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Coming to Terms with the Scientific Revolution[1]

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Was there a Scientific Revolution at any time between 1550 and 1800? The question comes to asking whether 'revolution' is a good metaphor for the course of natural knowledge during early modern times. According to the findings presented here, the metaphor is useful, that is, productive of insights, if it is taken in analogy to a major political revolution. It then suggests a later onset, and a swifter career, for the Scientific Revolution than is usually prescribed, and reveals Newton not as its culmination but as its counterpoise. The analysis also discloses an unexpected analogy between the universities of the thirteenth century and the learned societies of the seventeenth.

Words of wisdom

In a paper published in 1988, Tore Frängsmyr argued that, since language is the main tool of the historian, and metaphors, similes, and analogies are principal ingredients of language, we should take care to use them unambiguously. He finds that metaphors are for historians what models are for scientists, that is, heuristic approximations, not literal truths. 'Scientific Revolution' is such a metaphor. It must be understood as a model, not as a well-defined series of historical events, much less as a recurrent historical pattern.[2] In fact, if I understand him correctly, he thinks we would be better off avoiding the term 'scientific revolution' altogether.[3] That might be the best advice available.

I have not taken it. Instead, I distinguish between revolutionary ideas, revolutionary situations, and revolution. As for revolutionary ideas, I need say no more than that where they are encouraged and rewarded, there is no end to them. I take the notion of a 'revolutionary situation' from the great authority on political revolutions, R.R. Palmer. According to him, a revolutionary situation develops when people lose confidence in existing law and authority, when they reject obligations as impositions, regard respect for superiors as humiliation, and condemn privilege as unfair and government as irrelevant. A people or nation thus afflicted has lost its sense of community and is ripe for revolution. A revolution need not ensue, but the social and institutional base must suffer a significant alteration to avoid one.[4]

We must not take a revolutionary situation for a revolution. Thus, when Galileo cried out while lecturing on Aristotle's theories of motion, 'Good Lord! I am so tired and ashamed of having to use so many words to refute such childish objections as Aristotle['s]',[5] he expressed the rejection of authority, and the feeling of imposition and humiliation in having to respect it, typical of a revolutionary situation. Galileo did not convert his revolutionary situation into a revolution. He was a Voltaire rather than a Robespierre – witty, cutting, brilliant, a master of language, an ambitious courtier, an incisive critic, but not a fierce destroyer of the old with a grand vision of the new.

Cut and try

A popular question with those who search for the origins of modern science is, 'why was there no scientific revolution in China, or in ancient Greece, or in the Abbassid Empire'? A more pertinent question is, 'why was there no scientific revolution in the Europe in the late sixteenth century'? Many of the primary ingredients in the standard histories of science were by then available: Copernicus' *Revolutions* and Vesalius' *Fabrica*, which set the bases for a new astronomy and a new anatomy; the warlike bombast of Paracelsus and the new logic of Petrus Ramus; the mathematical ways of Archimedes and Plato; the secrets of Hermes, the natural magic of della Porta, and the technologies of Agricola and Biringuccio. These and other novelties, notably reports from the new world of exotic floras, faunas, and people were disseminated quickly in standard editions by a printing industry then a hundred years old. And yet no revolution in natural knowledge resulted. The schools took cognizance of the new facts, patched their teachings where necessary, and became more dogmatic as experience, information, and expectations at odds with their principles accumulated.

One reason for the failure of the revolutionary situation of 1550 to become a revolution was the engagement of many of the best minds in Europe in doctrinal disputes and the wars of the Reformation. Thomas Sprat, the historian-apologist of the Royal Society of London, observed that for many years before he wrote in 1667, an 'infinite number of Wits … [had] been chiefly taken up about … the *Writings* of the *Antients*: or the *Controversies* of *Religion*: or *Affairs* of *State*'. The engagement of only a few wits in natural philosophy had the result, as Sprat put it, that 'knowledge of nature has been very much retarded'.[6] We must keep firmly in mind that we deal with relatively small numbers of people, perhaps no more than a thousand when the putative Scientific Revolution was in full swing. A main subject of our inquiry must be the origin and recruitment of a sufficient number of revolutionaries to vanquish the old guard.

