The Spread of Western Science

A three-stage model describes the introduction of modern science into any non-European nation.

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A small circle of Western European nations provided the original home for modern science during the 16th and 17th centuries: Italy, France, England, the Netherlands, Germany, Austria, and the Scandinavian countries. The relatively small geographical area covered by these nations was the scene of the Scientific Revolution which firmly established the philosophical viewpoint, experimental activity, and social institutions we now identify as modern science. Historians of science have often attempted to explain why modern science first emerged within the narrow boundaries of Western Europe, but few if any of them have considered the question which is central to this article: How did modern science diffuse from Western Europe and find its place in the rest of the world?

The obvious answer is that, until fairly recent times, any region outside of Western Europe received modern science through direct contact with a Western European country (*1*). Through military conquest, colonization, imperial influence, commercial and political relations, and missionary activity the nations of Western Europe were in a position to pass on their scientific heritage to a wider world. This simple explanation is essentially correct, but it is entirely lacking in details. Who were the carriers of Western science? What fields of science did they bring with them? What changes took place within Western science while it was being transplanted? By what means is a flourishing scientific tradition fully recreated within societies outside of Western Europe? In this article I undertake to incorporate all these questions into a meaningful framework through the means of a model designed to aid our understanding of the diffusion of Western science.

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The Model

While making a preliminary survey of the literature concerning the diffusion of Western European science and civilization, I discovered a repeated pattern of events that I generalized in a model which describes how Western science was introduced into, and established in, Eastern Europe, North and South America, India, Australia, China, Japan, and Africa. The model, like the survey that produced it, is preliminary; it is a heuristic device useful in facilitating a discussion of a neglected topic in the history of science.

Three overlapping phases or stages constitute my proposed model. During "phase 1" the nonscientific society or nation provides a source for European science. The word *nonscientific* refers to the absence of modern Western science and not to a lack of ancient, indigenous scientific thought of the sort to be found in China or India; *European*, as used hereafter in this article, means "Western European." "Phase 2" is marked by a period of colonial science, and "phase 3" completes the process of transplantation with a struggle to achieve an independent scientific tradition (or culture).

These phases are conveniently represented by the three curves of Fig. 1. The shapes of the curves were not determined in any strict quantitative way, for qualitative as well as quantitative factors are to be included in the definition of scientific activity. In determining the height of a curve I am willing to consider quantifiable elements —number of scientific papers produced, manpower utilized, honors accorded —as well as the judgments of historians who evaluate, on a more subjective basis, the contributions of individual scientists. Furthermore, the curves describe a generalized process that must be modified to meet specific situations. Japan, for example, had an unusually long, and initially slow-growing, second phase because of the policy of political, commercial, and cultural isolation practiced by her rulers. This long interval quickly reached a peak after the Meiji Restoration (1868), when Japan was fully opened to Western influence.

Thus it should be clear that when I refer to the graph of Fig. 1, I will (i) be mainly concerned with the gross features of the curves and (ii) be using the curves to illustrate my discussion and not to bolster it with independent support from empirical sources (*2*).

The first phase of the transmission process is characterized by the European who visits the new land, surveys and collects its flora and fauna, studies its physical features, and then takes the results of his work back to Europe. Botany, zoology, and geology predominate during this phase, but astronomy, geophysics, and a cluster of geographical sciences—topography, cartography, hydrography, meteorology—sometimes rival them in importance. Anthropology, ethnology, and archeology, when they are present, clearly rank in a secondary position. These various scientific studies may be undertaken by the trained scientist or by the amateur who, in the role of explorer, traveler, missionary, diplomat, physician, merchant, military or naval man, artist, or adventurer, makes an early contact with the newly opened territory. Training and expertise in a science will increase the European observer's awareness of the value and novelty of his discoveries, but they are not the crucial factors. What is important is the fact that the observer is a product of a scientific culture that values the systematic exploration of nature.

Science during the initial phase is an extension of geographical exploration, and it includes the appraisal of natural resources. Whether the "New World" to be studied is North or South America, Africa, Antarctica, the moon, or a neighboring planet, it is first necessary to survey, classify, and appraise the organic and inorganic environment (*3*). If the territory under surveillance is to serve eventually as a settlement for European colonists, the observer will probably follow the advice Sir Francis Bacon offered 17th-century planters of colonies (*4*). First, he counseled, "look about [for] what kind of victual the country yields of itself" and then "consider . . . what commodities the soil . . . doth naturally yield, that they may some way help to defray the charge of the plantation." Botany, zoology, and geology have a direct relevance to this search for foodstuffs and exportable natural products.

Phase-1 science is not limited to the uncivilized country where European settlement is the object. It is also to be found in regions already occupied by ancient civilizations, some with indigenous scientific traditions. India and China, two nations in this category, fell under the scrutiny of European scientists when they came into continuous contact with the West. Although the possibilities for trade in exotic items partly explain European interest in the natural history of these countries, commerce did not supply the major impulse. Trade and the prospect of settlement both influence the European observer's investigation of a new land, but ultimately his work is to be related to the scientific culture he represents. He is the heir to the Scientific Revolution, that unique series of events that taught Western man the physical universe was to be understood and subdued not through unbridled speculation or mystical contemplation but through a direct, active confrontation of natural phenomena. The plants, animals, and landscape of Europe had revealed their secrets when subjected to this method of inquiry; why should not the flora, fauna, and geology of an exotic land reveal as much or more?

The historical record is filled with examples of European naturalists collecting and classifying the plant and animal life they find in remote jungles, deserts, mountains, and plains and then publishing the results for the illumination of the European scientific community. In the Americas we begin with Gonzalo Fernández de Oviedo, called the first naturalist of the New World, and his book delineating the natural history of the West Indies (1535). From Oviedo in the 16th century, through the 17th and 18th centuries, there is a constant stream of Spanish, French, German, Dutch, Swedish, and English naturalists traveling on scientific expeditions to South America. In the early decades of the 19th century this movement culminates in the work of Alexander von Humboldt and Charles Darwin (*5*).

Thomas Harriot, a 16th-century traveler and writer on the natural products and natives of Virginia, is the progenitor of a North American group of collectors, geologists, and surveyors. During the 18th century American colonial naturalists joined their European-based colleagues and continued the task of expanding European knowledge of the natural history of the northeastern and southeastern United States. Mark Catesby, John and William Bartram, Alexander Garden, Peter Kalm, and John Clayton are familiar names in this scientific enterprise. By 1800 the region east of the Mississippi River had been explored; now there was a shift of interest to the Western lands.

