

1987 "Period and Process in National and Colonial Science"
in *Scientific Colonialism*, eds. Nathan Reingold and Marc Rothenberg, Smithsonian Press: 297-321.

PERIOD AND PROCESS IN COLONIAL AND NATIONAL SCIENCE

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A great deal of scholarly time and energy have been invested in the division of the past into chronological periods. The boundaries of these periods are defined by reference to significant turning points and to emergent and declining social and intellectual forces. Unfortunately, many of these studies lose sight of how artificial, how contrived to special purpose, and how finally arbitrary such chronological periods may be. The conventional triumvirate of ancient, medieval, and modern has been subdivided and recombined into a complex and contradictory array of periods, epochs, ages, and eras, predicated on such factors as political change, intellectual development, geographical boundaries, technological revolution, and institutional transformation—all, of course, seen in ideological and cultural perspective.

Historians of science and technology are in a position to look at the whole question of periodization with a critical eye, since the well-known periods imposed by European political history seem largely irrelevant for many, if not most, of their purposes. Historians of science have made lesser use of periods defined by political considerations than of those defined by intellectual movements, such as the Renaissance, the Scientific Revolution, and the Enlightenment. And even these intellectual periods have been adopted with a degree of reflection and restraint, as when the study of the medieval-to-modern transition gave rise to useful and informative debate. Indeed, it might be said that the discipline first came of age in the critical discussion of the Burckhardtian invention of the Renaissance.

Another milestone in the field, the internalist-externalist split, also has substantial implications for the periodization problem. As noted, in a close look at European science, periods are found that are largely defined by intellectual, or internalist, criteria. Colonial scientific periods, on the other hand, are far more likely to be defined by contextual, or externalist, criteria. Why should this be true: Historical explanations that incorporate an astute balance of internal and external factors might well produce a need for different periodization schemes in both the European center and the colonial periphery. Under the domination of internalist thinking, the belief was widespread that the initial generation of scientific ideas was a process not subject to social conditioning. In a colony, however, ideas were not "generated" but were "imported" or "received" and thus were considered subject to social conditioning. This is truly nonsense. The generation and construction of ideas and the importation and reception of ideas are all processes that occur constantly in all countries.

It is more productive to think of ideas as existing in a process of continuous construction, reconstruction, and transformation, always on the basis of both social and intellectual parameters

and variables. The concept of reception often implies wholesale and passive transplantation of certain significant ideas, which then displace, or overcome, local, outdated ones. On the other hand, if reception is regarded as a more complex, interactive process, then study of it will involve the selection and interpretation of foreign ideas, whose subsequent redefinition occurs as these exotic threads are mixed into the native intellectual fabric.

The imposition of European intellectual periods onto colonial settings may have an unfortunate influence on the history that is written. How does the use of the scientific revolution, for example, that most sacrosanct internalist period, affect the analysis of colonial scientific development: Principally in one way: by concentrating attention on the question of how quickly, and in what manner, knowledge and ideas were diffused from center to periphery. While this is a legitimate question, it is not a balanced focus for the writing of, say, Asian or Latin American history. Even in the face of powerful cultural and economic influences from abroad, the focus of colonial history must be the colony itself. The scientific revolution did not take place in Upper Canada, in New England or New Spain, in Manchester, or even—and we often wonder why not—in China. Intellectualist periodization, based as it is on certain European centers, has engendered neglect of important contextual questions and has also made the study of provincial science itself a second-rate enterprise, no matter what approach is taken.

In the colonial setting, for example, the vital question of modernisation is directly related to what is often seen as a causal connection between scientific revolution and industrial revolution. Because internalist periodization focused this discussion on the European experience—and on the Whiggish notion of modern science coming into being in one place, at one time, for all time—historians of science have had little to say to third world aspirations to modernise, apart from emphasising the importance of emulating Europe or, more to the point, the importance of joining the European scientific enterprise, albeit as inferior partners. The implicit message to the non-European world that science advances in linear progression through predictable stages seems to allow no alternative patterns of development. Thus, description becomes prescription.

While the Scientific Revolution, considered as a chronological period, may have only limited value for the colonial historian, it might be supposed that the period of the Enlightenment, on the other hand, by its very nature and essence, would prove more relevant to the colonial setting. Certainly a great many Latin Americanists have found the Enlightenment helpful in their work. In this essay I shall attempt to show that that sort of periodization is often misleading and, in the hands of some authors, actually procrustean. In spite of a small band of Peraltas, Alzates, and Franklins, the colonial New World exhibits European Enlightenment only in traces and in part.