The Peace of Augsburg of 1555 did not open a period of leisure for the engaged learned. It was but a pause. Where Rome could exercise power, the new machinery of the Counter Reformation, especially the decrees of the Council of Trent and the operations of the Society of Jesus, enforced a doctrinal conformity little conducive to innovation in natural philosophy. The retrospective appointment of Thomas Aquinas as doctor of the Roman Catholic Church created an unprecedented and unfortunate unity of philosophy and theology. As Descartes put the point in 1629, 'theology … has been so subjected to Aristotle that it is almost impossible to set out another philosophy without its appearing at first contrary to faith'.[7] The Tridentine inter-disciplinary synthesis made it more difficult than ever to topple the teachings of the schools in Catholic countries – especially since the Jesuits ran the best schools. The situation came to a head with the trial and condemnation of Galileo in 1633. That made him a martyr of the ensuing revolution, but not its instigator.

Again, a look at the political situation during the first half of the seventeenth century suggests why the pursuit of natural knowledge did not have high priority in Europe then. The Thirty Years War had devastated the German states and absorbed the energies of what would be the Dutch Republic. England went from Civil War to Puritan crackdown to, in 1660, the Stuart restoration. France ruined itself in the Thirty Years War, the subsequent Frondes, and its private war with Spain, which dragged on until 1659, the year when Louis XIV reached his majority and began to reign on his own. Not until the second half of the seventeenth century was an exhausted Europe able to devote what energy it had left to improving and disseminating natural knowledge. After a century of war and strife, an investment in the arts and sciences, especially in sciences removed from theology, and a measure of tolerance in their pursuit, seemed a promising way simultaneously to soothe and advance society.

Sprat's 'history' stressed the importance of a place where people who might not agree on politics or religion could meet civilly and productively over a common interest in what the Royal Society's charter called 'natural knowledge'. The membership agreed not to take up contentious topics – religion specifically – likely to produce altercation and disintegration.[8] In their book, *Leviathan and the Air Pump*, Steve Shapin and Simon Schaffer developed this theme from Sprat into a model of what they call the 'experimental life'. In their interpretation, the circle around Robert Boyle, the Society's most prolific aristocratic experimentalist, aimed to create matters of fact beyond dispute, and unassertive, eclectic theories about them that did not provoke unpleasant confrontations.[9]

Another connection between the coming of peace and the promotion of natural philosophy was the air pump, the era's showcase weapon in the hunt for natural knowledge. Its inventor, Otto von Guericke, an engineer who served as mayor of Magdeburg, brought this fruit of his scarce leisure to the Imperial Diet convened in Regensburg in 1654 to plan the rebuilding of the Empire after the catastrophic Thirty Years War. His purpose in bringing the machine was to entertain his fellow delegates while they rested from their labours. Guericke was a Lutheran. Among the delegates at Regensburg was the Catholic Bishop of Würzburg. He took a great interest in Guericke's spectacular demonstrations of the power of nothing, bought the pump, and presented it to the Jesuit College in Würzburg. There the professor of mathematics, Gaspar Schott, set about analyzing and improving the pump. His account of what he called the Magdeburg experiments, published with Guericke's permission, carried news of the machine even to England, where the Anglicans Boyle and Hooke made their version. This vignette, like Sprat's apology for the Royal Society, directs our attention to the 1650s and 1660s as a period of dramatic change in the material circumstances in which natural knowledge was cultivated, and in the level of religious toleration in the republic of letters.

Four years after the restored Stuart King Charles II chartered the Royal Society of London, the recently mature and secure Louis XIV set up, as a sort of government bureau, the Académie Royale des Sciences. The establishments of the French and English kings followed by only a few years the Accademia del Cimento, created in 1657 by the Grand Duke of Tuscany and his brother to carry out experiments with a minimum of theorizing. The Florentine academicians were to proceed by trial and error, *provando* and *riprovando*, testing and retesting matters of fact.[10] Unlike the royal academies of experiment in France and England, the Cimento did not survive very long, but its example nonetheless inspired many imitators in Italy and the German States. Before 1650 there were at most two or three short-lived academies of experiments, and these quite insignificant despite Galileo's pride in belonging to the Lincei; in the second half of the seventeenth century, many were founded, some with royal or high ecclesiastical patronage.