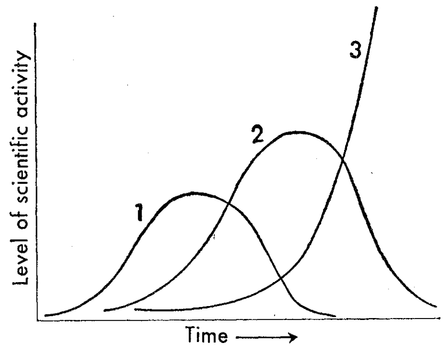


Fig. 1. Sequence of phases in the diffusion of Western science.

The wave of modern science had traveled from Europe across the Atlantic to the eastern and middle-western United States. During the 19th century science maintained its westward thrust as it was carried beyond the Mississippi by a series of government-supported and privately supported exploratory expeditions. From Lewis and Clark to the Colorado River venture of John Wesley Powell (1804–1870), the American West was the scene of phase-1 science. The sponsors of this science, however, did not reside in the older scientific capitals of Western Europe—London, Paris, Berlin—but lived in the eastern United States—in Boston, Philadelphia, and Washington, the emerging counterparts of the older capitals. This region, moving through the second into the third phase of the transmission process, was now in a position to act as a center for the diffusion of modern science. The time lag between the phases in the various geographical sections of the United States has had its effect on the current American scientific scene. The unequal distribution of scientific centers of excellence throughout the nation is due, *in part*, to the fact that some sections began the process of transplanting and nurturing science at a later date than others (*6*).

The Pacific Ocean was opened to European scientists by the three exploratory voyages undertaken by Captain James Cook between 1768 and 1780. Cook carried Sir Joseph Banks with him on his initial voyage, and it was the latter who uncovered the botanical, zoological, and ethnological treasures of the Australian continent. Botanist Robert Brown, spurred on by Banks's success, gathered some 3900 species of Australian plants and produced *Prodromus florae novae Hollandiae et insulae Van-Diemen* (1810), a classic in botanical literature. Later in the century Sir Joseph Dalton Hooker and Alfred Russell Wallace were to make significant contributions to science, based on their collecting ventures in, respectively, Antarctica (1839–43) and the Malay Archipelago (1856–62) (*7*).

China, India, and Japan posed new problems for the spread of Western science. Ancient and civilized peoples inhabited these nations, not the primitives encountered elsewhere. Nevertheless, the first Europeans who visited them began the surveying and collecting of plant and animal life that has consistently marked their early contract with new territory. Natural history was studied in Japan prior to the arrival of the Christian missionaries in the late 16th century, but this native endeavor was soon to be dominated by Europeans, with their superior classificatory systems. Two Germans, Andreas Cleyer and Engelbert Kaempfer, are noted for their botanical work in 17th-century Japan. In the succeeding century Carl Peter Thunberg and Philipp Franz von Siebold, two medical officers in the employ of the Dutch East India Company, made lasting contributions to the study of Japanese natural history (*8*).

China, once it was opened to Western ideas by the Jesuits in 1583, provided vast new opportunities for European scientific exploration. One customarily reads of the Jesuit missionaries as carriers of the new astronomy of Copernicus and Galileo to the learned men of China, but their correspondence and memoirs attest to their interest in the biological and geological sciences. The natural history studies of the first missionaries were soon to be expanded as hundreds of European scientists journeyed to China in the 17th, 18th, and 19th centuries. Botany alone caught the attention of so many of these Europeans that over 1000 pages in a two-volume history of European botanical discoveries in China (*9*) are devoted merely to a listing of their names and accomplishments!

The Portuguese, in pursuit of the spice trade, opened a sea route to India, bringing with them the first European science-collectors to that continent. When, in the 17th century, England replaced Portugal as the major influence in Indian affairs, English missionaries and physicians assumed the task of investigating Indian natural history. In the 18th century the English became masters of Indian trade, and the men attached to the East India Company turned naturalists. They acquired extensive collections of flora and fauna and hired native artists to sketch the specimens in their proper colors and ecological setting. The Company formally acknowledged the economic importance of its servants' botanical labors by establishing the Botanic Gardens at Calcutta in 1787. The travels and writings of Sir Joseph Dalton Hooker, whose botanical expedition to the Himalayas was the basis for his *Flora Indica* (1855) (see *10*), are a reminder that professional scientists were also actively engaged in study of the natural history of India.

The western coastline of Africa was explored by 15th-century Portuguese navigators, but the easy availability of gold and slaves on the coast, and the natural barriers to the exploration of the interior, kept substantial European contact limited to the periphery of the continent until the late 19th century. The Cape area, however, serving as a way station for India-bound vessels, had a European settlement in 1652. South Africa, offering communities of European settlers and the advantages of a southerly location for telescopic observation, early attracted naturalists and astronomers, who came to observe its plants and animals, its geography and geology, and its heavens (*11*).

In the second half of the 18th century a small number of observers from France, England, Sweden, and Denmark began a more intensive investigation of the natural history of the continent of Africa. The most ambitious 18th-century scientific expedition was mounted in 1798 by Napoleon Bonaparte as part of his military campaign in Egypt (1798–1801). Naturalist Geoffroy St. Hilaire, attached to the Napoleonic venture, collected Egyptian flora and fauna, paying special attention to the native fishes. His colleagues, including some eminent French scientists of the day, analyzed the soil and water of Egypt, made astronomical observations, and sketched and gathered Egyptian antiquities, thereby laying the foundations for modern Egyptology (*12, 13*).

One should not conclude from this swift survey of world history that phase-1 science is confined to the period beginning in the 16th and terminating in the mid-19th century. Late in the 19th century, when Germany became an imperial power by acquiring territory in Africa and the Pacific, she assessed her colonial wealth in *Das Deutsche Kolonialreich* (1909–10), a work that includes studies by zoologists, botanists, geologists, and geographers. In the first half of the 20th century the polar regions were the goals of the scientific explorer. The current need for natural history studies in underdeveloped regions (*14*) and the prospects of lunar and planetary exploration promise new tasks for the phase-1 scientist.

All of the plant, animal, and mineral specimens collected in the foreign lands, as well as the information amassed there, were returned to Europe (or, at a later date, to the United States) for the benefit of its scientists. Phase-1 science may be scattered around the globe, but only nations with a modern scientific culture can fully appreciate, evaluate, and utilize it.

As early as the 17th century it was realized that contact with new lands is certain to affect the development of science at home. Bishop Sprat, in his history of the Royal Society of London (1667) (*15*), wrote that maritime nations were "most properly seated, to bring home matter for new Sciences, and to make the same proportion of Discoveries . . . in the Intellectual Globe, as they have done in the Material" (see Fig. 2). The "matter" sent back by the collectors filled the zoological and botanical gardens, herbariums, and museums of Europe; made obsolete the classificatory systems devised for European flora and fauna; gave rise to the new studies of plant and animal geography; and decisively influenced the Darwinian theory of organic evolution (*16*).

