6 below). Oldenburg made scientists communicate their discoveries, which he would pass on in correspondence or publish in the Society's own journal, *Philosophical Transactions*, which he edited with enormous industry and enterprise. He instigated the full Baconian programme of natural philosophy, declaring the Society's business to be "in the first place, to scrutinize the whole of Nature and to investigate its activity and powers by means of observations and experiments; and then in course of time to hammer out a more solid philosophy and more ample amenities of civilization". Where Bacon, at the age of 31, had written "I have taken all knowledge to be my province" (VIII, 109), Oldenburg reminded a correspondent "that we have taken to taske the whole Universe, and that we were obliged to doe so by the nature of our dessein".[18]

The Royal Society was not only a clearing-house for information but also a research centre in the sense that its weekly meetings included experiments (for many years performed by that mechanical genius Robert Hooke), which were commented on both orally and in the pages of the *Transactions*. Many scientists associated with the Society continued to work independently, often on private means (unlike present-day institutions it did not receive lavish government support), but still used its meetings to acquire and exchange information. There was no guiding principle for selecting or systematizing experiments, and the accounts of their activities given by Sprat, or

recorded in the *Transactions*, reveal a bewildering spread of energy into every possible area, important or trivial. The catholicity of their interest was a weakness in terms of organized, directed research, but a strength in so far as it allowed little of any importance to escape them. Yet their activities were not unanimously approved. Many critics wanted instant proofs of the success of the experimental method, and the question "what have they done?" was one that apologists, such as Sprat, Glanvill, Hooke, and Wallis, attempted to answer.[19] Some of the critics were disgruntled academics from Oxford and Cambridge, hostile to the growth of the new science, or concerned that their own prestige was at stake.[20] Others were conservatives or reactionaries who defended the philosophy of Aristotle as all-sufficient. Although some contemporary historians have championed the opponents, and although the achievements of the Royal Society by 1670 were not as great as might have been hoped, the work of Boyle, Hooke, Ray, Willughby, Wren, and Newton is ample justification for the existence of this institution.

The works represented here have been chosen to illustrate the main course of English science in this period. With the exception of one work by Bacon, originally written in Latin, whose importance was such as to justify the use of a translation, I have chosen texts written in English, even though this has meant excluding a number of major works. Various themes in the scientific tradition can be followed through these selections. One is the relation between science and religion.[21] While the critics of the new philosophy accused it of promoting atheism, Bacon had already produced a reasoned defence of the investigation into God's created universe from the charge of prying into "forbidden knowledge", and the scientists represented here are orthodox Christians, like Bacon. Both Henry Power and Robert Hooke are moved by the discoveries revealed by the microscope to exclaim at the beauties of creation and the skills of God, while Boyle and Newton, like all their contemporaries, believed in God as the first cause of creation.

Another specifically scientific issue reflected here is the rise of the "mechanical" or "corpuscularian" philosophy, a movement that united several philosophical traditions, including Epicurean atomism and Aristotelian concepts of "minima".[22] In his *Sceptical Chymist* (1660) Robert Boyle, having destroyed both the Aristotelian and the Paracelsian theories of the elements, modestly and diffidently introduced his own belief that the ultimate constituents of the physical universe are matter and motion. In *The Excellency and Grounds of the Mechanical Hypothesis* (1674) he developed this theory, which by then

Hooke had also adopted.[23] The source for both men was Descartes, whose theory of matter had a considerable influence on English science, even though he was criticized for his tendency to create a scientific system by pure deduction rather than by observation and experiment. Here the Baconian influence is again evident, in the distrust of systems as forming a too premature conclusion to the enquiry (Bacon preferred to write in aphorisms to avoid the sclerosis imposed by a system; Boyle chose the essay for the same reason), and in the suspicion of *a priori* experimentally indefensible hypotheses. Baconian science was to be "grounded" upon experiment and observation, forming "solid" knowledge.

Science and language

Those typically Baconian metaphors for the new philosophy highlight one of the great critical issues in this period, the relation between science and language. A main stream of linguistic philosophy, from Aristotle to John Locke and beyond, had agreed that language was a conventional sign-system, where words represent concepts according to agreed social usage. As Bacon put it, "words are but the current tokens or marks of Popular Notions of things" (III, 338). Thinkers in this tradition were agreed in condemning the magical concept of language, in which words were not arbitrary combinations of letters and sounds but somehow contained the essence of the thing they denoted.[24] Yet while we can observe this broad distinction between the occult tradition and the new experimental philosophy, Bacon drew attention to some dangers in the way that non-occult scientists used language, dangers inherent in language itself. In the "Idols of the Market-place" he noted that the "ill and unfit choice of words" can produce confusion and "idle fancies". Two kinds of false appearance are created by words. The first occurs when *res* and *verba*, subject-matter and language, do not correspond. Words mislead when they "are either names of things which do not exist", "fantastic suppositions" such as "Fortune", the "Prime Mover" and the "Element of Fire", or such vague abstractions as the concept "humid", which cannot be "reduced to any constant meaning". The second illusion occurs when words are "names of things which exist, but yet confused and ill-defined, and hastily and irregularly derived from realities". Some thinkers have concluded that the problem of ambiguity can be overcome by the use of strict definitions, but Bacon saw that "even definitions cannot cure this evil in dealing with natural and material

things; since the definitions themselves consist of words, and those words beget others: so that it is necessary to recur to individual instances" (IV, 61–2). Science must address the natural world directly while purging language of its imperfections.