Relative peace and effective organization do not make a revolution, however. Indeed, they seem rather opposed to a metaphor suggesting violent change. But then, the institutions that support the body of knowledge do not define it. We can have a violent alteration in ideas and practices that make use of organizations that were not established to change anything violently. That is what happened in natural knowledge in the second half of the seventeenth century, when ideas opposed to established learning took root in experimental academies. A possible comparison is the revolution caused by the rapid invasion of the newly created universities of the thirteenth century by the then newly recovered *libri naturales* of Aristotle. I offer this possibility as the first fruit of my inquiry. It suggests that the same coincidence of novel philosophy and fresh institutions that put Aristotle's system at the centre of European philosophy in the thirteenth century removed it to the periphery in the seventeenth.

The ingredients

I take from the preceding analysis the claim that our revolution in knowledge awaited the advent of political and social peace and reconstruction in Western Europe. Also by good luck, the ingredients that came together at this unusual juncture were just those normally required to make a good political revolution: a powerful program to supplant established ways and teachings, the existence of vigorous well-educated cadres devoted to the program and the creation of new institutions and instrumentalities with which to preserve the gains of the cadres.

The program

The revolutionary program appeared in its definitive form in 1644, as the *Principia philosophiae* of René Descartes, which was soon translated into French, reduced to manuals for teachers and, in so far as it pertained to natural knowledge, reworked into physics texts and demonstrations that attracted wide audiences outside the schools. I certainly need not rehearse for you the details of Cartesian physics – the distinctive universe of stars and tourbillons, of comets, moons, and planets swimming in vortices, of particulate streams that cause magnetism, of levers and springs and bellows that make up animal bodies, and so on. All this is as intelligible now as it was then, although no doubt it is not as compelling to us as it was to the expectant disciples Descartes had begun to collect on the strength of his *Discours de la méthode* (1637), his directions for the correct manner of reasoning.

Three mutually reinforcing factors gave Cartesian natural philosophy its revolutionary power. For one, it did away in one stroke with the scholastic bric-a-brac of forms, essences, potentialities, acts, sympathies, antipathies, and *qualitates occultae*. Where Aristotle populated the world with irreducible natures, Descartes insisted on explaining all the phenomena that fall under our senses as consequences of matter and motion. To be sure, the transfer of motion in collisions may be no more intelligible than an occult quality.[11] But even if we do not understand the metaphysics of collisions, we have intuitions about mobility, rest, size, and shape that enable us to reason further about the constitution and activity of the world – if we assume that it consists only of matter and motion. An Aristotelian, in contrast, could not deduce from his concepts of 'dogginess' and magnetism whether or not a dog is a magnet.

One of Descartes' ambitions was to live long enough to put medicine on as firm a foundation as the physics of the solar system.[12] He conceded that a great amount of experiment was necessary to determine which of the many ways he could conceive for the mechanical operation of the body God in fact had chosen. Once these ways were known, reason, exploiting the intelligibility of mechanical interactions, would swiftly find the means to promote health and longevity. This intelligibility came not only from everyone's intuition of extension and motion, but also from Descartes' mastery of mathematics. The geometrical ingredients of his vortical universe all lent themselves to mathematics.

Although few of Descartes' mechanisms ever in fact felt the yoke of mathematics, the possibility he revealed of a mathematical physics was as radical and exciting as the premise that everything is matter and motion. The school philosophy held in general that mathematics could not attain to truth, and hence had no significant use in natural philosophy. As exact description it had its utility, for example, in computing the positions of the sun, moon, and planets for navigational or calendrical or astrological purposes; but since the machinery for astronomical calculation was arbitrary and opportunistic, neither its successes nor its failures could confirm or refute physical principles. Nor was mathematics considered a useful tool of exploration in physics. 'After a great deal of calculation … I do not see any fruit other than a chimerical proportion, which reveals nothing about the things that are real in nature'. Thus, André Graindorge, cofounder of the Académie Royale de Physique of Caen, expressed the widespread view that mathematics could at best describe accurately the least interesting features of the physical world.[13] In Descartes' system, mathematics was neither opportunistic nor irrelevant. He derived the existence and nature of the world-moving tourbillons, and also their laws of motion, from first principles. Philosophers who were also mathematicians could develop Cartesian physics and bring to bear the great advances in mathematics achieved during the seventeenth century, not least by Descartes himself, confident that they reasoned from a true world picture.