The scientist who went out on an exploratory expedition often found that the experience gained from studying natural history in a foreign land modified his own scientific views. Michel Adanson, recalling his stay in Senegal (1749–54), commented (*17*): "Really, botany seems to change face entirely as soon as one leaves our temperate countries." And halfway across the earth in Australia, Sir James E. Smith (1793) concurred (*18*): "When a botanist first enters . . . so remote a country as New Holland, he finds himself . . . in a new world. He can scarcely meet with any fixed points from whence to draw his analogies." Thus European science, its practitioners forced to come to terms with exotic material at home and abroad, underwent a significant transformation while it was in the process of being diffused to a wider world.

Colonial Science

Colonial science (phase 2) begins later than phase-1 science but eventually reaches a higher level of scientific activity (Fig. 1) because a larger number of scientists are involved in the enterprise. Let me explain this use of the adjective *colonial.* First, as I use the term, colonial science is dependent science. At the phase-2 stage the scientific activity in the new land is based primarily upon institutions and traditions of a nation with an established scientific culture. Second, *colonial science* is not a pejorative term. It does not imply the existence of some sort of scientific imperialism whereby science in the non-European nation is suppressed or maintained in a servile state by an imperial power. Third, phase 2 can occur in situations where there is no actual colonial relationship. The dependent country may or may not be a colony of a European nation. This usage permits discussion of "colonial science" in Russia or Japan as well as in the United States or India (*19*).

Natural history and the sciences closely related to the exploration of new lands dominate phase 1. During the early years of phase 2, natural history is still the major scientific interest, with the first colonial scientists joining in the survey of the organic and inorganic environment conducted by the European observers. As colonial scientific activity increases, the range of the sciences studied is expanded and finally coincides with the spectrum of scientific endeavor in the nation, or nations, supporting the activity. There is a possibility that the colonial scientist will extend this spectrum, that he will open up wholly new fields of science, but this is unlikely, not because the colonial scientist is necessarily inferior to his European colleagues but because he is dependent upon an external scientific culture and yet not a fully participating member of that culture.

Who is this colonial scientist? He may be a native or a transplanted European colonist or settler, but in any case the sources of his education, and his institutional attachments, are beyond the boundaries of the land in which he carries out his scientific work. This pattern is found in 18th- and 19th-century North and South America, Russia, and Japan; in 19th-century Australia and India; and in 20th-century China and Africa. If formally trained, the colonial scientist will have received some or all of his scientific education in a European institution; if informally trained, he will have studied the works of European scientists and will have purchased his books, laboratory equipment, and scientific instruments from European suppliers. This training will direct the colonial scientist's interest to the scientific fields and problems delineated by European scientists. Colonial scientific education is inadequate or nonexistent; the same can be said for colonial scientific organizations and journals. Therefore, the colonial scientist seeks the membership and honors of European scientific societies (*20*) and publishes his researches in European scientific journals.

Does the dependency of colonial science mean that it must be inferior to European science? Any answer to this question must consider the vigor of the scientific culture upon which the colonial science is dependent. Colonial science in Latin America, for example, advanced slowly as compared with developments in Western Europe. Several possible explanations of this lag may be proposed, but included among them must be the realization that modern science had not been extensively cultivated by Spain and Portugal, the colonizers of South America. A case in point is Brazil. Brazilian science received its greatest impetus during the hiatus in Portuguese rule when the Dutch (1624–54) broke the old ties and brought the colony under the full influence of Western European culture (*21*).

Having mentioned the special case of Spain and Portugal, let me return to the general question of the inferiority of colonial science. As already noted, the colonial scientist works under handicaps at home and relies upon a scientific tradition located abroad. Although the group of men involved in the enterprise of colonial science is larger than that involved in phase-1 collecting, the number has not yet reached the critical size necessary for reciprocal intellectual stimulation and self-sustaining growth. The weakness, or lack, of colonial scientific institutions tends to cancel the advantages otherwise gained as the group approaches its critical size.

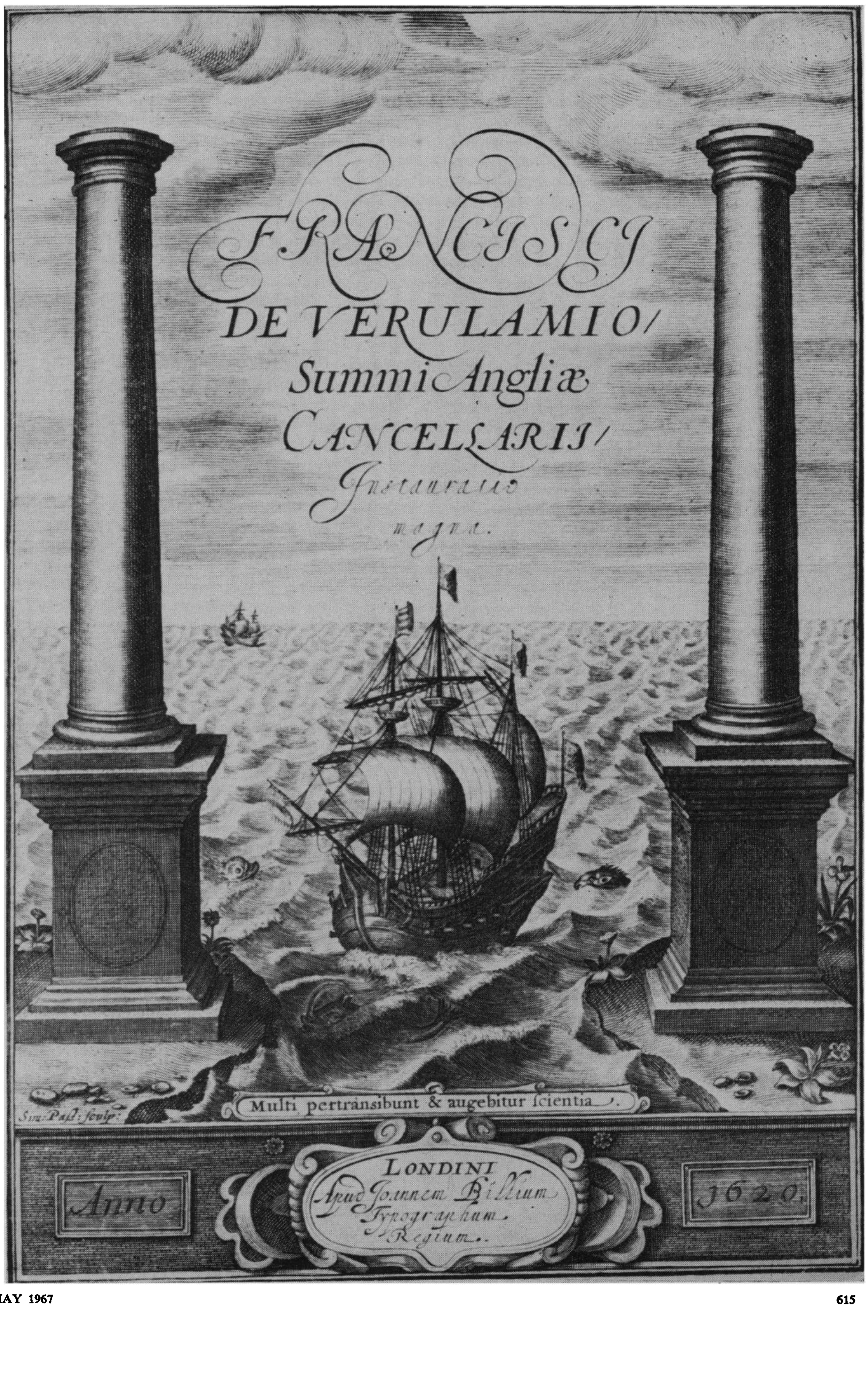
There is one final difficulty. Colonial scientists are oriented toward an established scientific culture but they cannot share in the informal scientific organizations of that culture. They cannot become part of the "Invisible Colleges" in which the latest ideas and news of the advancing frontiers of science are exchanged, nor can they benefit from the "continuing mutual education" provided by these informal groups of scientists (*22*). These are some of the disadvantages colonial scientists face even when they are in touch with the superior and vigorous scientific traditions of a France, Germany, Great Britain, or United States.

