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COMPARATIVE HISTORY OF SCIENCE

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Beginning a review in 1978 of a collection comparing the Mexican and United States revolutions, Don Higginbotham observed: "Historians in general, especially American historians, have not been notably interested in comparative studies. Until recent years at least, Clio's disciples have been markedly conservative in the way they have viewed their craft — 'conservative about everything but their politics,' as the saying goes."[1] To accentuate his thesis, Higginbotham entitles his review, "The uses and abuses of comparative history". Comparatists are marginal in the historical discipline, Higginbotham seems to contend. Following Friedrich Nietzsche's criticism of Jacob Burckhardt in the essay, *The use and abuse of history*, it is a querulous topic that admits to being used and abused: who would title an article, "The uses and abuses of economic history", or, "The uses and abuses of diplomatic history"?[2] Higginbotham's impressions reinforce the appraisal of Rushton Coulborn in 1970, that we should look to the future, when the art of literary history shall be transformed into the science of comparative history:

> The comparative study of civilized societies is at a critical juncture. Almost all the work which has been done has been that of very able scholars: Danilevski, Spengler, Toynbee, Sorokin, Kroeber. That some of these pioneers are eccentrics, or have an ulterior motive, is a familiar situation. What is now needed is the work of a large body of respectable historians. The majority of problems which arise in studying the rise and fall of civilized societies are historical problems which can be solved — if at all — only by synthesis skillfully done by putting together the results of documentary research. This is the historian's job; yet, of the authorities on the subject named here (or anywhere else) only one is a historian by profession.[3]

More recently, Robert Gregg has compared race relations in the United States and South Africa. In a book that deals extensively with theoretical questions, he devotes almost no discussion to comparative history, summarizing: "The most severe limitation of comparative literature has been its national and nationalist bent. The unit of analysis under comparison is, generally speaking, the nation (or proxies thereof)."[4] Michel Trebitsch, introducing a collection of essays on the comparative history of intellectuals, shares Gregg's opinion. Regarding comparison, he emphasizes,

> historians, notably those writing today, still remain prudent and timid, if not distrustful. The comparative approach already has its history, its long history, in the humanities and social sciences; it doesn't lack for eponymous heroes

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> among historians — one need only bring to mind the invocation of the great canonical texts of Marc Bloch or Henri Pirenne. Yet it remains, because of national historiography, a prisoner not only of the neo-positivist tendencies that continually confront historians who write about our time, but also a prisoner of its own contradictions — the structural dilemma that is evident between a micro-comparative approach to historical entities confined to one space, group, or event and a macro-comparative approach that is laced with universalist tendencies.[5]

Comparison in the social sciences and humanities indeed has a sketchy methodological basis, to judge from the encomium received by Charles C. Ragin's examination of comparison from the point of view of Boolean logic.[6]

Comparison may have a difficult time in Clio's classroom, but among writers on tools, methods, and trends, comparative history of science is denied even the dignity of marginality: it is off the historiographical chart. In a summary of comparative history written by the Americanist George M. Fredrickson for a volume published under the auspices of the American Historical Association in 1980, there is no mention of history of science.[7] Complementing Frederickson's pessimistic view, Robert J. Richards's inventory of methodological approaches to writing history of science, in 1981, is silent about comparison.[8] Comparison does not figure in the title of any of the 67 chapters comprising a recent, gargantuan vademecum of history of science.[9] Comparison is absent from Helge Kragh's useful 1987 study of historiography in history of science, which includes chapters on such themes as biography, prosopography, and scientometrics, and it receives no mention in the revised edition of François Russo's disciplinary survey.[10]

Shortly it will be seen that historical comparison has a long past, but a convenient date for the crystallization of a concerted enterprise is 1958. In that year Sir Ronald Syme, the great exponent of prosopography, delivered the third Whidden Lectures at McMaster University in Ontario, Canada. As his topic, he compared colonial élites in the three longest-lasting Western empires, the Roman, the Spanish, and the British. Syme concluded with an appeal to Sir Lewis Namier and emphasized the merits of comparison:

> Henry Adams said of history that it is "in essence incoherent and immoral". None the less, in the phrase of Namier, a notable enemy of system and dogma, it can be described as an "intelligible disorder". "Intelligible" is the word. Our occupations are not inevitably condemned to futility or pessimism. History is discovery. It broadens the horizon and deepens the understanding. It is a liberal and liberating force.[11]

Also in 1958, the distinguished journal *Comparative studies in society and history* was founded by the medievalist Sylvia Thrupp at the University of Michigan.[12] It served to focus both sociological and historical interest on comparative questions. The journal nevertheless followed Syme's lead in treating marginality, in this case situations far from imperial seats of power. Raymond Grew observed in 1980

that many of the five hundred manuscripts he received for *Comparative studies in society and history*, during his term as editor, concerned colonial matters: "The colonial experience offers a degree of analytic control not usually available to social scientists; new influences and pressures can be identified and their assimilation, distortion, or rejection can be traced."[13]

Grew's comments point to the importance of a longstanding international project to compare the history of India with the history of Indonesia, animated by the Centre for the History of European Expansion at the Rijksuniversiteit Leiden under the watchful eye of, among other scholars, H. L. Wesseling, C. A. Bayly, D. H. A. Kolff, P. C. Emmer, and Leonard Blussé.[14] Science is not a principal focus for the scholars at Leiden, although in the course of their collective endeavour it has proved impossible to neglect natural knowledge. Michael Adas, a United States historian with ties to Leiden who has written about impressions of modernity in modern empires, keeps science at arms' length.[15] Commenting on a series of recent essays dealing with Manchu colonialism, Adas avoids addressing conceptions of the natural world — even though one of the essays under consideration, concerned precisely with maps of North-Central and East Asia, fairly cries out for a comparative discussion of surveying command structures, measuring techniques, and printing practices.[16] The Leiden group did publish a brilliant comparative collection in 1991 with the Japan-Netherlands Institute in Tokyo as the third volume of the Institute's *Journal*, edited by W. G. J. Remmelink, which records the proceedings of a conference on the transfer of modern science between Europe and Asia. Many of the thirteen chapters radiate wide learning, but only two are explicitly comparative. H. Floris Cohen concludes in his contribution: "To distant China's science the West does not seem to owe much — partly because of the 'translation filter', partly as a result of the incommensurability of the natural philosophies of China and the West"; Harm Beukers reaches a related conclusion that, in early modern times, there was relatively little interchange of medical knowledge East and West, except for the Western use of Eastern medicinal herbs, and with recognition of the special case of Japan.[17] These promising explorations have remained within a relatively small community of scholars. Because historians of science still overwhelmingly study European and North American occurrences, they have paid little attention to innovations emanating from Leiden and elsewhere which deal with European expansion. History of science seems to follow the observations of the Sinologist Craig Clunas, who emphasizes, in reviewing a history of Western consumers: "Comparative work is all very well, but, with certain shining exceptions, it tends for the present to take place toward the periphery, not at the center, of the historical field."[18]

Philosophers have analysed science from first principles, and even Thomas Kuhn in his last writings sought to follow this path, but understanding also arrives through examination of many concrete examples taken from the natural world. Some knowledge — religious or artistic — may come directly from divine inspiration, but an apprehension of the world in the undertaking called natural knowledge is

won through a process of sorting things out into kinds. The disturbing sabotage of this view opens Michel Foucault's book, *Les mots et les choses*, where Foucault recounts Jorge Luis Borges's description of the animal kingdom in a medieval Chinese bestiary, organized in an apparently fabulous and nonsensical fashion.[19] Foucault, whose methodological animadversions seem guided by anarchist impulse, nevertheless places things in diverse heaps.[20] If generalization is granted to historians (the matter is contested), it comes following sustained reflection of comparable instance and example.

Notwithstanding the underground status of comparative history generally, the following pages contend that comparison has been a persistent feature of the discipline of history of science. Comparative studies have been among the most innovative and the most durable of scholarly undertakings in our field, and they have been carried out from a number of locations around the world. They have generated significant discussion, and they have stimulated new areas of inquiry. At the present time, when postmodernism has run its course and when scholars are looking to formulations based on constructive labour and clear prose, comparative history of science offers direction and inspiration. The very range and richness of what has appeared over the past generation, especially, recommend comparison as a solid foundation for research in the present decade.[21]

A particular merit of comparison derives from its ecumenical presence in the world of scholarship. Persuasive and original studies have issued from Cambridge and Berkeley, as well as from São Paulo and Tokyo, from the hand of doctoral students as well as distinguished professors. Today the application of comparison harbours no eponymous "school", whether deriving from a university town or a philosopher. It displays neither secret agenda nor code words, and it is intolerant of muddle-headed prose. By its nature, it resists appropriation by *bonzes* or *Gelehrter*. Comparative history of science may provide a path to scholarly reconciliation in a fissiparous discipline.[22]

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Comparison is implicit in nineteenth-century historical studies, which not infrequently sought to establish contrasting racial or regional styles. In the New World, comparison appeared explicitly in the two great commentators on democracy, Alexis de Tocqueville and Henry Adams, and in Domingo Faustino Sarmiento's novel about civilization and barbarism, *Facundo*. The French polymath Pierre Duhem contrasted British model-building to French mathematical abstraction.[23] In his history of European science, the Anglo-German wonder John Theodore Merz characterized the ideal type of German scientist by an attention to thoroughness, an awareness of the larger picture, a desire to create acolytes, and a predilection to deal with philosophy; English scientists were idiosyncratic and practical-minded; French scientists were analytical and pedagogical. This interpretive device has proved remarkably resilient.[24] The Swiss naturalist Alphonse de Candolle, in his work on foreign memberships in national academies, was explicitly comparative.[25]

Johannes Paulmann recently suggested that historical comparison is most effective on a European scale, where on occasion science is present.[26] The origin of this restriction lies in the faint presence of Western historical inquiry beyond the North Atlantic World. The asymmetry is acute: there are many treatments of Argentina and Indonesia by North Atlantic scholars, but very few in the reverse direction. A sense of the poverty may be obtained from a collection edited by Ivan Vallier in 1971, where a Eurocentric focus, from Karl Marx to Talcott Parsons, weighs heavily in the historical footnotes — in clear contrast to the extra-European discussion of anthropology.[27] When reason and enlightenment come into play, Europe still takes centre-stage. Indeed, in his comparative social history of the Enlightenment, Thomas Munck portrays Benjamin Franklin only as a kite-flying, masonic, American politician, rather than, more optimistically, a printer, diplomat, and American natural philosopher. Munck asserts: "Natural philosophy remained throughout the eighteenth century primarily in the hands of non-specialists", apparently mistaking physics for philosophy dealing with "basic scientific methodology".[28]

Robert H. Robins has traced the early development of the discipline from which comparative history derives. The inspiration for disciplined comparison comes from the enterprise of comparative linguistics. Appearing explicitly in the Renaissance through the work of scholars like Joseph Justus Scaliger, comparison of languages proceeded under the watchful eye of Leibniz, mindful of the practical translations upon which European expansion was predicated. Then, late in the eighteenth century, the field exploded with the labors of Sir William Jones, Jacob Grimm, Rasmus Rask, Franz Bopp, and Alexander von Humboldt, whose book, *Die Verschiedenheit des menschlichen Sprachbaues* appeared posthumously in 1836.[29] The notion behind comparative linguistics was simple: by comparing existing languages and thereby reconstructing extinct antecedents, it would be possible to extend historical reasoning back to a time before written documents.