Moving on to the nineteenth century, it has been suggested that the organisational and professional changes in science which occurred in this period are so important that they deserve to be called the Second Scientific Revolution.¹ In my view one scientific revolution is more than enough. Nevertheless, the point is well taken that the traditional periodization framework underemphasized such nineteenth-century developments as professionalisation, specialisation, and institutionalisation, whose significance has been ably demonstrated in recent years by a number of the participants in this conference.

If scholars have made it clear that the institutional revolution of nineteenth-century science is as consequential as the theoretical revolution of seventeenth-century physics, they have also shown that contextual aspects of scientific activity constitute more than a colourful backdrop to

scientific change. For one thing, treating the social and institutional framework of science as problematic-and not fixed or merely "given"-enables a more constructively nationalist approach to the problem of scientific development and modernisation, especially in those former colonial outposts that now constitute both the second and the third worlds.²

In this essay I shall tell a remarkable story of a serious eighteenth century attempt to establish an institutional base for European science in one of those so-called colonial outposts. I shall then consider three possible frameworks, or periodization schemes, that might be applied: the scholasticism-enlightenment model, the three-phase diffusion-of-science model, and the colonial-national model.

Mexican Science before 1867

The history of Mexico City does not, of course, begin with the arrival of Europeans. At the time of the conquest, which can be arbitrarily dated 1520, the population of Central Mexico was probably as large as that of present-day Australia, around 15 million, and Cook and Borah have estimated it to be as large as 30 million. Within a hundred years the indigenous population had been reduced to a small fraction of that number, but by the time of Alexander von Humboldt's arrival in 1803 the population of the Central region is known to have been around 6 million, at a time when New York, Massachusetts, and Pennsylvania together would have totaled less than 3 million. Mexico City was, as it is today, the largest city in all the Americas, North or South, the great majority of its inhabitants either Indian or Mestizo. Racially, culturally, and intellectually, indigenous culture has had a vast influence on modern Mexico-as of course has European culture. Some perspective on the maturity of European civilisation in Mexico can be gained by recalling that, in the year of Humboldt's visit, 1803-4, the University of Mexico was almost exactly twice as old as the University of Melbourne is today. The University of Mexico was founded nearly a century before Harvard.

For two hundred years in the colony of New Spain science was leisurely, aristocratic and eclectic: the serious concern of a few isolated scholars located at the University, in the colegios, and in the monasteries.³ First indications of the penetration of modern European science appeared in the eighteenth century in these institutions, where science served principally as a subject for rational discourse rather than empirical investigation.⁴

Then, shortly before the end of the eighteenth century and thirty years before political independence was achieved, a period of greatly heightened scientific activity got under way, marked by the formation of a small but lively scientific community and the earliest stages of scientific professionalisation. In institutional terms, I am referring to the appearance of the *Gazeta de Literatura*, edited by Jose Antonio Alzate, in January, 1788, to the founding of the Botanical Garden and its course of lectures in May 1788, and, above all, to the opening of the School of Mines on January 1st, 1792.⁵ The focus in this paper will be on the School of Mines.

In curriculum, faculty, and organisation, the Mexican School of Mines represented a greater departure from Latin American educational tradition than did l'Ecole Polytechnique from European tradition. But not only that, the Mexican School of Mines, founded in 1792, included

most of the pedagogical innovations introduced in Paris two years later.

To be sure, the Mexican reforms were less comprehensive, less influential in history, and probably less consciously revolutionary; yet many of the educational innovations for which l'Ecole is often given credit were in place in Mexico before the Parisian school opened its doors. Furthermore, it appears that principally German and Swedish, not French, technical schools were studied by the Mexican educators.⁶ This may seem surprising in the light of Mexico's general intellectual orientation to France.

Without any doubt Alexander von Humboldt was right to suggest in 1804 that Mexico City was a scientific centre to compare favourably with Philadelphia or Boston.⁷ Not only did the organisational plan of the School of Mines parallel that of the best technical schools in Europe, to my knowledge no other school anywhere in the Americas offered a wider range of scientific subjects: mathematics, including calculus; theoretical chemistry combined with practical laboratory work (quantitative and qualitative analysis); experimental physics, including mechanics, electricity, optics, and astronomy, in addition to hydrostatics and hydrodynamics; and of course mineralogy, palaeontology, and geology.⁸ The latest scientific discoveries, moreover, were being incorporated into the undergraduate curriculum with very little delay. At the commencement ceremonies of 1797, for example, two ranking seniors addressed themselves to the general principles of chemistry; treating these issues "according to the new theory of Senor Lavoisier, adopted by the principal chemists of the day.⁹ The students had learned Lavoisier's principles from his *Traite elementaire* in a Spanish translation made expressly for use at the Mexican School of Mines and published within eight years of the original French edition.¹⁰

All lectures and textbooks at the mining school were in Spanish, unlike those at the University and colegios, where lectures were given in Latin. A course in Spanish grammar was part of the first year of study, and French was also taught, though irregularly. The school charged no tuition fees and maintained an exceptionally large number of scholarship students. At all times the majority of degree candidates were receiving full scholarships. Thus, financial support to students, coupled with the gradual relaxation of caste restrictions on admission, promised that greater use of human manpower resources would be made.