Colonial science has its drawbacks, but it is in the fortunate position of being able to utilize the resources of existing scientific traditions while it slowly develops a scientific tradition of its own. Although colonial science will rarely create great centers or schools of scientific research, open new fields of science, or completely dominate older areas of scientific inquiry, it does provide the proper milieu, through its contacts with the established scientific cultures, for a small number of gifted individuals whose scientific researches may challenge or surpass the work of European savants. These few men become the heroes of colonial science, and the debt they owe the older scientific traditions is often obscured, as is the fact that they are not representative of the state of colonial science. Benjamin Franklin is such a hero. He was a creative experimentalist and theorizer whose researches on electricity overshadowed the contributions of many of his European contemporaries. However, in praising Franklin we should remember that his intellectual and institutional home was London and Paris, not Philadelphia, and that his model was Sir Isaac Newton (*23*). The 18th-century chemist Mikhail V. Lomonosov holds a similar position in Russian colonial science, and, similarly, his intellectual base was outside of Russia, in Germany (*24*). Colonial science need not be inferior to European science, and in the hands of a scientific genius it might be superior, but its ultimate strength lies in the growing number of practicing scientists whose education and work are supported by an external scientific tradition.

The United States and Japan provide interesting illustrations of the course and nature of colonial science. The American colonial period of science extended beyond the nation's colonial political status. In 1847 Swiss-born Louis Agassiz criticized American deference to England in scientific matters (*25*), and as late as 1922 American physicists preferred to publish in the prestigious English journal *Philosophical Magazine* rather than in the American *Physical Review* (*26*). By the second half of the 19th century, Germany and France, not England, had come to hold the greatest attraction for American scientists. The young Josiah Willard Gibbs received his doctorate in science from Yale (1863) and immediately left for Europe to complete his scientific education in Paris and Berlin. Gibbs was not alone. Hundreds of American chemists, physicists, and biologists in the late 19th and early 20th century pursued graduate studies, or gained Ph.D.'s, at Berlin, Leipzig, Göttingen, Heidelberg, Munich, or Paris (*27*). In 1904 the president of the American Mathematical Society estimated that 10 percent of its members held Ph.D.'s from German universities, and at least 20 percent had studied mathematics there (*28*). American scientific institutions could not provide the training or experience these men needed to bring them to the forefront of scientific knowledge.

"Of all the wonders of the world the progress of Japan . . . seems to me about the most wonderful." So wrote Charles Darwin in 1879 to Edward S. Morse, the American zoologist who had introduced the theory of organic evolution into Japan (*29*). The rapid progress of Japanese science that impressed Darwin was of relatively recent origin. Prior to the Meiji restoration (1868) Japanese colonial science grew at a slow pace, thwarted by governmental prohibition, linguistic barriers, and cultural resistance. European science, carried to Japan by 16th-century Jesuit missionaries, was banned in 1636 when the government moved to halt the infiltration of Western religion and thought. This seclusionist policy was

Fig. 2 (right). The title page of Sir Francis Bacon's major contribution to the philosophy of science pictorially associated the acquisition of new knowledge with the travels of ships to the lands beyond Europe. [From F. Bacon, *Instauratio Magna* (London, 1620), reproduced with permission of the University of Texas Library]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not relaxed until the first half of the 18th century, when Western ideas were permitted to enter in the form of Sino-Jesuit scientific treatises and Dutch books. The Dutch, having maintained limited commercial contacts during the period of isolation, provided the only direct channel of communication between Japan and Europe. Once the ban was removed, Japanese scholars took advantage of this channel by translating Dutch books summarizing Western science and learning. These books made available European knowledge of human anatomy and medicine, heliocentric astronomy, and developments in chemistry and physics. The Japanese translators went beyond their linguistic tasks and often repeated the experiments they learned about in their reading. Thus the physician Hashimoto Sokichi, while translating some Dutch books on electricity, decided to confirm their accuracy by repeating the electrical experiments of Benjamin Franklin (see Fig. 3) (*30*).

In the Tokugawa era (1600–1868) (see *31*), especially in the later years, a growing number of Japanese savants were attempting to assimilate European science and technology. Nevertheless, Meiji science far surpassed the modest accomplishments of the previous period. After 1868 the Japanese government undertook a deliberate program of modernization, a program that paid special attention to the science of the West. The Japanese imported American, German, English, and Dutch scientists, engineers, and physicians to serve in native universities as teachers of aspiring scientists. Between 1868 and 1912 over 600 students were sent abroad for special training in the scientific and technological centers of America and Europe. Linguistic barriers were overcome by the translation of Western scientific textbooks and by the compilation of a dictionary of technical words (Japanese, English, French, and German). Insofar as her science was concerned, Japan was as dependent upon the Western scientific culture as any of those countries that are conventionally classified as political colonies of the Western nations (*32*).

Colonial science begins when a small number of native workers or European settlers in the land recently opened to European science first participate in

Fig. 3. The Tokugawa physician Hashimoto Sokichi (1763–1836) used a tall pine tree, instead of a kite, in an experiment confirming Benjamin Franklin's claim that lightning is identical with static electricity. [From Hashimoto Sokichi, *Erekiteru kyūri gen* (Osaka, 1811), reproduced with permission of Osaka Prefectural Library, Osaka, Japan]

phase-1 exploration and then gradually shift their interest to a wider spectrum of scientific activity. All this takes place while the colonial scientist relies upon an external scientific tradition. The transition from phase 2 to phase 3 is more complex. Scientists in the third phase are struggling to create an independent scientific tradition; they are attempting to become self-reliant in scientific matters.