Anthropology provided a second scholarly focus for comparison in the nineteenth century and early twentieth century, and, inspired by Auguste Comte's writings, it led into ambitious programs for analysing the evolution of civilization. Franz Boas and Alfred Lewis Kroeber, for example, wrestled with comparison throughout their career, and anthropologists still provide many of the most interesting comparative studies with relevance to historical themes, for example, Tadataka Igarashi's study of astronomy in the Malay Archipelago.[30] The centre of comparative history at the University of Wisconsin owes a great deal to anthropological inspiration.[31] Roland Axtmann has observed that the nineteenth-century comparatists, whether anthropological or sociological, were evolutionist; they sought to classify cultures and societies and aimed "towards assigning cultural traits (or whole countries) to a specific stage of development". The comparative method "allowed investigators to see social and cultural differences as simply representing various stages of evolution".[32] The lines between anthropology, sociology, and history have been blurred for more than a century (a notable early example is found in the writings

of Pitirim Sorokin), despite the caution against such *mésalliance* in the controversy around Karl Lamprecht.

Fritz Ringer observed a generation ago that Lamprecht was at the centre of a controversy that became known as the *Methodenstreit*, the struggle over method. In the 1890s, Lamprecht, *ordinarius* of history at Leipzig, was publishing a multi-volume history of Germany which had a wide readership. Borrowing eclectically and carelessly from political historians, economic historians, and psychologists, Lamprecht enlisted a "rather turbulent mixture of anthropological information, imaginative portraiture, and embarrassingly superfluous rhetoric about psychosocial laws" to describe cultural epochs in terms of fundamental psychological resonances. Lamprecht's writings generated intensely negative feelings in the German historical community, for whom the aim of history remained the elaboration of decisive individual action in the development of the state. There was, however, no general agreement about Lamprecht's basic orientation, whether he was, indeed, idealist, materialist, or positivist. The Lamprecht controversy, Ringer concludes, "helped make German historians acutely conscious about their methods during the late 1890s and thereafter".[33]

Cultural history and its comparative focus fell into disrepute in Germany, but they enjoyed a rebirth in France during the late 1920s through the School of the *Annales*, founded by Lucien Febvre and Marc Bloch. To Marc Bloch falls the distinction of proposing a method for comparative history.

Elaborating remarks by Henri Pirenne, Bloch described comparative history as the process of identifying two or more phenomena that seem analogous and that appear in one or more social settings, and then considering how these phenomena resemble and differ from each other. A historical comparison required similarity between the observed phenomena as well as "a certain dissimilarity between the environments in which they occur". Bloch noted that there are two different ways of applying the comparative method. One may consider societies widely separated in space or time, like those in Sir James Fraser's *Golden Bough*, or one may take as unites of comparison societies that are geographical neighbours or historical contemporaries, as in the method of comparative linguistics. In either case, the comparative method helps the informed historian formulate questions to ask the documents that he confronts. The comparative approach allows the historian to discover phenomena that a first glance seem to be lacking in one geographical area or society. The comparative method can illuminate divergent evolution, when a phenomenon becomes extinct in one place but persists in another. It is sometimes indispensable in the search for historical causes.[34]

The program of the *Annaliens* brought them to study long-term economic trends, which eventually took them into the terrain of science and technology.[35] Two critics have identified a restriction that in their view is fundamental to Bloch's program: "What ought to be compared in any study that claims to follow the method used in comparative historical linguistics is *all and only* the phenomena in a related group."[36] That is, just as the construction of Proto-Romance requires studying all living

descendants of this extinct language, so understanding the origins of feudalism requires an analysis of all its later, medieval manifestations.

Comparative history has gone beyond Bloch's prescriptions. Theda Skocpol and Margaret Somers identify three different kinds of comparative history: macro-causal analysis, which resembles multivariate hypothesis-testing; the parallel demonstration of theory; and the contrast of contexts.[37] Charles Tilly, after examining the state of global, historical comparison, divides scholarship into four categories: individualizing comparisons, universalizing comparisons, variation-finding comparisons, and encompassing comparisons. In general, he notes, "Historically grounded huge comparisons of big structures and large processes help establish what must be explained, attach the possible explanations to their context in time and space, and sometimes actually improve our understanding of those structures and processes".[38] A. A. van den Braembussche points to the value of comparison operating in three "mixed" forms which he calls generalizing (where differences between instances move to centre-stage), macrocausal (hypothesis-testing), and inclusive (where the instances to be studied are found within one large context, for example, a world economy).[39] Maurice Mandelbaum classifies comparative history into the evolutionary approach (for example, the sociology of Auguste Comte), the genetic approach (tracing similarities among societies through their lines of descent), and the analogical approach (further divided into a phenomenological form of carrying out direct description and an analytical form of identifying implicit resemblances).[40] A sense of the many moods of comparatists and also of the heavy theoretical machinery invoked to put a compass to them may be obtained from a forum on comparative historiography at the second European Social Science History Conference in 1998.[41] Levels of theory cascade one upon the other in Jörn Rüsen's discussion of comparative historiography.[42] By way of temperamental and literary contrast, Robert Darnton, an historian working with primary sources, has offered a practical agenda for a comparative history of the book.[43] An understanding of comparison certainly differs from one historian to another, but nearly all writers would agree with Christophe Charle, in his comparative study of intellectuals in the nineteenth century, that the merit of comparison is not to confirm propositions that are in essence tautological, of the kind: "French intellectuals behave in a certain way because they are French."[44] Just as in other parts of history, comparison allows for generating deeper explanatory hypotheses.[45]

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Sophisticated, comparative history of science appeared through the labour of four scholars in the 1950s: Edward Shils, Ludwig Fritz Haber, Joseph Ben-David, and Derek J. de Solla Price. Shils, a conservative sociologist at the University of Chicago and the founder of the periodical *Minerva*, focused on élites in academia; Haber stayed close to the record of technology; Ben-David compiled historical statistics to sustain his thesis about the vitality of free-market, competitive academia;

and Price sought to transform the history of science into a science itself, where quantitative indicators could map vitality and torpor.[46] The 1960s saw additional interest. Hrothgar John Habakkuk published a comparison of invention in American and British technology, a comparison later reconsidered by Nathan Rosenberg.[47] Background to the issue of professionalization of science came from John J. Beer and W. David Lewis; scientists as political actors formed the subject of an analysis by W. H. G. Armytage; Donald Cardwell compared scientific research at British and German universities.[48] The most interesting of comparative studies related to science on a world scale: Donald Fleming and then George Basalla compared early science in the New World with that of other developing nations. Basalla's three-stage model for the evolution of an independent scientific community has become a classic in the field of science and imperialism.[49]

The comparative euphoria of the 1960s, where scholars elaborated broad themes over long periods of time, took new shape in the 1970s. One of the last of the broad treatments was Odin Waldemar Anderson and Ronald Andersen's comparative treatment of health care in the United States, Sweden, and England.[50] The 1970s may be, to borrow from David S. Landes's expression for the decades after the dramatic expansion of the First Industrial Revolution, a time of "short breath and second wind". Scholars sought clear and careful comparisons over a short range. Leading the way was Stanley Goldberg's doctoral dissertation at Harvard University comparing the reception of special relativity in Europe and the United States, completed in 1969.[51] Following this approach came Thomas F. Glick's collection of essays about Darwinism in various cultural settings and Sal P. Restivo and Christopher K. Vanderpool's collection of comparative essays on science and society.[52] Charles Weiner studied cylotrons in European, American, and Japanese settings; R. G. A. Dolby investigated nineteenth-century physical chemistry in Great Britain and the United States, and Dieter B. Herrmann examined astrophysics in Germany and the United States. Stephen G. Brush considered a number of scientist revolutionaries *circa* 1905 in an attempt to evaluation the notion of a scientific revolution.[53] Analytically, three texts stand out. First is Nathan Reingold's characterization of the American national style in science, read in 1978 at the International History of Science Congress in Edinburgh, with its remarkable, comparative tables.[54] Second is Russell McCormmach's original and penetrating comparison of the general attitudes of scientists in Wilhelmian Germany and in the United States during the 1960s.[55] The major comparative effort of the 1970s is the *Dreimännerarbeit* of Forman, Heilbron and Weart, published as a separate volume in McCormmach's *Historical studies in the physical sciences*.[56]

The *Dreimännerarbeit,* or three-man work, followed the major archival project of the 1960s, Sources for the History of Quantum Physics, led by Thomas S. Kuhn and conducted with the help of Heilbron and Forman.[57] The Sources project sought to assemble letters from and interviews with the major actors in the revolution of twentieth-century physics. The project led to the extraordinary resources available today through the Center for the History of Physics at the American Institute of

Physics. The material allowed Kuhn, Heilbron and Forman to produce remarkable works of scholarship, notably Kuhn and Heilbron's tracing of Niels Bohr's path to his atomic model and Forman's thesis that the reception of Heisenberg's Uncertainty Principle in Germany was a response by physicists to a cultural environment that was hostile to traditional reason and causality.[58] Forman in fact elaborated the contrast between Germany and England in this regard.[59] Stimulated in part by the work of the Institute for Scientific Information in Philadelphia and its *Science citation index*, in part by the indefatigable optimism of scholars like Price, quantitative analysis was on the agenda for historians of science in the 1970s.[60]

Forman, Heilbron and Weart set out to provide a comparative, statistical picture of physics at academic establishments around the world in the year 1900, the eve of the quantum revolution. They compared physical size, budget, and staff of laboratories and institutes, as well as the literature output of national sectors. The information was assembled from a wide variety of published sources, and it appealed to the extensive archival record. They concluded that Germany dominated physics, although the United States was rising rapidly in the discipline; France was declining. The study is remarkable for having resolved many issues that confound comparison, for example, fluctuating currency exchanges and distinctive command structures. Other persuasive comparisons on related material have appeared, but the *Dreimännerarbeit* remains unique in scale and sophistication.[61]

Complementing the master-work of Forman, Heilbron and Weart were other significant comparative studies in the 1970s. Jack B. Morrell provided a paradigmatic study comparing the success of Liebig's school of organic chemistry in Germany and the relative eclipse of Thomas Thomson's chemical school in Scotland, a form of institutional comparison that continues to generate fruitful results.[62] Loren Graham studied how eugenics came to Germany and Russia in the 1920s.[63] John Heilbron presented a comparative picture of physicists in seventeenth- and eighteenth-century Europe in his definitive early history of electricity.[64] Comparison continued into the 1980s with major, new statements by David Landes on clocks and clockmaking, Daniel J. Kevles on eugenics in Great Britain and the United States, and Thomas P. Hughes on large networks of electrical power in Europe and America.[65] In Hughes's nuanced study, he shows that there was no inevitability to the development of electrical power, for technological choices (such as direct versus alternating current) abounded; the architecture of networks derived from social, not technological, imperatives; that technologists sought to resolve thorny problems, rather than remand them to scientists; that electrical power came as part of a vertical integration of banks and factories; and that when established, technology acquires a 'momentum' of its own, which shapes and constrains many social enterprises.[66]