The third thread in Cartesian natural philosophy (besides its rejection of scholastic forms and its privileging of quantifiable concepts) was its comprehensiveness. Here, a comparison with the writings of Francis Bacon is useful. As a critic of scholastic philosophy, Bacon was more effective than Descartes; and, as a methodologist, he offered a fuller and, as it turned out, a better long-range plan for achieving a new philosophy. But he did not get there himself, and made no use of Galileo's physics, Gilbert's magnetism, or Kepler's optics and astronomy. And even if Bacon had known how to appreciate these fragments, he would not have been able to unseat the school philosophy. Quantified *disjecta membra* do not make a physics, or even, in the eyes of the seventeenth century, a start on one.

We know that there is no truth in the application of mathematics in the absence of physical principles known to be sound prior to quantification. But that is not the main reason that Bacon could not have made a sound physics from the pieces that Galileo, Gilbert, and Kepler supplied. The main reason is that philosophers abhor a vacuum even more than nature does. 'I have no reason to believe that vacuum does not exist', says Guarino Guarini, 'except that I have not seen completely convincing proofs; and without them, I have seldom left my Aristotle'.[14] Descartes invoked this *horror vacui* – let us call it the first law of philosophy – in his evaluation of Galileo's *Discourses on Two New Sciences* (1638), one of the key texts of the usual account of the Scientific Revolution:

> I find that he philosophizes much better than is usual because he rejects the errors of the schools as far as he can and tries to examine physical matters with mathematical reasoning. I agree entirely with him in that, and believe that there is no other way of finding the truth. But it seems to me that he lacks a lot since he continually digresses and does not stop to explain anything thoroughly, which shows that he has not examined things in order; without investigating the first causes of nature he has only tried to give reasons for some effects and so he has built without foundations ….[15]

This is of course nonsense, as is much else in Descartes' physics, but you do not have to be right to make a revolution. You have to have a comprehensive programme.

The cadres

Cartesianism quickly gained influential recruits throughout the Republic of Letters. At the top was Queen Christina, whose interest proved as fatal as it was flattering. A lesser and safer princess was Elizabeth of Bohemia, a good mathematician and metaphysician in her own right, who helped disseminate Descartes' ideas. In an instructive letter, she described to him the conversion process of a doctor Weis, whose confidence in Aristotle and Galen had been shaken by reading Bacon. That had not made him abandon the ancients. But, Elizabeth reported, 'your *Méthode* made him reject it altogether and [moreover] convinced him of the circulation of the blood, which destroys all the ancient principles of medicine'.[16]

There are at least three significant points about this short story. Firstly, in keeping with the horror vacui philosophici, Weis could not abandon Aristotle without an adequate replacement. Secondly, Weis' *itinerarium ad veritatem*, beginning with Bacon's condemnations and compilations and ending in Cartesian truth, became a standard route, and was the path recommended by Descartes himself.[17] Thirdly, Descartes' concept of a living body as a machine perfectly accommodated the discovery of the circulation of the blood, although Descartes rejected Harvey's identification of the heart with a pump.[18] Up-to-date physicians, especially younger ones, found Cartesian philosophy a welcome weapon in their fight against Galenic physiology and professional conservatism.

These modernizing doctors made a strong and effective cadre. They pushed Descartes' ideas into the medical schools beginning with Utrecht and Leyden in the 1640s and 1650s, whence Cartesianism spread throughout Europe.[19] An early and persistent example is Naples, where physicians marched under Descartes' banner against the educational and political establishment on and off throughout the seventeenth century.[20] Despite its deserved reputation for conservatism, the medical profession played an important part in fomenting scientific revolution. So did lawyers. In France, Cartesian doctors made common cause with lawyers, with the *noblesse de robe*, from whom Descartes sprang. A group supported by Henri de Montmor, a lawyer in Paris, pushed the Cartesian philosophy to the doorstep of the Académie royale des sciences, albeit with a litigious spirit perhaps too lively for the republic of letters.[21] Popular lecturers on the physics of tourbillons made a good living catering to doctors, lawyers, and ladies.[22]