What spurs the colonial scientist to move from dependency to independency? Nationalism, both political and cultural, can sometimes be identified as the moving force. After the American Revolution there was nationalistic sentiment in the new nation which encouraged the building of an American science upon a native foundation (*33*). Similar sentiment appeared in the South American colonies after their break with Spain (*34*). In 1848 Andrés Bello, a Venezuelan thinker and educator, called for a South American science, bearing the stamp of its national origin, that would not "be condemned to repeat servilely the lessons of European science." "European science seeks data from us," he said, and then asked rhetorically, "shall we have not even enough zeal and application to gather it for them?" The answer was that data-gathering was not to be the only job of the Latin-American scientist, for the American republics had a "greater role to play in the progress of the sciences."

Nationalistic feelings may be significant in the transition from phase 2 to phase 3, but there are more fundamental forces working to bring about this change. Colonial science contains, in an embryonic form, some of the essential features of the next stage. Although the colonial scientist looks for external support, he does begin to create institutions and traditions which will eventually provide the basis for an independent scientific culture. A modest amount of scientific education will be undertaken by the colonial scientist, he will agitate for the creation of native scientific organizations, he may work for the establishment of a home-based scientific journal, and he begins to think of his work, and of the researches of his immediate colleagues, as being the product of his own nation. Colonial science has passed its peak when its practitioners begin a deliberate campaign to strengthen institutions at home and end their reliance upon the external scientific culture.

Independent Scientific Tradition

The struggle to establish an independent scientific tradition, which takes place during the third phase, is the least understood, appreciated, or studied aspect of the process of transference of modern science to the wider world. Historians and sociologists of science have failed to realize the difficulty of fully integrating science into a society that previously had little contact with Western science. The easy success of colonial science does not adequately prepare a country for the arduous task of creating and supporting native scientific institutions and fostering attitudes conducive to the rapid growth of science. Scientists working in phase 3, and historians who later attempt to plot the development of science during phases 2 and 3, often misunderstand the era of colonial science. In both cases they tend to praise the high level of scientific activity reached in the colonial era and forget that that level of attainment was made possible through a reliance upon an older, established scientific tradition.

The colonial scientist, who was a member of a relatively small group of men oriented toward an external scientific culture, is to be replaced during the course of phase 3 by a scientist whose major ties are within the boundaries of the country in which he works. Ideally, he will (i) receive most of his training at home; (ii) gain some respect for his calling, or perhaps earn his living as a scientist, in his own country; (iii) find intellectual stimulation within his own expanding scientific community; (iv) be able to communicate easily his ideas to his fellow scientists at home and abroad; (v) have a better opportunity to open new fields of scientific endeavor; and (vi) look forward to the reward of national honors—bestowed by native scientific organizations or the government—when he has done superior work. These six elements are more in the nature of goals to be attained than common characteristics of phase-3 science. Since phase 3 is marked by a conscious struggle to reach an independent status, most scientists will not personally achieve all of these goals, but there will be general agreement that an overt effort should be made to realize them.

If a colonial, dependent scientific culture is to be exchanged for an independent one, many tasks must be completed. Some of the more important ones are as follows.

1) Resistance to science on the basis of philosophical and religious beliefs must be overcome and replaced by positive encouragement of scientific research. Such resistance might be ignored or circumvented by the colonial scientist, but it must be eradicated when science seeks a broad base of support at home.

The slow development of science in China can be explained, in large measure, by the inability of modern science to displace Confucianism as the prevailing philosophy. Confucian thought stressed the importance of moral principles and human relationships and discouraged systematic study of the natural world. The Confucian rejection of scientific knowledge is epitomized in a poem written in the early 19th century by a Chinese dignitary (*35*):

> With a microscope you see the surface of things.
> It magnifies them but does not show you reality.
> It makes things seem higher and wider,
> But do not suppose you are seeing the things in themselves.

Attitudes of this sort persisted in China until the end of the 19th century, at which time the Confucian ideals were decisively challenged and gradually replaced by value systems closer to the spirit of Western science (*36*).

2) The social role and place of the scientist need to be determined in order to insure society's approval of his labors. If science in general, or some aspect of the scientist's work, is considered suitable only for the socially inferior, the growth of science may be inhibited. When Louis Agassiz visited Brazil in 1865 he was surprised to find that the higher social classes held a strong prejudice against manual labor. This prejudice had its effect upon the development of science in Brazil. Agassiz noted (*37*) that as long as Brazilian "students of nature think it unbecoming a gentleman to handle his own specimens, to carry his own geological hammer, to make his own scientific preparation, he will remain a mere dilettante in investigation" (see Fig. 4). The Brazilian naturalists were thoroughly acquainted with "the bibliography of foreign science," but their social mores cut them off from "the wonderful fauna and flora with which they [were] surrounded." Prejudices so deeply rooted in the social structure are

not likely to be removed easily, and science is retarded.

3) The relationship between science and government should be clarified so that, at most, science receives state financial aid and encouragement and, at least, government maintains a neutral position in scientific matters. The history of Japanese science affords examples of the several possibilities in a government's response to science. Western science was suppressed by the Japanese government in the 17th century, partially accepted in the 18th century, and then enthusiastically supported after 1868. At no time was the Japanese government reacting to the general will of its people.

In those nations where public opinion is more instrumental in the shaping of government policy, state aid to science will depend upon the citizen's evaluation of the significance of science. This was the case in Australia in the 1830's, when there was some hope for the establishment of a national geological survey. A Sydney newspaper, however, expressed the prevailing sentiment when it declared editorially (*38*): "Zoology, Mineralogy, and Astronomy, and Botany are all very good things, but we have no great opinion of an infantile people being taxed to support them. An infant colony cannot afford to become scientific for the benefit of mankind." Scientists seeking the help and recognition of the state have, until recently, found it difficult to justify the expenditure of public funds to promote scientific research.

4) The teaching of science should be introduced into all levels of the educational system, provided, of course, an adequate educational system already exists. This will entail the building, staffing, and equipping of schoolrooms and teaching laboratories; the training of science teachers and of instructors in supporting disciplines; the production of science textbooks in an appropriate language; and the founding of libraries of science. Education in the sciences is not enough; a parallel program must be instituted to train the "foot soldiers of the scientific army"—the technicians, instrument makers, and their like. These changes can only be made if they are judged worth while by society, and if they are not too strongly opposed by conservative educators who are committed to other educational patterns. In view of the many possible sources of resistance to innovation in education, the creation of adequate programs in the teaching of science must necessarily be a long-term process. It is for this reason that American scientists were still seeking European scientific training after the United States had acquired many of the other features of an independent scientific tradition.