In the 1980s, generalizations emerged based on extensive comparison, notably Gerald L. Geison's classification of specialties and research schools.[67] Sal Restivo's broad characterizations of science, East and West, and Margaret Lock's characterization of Japanese and Western medicine found a complement in the

contributions to the proceedings of the Ninth Annual Conference of the Center for Medieval and Early Renaissance Studies at the State University of New York at Binghamton, devoted to "Islam and the medieval West", where George Makdisi compared the college in Islam and the West and Albert Dietrich compared pharmacology in Islam and the West.[68] Jonathan Harwood compared genetics in Germany and the United States, and Erik Baark, Andrew Jamison and their colleagues at the University of Lund examined national styles of administration of science and technology.[69] In his doctoral dissertation at Johns Hopkins University, Louis Barry Rosenblatt compared early Victorian geology with early Victorian classical history.[70]

Two enterprises based extensively on both primary and secondary sources merit special attention. Jens Høyrup undertook to reformulate the social conditions for mathematics in Antiquity and the medieval period, an enterprise complementing the technical analyses of Otto Neugebauer's school and in any case appealing to a good number of ancient and modern languages. His approach was modest. He sought

> to investigate how the character of mathematical thinking depends on the institutional situation in which mathematics is *practiced as knowledge* — perhaps as theory, perhaps as techniques one should know in order to apply them — in interplay with the wider cultural settings and societal determinants of institutions. The method is cross-culturally and cross-historically comparative, but no effort is made to find the same parameters in all cases, apart from the choice of teaching as a critical factor.... Nor do I, indeed, believe that a schematization aiming at finding a rigid common grid of explanatory factors makes much sense in cultures as widely divergent as those dealt with here.[71]

For the modern period, Susan Sheets-Pyenson undertook a pioneering comparative study of popular-science publications in London and Paris during the middle of the nineteenth century, concluding that French science popularizers were "high-science watchers" while English science popularizers were "high-science boosters". The French popularizers reported passively on academy and laboratory, while the English amateur scientist could and did contribute to academic science.[72] She then published a landmark study comparing nineteenth-century natural-history museums in Argentina, Australia and New Zealand, and Canada. Sheets-Pyenson's approach was an integrating one, in the manner of social historians. Her book on colonial natural-history museums avoids superfluous appeal to methodology. The five institutions considered in her book constitute type specimens of the "colonial museum". She writes: "The patterns of development drawn from the five cases ... are typical of the more successful among colonial museums." Generalizations are omnipresent, whether on matters of personnel, funding, or institutional organization, and they are presented inobtrusively to draw the reader in; just as with Høyrup's study, absent is rhetoric about abstract constructions such a role-set, ideology, and

power, of the kind displayed in sociology of science.[73]

As Sheets-Pyenson's work demonstrates, in addition to encouraging a certain economy of explanation, comparison discourages triumphal writing, for in any historical comparison, even the most successful example carries less than desirable traits. (Otto Neugebauer remarked, for example, that while Babylonian science was clearly more sophisticated than Egyptian science, he would certainly have preferred to live in Egypt over Babylon.) Comparison cautions enthusiasm. Early in the 1980s, Joseph Needham published his Ch'ien Mu Lectures at the Chinese University of Hong Kong. The book is an accessible meditation on science East and West, continually comparing figures, inventions, and understandings. To cite one of a very great many examples, Needham holds that "the centralised feudal bureaucratic style of social order was in the early stages favourable to the growth of applied science". This social order, controlled by the *shih*, or scholar-bureaucratic meritocracy, departed from the "aristocratic military" feudalism of the West, and it permitted grand enterprises like the "Big Science" of the twentieth century:

> Chinese society in the Middle Ages was able to mount much greater expeditions and much more organised scientific field work than was the case in any other society of that time. A good example of this is the survey of the meridian arc carried out early in the +8th century under the auspices of I-Hsing ... and the astronomer Nankung Yüeh. This was a geodetic survey covering a line no less than 2500 km long, ranging from Indo-China to the borders of Mongolia. At about the same time an expedition was sent down to the East Indies for the purpose of surveying the constellations of the southern hemisphere within 20° of the south celestial pole.

He reviews the complex development of gunpowder, concluding: "While gunpowder blew up Western military aristocratic feudalism, the basic structure of Chinese bureaucratic feudalism after five centuries or so of gunpowder weapons remained just about the same as it had been before the invention had taken place." He reconsiders the origin of Islamic alchemy, observing Chinese antecedents in macrobiotics and the invention of automata. Needham concludes: "Arabic alchemical theory was a marriage between the Taoist idea of longevity or immortality, brought about by the ingestion of chemical substances, and the Galenic rating of pharmaceutical potency, in accordance with the *krasis,* the *mizaj*, and *'adal* — the balance of the four primary qualities, the natures." The attempt of Jabir ibn Hayyan to create life in an alembic is the union of Chinese medicinal alchemy and Greek metallurgical chemistry, and "If nothing living was really ever seen to step forth from Jabir ibn Hayyan's cosmic incubators, chemotherapy with all its marvellous achievement of today was certainly born from the Chinese-Arabic tradition with Philippus Aureolus Theophrastus Paracelsus Bombastus von Hohenheim as its great midwife". And it was neither William Harvey nor the Damascus physician of the thirteenth century, Ibn al-Qarashi al-Nafis, who originated the circulation of the blood: it was the Chinese, although to Harvey fell the notion of the heart as a pump.

Needham's eye for detail did not prevent him from issuing broad generalization. The preceding extracts suggest the extent to which his project is animated by a comparative urge.[74]

Needham's comparison finds an extension in other syntheses. Shigeru Nakayama, in a comparative work first appearing in Japanese in 1974, proposes that East Asian knowledge derived from documentary scholarship, while Mediterranean knowledge stemmed from rhetorical learning, and he examines why, "among the multitude of theories and arguments afloat in classical Greece and Warring States China, those of Aristotle and Confucius assumed the paradigmatic mantle". Aristotle and Confucius achieved the status of an authority in part as a result of a tradition of "manuscript-centered, classics-oriented scholarship". The tradition, which in each case lasted more than 1500 years, required an originator of some sort: "The question of authorship was not a significant issue. The name of the progenitor and the texts associated with him were used first of all as an invisible yet commonly understood badge of identity by which scholars knew themselves and were known to others." Nakayama's text is unusually rich in its comparative style; that is, comparative discussion often occupies many consecutive paragraphs, for example, distinguishing the classificatory mode of Chinese science, which easily accommodates Kuhnian anomalies, from the Western science of unitary, nomological explanation, which eventually breaks under the weight of growing numbers of anomaly.[75]

Toby E. Huff has reconsidered science from the perspective of the social philosopher Benjamin Nelson and through the impetus of Joseph Needham. "Without doubt", Huff writes, "Joseph Needham's monumental study, *Science and civilisation in China*, did more than any other work in the twentieth century to draw attention to the need for a comparative, historical, and sociological study of the rise of modern science". Huff's appeals to sociology detract from a comparative inquiry that may stand on its own merits. One of Huff's original contributions is to identify the special character of law in European, Islamic, and Chinese civilization, and to contend that only European legal tradition, both conceptual and institutional, paved the way for the formulation of natural laws in modern science: "By the end of the thirteenth century, along with the formal elements of the Aristotelian corpus, a powerful, methodological sophisticated, intellectual framework for the study of nature had been institutionalized" in European universities. For Huff, universities, far from being bastions of ignorance and prejudice, were the engine of the Scientific Revolution:

> Sociological and historical accounts of the role of the university as an institutional locus for science and as an incubator of scientific thought and argument have been vastly understated.... The universities were highly instrumental in disseminating many new intellectual currents in scientific thought, and, most important of all, they were the primary locations of severe criticism of both old and new ideas.[76]

Edgar Zilsel's fruitful emphasis on artisans and craftsmen as the non-academic

builders and measurers of the world recedes in favour of a focus on the traditionally maligned schoolmen as disseminators of the new knowledge.[77]

Sophisticated comparison is now a structural feature of scholarship dealing with East Asia. The Seventh International Conference on the History of Science in East Asia, held in Kyoto in 1993, produced a number of sensitive studies in this direction. There Nathan Sivin outlined a program to delve more deeply into comparing ancient Greek and Chinese science. Comparisons have accumulated "a certain number of facts and dates ... but the conclusions drawn in the many published comparisons seldom affect our daily work or our understanding of the world we study", that is, the details of East Asian science. Sivin offered that many comparisons were made "out of context one at a time, whether they are concepts, values, machines, or groups of people". He presented a project undertaken with G. E. R. Lloyd to focus on the period 300 B.C. to A.D. 200 in both the Greek and Chinese ambit. Sivin's preliminary conclusions identify a Greek culture of disputation and a Chinese culture of consensus; the Chinese notion of 'polis' was unifying and centralized, while in Greek learning there was a multiplicity of political concepts; Chinese rulers established a loyal civil service and they were disposed to acknowledge political limitations offered by their *clercs*, while Greek rulers and their successors ignored the advice of philosophers, a situation that encouraged heterodoxy; Greek learning was a competitive affair, functioning by oral disputation, while Chinese scholars offered their thoughts directly to rulers, and in this way sought to avoid disagreement. In the same proceedings, Karine Chemla compared algebraic equations in Babylonian, Greek, and Chinese traditions, identifying two unique features of the Chinese literature: equations were imagined as arithmetical operations, and equations were solved within a framework of root extraction. By philological analysis involving a number of Arabic texts, Chemla posited a debt by Arabic algebra to Chinese tradition. Jianjun Mei and Tsun Ko compared copper, iron, and zinc technology in India and China. Hans Ulrich Vogel compared Chinese and Western accounts of subterranean brine and gas wells. In view of some confused postmodernist rhetoric that the conference sustained, Vogel's conclusion is strikingly reasonable: "Western explanations of the seventeenth century were in no way superior to their Chinese counterparts. Only with the development of modern chemistry and geology towards the end of the eighteenth century were Western scholars in a better position to forward, in the long run, more realistic explanations." Vogel shares Needham's emphasis on the unique importance of the European Scientific Revolution.[78]

* * *

Notwithstanding the sophisticated, *sachlich* comparisons of the Asianists, less ambitious individual "comparisons" are a standard feature of scholarship now, and the word has acquired a wide meaning. David B. Wilson has written a segmented biography of two nineteenth-century British physicists who engaged related scientific questions, notably the electromagnetic ether. R. D. Harvey has performed a

similar analysis for William Bateson and Erwin Baur, with regard to eugenics. Alan J. Rocke has offered a "comparative perspective" on the early nineteenth-century organic analysis of Liebig, Dumas, and Berzelius; the 'comparison' is summarized weakly: "The battles over elemental organic analysis *circa* 1830 provide an interesting window on wider aspects of chemistry, science, and European culture. Liebig borrowed essential elements of French culture and French chemistry, some of which remained with him for the rest of his life, but he added other elements as well, including German and Berzelian."[79]

A fine comparison of two contemporaries has been provided by Russell McCormmach in his study of the response by Albert Einstein and writer Hermann Broch to the horrors of the 1930s and 1940s: "Among the realistically hopeful and humane critics of the actions of politicians and the publics who supported them were a number of scientists and artists who included the physical scientist who was perhaps the most gifted since Newton, and one of the century's greatest writers of fiction — Einstein and Broch." Both men knew,

> as we know, that the recent barbarism arose "from within, from the core of European civilization" where great works of art were produced and where the great scientific and technical institutes were. The extermination of tens of millions of Europeans by Europeans, to say nothing of the related extermination of and by non-Europeans, in a brief thirty years following 1914 makes the normally reflective person question whether or not science and art have had any significant influence for the better on the political life of the West.