The universities also furnished cadres for the revolution. As an extreme example, I offer you the English, who tend to be over-susceptible to French philosophy until, on more mature judgement, they reject it altogether. Smitten with Descartes in the 1650s, Oxbridge dons extolled him as 'incomparable', 'precious and incomparable', 'most excellent', 'the miracle of men'.[23] According to the Cambridge philosopher Henry More, Descartes was the 'very secretary of nature', far more penetrating than Galileo, indeed, than everyone and anyone: 'all those who have attempted anything in natural philosophy hitherto are mere shrimps and fumblers in comparison'.[24] A more representative example is Petrus Hoffwenius, whom I choose as standard-bearer only because he taught at Frängsmyr's university. Hoffwenius drank directly from the Cartesian spring in Leyden before setting up as a satellite fountain in Uppsala in the early 1660s, where and when he began to open the mechanical worldview to students of medicine.[25]

The professional people and professors who made up the Cartesian cadres went to work, as revolutionaries do, on colleagues without fixed allegiances who were dissatisfied by all else on offer. These potential fellow travellers or, rather eclectics, adopted various forms of mechanical philosophy, paid lip-service at least to the rhetoric of mathematics, recommended and sometimes even practiced experiment, and brought forward useful things from the ancients. Their hero was Robert Boyle and their motto, '*Amicus Plato, amicus Aristoteles, amicus Cartesius, sed magis amica veritas*'.

Among the large and diverse group of fellow travellers even Jesuits could be found, for example, Gaston Pardies, whose colourful characterization of his position deserves to be preserved: 'Just as formerly God allowed the Hebrews to marry their captives after many purifications, to cleanse them of the traces of infidelity, so after having washed and purified the philosophy of M. Descartes, I could very well embrace his opinions'. Descartes' 'new way of philosophizing [is] much more valuable than the philosophy itself, a good part of which is false, or very uncertain,' said Fontenelle. '*Il faut admirer toujours Descartes, et le suivre quelquefois*'.[26]

The cadres and fellow travellers met strong resistance. The curators of the Dutch universities under attack by Cartesian doctors prohibited the teaching of any philosophy but Aristotle's.[27] The Paris Parlement reaffirmed an edict it had passed in 1624, prohibiting the teaching of any philosophy but Aristotle's.[28] The Archbishop of Paris shut down public lectures on Cartesian physics; the Holy Office in Rome condemned the *Principia philosophiae*; the Jesuits proscribed Descartes' writings again and again within their own order and initiated the proceedings that placed his works on the Index of Prohibited Books.[29] The Papal and Spanish authorities occasionally jailed the Cartesian doctors and lawyers of Naples.[30] Under pressure from theologians, the Swedish Rigsdag condemned Cartesian philosophy in 1664, just after the Roman Catholic Church had indexed it and largely for the same reason, its bearing on the doctrine of the Eucharist.[31]

Our revolutionary model requires that we follow these battles and report the changing fortunes of the two sides, expecting, as was the case, different sorts and levels of conflict in different theatres of war. The most dramatic and instructive confrontations occurred where the Roman Catholic Church was strongest, the least exciting and instructive where representative government had a grip. In England, the Scientific Revolution was as bloodless as the Glorious Revolution, which deposed the Catholic King James II almost without firing a shot. Our model directs our attention away from England. It is a mistake to derive general lessons about the Scientific Revolution, much less about science in general, from the doings of Robert Boyle.

The smoke cleared around 1700. By then, or shortly after, even the Jesuits allowed the teaching of Cartesian physics, albeit as a hypothesis, and by 1720, according to an old expert on the intellectual development of Italy, the moderns could anticipate a full and imminent victory.[32] On the other side of the aisle, the rector of the Calvinist Academy of Geneva urged Descartes' approach on his students and faculty. It was 'incomparable', he said, 'the best human reason has found', no less than 'royal', a great compliment in a republic.[33]

About the same time, in 1699, the Paris Academy of Sciences reorganized under its Cartesian secretary Fontenelle. In his éloges of deceased members, Fontenelle developed a standard account of enlightenment beginning with the discovery of Descartes and ending with admission to the pantheon of science. The Oratorian priest Nicolas Malebranche was exemplary. At first, owing to his scholastic education, he could read Descartes' natural philosophy only in homeopathic doses, as it gave him palpitations of the heart, ‘which obliged him sometimes to interrupt his reading’. With perseverance he learned to handle stronger doses, and so advanced from scholastic darkness to the light of mathematics and true physics and, in good time, to the comfort of a seat in the Paris Academy.[34]

The institutions and instrumentalities

We come to the academies, the institutions in which the gains of the revolution were preserved and multiplied. The Royal Society of London and the Académie Royale des Sciences of Paris are to the movement what Queen Christina and Princess Elizabeth were to the cadres, the peaks of the groups that formed during the second half of the seventeenth century to perform and witness experiments, learn and impart natural knowledge, and exchange the news and rumours of the Republic of Letters. There were academies around princes and prelates, librarians and lawyers, and, perhaps most significant of all, professors.