5) Native scientific organizations should be founded which are specifically dedicated to the promotion of science. These would include general professional associations, working for the advancement of the whole scientific profession; specialist societies, serving the particular needs of men engaged in research within a given field of science; and elite, honorific organizations, providing rewards for those who make the greatest contribution to the advancement of science. Scientific societies have always been closely associated with Western science; the foundation, in the 17th century, of the Accademia del Cimento, the Royal Society of London, and the Académie des Sciences is usually cited as one proof of the emergence of modern science in that era.

Napoleon Bonaparte acknowledged the importance of scientific societies when he founded the Institut d'Egypte, patterned after the major contemporary French scientific society, the Institut de France. Determined to bring the science of Western Europe to the ancient Near East, he attempted to recreate the Institut de France in Egypt in the hope that the new organization would play a part in the growth of Egyptian science as important as the part its progenitor had played in France. Military defeat (1801) ended Napoleon's plans, and it is doubtful whether the Institut alone could have carried the burden of introducing Western science into Egypt (*13, 39*). Nevertheless, Napoleon was correct in believing that scientific organizations were crucial to the establishment of modern science in a land hitherto untouched by Western influence.

6) Channels must be opened to facilitate formal national and international scientific communication. This can be accomplished by founding appropriate scientific journals and then gaining their widespread recognition. Many problems are likely to be encountered here (*40*). A scientific journal cannot flourish unless there are enough scientists and subscribers to fill its pages and pay its costs. Even if the requisite number of potential contributors exists, there remains the question of its prestige. The colonial scientist, who is accustomed to writing for established European scientific journals, may not wish to jeopardize his international reputation by reporting his work in an unknown native periodical. Will the 18th-century American scientist, or his counterparts in 19th-century India or Australia, whose contributions appear in the *Philosophical Transactions of the Royal Society of London*, be satisfied to write for a natively produced periodical with few readers and little influence?

Finally, there are the difficulties presented by language. Should national pride dictate that the contributions to the new journal be printed in the mother tongue when that language is not familiar to Western Europeans, or should some concession be made in order to gain European readers? This was the question faced by the founders of scientific periodicals in Japan, in China, and (in the case of Rumania) in Central Europe (*41*). Despite these problems, it is important that a country struggling to create an independent scientific tradition should publish journals of science filled with the researches of its own scientists.

7) A proper technological base should be made available for the growth of science. Western Europe had reached an advanced state of technical progress when modern science first made its appearance, and since that time it has been assumed that the two are fundamentally related. The exact nature of that relationship has not as yet been revealed by historians of science and technology.

Even without clear guidelines it is possible to indicate some of the links between science and technology that are significant for this discussion. A nation hoping to be self-sufficient in the realm of science certainly must maintain a level of technology that will produce the scientific instruments and apparatus needed for research and teaching. That this level is not to be reached without some difficulty is proved by the American example. European technology was transmitted to North America by the early settlers, but the colonies were slow to develop a craft tradition that specialized in the construction of scientific instruments for purposes other than navigation and surveying. Fine scientific instruments, to be used by American scientists in research, teaching, and exploration, were customarily purchased in England and France until the second half of the 19th century (*42*). If America found it necessary to rely on Europe, one can imagine that an African or Asian culture, existing beyond the influence of Western technology, would find it much more difficult to reach the desired technological level and make its own instruments.

Economic determinists, along with some historians of technology, argue that technology has more to offer science than a mere collection of scientific instruments. They say that technology poses the very problems that dominate a scientific field in a given era. For the most part, historians of science reject this external interpretation and concentrate on the internal, conceptual development of science. If technology does direct scientific inquiry, as the first group contends, then it will be the overriding factor in the establishment of an independent scientific culture; if it does not, then it should be reduced to its role of provider of gadgetry for the scientist.

These are the extreme positions, but there is the possibility of a compromise that calls for a recognition of the complexity of the relationship between science and technology and demands a more subtle analysis. A proponent of this compromise will ask that the following investigations be made. First, we should determine to what extent a lifelong familiarity with a variety of machines prepares and predisposes an individual or culture to accept and extend the predominantly mechanical view of the physical universe

Fig. 4. Nineteenth-century Brazilian naturalists, disdaining manual labor, assigned their Negroes the job of collecting and preparing specimens. [From D. P. Kidder, *Sketches of Residence and Travels in Brazil* (Philadelphia, 1845), vol. 1, p. 129, reproduced with permission of the University of Texas Library]

bequeathed to us by the founders of modern science. Second, we should study the products of technology not merely as mechanical contrivances designed to fulfill specific, limited purposes but as cultural complexes that carry with them the attitudes, skills, and ideas of the culture that produced them. The latter topic has been explored in a recent book on the introduction of steamboats on the river Ganges in the 1830's (*43*). These vessels provided far more than a rapid and effective means of transportation. They were vectors of Western civilization carrying Western science, medicine, and technical skills into the interior of India. In exploring these two topics we are likely to uncover the nature of the links between science and technology and learn more about the technological underpinnings of an independent scientific tradition.

Any one of the seven tasks listed above would present major problems for those who wished to gain an independent stronghold for modern science. Collectively, they present so severe a challenge that even a concerted effort on the part of the scientists will not soon bring noticeable results. Because of the difficulties involved in the completion of the tasks, I speak of a "struggle to establish an independent scientific tradition," and I illustrate it by the slowly rising curve of phase 3 (Fig. 1). Note, however, that, if the outcome of the struggle is successful, the curve rises abruptly, signifying the emergence of the nation among the leaders of world science (*44*).

If my analysis of phase 3 is correct, then we should find that the non-European nations, after a long period of preparation, have only recently approached the supremacy of Western Europe in science. The leadership achieved by Western Europe at the time of the Scientific Revolution was not challenged until the United States and Russia emerged as leading scientific nations in the period between world wars I and II. America first gained scientific eminence in the fields of genetics and big-telescope astronomy. In 1921 the English geneticist William Bateson, commenting upon recent American contributions to genetics, was moved to say in his address to the American Association for the Advancement of Science (*45*): "I come at this Christmas Season to lay my respectful homage before the stars that have arisen in the West." The stars were the American biologists who had finally attained European recognition with their work in a new field of science. Physics in America came of age within two decades of Bateson's speech. Recalling the state of American physics in 1929, and testifying to the beneficent influence of J. R. Oppenheimer upon its maturation, I. I. Rabi remarked (*46*): "When we first met in 1929, American physics was not really very much, certainly not consonant with the great size and wealth of the country. We were very much concerned with raising the level of American physics. We were sick and tired of going to Europe as learners. We wanted to be independent. I must say I think that our generation . . . did that job, and that ten years later we were at the top of the heap."