Neither man questioned his own search for meaning and harmony in science and in art, although Broch "did question ... the value of the pure quest for beauty, and he made that question, paradoxically, the heart of his mature artistic work". McCormmach allows that if, today, we are inclined not to take their notions seriously, it is an artifact of the timelessness of ethics: "If their admonitions sound like moral platitudes — so they have been called — it is because the standard of moral judgments is not originality." McCormmach's essay concludes:

> Science and art, as Einstein and Broch knew, may not make our character better, but they jointly shape many of our perceptions of reality. Ethical judgements and actions take their starting point both in character and in perceptions of reality. In this sense, both science and art serve as guides through our ethical universe.[80]

The assessment gives meaning to our own specialty, which frequently seeks to evaluate the character of reality perceivers.

As part of her extensive work on the Nobel institutes and prizes, Elisabeth Crawford has indicated three ways of undertaking comparison in history of science. The first is to study disciplines, specialties, and schools; the second is to focus on élite stratification of scientists; the third is to divide the world into centre and periphery. Crawford undertakes a prosopography of the group consisting

of nominators and nominees for Nobel prizes to explore these three senses of comparison, and she applies her results to evaluate the notion of internationalism in science. Her felicitous choice of data allows her to go beyond impressionistic generalizing. It remains a rare, sophisticated comparative study dealing explicitly with European science. A fourth form of comparison places comparable instances alongside each other, notably in considering the reception of scientific innovations in a national context.[81] Thomas Glick has used the national-reception comparison effectively in a collective volume considering how people responded to Einstein's relativity. The chapters in the volume focus on particular national sectors, and it is left for the reader to propose explanations for differences and similarities. One of the chapters does explicitly engage comparison, considering how the structure of the German response to relativity, called a scientific revolution, compares with the structure of the French Revolution.[82] A related collection considers science separately in the United States and in Australia, although the volume includes a scintillating comparative chapter by Susan Sheets-Pyenson and a comparison of science in Ireland and in Quebec during the nineteenth century by Richard A. Jarrell; a companion volume comparing science in Canada and Australia features only three explicitly comparative chapters in a total of nine, and of the three only one focuses on science.[83]

Historians with a theoretical bent have not hesitated to offer prescriptions to their colleagues, but comparison in the history of science, undertaken by theorizing authors, often remains indistinguishable from conflation. The result may be persuasive and original, even if comparison is not a primary desideratum, as in David S. Landes's *Unbound Prometheus*, but the danger is superficial narrative, or 'potted' history.[84] Colin A. Russell's survey of two centuries of European science appears in a series devoted (according to the editor's foreword) to themes "in a comparative context, drawing on material from western societies as well as those in the wider world". Russell's focus is heavily British, with comparisons most effective between England and Scotland: "Scotland differed from England in its dedication to cultural and economic improvements, in its Calvinist ethic and in its University at Edinburgh uniquely tuned to the needs and aspirations of the local and national community."[85] In an examination of the introduction of Western astronomy into China during the seventeenth century by the Jesuit Johann Adam Schall von Bell, Zhu Weizheng analyses Schall's confrontation with the courtier Yang Guangxian; the only element of comparison concerns the two astronomical systems — Western and Chinese. Zhu also writes about Han learning and Western learning in the eighteenth century; where one might have expected a comparison between the European Renaissance and the Han renascence, we see only European writings in China placed alongside the Han classics.[86] The proceedings of the 13th International Symposium on the Comparative History of Medicine, East and West, follows Zhu's approach, restricting comparison entirely to the conflation of Western and Japanese views of medicine and illness.[87]

Seeking to reevaluate "the context of dependency", Michel Paty has recently

called for careful comparison:

> Only by 'differential' studies, whose subject is restricted but which are accurate and varied, concerning different but in some respect comparable situations (this is indeed the original meaning of the term differential: different but very close), can legitimate comparative statements be made. It is with these differences and these similarities as starting point, situated exactly, that appropriate concepts and categories can be formulated to clarify facts, help to understand them in their own reality, and broaden the field of investigation which corresponds to them.[88]

But we have seen that scholars addressing science beyond Europe and the United States arrived safely in the harbour of judicious comparison some time ago. Comparative citation studies, in fact, have been used for more than twenty years, and they continue to inform a growing area of inquiry.[89] R. W. Home and Masao Watanabe, in the late 1980s, compared the development of physics in Australia and Japan during the years before 1950. They observe that differences in the way that the physics discipline came to the two countries "derive not so much from the different cultural settings as from straightforwardly political factors, and in particular, from the fact that Japan remained an independent power while Australia was, throughout this period, a mere subsidiary unit within that vast British Empire upon which the Sun, so it was said, never set".[90] One of the most compelling comparisons is Jaime Larry Benchimol and Luiz Antonio Teixeira's study of the institutes founded by Oswaldo Cruz in Rio de Janeiro and Vital Brazil in Saõ Paulo. Both institutes arose following the outbreak of bubonic plague in the port of Santos in 1899. Their task was to produce serums. By 1911, both institutes presented papers at an international congress in Dresden, "and from this combined effect resulted an increase of international esteem — and as a consequence national esteem — of 'scientific Brazil'". Both institutes competed against faculties of medicine and the Pasteur institutes, which had their own agendas. The institutes also contested with each other for authority in the field of public health.[91]

From the standpoint of historians, political scientists may seem to use broad brush strokes. Notwithstanding the use of solid data, impressionistic conflation is the order of the day in comparative science-policy studies, for example Peter S. Biegelbauer's monograph, apparently deriving from a doctoral dissertation at MIT, where Biegelbauer evaluates how Hungary adopted "paradigms" for organizing science from other countries and comments on the experience of other nations in Central Europe.[92] As impressionistic is David Barling's survey of government response in the United States and Europe to genetic modification of foods in a volume that, notwithstanding its subtitle, hardly compares things at all.[93] More compelling is John Connelly's study about higher education in communist Eastern Europe. Connelly examines why "an intelligentsia beholden to the needs of a socialist state" emerged with particular intensity in East Germany, compared to Poland, Czechoslovakia, and Hungary. ("Why is East Germany like a hot pepper?",

my East Berlin host asked me early in the 1980s. "Because it is the smallest, the reddist, and the sharpest.") The Polish communists did not effectively purge old professors in the universities, and the Czech communists, while purging professors, "did not achieve a significant change in the sociocultural make-up of the student body". Neither the Polish nor the Czech communists created loyal élites in the universities.[94] Thomas Glick's model of national conflation is preferred by the political scientist Etel Solingen in her edited collection of eclectic treatments about national and international science; it merits interest here only because several chapters (notably the Soviet Union and Japan) appear by the hand of historians of science.[95] Conflation of separately-developed cases is also the sense of comparison discussed by John M. MacKenzie, an historian of imperial Britain who has addressed themes in colonial science.[96]

The attributes of vague comparison have come to buoy to the last of the postmodernist writers, now struggling to hold their head above water. David Turnbull has published a collection of case studies to ascertain "the way knowledge is constructed by different groups of people". His examples are based largely on secondary works and include medieval architects, Polynesian seafarers, and tropical physicians — fields of knowledge that are far, indeed, from the precision and verifiability of the exact sciences. Turnbull's examples are intended to verify his presupposition: "The strength of the sociology of scientific knowledge is its claim to show that what we accept as science and technology could be other than it is." (Presumably his meaning is figurative; he does not explicitly assert that the loading strength of cathedral walls might have defied a modern, mechanical analysis.) Turnbull's chapter on maps inadvertently disproves the contention, for it persuades a reader about the gradual and regular improvement of a picture of the world. The notion of "comparative knowledge traditions" is introduced to relativize, in a way that is not defined, all visions of the natural world:

> The most important consequence of the recognition of the localness of scientific knowledge is that it permits a parity in the comparison of the production of contemporary technoscientific knowledges with knowledge production in other cultures. Previously the possibility of a truly equitable comparison was negated by the assumption that indigenous knowledges were merely local and were to be evaluated for the extent to which they had scientific characteristics.... Treating science as local simultaneously puts all knowledge systems on a par and renders vacuous any discussion of their degree of fit with transcendental criteria of scientificity, rationality, and logicality.[97]

Little purpose is served in following this chain of scholastic rhetoric. The question is precisely to identify sound and persuasive reasoning, whether the reasoning appear ideological (in the view of Karl Marx) or transcendental (in the view of Paul Forman) to our eyes.[98]

Historical comparison continues to be pursued by sociologists. Peter Weingart has compared eugenics in Nazi Germany and democratic Sweden. He finds "a virtual

identity of the eugenic and race-hygiene discourse in Sweden and in Germany as well as a striking similarity in the sterilization practice", and he supports the notion that the horror of Nazi eugenics was isolated or "bracketed", in a political way, from essentially comparable disciplines in other countries. Weingart concludes that "the development of science (here eugenics) is hardly directly affected by political circumstances". Rather, politics selects out "certain factions within the scientific community" that "would not survive the scientific debates".[99] Brigitte Chamak has compared the development of the discipline of cognitive science in the United States and in France in a narrative that is less focused than Weingart's.[100] H. C. Bolton and Alan Roberts have measured sentence-length in an attempt to distinguish between scientific and literary styles.[101] The lure of comparison, by means of invoking general principles, appeals to Patrick Carroll, who, notwithstanding his focus on nineteenth-century Ireland, contends that "the modern state, in a crucial sense, is a configuration of subject-bodies and material spaces, realized within a network of heterogeneous practices, in which both government and science and integral".[102] Perhaps we do have science to thank for Margaret Thatcher.

* * *

Rudyard Kipling's "Ballad of East and West" concerns a Muslim rebel under the British raj who steals the prized horse of a post commander. The commander's son goes out to recover the horse and, through exemplary courage, befriends the thief. The son returns with both the horse and the thief's son, who is instructed to learn the ways of the British invader. In 1931 George Sarton, a contemporary of Kipling's, lectured on "East and West" at Brown University. "Oh, East is East and West is West, and never the twain shall meet", he quoted. Then he generalized Kipling's point about the common quality of courage to emphasize the universal attributes of an apperception of nature:

> However divided it may be with regard to material interests and other trifles, mankind is essentially united with regard to its main purpose. East and West are often opposed one to the other, but not necessarily so, and it is wiser to consider them as two visages, or let us say, too moods of the same man.