Let us begin with Italian examples: the Accademia fisico-matematica founded in Rome by Giovanni Giusti Ciampini;[35] the groups that gathered around Geminiano Montanari in Bologna and Padua;[36] and the Accademia degli Inquieti set up in Bologna by Eustachio Manfredi.[37] Ciampini, the impresario of the Rome academy, was a monsignore high up in the papal bureaucracy; his academy lasted twenty years, until his death in 1698. Montanari and Manfredi were professors of mathematics. Montanari’s academy at Bologna was a forerunner of Manfredi’s, which became the nucleus of the Bologna Academy of Sciences, one of the most important of the old academies. It still exists.

For a long time the leading member of Ciampini’s Accademia fisico-matematica romana was Francesco Eschinardi, professor of mathematics at the Jesuit College in Rome. He developed Galileo’s mathematics, experimented usefully on optics, and abhorred Galileo’s and Descartes’ cosmologies.[38] It may not be farfetched to compare his conservative moderating role in the academy to the effective collaboration between representatives of the lower clergy and the third estate during the early days of the French Revolution.

Montanari was a second generation Galilean and sometime collaborator of the Accademia del Cimento. He began teaching mathematics and astronomy at Bologna in the early 1660s and was soon offering instruction, in his own academy, in the sort of experiments that he had seen the Florentine academicians perform. As the capital of the Papal States, Bologna faced a censorship as strict as Rome’s; yet astronomy, mathematics, and physical experiments flourished there provided they were not exploited noisily in favour of novelty. At Padua, Montanari had a freer hand. He started a regular programme of observations, which resulted in the discovery of several comets and the variability of stars; and he gave a course of what he called ‘physical-mathematical experiments’, which he interpreted in the manner of Descartes. The participants in this course became the nucleus of an academy.[39]

Montanari's successor at Bologna, Manfredi, taught the same sort of things and in much the same way, but his situation in the Papal States bred in him a caution, even timidity, so great that his aptly named Accademia degli Inquieti had no need of external censorship.[40] In contrast, the short-lived Accademia degli Aletofili of Verona, established by Montanari's prize student Francesco Bianchini and some doctors dissatisfied with the usual teaching in the medical schools, asserted a vigorous corpuscularian research program. It languished not because of its advocacy of the mechanical and experimental philosophy, but because Bianchini moved to Rome, where he became a leading light in Ciampini's academy.[41]

These indications may lack the whiff of gun smoke. A few examples of the guerrilla warfare around the academies may therefore be in order. A priest was recommended to the Accademia del Cimento as sufficiently open-minded that 'he sometimes rejects Aristotle, in favour of some modern opinion … although he will hear nothing about the mobility of the earth; [still] I would guess that he could be persuaded quickly not to rail at that ingenious system so much, since he seems a man of honour [*Galantuomo*]'. This suggests recruitment on the basis of a proven record of eclecticism and gentlemanly behaviour, rather than on the basis of subscription to a particular world system. On the other hand, a 'rotten and mouldy [*marcio e muffo*] peripatetic', who wanted to appear 'a free and modern philosopher',[42] is blackballed; a revolutionary cadre must guard against infiltration. Or, to take a subtler means of cooptation, the censor who passed Montanari's major work in physico-mathematics, which describes experiments on capillary rise from a corpuscular point of view, judged that it disposed of many 'fallacies and discrepancies of the various philosophical schools … That obliges me to confess [he was a priest!] that sometimes experiment satisfies minds searching for truth better than speculation'. Decoded, this signifies that Aristotle is not to be preferred to modern explanations founded on or illustrated by experiments and suggests that the censor had enlightened himself by reading books as a consultant to the Index of Prohibited Books.[43]