In his *Parasceve*, or *Preparative towards a Natural and Experimental History*, appended to the *Novum Organum*, Bacon outlined the principles for collecting the observations of nature on which axioms or general laws would be established. The scientist must inspect nature at first hand, and do away "with antiquities, and citations of authors", that is, all literary traditions not tested against reality.

> And for all that concerns ornaments of speech, similitudes, treasury of eloquence, and such like emptiness, let it be utterly dismissed. Also let all those things which are admitted be themselves set down briefly and concisely, so that they may be nothing less than words. For no man who is storing up materials for ship-building or the like, thinks of arranging them elegantly . . . all his care is that they be sound and good, and that they be so arranged as to take up as little room as possible in the warehouse. (IV, 254–5)

Bacon's injunctions apply only to the establishment of a body of scientific data, not to language as a whole. As Peter Shaw commented in 1733, "the business is not now to gain upon Men's Affections, or win them over to *Philosophy* by Eloquence, Similitudes, or the Art of Writing; which the author practised in *De Augmentis*; but carefully to enquire into, and firstly to copy and describe Nature as she is in herself; and there the Style cannot well be too plain and simple".[25] When the statutes of the Royal Society were published in 1728 they included the article that "In all Reports of experiments to be brought into the Society, the Matter of Fact shall be barely stated, without any Prefaces, Apologies, or Rhetorical Flourishes. . . ."[26]

Bacon's distinction between the proper language for recording observations and experiments, and language in all other contexts, where appeal from and to the imagination was legitimate, was correctly understood by many seventeenth-century writers. In his *History of the Royal Society* Sprat praised Bacon's "strong, cleer, and powerful Imaginations", expressed in a "vigorous and majestical" style, "the Wit Bold, and Familiar: The comparisons fetch'd out of the way, and yet the most easie" (p. 36). In their published work scientists showed themselves to be well aware of the hazards of language. Robert Boyle prefaced his collection of *Physiological Essays* (1661) with "Some Considerations touching Experimental Essays in general", preferring the essay for its unsystematic and discursive form, and announcing that as far as style is concerned, he had

endeavoured to write rather in a philosophical than a rhetorical strain, as desiring that my expressions should be rather clear and significant than curiously adorned ... And certainly in these discourses, where our design is only to inform readers, not to delight or persuade them, perspicuity ought to be esteemed at least one of the best qualifications of a style; and to affect needless rhetorical ornaments in setting down an experiment, or explicating something abstruse in nature, were little less improper than it were (for him that designs not to look directly upon the sun itself) to paint the eye-glasses of a telescope, whose clearness is their commendation, and in which even the most delightful colours cannot so much please the eye, as they would hinder the sight.[27]

Nevertheless, the "dull and insipid way of writing which is practised by many chymists" should be avoided, for a philosopher's style should not "disgust his reader by its flatness" (p. 304). Boyle's analogies are economical, and effective.

Robert Hooke was equally concerned to find the appropriate style for science. In his *General Scheme or Idea of the Present State of Natural Philosophy* he follows Bacon closely, cautioning that we be "very careful in what Sense we understand Philosophical Words already in use", which are bound to reflect prejudice and confusion. As things stand, the "Philosophical words of all languages ... seem to be for the most part very improper Marks set on confused and complicated Notions", so that "the Reason of a Man is very easily impos'd on by Discourse".[28] One remedy is to invent new words, then abandon the old and erroneous terms. In registering experiments the words chosen must contain nothing superfluous, and be

such as are shortest and express the Matter with the least Ambiguity and the greatest Plainness and Significancy ... avoiding all kinds of Rhetorical Flourishes, or Oratorical Garnishes ....

If possible the matter should be treated like "Geometrical Algebra, the expressing of many and very perplex Quantities by a few obvious and plain Symbols".[29] In the Cutlerian Lectures delivered to the Royal Society Hooke certainly followed his own recommendations. In the lectures on light, delivered in 1680, he complains that most extant definitions of light have confused the issue, writers having "spoken of it as it were Metaphorically and by Similitudes", their science consisting of "Rhetorical Embellishments, and no way tending to the Physical Explanation of its Effects and Proprieties" (that is, properties).[30] In his *Discourse of the Nature of Comets* (1682) Hooke pauses to take care

that I may not be mistaken in Expressions, and that the words I make use of, which are commonly used but by various Men are understood to signify various and very differing notions ....