Sarton continues: "Scientific truth is the same East and West, and so are beauty and charity. Man is the same everywhere with a little more emphasis on this or that."[103]

Is science indeed one or many? Is knowledge Platonic or Aristotelian? Shall we in the matter, to use the terms of anthropologists, be *etic* or *emic*?[104] The unitary or Platonic view, prominent half a century ago, has been unfashionable recently. George Sarton, just mentioned, saw himself as a Platonist. In his notes for the Keiser Lecture at the Library of Congress, Sarton emphasized:

> History of culture should be focussed upon the hist. of science (h. of knowledge). Man different from animals — because of his interest in religion, justice, beauty,

> truth. Without this — man is nothing but a beast, the most efficient & the most cruel. — Now — history of science is the center — because it is cumulative & progressive. Everything hangs on knowledge, justice & love.

Progress, he notes, did not occur to the ancients; Hesiod, for example, believed that things began with a golden age of perfection, which then regressed into ages of silver, bronze, and iron. The Western notion of progress extended through the Victorian age and into the twentieth century, despite revolutionary discoveries in physics. "In the long run, progress is certain — but our own life is a short run", he commented wistfully.[105] Sarton's view was shared by Joseph Needham, who emphasized, also with Sarton, the significance of the European Scientific Revolution, which forged reliable procedures for discovering new truths about nature. In Needham's view, science was unitary; it could be represented by a great river flowing to the sea, fed by many tributaries. To this end, he identified science writers in Chinese history as counterparts of natural philosophers in the European and Mediterranean traditions, and he dignified particular Chinese endeavours as distinctive scientific disciplines. The course of science, in his view, was a "grand titration".[106]

The particularist or Aristotelian view is prominent today, and not only by postmodernist relativists. People who look over the torrent of specialized theses and dissertations issuing from our universities may sense the broad spectrum of norms that govern scientific disciplines: what is half-baked for one specialist may be burned to a crisp for another. In some disciplines, language takes unusual turns, emphasizing passive voice (where experiments conduct themselves) and strange vocabulary (consider, for example, the rise of the word *discourse* over the past generation, as well as the way titles in English now preferentially begin with an ambiguous gerund instead of the definite article). Disciplines and their norms evolve. Chemical experiments three hundred years ago may seem bizarre today, and what was considered an adequate mathematical proof three hundred years ago may no longer be credible. Today's corpus of chemistry and mathematics departs substantially from what was taught in the eighteenth century.

In her publications on traditional Chinese technologies, Joseph Needham's collaborator Francesca Bray has challenged his ecumenical vision. She writes: "Needham's lyrical accounts of Chinese achievements in science and technology transformed the public image of China and its place in history around the world. Needham criticized using science to bolster Western suprematism, but like the other scientists of his generation he fully shared the teleology of the 'whig position'", the view of an inevitable progress from the past to the present. "Yet precisely what is most interesting about non-Western societies is that the material worlds they produced did *not* embody the same values as our own." Bray asks for "a new materialism that takes into account social and symbolic as well as — or, where appropriate, instead of — economic and mechanical efficiency".[107]

To the extent that Francesca Bray's comments are weakly constructivist and go in the direction of contextualization without challenging causality, to the extent

that they give dignity to a wide range of intellectual enterprise, they are situated firmly in the centre of scholarship over the past several generations.[108] My sense is that she wishes to maintain that all views of nature are equally useful, a view that Needham would not have supported. Would such a "new materialism" — freed from the material struggle for survival that dominated Marxist thought — hold that there can be as many kinds of astronomy, metallurgy, and medicine as there are cultures, and that one kind is not better than another? Would such a new materialism advocate that the *truth* of any apprehension of nature — a judgmental ethnocentrism of Greek science in Antiquity — is a matter of indifference? If so, it would be a materialism extending back more than a century to find antecedents in *fin-de-siècle* England. In Chapter 2 of "A study in scarlet", by Sir Arthur Conan Doyle, Watson is amazed at Sherlock Holmes's ignorance of astronomy and tries to relate the nature of the solar system. Holmes becomes annoyed: "'What the deuce is it to me?' he interrupted impatiently: 'You say that we go round the sun. If we went round the moon it would not make a pennyworth of difference to me or to my work.'" Sherlock Holmes shares this indifference with Dante Gabriel Rossetti, a central figure in the anti-modernist artistic and literary movement known as the Pre-Raphaelite Brotherhood, who did not care if the Earth circled the Sun or *vice versa*.[109]

Notwithstanding the considered views of the great master of deductive reasoning and the great champion of sentiment, it seems to me that the radically relativist point of view, just outlined, is incorrect. Since we no longer place credence in astrology, the stars may seem remote and irrelevant, as Sherlock Holmes contends. But consider for a moment the field that is most likely to sustain a relativist thesis, medicine. It is true that before the nineteenth century, with regard to therapeutics, Galenic medicine was hardly superior to the Chinese medicine of acupuncture and moxibustion. Nevertheless, while both traditions of medicine supported the sciences of botany (for materia medica) and chemistry (for concocting cures), European medicine sustained astronomy (for casting horoscopes), and after the Renaissance it slowly embraced descriptive anatomy. With aliquots of post-Baconian science, European medicine was eventually able to intervene in the course of disease in a way unlike that of Chinese medicine; the basis for intervention was statistically verified success. For better or worse, medical practice today owes very little, if anything, to Chinese tradition. (What is the non-Western contribution to a recent, newsworthy medical intervention, the implantation of a cardiac rhythm-management device into a prominent United States politician?) Technology, despite Francesca Bray's relativizing contentions, even more clearly follows one criterion for success, East and West. Nuclear weapons, intercontinental ballistic missiles, the internal combustion engine, synthetic insulin, and microelectronics function in one way, whether in Beijing or Paris; so did, in late medieval times, the magnetic compass, firearms, and the moveable sternpost rudder.[110]

Joseph Needham knew that comparison requires a framework of some kind, a standpoint for recognizing similarities and differences. The framework can be

rigid and inflexible. In a recent, comparative work, *The secret of the West*, David Cosandey contends that the secret behind the rise of science and technology in Western Europe is a tradition of competition among stable, independent, and prosperous political entities (a *méreuporie*) located on a relatively large land mass with a highly articulated coastline. Land wars facilitate competition and encourage the transmission of new technologies. Ready access to the high seas allows for large-scale commerce, on which prosperity and invention depend. The form of the argument recalls scholastic disputes. Africa, for instance, does not enjoy a sufficiently articulated coastline (as calculated by its fractal dimensions according to the author's technique of *thalassographie*) for sustained innovation in science and technology. When the coastline and other conditions are present and science is absent, a big deficiency is invoked: no science in the Arctic because it is too cold; no science in the eastern part of aboriginal North America because the continent is too vast. In Cosandy's story, merchants are the impetus for, and soldiers the means of, spreading science.[111]

The evocation of comparison transcends a mastery of literary tropes. Entirely straightforward prose can achieve a stunning effect by displaying carefully chosen similarities and differences. Generalizations deriving from comparison, even if they prove ephemeral, retain a certain currency. Joseph Ben-David's contrast of centralized French science with free-market German science and George Basalla's stages of colonial science remain useful and fruitful analyses, as does John Theodore Merz's characterization of science in England, France, and Germany. Charles Gillispie has recently reminded us: "One of the mercies of being a historian instead of a practitioner of a more rigorous discipline is that somehow our books turn out to be better than our theories."[112] Historians do continually ask to see new evidence, but give us comparative theses, Lord, if they keep boredom at bay!

In contrast to Cosandey's rigid generalizations, G. E. R. Lloyd has collaborated with Nathan Sivin to provide a close and careful reading of Greek and Chinese texts from the period of the 'Greek miracle' and the one hundred schools in the Warring States era in an attempt to characterize the sense of science understood in the West and East. Lloyd cautions that the great diversity of thought in each setting, as well as the incommensurability of many discourses, make comparison extremely difficult:

> We cannot start from the Greek side, let us say, by identifying some particularly prominent theory of concept and then asking what the Chinese equivalent is — as if it is a foregone conclusion that the will *be* any such equivalent. We cannot assume, in the period we are dealing with, that there *is* a single set of theories or concepts fundamental to early science that will turn out to play analogous roles in both China and Greece.

Lloyd finds merit in a revision of the notion that the Greeks were adversarial while the Chinese were irenic, by examining texts outlining their views of nature. Both settings knew schools and discursive traditions, which included a wide range of

behaviour. The assertive Greek emphasis on the priority of what we might call 'pure' science, and the argumentative path to achieving certainty in it, in part reflected the relative lack of influence that philosophers exerted over temporal rulers; Chinese savants were more closely tied to political life, and their precepts were designed to intensify the connection. Savants in both settings sought to know causes, but Greek learning was fractious in this search, with schools speaking at cross-purposes, while the savants of the Han period were able to "consolidate a comprehensive world-view". Differences in astronomy follow, although not directly:

> The types of astronomical model developed in Greece and China reflect the influence of the styles of intellectual exchange cultivated in each society. The modes of rivalry among astronomers differed, in that, in Greece, the stakes were those of strict proof. The Chinese demand ... was for accuracy in prediction: there was plenty of competitiveness in delivering that. But deductive certainty, incontrovertibility, were a red herring. The enterprise of demonstrating the movements of the planets by way of geometrical models, if it had been attempted — which it was not — would have been considered irrelevant.

Lloyd is convinced that Greek and Chinese science differ from one another, but he is cautious about explaining why:

> Not only are there going to be no final explanations of the complex phenomena we refer to under the rubrics of Greek and Chinese philosophy and science: there are not even going to be any hard-edged explanations that are at all comparable to those we would demand in other contexts, for example in explaining physical interactions or even clearly motivated intentional acts in terms of those intentions. The best we can hope for it to identify possible influences, possible correlations or conjunctions, that may enable us to understand how the philosophy and science produced related to the circumstances of their production. It is precisely here that comparative studies can prove so useful, both by highlighting points that might otherwise be missed, and by checking hypotheses as to the interaction of particular factors. Certainly any proposals as to the one-way or mutual influences of some factors on others can be tested by examining whether or not similar combinations of actors cluster elsewhere.

Lloyd is sensitive to charges of relativism. The stars appear for us today just as they did for the ancient Greeks and Chinese; our physical body is not different from theirs. But the view of nature varied:

> To be sure, reality is always social constructed in a sense: but that construction reflects the investigators' claims (varied ones, for sure) that it was indeed reality that they were investigating, and that sometimes acts as a check on the investigations, even if sometimes a reality claim is just a persuasive device, and even if no one can step completely outside the conceptual framework

within which they operate.[113]

He has made a reasonable case for a dialectic between the *etic* and the *emic* in natural knowledge. He suggests why we are wise to invoke comparison explicitly, once more, to that end.

Nearly a decade ago, John R. R. Christie surveyed writings in the history of science during the 1970s and 1980s. He observed the decline of "'Big Pictures,' those texts, starting with William Whewell's *History of the Inductive Sciences* (1837), which addressed the whole history of science, or much of it, in Western Civilization". Inspired by a relativist reading of Thomas Kuhn's methodological writings (while apparently ignoring Kuhn's concrete historical research), historians of science focused on the generation of ideas from social settings. Scholars were deterred by the complexity required of any prospective synthesis:

> It was not just that increased research from larger numbers of historians made the coverage of science in history much more demanding. Even more demanding were the methodological imperatives: to be one's own social, political, economic, intellectual historian in addition would have been a dismaying methodological prospect for any but the supernaturally gifted historian of science, if a "Big Picture" for social history of science, comparable to the older synthetic works of 1837–1960, were to be contemplated.