Contrary evaluations of Soviet science offered by friends and foes of the Communist ideology (*47*) have made it difficult to determine objectively the state of science in the U.S.S.R. In the 1940's, proponents of planned economy and planned science hailed Soviet scientific achievements, while opponents, pointing to the damaging influence of ideology on the biological sciences, held little hope for science in a totalitarian regime. Russia's advancement in weaponry and space technology during the next decade left no doubt that a strong program in basic science supported these technical feats. Critics might still complain of a bias toward applications in Soviet science, and point to the relatively small number of Russian scientists who have won the Nobel prize, but there is general agreement that the U.S.S.R. has taken her place as one of the leaders of world science (*48*).

After several centuries of contact with European science the United States and the U.S.S.R. finally reached, and in some cases surpassed, the science of the Western European nations. This cannot be said of any other land outside of Western Europe. Japan, Australia, and Canada have shown signs of vigorous scientific growth, but they definitely rank below these two nations. China, India, and perhaps some South American and African countries may be placed in a third grouping of nations with great potential for future scientific growth and with major obstacles to be overcome before they establish their independent scientific cultures.

Conclusion

There is no need to summarize the features of this simplified model, which describes the manner in which modern science was transmitted to the lands beyond Western Europe. The graph of Fig. 1 and the examples drawn from science in various lands should have made them clear. It may be in order, however, to reiterate that there is nothing about the phases of my model that is cosmically or metaphysically necessary. I am satisfied if my attempt will interest others to go beyond my crude analysis and make a systematic investigation of the diffusion of Western science throughout the world.

Such an investigation would include a comparative appraisal of the development of science in different national, cultural, and social settings and would mark the beginnings of truly comparative studies in the history and sociology of science. The present lack of comparative studies in these disciplines can be attributed to the widespread belief that science is strictly an international endeavor. In one sense this is true. As Sir Isaac Newton remarked in his *Principia* (*49*), "the descent of stones in Europe and in America" must both be explained by one set of physical laws. Yet, we cannot ignore the peculiar environment in which members of a national group of scientists are trained and carry on their research.

While I do not hold with the Nazi theorists that science is a direct reflection of the racial or national spirit (*50*), neither do I accept Chekhov's dictum (*51*) that "there is no national science just as there is no national multiplication table. . . ." In emphasizing the international nature of scientific inquiry we have forgotten that science exists in a local social setting. If that setting does not decisively mold the conceptual growth of science, it can at least affect the number and types of individuals who are free to participate in the internal development of science. Perhaps the effect is more profound; only future scholarship can determine the depth of its influence.

References and Notes

1. Since World War II the United States and Russia have been in a strong position to act as agents for the introduction of modern science to underdeveloped regions, but their examples do not break the line of transmission I have indicated. It is an easy matter to trace American and Russian scientific traditions back to the nations originally participating in the Scientific Revolution.

2. I. Bernard Cohen's "The New World as a source of science for Europe," *Actes du Neuvième Congrès International d'Histoire des Sciences* (Barcelona-Madrid, 1959), provided the inspiration for the model. Other works which influenced it included "Basic Research in the Navy," *Naval Res. Advisory Comm. Publ.* (1959); G. Holton, *Daedalus* **91**, No. 2, 362 (1962); T. S. Kuhn, *The Structure of Scientific Revolutions* (Univ. of Chicago Press, Chicago, 1962); D. J. de Solla Price, *Little Science, Big Science* (Columbia Univ. Press, New York, 1963); and W. W. Rostow, *The Stages of Economic Growth* (Cambridge Univ. Press, Cambridge, 1960). Donald Fleming's "Science in Australia, Canada, and the United States," *Actes du Dixième Congrès International d'Histoire des Sciences* (Hermann, Paris, 1964), vol. 1, sharpened my analysis, but Fleming and I disagree on fundamental points. I thank Dr. Everett Mendelsohn, Harvard University, and Dr. David D. Van Tassel, University of Texas, for advice on matters relating to phase 3 of my model.
3. Donald Fleming [*Actes du Dixième Congrès International d'Histoire des Sciences* (Hermann, Paris, 1964)] speaks of the "reconnaissance of natural history" as a part of the Age of Discoveries. See also Robert Boyle's "General heads for a natural history of a countrey, great or small," *Phil. Trans. Roy. Soc. London* **1**, 186 (1665); *ibid.* **2**, 315 (1666); *ibid.*, p. 330. Boyle has written a guide for the European observer in a foreign land.
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5. G. Fernández de Oviedo, in *Natural History of the West Indies*, S. A. Stoudemire, Ed. (Univ. of North Carolina, Chapel Hill, 1959); A. R. Steele, *Flowers for the King: The Expedition of Ruiz and Pavon and the Flora of Peru* (Duke Univ., Durham, N.C., 1964); V. Wolfgang von Hagen, *South America Called Them* (Knopf, New York, 1945). I thank Susan Lane Shattuck, School of Library Science, University of Texas, for information she provided on botanical expeditions to colonial South America.
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7. B. Smith, *European Vision and the South Pacific: 1768–1850* (Oxford Univ. Press, London, 1960); F. W. Oliver, Ed., *Makers of British Botany* (Cambridge Univ. Press, Cambridge, 1913), pp. 108–125; L. Huxley, *Life and Letters of Sir Joseph Dalton Hooker* (Murray, London, 1918), vol. 1, pp. 54–167; A. R. Wallace, *My Life* (Dodd, Mead, New York, 1906), vol. 1, pp. 337–384. For early scientific collecting in other areas of the Pacific, see J. A. James, *The First Scientific Exploration of Russian America* (Northwestern Univ. Press, Evanston, 1942); S. P. Krasheninnikov, *The History of Kamtschatka* (Quadrangle, Chicago, 1962), pp. 57–167; P. Honig and F. Verdoorn, Eds., *Science and Scientists in the Netherland Indies* (Board for the Netherland Indies, New York, 1945), pp. 295–308; *Encyclopedia of the Philippines* (Philippine Education Company, Manila, 1936), vol. 7, pp. 52–107, 476–503.
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11. E. A. Walker, Ed., *Cambridge History of the British Empire*: vol. 8, *South Africa, Rhodesia & the High Commission Territories* (Cambridge Univ. Press, Cambridge, 1963), pp. 905–914.
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18. See B. Smith, *European Vision and the South Pacific: 1768–1850* (Oxford Univ. Press, London, 1960), p. 6.
19. Compare this description of colonial science with the one found in D. Fleming, *Actes du Dixième Congrès International d'Histoire des Sciences* (Hermann, Paris, 1964), vol. 1, pp. 179–196, and in *Cahiers Hist. Mondiale* **8**, 666 (1965).
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29. F. Darwin, *More Letters of Charles Darwin* (Appleton, New York, 1903), vol. 1, pp. 383–384.
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34. See L. Zea, *The Latin American Mind*, J. H. Abbott and L. Dunham, trans. (Univ. of Oklahoma, Norman, 1963), pp. 100–103.
35. Quoted from H. Bernard, *Yenching J. Social Studies* **3**, 220 (1949).
36. For opposition to Western science, see Y. C. Wang, *Chinese Intellectuals and the West: 1872–1949* (Univ. of North Carolina Press, Chapel Hill, 1966), pp. 3–37; G. H. C. Wong, *Isis* **54**, 29 (1963). Religious beliefs may act to spur on the acceptance and growth of science. Max Weber and others have attempted to link the initial appearance of modern science with the prevailing Protestant ethic. See R. K. Merton, *Osiris* **4**, 359 (1938).
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43. H. T. Bernstein, *Steamboats on the Ganges* (Orient Longmans, Calcutta, 1960).
44. Certain factors affecting the acceptance or rejection of modern science have not been listed here because they are so fundamentally related to the culture within which the struggle for an independent scientific tradition takes place that the participants in the struggle are not in a position to alter them, even if they are aware of their existence. Furthermore, we know very little about these factors. The following are some examples. (i) *Language.*