Against this process of recruitment and cooptation, sterner censors and other guardians of the past could try to mobilize the church's formidable machinery of repression, which was not limited to the Index and the Inquisition. At Bologna in 1661 the medical faculty decided to require an oath of their students not to stray from Aristotle, Galen, and Hippocrates. In a later crackdown, a professor of medicine led an attack on the home of the modernizing doctor and naturalist Marcello Malpighi, a member and correspondent of the Royal Society of London, broke his instruments, and vandalized his library. It was not an isolated incident. But as princes like the Grand Duke of Tuscany appointed men more open to modern ideas to chairs of medicine, the counter revolution of the Galenists was turned; in 1714, thirteen cardinals and 50 prelates celebrated the gift to a teaching hospital in Rome of the large up-to-date library of the pope's modernizing physician, Giovanni Maria Lancisi.[44]

Like Italy, the German states had groups that cultivated experimental philosophy with one foot inside and the other outside a university. On the inside the doctoral thesis could serve as the vehicle for the student and professor to develop ideas or arguments around a set of experiments also viewed and perhaps performed by people from outside. An example was the group around Johann Andreas Schmidt, who taught physics at the University of Helmstedt and accumulated a set of experimental apparatus that Leibniz, who viewed it in action, thought exemplary. Schmidt taught an eclectic natural philosophy that built on mathematics and mechanics, and above all, on experiment. 'Follow the watchword of the Royal Society [he told his students], and swear in no one's words'. Schmidt praised four or five people for their exemplary practice of this method. They included Descartes and Johann Christoph Sturm, author of an eclectic *Physica electiva* (1697–1722). *Neminem sequere, et omnes*, 'follow no one and everyone', Schmidt told his audience, and read and reread Sturm's eclectic dissertations.[45]

Sturm had imbibed Cartesianism from the master's first disciples in Leyden in the 1650s. He developed a course of lectures at the University of Altdorf and set up a Collegium experimentale there, in emulation of the Accademia del Cimento. It was perhaps the first such course and academy in Germany.[46] Through Sturm and Schmidt the methods and instruments of the Dutch universities and Italian academies made their way to Germany, and also through Leibniz, who attended meetings of the Accademia fisicomatematica romana during his visit to Italy in 1690. Leibniz's proposals for an academy of sciences in Berlin mix together the courses of experiments offered by Sturm and Schmidt, the wider programmes of the Italian academies, and the royal sponsorship of the scientific institutions of London and Paris. His German academy was to incorporate the best practices of all the others, and of the Society of Jesus too, and so perfect a prime instrument for the advancement of science and society.[47]

A fruitful concept?

In attempting to fit the metaphor of revolution to the development of natural knowledge during the seventeenth century I think that I have arrived at the following results:

- From the 1660s we can speak of a continuous reinforcing institutionalized pursuit of experimental philosophy within a progressive program. The timing had to do with relative peace, which abetted the transformation of a revolutionary situation into a revolution.

- The characteristic marks of this revolution are corpuscular philosophies and academies of experiment; its favourite weapon was the air pump; its slogans, '*libertas philosophandi*', '*provando e riprovando*', and '*nullius in verba*'.
- The academies and groups that met to do and witness experiments tended to emphasize the features of the new science deemed useful to the newly stabilized states. These features, applied mathematics and practical experiments, were also the cardinal characteristics of the new science.
- In England, the revolution was quiet, a forerunner of the bloodless Glorious Revolution. The main battlefields were Italy and the Northern States, including Sweden, which have been neglected in our historiography owing to a confusion of product and process. England led the way in discovery largely because it did not suffer the guerrilla fighting of the politically divided peninsula and the religiously divided continent. In Germany, as in Italy and for some of the same reasons, the spotlight falls on small experimental academies associated with universities.
- The Scientific Revolution is not just, or primarily, a story of Galileo, Descartes, and Newton. Eclectics, érudits, doctors, waverers, trimmers, compromisers, and fellow travellers played an important part in the revolutionary process.
- The model directs attention to the histories of medicine and education, printing and communication, the recruitment and activities of cadres, and to general history. It suggests that comparisons of the pursuits of natural knowledge under various religious, political, and social regimes can still yield something of interest, and it integrates internal and external factors and approaches.