In place of the intelligible narrative came the relativist notion that scientific texts were at base nothing more than social interactions: understanding knowledge past became an exercise in revealing who had "power" over whom, and the exercise focused on "concrete, localized and relativized knowledge". Christie hoped to see a rise of interest in instruments, instrumentation, and physical human agency: "Scientists always were and are bodies, bodies whose agency of variegated disciplinary skills were always essential to the performance of science." He looked forward to the year 2001 for answers to many of the questions he posed.[114]

The present focus departs substantially from Christie's assessment. The range and accomplishment of comparative writing over the past generation is encouraging. "Big Picture" research is certainly alive and well. The best parts of comparative writing in the discipline of history of science proceed carefully and systematically, drawing upon results obtained by other specialists. Comparative research has shown that, in the evolution of natural knowledge, scientific disciplines (however one is to refer to kinds of knowledge like astronomy, algebra, or medicine) have greater or lesser discursive cohesion and appear to respond to broader social settings in special ways (some disciplines have little in common across space and time, while others remain surprisingly invariant). Whatever else may be said about comparative research, it has generated unusual enthusiasm among its practitioners. The results, where dogma and cant occupy a relatively small place, have found wide appeal. In its many forms, comparison offers a promising way of tracking around the convoluted cataracts of recent methodological discussions.

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15. Leonard Blussé, "Qua patet orbis: An interview with world historian Michael Adas", *Itinerario*, xvii (1993), 9–20, p. 19: "The *Machines as the Measure of Men* study and my current work on African and Indian responses to Western scientific and technological dominance grew out of my fascination with efforts by intellectuals and Westernised political leaders to cope with the

challenges created by the same differential in material power that peasants struggled with at other levels." The interview is otherwise innocent of an appeal to history of science.

16. Michael Adas, "Imperialism and colonialism in comparative perspective", *International history review*, xx (1998), 371–88; Peter C. Perdue, "Boundaries, maps, and movement: Chinese, Russian, and Mongolian empires in early modern Central Eurasia", *International history review*, xx (1998), 263–86. The discussions pussyfoot around the essential question for a historian of science: the extent to which a technical understanding of nature, for example in astronomy or taxonomy (something more than a vague prejudice or general apprehension), is determined by social or cultural norms. One has the impression that with regard to science, historians of European expansion take their cue from the eunuch in the harem: they see it done every day, but they have little sensibility for its details.
17. W. G. J. Remmelink (ed.), *Journal of the Japan-Netherlands Institute*, iii (1991), the volume titled: "Papers of the First Conference on the Transfer of Science and Technology between Europe and Asia since Vasco da Gama (1498–1998)": H. Floris Cohen, "The emergence of early modern science in Europe, with remarks on Needham's 'grand question,' including the issue of the cross-cultural transfer of scientific ideas", 9–31, quotation on p. 31; Harm Beukers, "Medicine and the life sciences in Europe and Asia", 125–35.
18. Craig Clunas, "Modernity global and local: Consumption and the rise of the West", *American historical review*, civ (1999), 1497–511, p. 1506.
19. Michel Foucault, *Les mots et les choses*: *Une archéologie des sciences humaines* (Paris, 1966).
20. On St Michel as an anarchist: Lewis Pyenson, "Imperium in imperio: The natural history of natural knowledge", *Historia scientiarum*, x (2000), 1–15, pp. 3–4.
21. Quantitative history, on occasion called cliometrics, is by its nature comparative, and some quantitative approaches such as prosopography and citation analysis have generated comparative studies in the history of science. The literature on these approaches is enormous, and it merits special review in another place. Studies of technology transfer, which relate to "dependency theory" in economics, also constitute an enormous literature, much of which is comparative. A sense of the literature from the point of view of Latin American may be obtained from several classic sources: Jorge A. Sábato (ed.), *El pensamiento latinoamericano en la problemática ciencia-tecnología-desarrollo-dependencia* (Buenos Aires, 1975); Sábato, *Transferencia de tecnología: Una selección bibliográfica* (Mexico City, 1978). For a persuasive essay in dependency theory: Eduardo Galeano, *Open veins of Latin America: Five centuries of the pillage of a continent*, trans. by Cedric Belfrage (New York, 1973). The present text for the most part directs itself away from technology and economics.
22. Over the past quarter century the author has published a number of comparative works. They shall generally not be addressed in what follows, but for the sake of completeness the more recent ones are listed here: "Elegant Sartons: Platonic science, Platonic letters", in *Elegance: Beauty and truth*, ed. by Lewis Pyenson (Lafayette, La., 2001), 5–13 [comparing the *oeuvre* of George Sarton and May Sarton]; "Imperium in imperio: The natural history of natural knowledge", *Historia scientiarum*, x (2000), 1–15; "La historia natural del conocimiento natural: Utilidades de la comparación", in *La ciencia en la Argentina entre siglos: Textos, contextos e instituciones*, ed. by Marcelo Montserrat (Buenos Aires, 2000), 87–97; "International activity and national norms in the memory of American and Dutch science", in *Memory, past and future*, ed. by Lewis Pyenson (Lafayette, La., 2000), 48–72; (with Susan Sheets-Pyenson) "Curricular value: Natural history in early nineteenth-century medicine", in *Value: Pondering goodness*, ed. by Lewis Pyenson (Lafayette, La., 1999), 23–53 [comparing natural history in medical curricula at Philadelphia, New York, and Montreal]; "Etica e ideologia na ciência de Nollet e Franklin", *História, ciências, saúde — Manguinhos* (Oswaldo Cruz Foundation, Rio de Janeiro), v (1998), 7–33; "Academic words", in *Word and icon: Saying and seeing*, ed.

by Lewis Pyenson (Lafayette, 1998), 9–25 [comparing T. Clifford Allbutt's and Umberto Eco's instructions for writing dissertations]; "Higher learning and its kinds", in *Disciplines and interdisciplinarity in the new century*, ed. by Lewis Pyenson (Lafayette, La., 1997), 20–35 [comparing *Naturwissenschaften* and *Geisteswissenschaften*]; "Inventory as a route to understanding: Sarton, Neugebauer, and sources", *History of science*, xxxiii (1995), 253–82; "Cultural imperialism and exact sciences revisited", *Isis*, lxxxiv (1993), 103–08; "Typologie des stratégies d'expansion en sciences exactes", in *Science and empires: Historical studies about scientific development and European expansion*, ed. by Patrick Petitjean, Catherine Jami, and Anne Marie Moulin (Dordrecht, 1992), 211–17; "Habits of mind: Geophysics at Shanghai and Algiers, 1920-1940", *Historical studies in the physical and biological sciences*, xxi (1990), 161–96; "Why science may serve political ends: Cultural imperialism and the mission to civilize", *Berichte zur Wissenschaftsgeschichte*, xiii (1990), 69-81, reprinted in *XVIIIth International Congress of History of Science, Hamburg-Munich, 1st–9th August 1989: Final report*, ed. by Fritz Krafft and Christoph J. Scriba (Stuttgart, 1993) [*Sudhoffs Archiv*, xxx], 39–54.

23. Pierre Duhem, *The aim and structure of physical theory*, transl. by Philip Wiener (Princeton, 1954).
24. John Theodore Merz, *A history of European scientific thought in the nineteenth century* (Edinburgh, 1904–14).
25. Alphonse de Candolle, *Histoire des sciences et des savants depuis deux siècles suivie d'autres études sur des sujets scientifiques en particulier sur la sélection dans l'espèce humaine* (Geneva, 1873).
26. Johannes Paulmann, "Internationaler Vergleich und interkultureller Transfer: Zwei Forschungsansätze zur europäischen Geschichte des 18. bis 20 Jahrhunderts", *Historische Zeitschrift*, cclxvii (1998), 649–85.
27. Ivan Vallier (ed.), *Comparative methods in sociology: Essays on trends and applications* (Berkeley, 1971).
28. Thomas Munck, *The Enlightenment: A comparative social history 1721–1794* (London, 2000), 13, 19, 70, quotation on p. 12.
29. Robert H. Robins, "Leibniz and Wilhelm von Humboldt and the history of comparative linguistics", in *Leibniz, Humboldt, and the origins of comparativism*, ed. by Tullio de Mauro and Lia Formigari (Amsterdam, 1990), 85–102. Robins has emphasized that in the nineteenth and early twentieth centuries, to paraphrase Otto Jesperson, linguistics generally "was mainly a historical study". Robins, *A short history of linguistics* (London, 1967), 164.
30. Tadataka Igarashi, "Sidereal-lunar time reckoning in Nusantara: A brief comparison", in *Studies on the dynamics of the frontier world in insular Southeast Asia*, ed. by Tsuyoshi Kato (Kyoto, 1997), 119–36. Since the nineteenth century, ethnographical specialties have generated significant insight for the history of science, notably in Southeast Asia. Their accomplishments in this regard have not yet been surveyed systematically. The present text for the most part excludes consideration of work in ethnobotany, ethnoastronomy, ethnomathematics, and (following Thomas Kuhn's appropriation of music as a "classical science") ethomusicology. Ambitious programs in these specialties are outlined in: Richard Evans Schultes and Siri von Reis, *Ethnobotany: Evolution of a discipline* (Portland, Or., 1995); Paul E. Minnis (ed.), *Ethnobotany: A reader* (Norman, Ok., 2000); Anthony Aveni, *Empires of time: Calendars, clocks, and cultures* (New York, 1989); Ubiratan D'Ambrosio, *Ethnomathematics: The art or technique of explaining or knowing*, transl. by Patrick B. Scott (Las Cruces, 1998); Paulus Gerdes, *Geometry from Africa: Mathematical and educational explorations* (Washington, D.C., 1999); Arthur B Powell and Marilyn Frankenstein (eds), *Ethnomathematics: Challenging Eurocentrism in mathematics education* (Albany, 1993); Helen Myers (ed.), *Ethnomusicology:*

Historical and regional studies (London, 1993).