B. L. Whorf [*Language, Thought, and Reality* (M.I.T. Press, Cambridge, 1966), pp. 57–64, 207–219] has argued that a people's view of physical reality is conditioned by the structure of their language. Scientific concepts developed in one culture might be rejected, or misunderstood, in another. According to Whorf, the Hopi language embodies a metaphysics of space and time that is opposed to the classical Newtonian world view. (ii) *Child-rearing patterns.* A Japanese sociologist has suggested that "the introduction of modern science over the last century [has] been especially accelerated because Japanese culture values childhood curiosity and, unlike some other societies, does not attempt to repress it" [*Science* **143**, 776 (1964)]. (iii) *Political nature of a society.* A. de Tocqueville [*Democracy in America*, P. Bradley, Ed. (Knopf, New York, new ed., 1948), vol. 2, pp. 35–47] believed that a democratic nation, fostering the individual's pursuit of profit and power, would necessarily excel in technology and applied science, while aristocratic societies would be predisposed to cultivate the theoretical aspects of science.
45. See *Science* **55**, 55 (1922).
46. See *In the Matter of J. Robert Oppenheimer: Transcript of Hearing Before Personnel Security Board* (Government Printing Office, Washington, 1954), pp. 464–465. Remarks made by two other scientists on the late emergence of American science may be found in J. H. Van Vleck, *Phys. Today* **17**, 21 (1964), and F. Seitz, *Science* **151**, 1039 (1966). Many historians claim that American science achieved maturity at an earlier date, sometime in the 19th century. D. Fleming does not think so [see *Cahiers Hist. Mondiale* **8**, 666 (1965)].
47. For the controversy over "free" and "planned" science in Great Britain, see N. Wood, *Communism and British Intellectuals* (Columbia Univ. Press, New York, 1959), pp. 121–151, 190–193.
48. For recent evaluations of Soviet science, see *Survey: A Journal of Soviet and East European Studies* **1964**, No. 52 (July 1964); J. Turkevich, *Foreign Affairs* **44**, 489 (1966).
49. I. Newton, *The Mathematical Principles of Natural Philosophy*, F. Cajori, Ed. (Univ. of California Press, Berkeley, 1934), p. 398.
50. See R. K. Merton in *The Sociology of Science*, B. Barber and W. Hirsch, Eds. (Free Press, Glencoe, Ill., 1962), pp. 19–22.
51. See *The Personal Papers of Anton Chekhov* (Lear, New York, 1948), p. 29.

NEWS AND COMMENT

Educational Testing: National Program Enters Critical Phase

Although school children are taking a variety of tests, from standardized achievement tests in reading and other subjects to "college boards," none of the testing now being done provides a uniform, nation-wide measure of educational achievement. The idea that the results of the taxpayer's huge, multi-billion-dollar investment in education should be systematically assessed through a national testing program is not terribly radical. Yet the first effort to initiate such a program faces opposition from a number of members of the educational establishment who contend that it would generate coercive pressures leading to a "national curriculum."

The object of these fears is the experimental "National Assessment of Educational Progress" (NAEP), a program which was begun in mid-1964 under Carnegie Corporation sponsorship and which has now reached a phase where answers will have to be forthcoming to several major questions —all more or less controversial. First, judgments must be made as to the value and administrative feasibility of the tests and sampling techniques which have been developed. Second, if current tryouts of the test instruments prove satisfactory, what kind of body will actually administer the national assessment? Third, who will finance the assessment?

The controversy over NAEP seems to arise partly from the circumstance that the program has come along at a time when the federal role in education is expanding rapidly. Through new programs such as the Elementary and Secondary Education Act of 1965, the government has become a major force in shaping the policies of local school districts. Although under private auspices, the NAEP program grew out of a proposal made to the Carnegie Corporation in 1963 by Francis Keppel, who was then U.S. Commissioner of Education. It got under way the next year when Carnegie, after holding a series of conferences with school people and testing experts, set up an Exploratory Committee on Assessing the Progress of Education. Ralph W. Tyler, director of the Center for Advanced Study in the Behavioral Sciences at Stanford, was named chairman.

The Tyler committee, which has several state and local school administrators among its members, has called on teachers, curriculum specialists, and others in the education establishment and interested lay public to help in developing and reviewing the NAEP tests. However, a number of school administrators—aware that some day NAEP might exercise a strong influence on their districts—have felt left out.

Some observers of the internal politics of the education establishment believe that the Tyler committee blundered in not involving the American Association of School Administrators (AASA) in the NAEP project early in the game. As matters have developed, much of the opposition has come from association leaders, such as Forrest E. Conner, the executive secretary, and Harold Spears, immediate past president of AASA and superintendent of the San Francisco schools. The association itself has adopted resolutions opposing some key elements in the NAEP concept. However, given AASA's attitude, it is arguable whether or not the association could have been drawn into the project without hamstringing it.

Tyler has said repeatedly that the purpose of NAEP is not to evaluate the performance of individual students, teachers, and school districts. The purpose, Tyler says, is to provide census-like data on the educational achievement of broad segments of the school-age and young adult population. The present plan is to "assess a probability sample for each of 256 populations defined by the following subdivisions: boys and girls, four geographic regions [Northeast, South, Midwest, and Far West], four age groups (9, 13, 17, and adult), four divisions by large city, small city, suburban and rural classifications, and two socio-economic levels." The sampling will include children in private as well as public schools. No comparisons will be made below the regional level, Tyler has emphasized.

"The fact that populations are to be assessed and not individuals makes it possible to extend the sampling exercises far beyond that of an individual test in which the person takes it all," Tyler says. The tests will assess reading and writing skills, and knowledge and skills in the fields of science, mathematics, social studies, citizenship, art, music, literature, and vocational education.

The assessment, which might be repeated at 3- to 5-year intervals, would