You perhaps have wondered what happened to Newton. Our model has a place for him. He is the Napoleon of the piece, the Prince of Physics, the Emperor of Science. Like Napoleon, he consolidated the gains of a revolution fought by others and extended it beyond their wildest dreams. But to extend it Newton had to deny the strict mechanical programme on which it was founded, just as Napoleon rejected the republic that had given him his start. I need not describe Newton's other imperial characteristics, like denying Leibniz a share in the invention of the calculus and, in his capacity of Master of the Mint, prosecuting to execution clippers of the coin of England.

One final revolutionary conclusion from my model of the Scientific Revolution: it was less significant to its participants than we usually reckon. That is because as it progressed its opponents came to face a much graver danger than the substitution of a world of pushes and pulls for the rich diversity of the scholastic universe. In the later seventeenth century serious savants began to question the inspired authorship of the bible, made the Old Testament the work of several anonymous hands, reduced its stories to imaginative literature, and contemplated the existence of men before Adam. Here were the makings of a revolution! It caused confrontation everywhere, even in England. Its outcome was glorious, but not its process.

References and Notes

1. This article is a shortened version of the Hans Rausing Lecture given at the University of Uppsala in December 2005 on the occasion of the retirement of Professor Tore Frängsmyr.
2. T. Frängsmyr (1988) Revolution or evolution: how to describe changes in scientific thinking, in W. R. Shea (Ed) *Revolutions in Science: Their Meanings and Relevance* (Canton, MA: Science History Publications), pp. 164–173, at 164.
3. T. Frängsmyr (1988) Revolution or evolution: how to describe changes in scientific thinking, in W.R. Shea (Ed) *Revolutions in Science: Their Meanings and Relevance* (Canton, MA: Science History Publications), pp. 165–169; T. Frängsmyr (1999) *A la recherche des lumières. Une perspective suédoise* (Pessac: Presses Universitaires de Bordeaux), pp. 12–13.
4. R.R. Palmer (1959/1964) *The Age of the Democratic Revolution. A Political History of Europe and America, 1760–1800*, 2 vols (Princeton: Princeton University Press), 1, p. 21. An alternative set of criteria, in J. A. Goldstone (1991) *Revolution and Rebellion in the Early Modern World* (Berkeley: University of California Press), p. xxiii, requires a financial crisis, divisions among the elite, and potential to mobilize a sizeable population already aggrieved. A scientific revolution modelled on these criteria would emphasize resources and instruments, fights over school curricula, and the belief that traditional learning was worthless.
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7. Descartes to Marin Mersenne, 18 December 1629, in R. Descartes (2005) *Tutte le lettere 1619–1650. Testo francese, latino e olondese*, G. Belgioioso (Ed) (Bologna: Bonpiani), p. 100.
8. T. Sprat (1958) *History of the Royal Society* [1667], J. I. Cope and H. W. Jones (Eds) (St Louis: Washington University Press), pp. 32–33, 55–56, 82.
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12. Or, to be fair, 'to deduce rules of medicine more certain than those we have at present'; R. Descartes (1982) *Discours de la méthode & Essais* [1637], in *Oeuvres*, C. Adam and P. Tannery (Eds) (reprint, Paris: Vrin), 6, p. 78.
13. Graindorge (a physician) to Pierre Daniel Huet, 11 November 1665, in D. S. Lux (1989) *Patronage and Royal Science in Seventeenth-Century France. The Académie de physique in Caen* (Ithaca: Cornell University Press), 48. Cf. the opinion of Lucantonio Porzio, in M. Torrini (1979) *Dopo Galileo. Una polemica scientifica (1684–1711)* (Florence: Olschki), 176–179.
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17. Descartes to Mersenne, 23 Dec 1630, in R. Descartes (2005) *Tutte le lettere 1619–1650. Testo francese, latino e olondese*, G. Belgioioso (Ed) (Bologna: Bonpiani), p. 190.
18. R. Descartes (1982) *Discours de la méthode & Essais* [1637], in *Oeuvres*, C. Adam and P. Tannery (Eds) (reprint, Paris: Vrin), 6, pp. 46–54.
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25. T. Frängsmyr (2000) *Svensk idéhistoria. Bildning och vetenskap under tusen år* (2 vols, Stockholm: Natur och Kultur), 1, pp. 150–152.
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