31. Craig A. Lockard, "The contributions of Philip Curtin and the 'Wisconsin School' to the study and promotion of comparative world history", *Journal of Third World studies*, xi (1994), 180–223.
32. Roland Axtmann, "Society, globalization and the comparative method", *History of the human sciences*, vi (1993), 53–74, pp. 64–65.
33. Fritz Ringer, *The decline of the German mandarins: The German academic community, 1890–1933* (Cambridge, Mass., 1969), 302–4. Ringer considers comparative history to be unproblematic. In a recent, comparative work where methodology is much in evidence, he avoids all discussion of the comparative method. Ringer, *Fields of knowledge: French academic culture in comparative perspective, 1890–1920* (Cambridge, 1992). On Lamprecht: Roger Chickering, *Karl Lamprecht: A German academic life (1856-1915)* (Atlantic Highlands, N.J., 1993).
34. Lewis Pyenson, *Cultural imperialism and exact sciences: German expansion overseas, 1900–1930* (New York, 1985), 298–9. Ole Bay discounts a Lamprechtian inspiration for Bloch's comparative history, even though Bloch "must have known" about Lamprecht. Bay, "The evolution of the historical thought of Marc Bloch", *Theoretische geschiedenis*, xv (1988), 149–62, p. 152.
35. For example, Jean-Claude Hocquet, "Métrologie du sel et histoire comparée en Méditerranée", *Annales ESC*, xxxix (1974), 393–424, a comparative work on standards for measurement in medieval and early modern times. Hocquet's study follows the precepts of comparative linguistics.
36. Alette Olin Hill and Boyd H. Hill, Jr, "Marc Bloch and comparative history", *American historical review,* lxxxv (1980), 828–46, p. 834.
37. Theda Skocpol and Margaret Somers, "The uses of comparative history in macrosocial inquiry", *Comparative studies in society and history*, xxii (1980), 174–97.
38. Charles Tilly, *Big structures, large processes, huge comparisons* (New York, 1984), 145.
39. A. A. van den Braembussche, "Historical explanation and comparative method: Towards a theory of the history of society", *History and theory*, xxviii (1989), 1–24.
40. Maurice Mandelbaum, "Some forms and uses of comparative history", *American studies international*, xviii/2 (1980), 19–34.
41. Chris Lorenz, "Comparative historiography: Problems and perspectives", *History and theory*, xxxviii (1999), 25–39, introducing a number of special treatments that follow his.
42. Jörn Rüsen, "Some theoretical approaches to intercultural comparative historiography", *History and theory*, xxxv/4 (1996), 5–22, in a number devoted to "Chinese historiography in comparative perspective".
43. Robert Darnton, "Histoire du livre, Geschichte des Buchwesens: An agenda for comparative history", *Publishing history*, no. 22 (1987), 33–41.
44. Christophe Charle, *Les intellectuels en Europe au XIXe siècle: Essai d'histoire comparée* (Paris, 1996).
45. Michael Adas, "Scientific standards and colonial education in British India and French Senegal", in *Science, medicine and cultural imperialism*, ed. by Teresa Meade and Mark Walker (New York, 1991), 4–35, arrives at conclusions of the type that Charle criticizes. (The "scientific standards" in the title refer neither to weights and physical measures nor to experimental philosophies.) South Asia and Senegal resist informed comparison; South Africa and Senegal or India and Indo-China seem more felicitous choices.
46. Edward Shils, "The intellectuals and the powers: Some perspectives for comparative analysis", *Comparative studies in society and history*, i (1958), 15–22; Shils, "The traditions of life: Their conditions of existence and growth in contemporary societies", *International journal*

of comparative sociology, i (1960), 177–94; Shils, "Tradition, ecology, and institution in the history of sociology", *Daedalus*, xcix (1970), 760–825; Ludwig Fritz Haber, *The chemical industry during the nineteenth century: A study of the economic aspect of applied chemistry in Europe and North America* (Oxford, 1958); Joseph Ben-David, "Scientific productivity and academic organization in nineteenth century medicine", *American sociological review,* xxv (1960), 828–43; Ben-David, "The universities and the growth of science in Germany and the United States", *Minerva*, vii (1968), 1–35; Ben–David, *The scientist's role in society: A comparative study* (1971; Chicago, 1984); Derek J. de Solla Price, *Little science, big science* (New York, 1963); Price, "Networks of scientific papers", *Science*, cxlix (1965), 510–15.

47. Hrothgar John Habakkuk, *American and British technology in the nineteenth century: The search for labour-saving inventions* (Cambridge, 1962); Nathan Rosenberg, *Perspectives on technology* (New York, 1976).
48. John J. Beer and W. David Lewis, "Aspects of the professionalization of science", *Daedalus*, xlii (1963), 764–84; W. H. G. Armytage, *The rise of the technocrats: A social history* (London, 1965); D. S. L. Cardwell, "The development of scientific research in modern universities: A comparative study of motives and opportunities", in *Scientific Change*, ed. by Alistair Crombie (London, 1963), reprinted in *Comparative studies in science and society*, ed. Sal P. Restivo and Christopher K. Vanderpool (Columbus, Ohio, 1974), 31–45.
49. Donald Fleming, "Science in Australia, Canada, and the United States: Some comparative remarks", in *Actes du Xe Congrès International d'Histoire des Sciences* (Paris, 1964), i, 179–96; George Basalla, "The spread of Western science", *Science*, clvi (1967), 611–22.
50. Odin Waldemar Anderson and Ronald Andersen, *Medical care in Sweden and the United States: A comparative analysis of systems and behavior* (Chicago, 1970).
51. In its published form: Stanley Goldberg, *Understanding relativity: Origins and impact of a scientific revolution* (Boston, 1984).
52. Thomas Glick (ed.), *The comparative reception of Darwinism* (Austin, 1974); Sal P. Restivo and Christopher K. Vanderpool (ed.), *Comparative studies in science and society* (Columbus, Ohio, 1974).
53. Stephen G. Brush, "Scientific revolutionaries of 1905: Einstein, Rutherford, Chamberlin, Wilson, Stevens, Binet, Freud", in *Rutherford and physics at the turn of the century*, ed. by Mario Bunge and William R. Shea (New York, 1979), 140–71.
54. Nathan Reingold, "National style in the sciences: The United States case", in *Human implications of scientific advance*, ed. by Eric G. Forbes (Edinburgh, 1978), 163–73; Nathan Reingold and Joel N. Bodansky, "The sciences, 1850–1950: A North Atlantic perspective", *Biological bulletin,* clxviii, supplement no. 3 (1985), 44–61.
55. Russell McCormmach, "On academic scientists in Wilhelmian Germany", *Daedalus*, ciii/3 (1974), 157–71.
56. Paul Forman, John L. Heilbron, and Spencer Weart, "Physics ca. 1900: Personnel, funding, and productivity of the academic establishments", *Historical studies in the physical sciences*, v (1975), 1–185.
57. Thomas S. Kuhn, John L. Heilbron, Paul Forman, and Lini Allen, *Sources for the history of quantum physics: An inventory and report* (Philadelphia, 1967).
58. John L. Heilbron and Thomas S. Kuhn, "The genesis of the Bohr atom", *Historical studies in the physical sciences*, i (1969), 211–90; Paul Forman, "Weimar culture, causality, and quantum theory, 1918–1927: Adaptation by German physicists and mathematicians to a hostile intellectual environment", *Historical studies in the physical sciences*, iii (1971), 1–115.
59. Paul Forman, "The reception of an acausal quantum mechanics in Germany and Britain", in *The reception of unconventional science*, ed. by Seymour H. Mauskopf (Boulder, Col.,

1978), 11–50.

60. Eugene Garfield, "Historiographs, librarianship and the history of science", in Garfield, *Essays of an information scientist*, ii (Philadelphia, 1977), 136–59; Derek Price, "Measuring the size of science", *Proceedings of the Israel Academy of Sciences and Humanities*, iv (1969), 98–111.
61. For example, Robert Fox and Anna Guagnini, "Laboratories, workshops, and sites: Concepts and practices of research in industrial Europe, 1800–1914", *Historical studies in the physical and biological sciences*, xxix (1998/99), 55–294.
62. Jack B. Morrell, "The chemist breeders: The research schools of Liebig and Thomas Thomson", *Ambix*, xix (1972), 1–46; J. D. Hunley, "Comparative history of rocket development at Peenemünde in Germany and at the Jet Propulsion Laboratory in the U.S.A. from 1932 to 1945", *Acta astronautica*, xliii (1998), 61–62.
63. Loren Graham, "Science and values: The eugenics movement in Germany and Russia in the 1920s", *American historical review*, lxxxii (1977), 1133–64.
64. John L. Heilbron, *Electricity in seventeenth and eighteenth centuries: A study of early modern physics* (Berkeley, 1979).
65. David Landes, *Revolution in time: Clocks and the making of the modern world* (Cambridge, 1983); Thomas Parke Hughes, *Networks of power: Electrification in Western society, 1880–1930* (Baltimore, 1983); Daniel J. Kevles, *In the name of eugenics: Genetics and the uses of human heredity* (New York, 1985).
66. Daniel Little, "Explaining large-scale historical change", *Philosophy of the social sciences,* xxx (2000), 89–112, for commentary on Hughes's analysis of electrification.
67. Gerald L. Geison, "Scientific change, emerging specialties, and research schools", *History of science*, xix (1981), 20–40.
68. Sal P. Restivo, "Joseph Needham and the comparative sociology of Chinese and modern science", *Sociology of knowledge, sciences, and arts*, ii (1979), 25–52; Margaret Lock, "L'homme-machine et l'homme microcosme: L'approche occidentale et l'approche japonaise des soins médicaux", *Annales ESC*, xxxv (1980), 1116–36; in *Islam and the Medieval West: Aspects of intercultural relations*, ed. by Khalil I. Semaan (Albany, 1980): George Makdisi, "On the origin and development of the college in Islam and the West", 26–49, and Albert Dietrich, "Islamic sciences and the Medieval West: Pharmacology", 50–63.
69. Jonathan Harwood, "National styles in science: Genetics in Germany and the United States between the world wars", *Isis*, lxxviii (1987), 390–414; Erik Baark and Andrew Jamison (eds), *Technological development in China, India, and Japan* (New York, 1986); Andrew Jamison, "National styles of science and technology: A comparative model", *Sociological inquiry*, lvii (1987), 144–58. Harwood has subsequently compared broad-thinking or comprehensive geneticists to more focused or pragmatic geneticists in early twentieth-century Germany. Harwood, *Styles of scientific thought: The German genetics community 1900–1933* (Chicago, 1993), chap. 7.
70. Louis Barry Rosenblatt, "Fossils and myths: A comparative study of geology and classical history in early Victorian England", Ph.D. dissertation, Johns Hopkins University, 1984, 448–9: "The parallels between early Victorian geology and classical studies do not imply an explicit connection or migration across these two domains. Rather, they speak to the dynamics of historical criticism." In Rosenblatt's view, the analogy points to a deeper set of shared values.
71. Jens Høyrup, "Varieties of mathematical discourse in pre-modern sociocultural contexts: Mesopotamia, Greece, and the Latin Middle Ages", in *In measure, number, and weight: Studies in mathematics and culture* (Albany, 1994), 1–87, p. 1. The essay originally appeared in *Science and society*, xlix (1985), 4–41.

72. Susan Sheets-Pyenson, "Low scientific culture in London and Paris, 1820–1875" Ph.D. dissertation, University of Pennsylvania, 1976; Susan Sheets–Pyenson, "Popular science periodicals in Paris and London: The emergence of a low scientific culture, 1820–1875", *Annals of science*, xlii (1985), 549–72.
73. Susan Sheets-Pyenson, *Cathedrals of science: The development of colonial natural history museums during the late nineteenth century* (Montreal, 1988), 21.
74. Joseph Needham, *Science in traditional China: A comparative perspective* (Hong Kong, 1981), quotations on pp. 25–26, 56, 79–80, 105.
75. Shigeru Nakayama, *Academic and scientific traditions in China, Japan, and the West*, transl. by Jerry Dusenbury (Tokyo, 1984), 31, 45, 59.
76. Toby E. Huff, *The rise of early modern science: Islam, China, and the West* (Cambridge, 1993), 32, 337, 341.
77. Edgar Zilsel, *The social origins of modern science*, ed. by Diederick Raven and Wolfgang Krohn (Dordrecht, 2000).
78. In *East Asian Science: Tradition and beyond*, ed. by Keizô Hashimoto, Catherine Jami, and Lowell Skar (Osaka, 1995): Nathan Sivin, "Comparing Greek and Chinese science", 23–32; Karine Chemla, "Algebraic equations East and West until the Middle Ages", 83–90; Jianjun Mei and Tsun Ko, "A comparison of ancient metallurgy in India and China", 233–42; Hans U. Vogel, "Chinese and Western scientific explanations of Sichuan brine and natural gas deposits prior to 1900", 479–88. The unusually vague and to my eye unfathomable paean to postmodernism: Morris Low, "Beyond modernisation: Towards a post-modern history of East Asian science and technology", 147–54.
79. David B. Wilson, *Kelvin and Stokes* (London, 1987); R. D. Harvey, "Pioneers of genetics: A comparison of the attitudes of William Bateson and Erwin Baur to genetics", *Notes and records of the Royal Society of London*, xlix (1995), 105–17; Alan J. Rocke, "Organic chemistry in comparative perspective: Liebig, Dumas, and Berzelius, 1811–1837", in *Instruments and experimentation in the history of chemistry*, ed. by Frederic L. Holmes and Trevor H. Levere (Cambridge, Mass., 2000), 273–310, pp. 300–1.
80. Russell McCormmach, "Albert Einstein and Hermann Broch: Science and art in a world in crisis", in *Disciplines and interdisciplinarity in the new century*, ed. by Lewis Pyenson (Lafayette, La., 1997), 1–19, on pp. 1, 16, 17, 18, quoting George Steiner.
81. Elisabeth Crawford, *Nationalism and internationalism in science, 1880–1939* (Cambridge, 1992).
82. Lewis Pyenson, "The relativity revolution in Germany", in *The comparative reception of relativity*, ed. by Thomas Glick (Boston, 1987), 59-111. Stephen G. Brush has reconsidered the chapters in Glick's volume, explicitly invoking national comparison: Brush, "Why was relativity accepted?", *Physics in perspective*, i (1999), 184–214.
83. Susan Sheets-Pyenson, "Civilizing by nature's example: The development of colonial museums of natural history, 1850–1900", in *Scientific colonialism: A cross-cultural comparison*, ed. by Nathan Reingold and Marc Rothenberg (Washington, D.C., 1987), 351–78; Richard A. Jarrell, "Differential national development and science in the nineteenth century: The problems of Quebec and Ireland", in *Scientific colonialism*, 323–50. In Roy MacLeod and Richard Jarrell (ed.), *Dominions apart: Reflections on the culture of science and technology in Canada and Australia 1850–1945* (Concord, Ontario, 1994) [Scientia Canadensis, xvii, nos 1 and 2]: Richard Jarrell, "Measuring scientific activity in Canada and Australia before 1915: Exploring possibilities", 27–52; James Hull, Ian Rae, and Andrew Ross, "The development of chemical industries in Australia and Canada, 1850–1950", 205–54; David Zimmerman, "The Royal Australian and Canadian navies and high technology in the Second World War", 255–68.

84. David S. Landes, *The unbound prometheus*: *Technological change and industrial development in Western Europe from 1750 to the present* (Cambridge, 1969). Ian Inkster has continued Landes's promising approach to make global comparisons: "Motivation and achievement: Technological change and creative response in comparative industrial history", *Journal of European economic history*, xxvii (1998), 29–66. Inkster's earlier comparison, "Made in America but lost to Japan: Science, technology and economic performance in two capitalist superpowers", *Social studies of science*, xxi (1991), 157–78, illustrates the hazards of dealing with recent events; one might imagine that an interpretation of the relationship through the early years of the new millennium could reverse the roles.
85. Colin A. Russell, *Science and social change, 1700–1900* (London, 1983), 91.
86. Zhu Weizheng, *Coming out of the Middle Ages: Comparative reflections on China and the West*, transl. and ed. by Ruth Hayhoe (Armonk, NY, 1990).
87. Yosio Kawakita, Shizu Sakai, and Yasuo Otsuka (eds), *History of epidemiology* (Tokyo, 1993).
88. Michel Paty, "Comparative history of modern science and the context of dependency", *Science, technology, and society*, iv/2 (1999), 171–204, p. 178. Notwithstanding the call, Paty's text refers to only a handful of explicitly comparative studies; most of the comparisons derive from generalization of studies on univalent topics.
89. Yakov Rabkin and H. Inhaber, "Science on the periphery: A citation study of three less developed countries", *Scientometrics*, ii (1979), 261–74; Jacques Gaillard, *Scientists in the Third World*, transl. by Tilly Gaillard (Lexington, Ky., 1991).
90. R. W. Home and Masao Watanabe, "Physics in Australia and Japan to 1914: A comparison", *Annals of science*, xliv (1987), 215–35, p. 216; Home and Watanabe, "Forming new physics communities: Australia and Japan, 1914–1950", *Annals of science*, xlvii (1990), 317–45.
91. Jaime Larry Benchimol and Luiz Antonio Teixeira, *Cobras, lagartos & outros bichos: Um história comparada dos institutos Oswaldo Cruz e Butantan* (Rio de Janeiro, 1993), 103.
92. Peter S. Biegelbauer, *130 Years of catching up with the West: A comparative perspective on Hungarian industry, science and technology policy-making since industrialization* (Aldershot, 2000).
93. David Barling, "Regulating GM foods in the 1980s and 1990s", in *Food, science, policy and regulation in the twentieth century: International and comparative perspectives*, ed. by David F. Smith and Jim Phillips (London, 2000).
94. John Connelly, "The foundations of diversity: Communist higher education policies in Eastern Europe, 1945–1955", in *Science under socialism: East Germany in comparative perspective*, ed. by Kristie Macrakis and Dieter Hoffmann (Cambridge, Mass., 1999), **000–00**, p. 137; related matters in J. Kozlowski, S. Radosevfic, and D. Ircha, "History matters: The inherited disciplinary structure of the Post-Communist science in countries of Central and Eastern Europe and its restructuring", *Scientometrics*, xlv (1999), 137–66.
95. Etel Solingen (ed.), *Scientists and the state: Domestic structures and the international context* (Ann Arbor, 1994).
96. John M. MacKenzie, "European imperialism: Comparative approaches", *European history quarterly*, xxii (1992), 415–29.
97. David Turnbull, *Masons, tricksters and cartographers: Comparative studies in the sociology of scientific and indigenous knowledge* (Amsterdam, 2000), 1, 46, 40.
98. Marx understood ideology as false consciousness. George Lichtheim, "The concept of ideology", in *Studies in the philosophy of history*, ed. by George H. Nadel (New York, 1965), 148–79. Paul Forman is uncomfortable with idealist formulations in the history of science. Forman, "Independence, not transcendence, for the historian of science", *Isis*, lxxxii (1991), 71–86. A summary of the evolution of "ideology" from the time of its first formulation under Antoine

Destutt de Tracy to Karl Marx in Eric R. Wolf, *Envisioning power: Ideologies of dominance and crisis* (Berkeley, 1999), 25–34.

99. Peter Weingart, "Science and political culture: Eugenics in comparative perspective", *Scandinavian journal of history*, xxiv (1999), 163–77, pp. 173, 175. The cottage industry of comparative eugenics continues to flourish.
100. Brigitte Chamak, "The emergence of cognitive science in France: A comparison with the USA", *Social studies of science*, xxix (1999), 643–84.
101. H. C. Bolton and Alan Roberts, "On the comparison of literary and scientific styles: The letters and articles of Max Born, F.R.S.", *Notes and records of the Royal Society of London*, xlix (1995), 295–302.
102. Patrick Carroll, "Science, power, bodies: The mobilization of nature as state formation", *Journal of historical sociology*, ix/2 (1996), 139–67, p. 140.
103. George Sarton, "East and West", in *The history of science and the new humanism* (1931; New York, 1956), 59–110, pp. 66 and 108.
104. "Emic statements refer to logico-empirical systems whose phenomenal distinctions or 'things' are built up out of contrasts and discriminations significant, meaningful, real, accurate, or in some other fashion regarded as appropriate by the actors themselves.... Etic statements depend upon phenomenal distinctions judged appropriate by the community of scientific observers." Marvin Harris, *The rise of anthropological theory* (New York, 1968), 571, 575. We might extrapolate that *emic* statements refer to local knowledge; *etic* statements posit generality. If *emic* is *gemeinschaftlich* in the formulation of Ferdinand Tönnies, then *etic* would be *gesellschaftlich*.
105. George Sarton, "Incubation of W. Culture in the Middle East", manuscript consulted at York, Maine, in the papers of May Sarton, since removed to Houghton Library, Harvard University. The published version approved by Sarton appeared in Arabic: *The incubation of the Western culture in the Middle East*, transl. by Omar A. Farrukh (Beirut, 1952); an illuminating treatment of progress and development in Antiquity is found in Victor Davis Hanson's comparative reflections, "Agricultural equilibrium, ancient and modern", *Journal of the Historical Society* [Boston], i (2000), 101–33.
106. Joseph Needham, *The grand titration* (London, 1969).
107. Francesca Bray, "Technics and civilization in Late Imperial China", *Osiris*, xiii (1998), 11–33, pp. 14–15.
108. A generation ago, Paul Forman emphasized how difficult it was to contextualize while maintaining causal explanations. He began his study of Weimar uncertainty by insisting that "the historian cannot rest content with vague and equivocal expressions like 'prepared the intellectual climate for,' or 'prepared, so to speak, the philosophical background for,' but must insist upon a causal analysis, showing the circumstances under which, and the interactions through which, scientific men are swept up by intellectual currents". He ended by capitulating to contextualization. His sociological model "provides a general framework, and seems to work especially well in certain extreme cases. But in order to account for its special applicability to some physicists and its special inapplicability to others one must invoke precisely those factors which are excluded from the model — individual personality and intellectual biography. The mechanism advanced for the entrainment of the German physicists and mathematicians by the *Zeitgeist* is thus clearly not sufficient". Forman, "Weimar culture" (ref. 58), 3, 114.
109. Rossetti's opinion is related in an electronic publication by George P. Landow of Brown University.
110. The ecumenical orientation of Joseph Needham's *Science and civilisation in China* is evident in his wide choice of collaborators, from Francesca Bray to Christoph Harbsmeier. Yung Sik Kim, "Towards a 'comparative history of the foundations of science': Language and logic in

traditional China", *Annals of science*, lvi (1999), 451–60. Kim points out that Harbsmeier shares many of Needham's perspectives.

111. David Cosandey, *Le secret de l'Occident: Du miracle passé au marasme présent* (Paris, 1997), 312–13, 125, 248.
112. Charles C. Gillispie, commenting in *Technology and culture*, xxxix (1998), 742.
113. G. E. R. Lloyd, *Adversaries and authorities: Investigations into ancient Greek and Chinese science* (Cambridge, 1996), 5, 116, 184, 214, 226–7.
114. John R. R. Christie, "Recent and contemporary trends in science historiography", in *L'étude social des sciences: Bilan des années 1770 et 1980 et conséquences pour le travail. Journée d'étude du 14 mai 1992, Communications*, ed. by Dominique Pestre (Paris, [1992]), 87–94.