From the time of its founding the mining school was almost entirely secularised. Admission was based on previous training and on competitive examinations, with consideration given to geographic distribution across the country.¹¹ Teaching and research were brought together, as indeed were theoretical and practical concerns. After 1801 advanced students were used as teaching assistants (*ayudantes de clases*) with the responsibility of assisting professors, both in laboratory exercises and in actual research.

During the early years money was available in some abundance. Mineralogical collections, demonstration equipment, scientific apparatus, and books were being purchased locally and in Europe. I. B. Cohen has noted that the school's instrument collection "greatly resembled that of Harvard in both its scope and the nature of the instruments.¹² Furthermore, great pains were taken to assemble an outstanding faculty. The first professorships at the school were filled by men educated in Europe, but as vacancies developed native talent was put to use.

Thus, the School of Mines—and to a lesser extent the Botanical Garden—financed by government and industry, provided jobs, facilities and tools, professional training, intellectual stimulation,

channels of communication to Europe and within Mexico, popular prestige, and the beginnings of professional authority for the fledgling scientific community.

In spite of such achievements and bright prospects, these institutions never fulfilled their potential. In 1811, at the start of the war for independence, they fell into a decline from which they did not begin to recover for fifty years. The extent of this abruptly downward plunge may be demonstrated by comparing the absolute number of teachers, students, and journals of science during the twenty-year period of activity with the same figures taken from the years of decline that accompanied and followed the war of independence.

In 1795 perhaps a dozen men earned their living in scientific occupations of teaching, research, or journalism; thirty years later it is not certain that even one received a regular salary for his scientific work alone. Between 1788 and 1795 had been published the *Gazeta de Literatura*, a journal containing both popular and technical science; yet the *Gazeta* was not equalled in quality until 1832, or in regularity of publication until the 1850's.¹³ Furthermore, during the period between 1788 and 1811 well over a hundred persons received extended professional scientific training in Mexico City—a number that includes only graduates of the School of Mines and the Botanical Garden—whereas during the first years of the republic science courses, when offered, were ill attended.

Why did this happen? Why should Mexican scientific progress suddenly cease altogether for several generations after the war for independence? Great cultural advancement is not ordinarily expected in a small, economically exploited poverty-stricken, war-torn country during its first years of independence. Nevertheless, the seemingly complete break in the continuity of scientific institutions established in reasonably auspicious circumstances needs further analysis.

It might at first be supposed that these institutions were simply a premature attempt by Europeans to give Mexico science, that the institutions were a purely European activity imposed on a primitive Mexican landscape. The reality is far more complex. After all, in the founding of the schools, Mexicans were intimately involved in all aspects of institutional planning and finance. Although in the beginning the schools were staffed by European settlers in Mexico, as early as 1805 the majority of the science professors were Mexican born and Mexican-educated.¹⁴ These young Mexican teachers had been trained at the School of Mines.¹⁵ Furthermore, the numerous attempts recorded in the annals of Mexican legislation to revitalise the scientific schools throughout the nineteenth century indicate that their decay was not indicative of a lack of Mexican concern.¹⁶

The first and most important reason for this decline was economic. Industrialisation and capitalisation were almost entirely lacking in the Mexican economy; a number of governments were overthrown because of bankruptcy. Production in the mines was at an all-time low. Mexico was an economically exploited country, held in feudalism by the depredation's, first of the Spanish, then of the British, and finally of the United States.

Another explanation for the decline of scientific institutions is the pattern of severe civil disorder and social upheaval that prevailed throughout the first half of the century. War is not necessarily destructive of institutions. In modern times war—and the threat of war—have marched hand in hand with scientific and technological advance. Schools and research centers are sometimes mobilised into feverish activity in support of the military effort.¹⁷ On the other hand, violent class warfare

accompanied by sustained economic instability and political chaos may have quite another effect. In Mexico nearly fifty years of class warfare, revolution, corruption, foreign exploitation, and military invasion devastated the country's economic and cultural institutions.¹⁸ Apart from bringing financial ruin, the civil disorders took a certain toll in the lives of men with scientific training. Several of the most promising graduates of the School of Mines were killed in the war with Spain, and scientific personnel were not spared in the decades of civil war that followed.¹⁹ Considering the economic and political circumstances of the first half of the nineteenth century, it is surprising to find scientific establishments surviving at all.

An upturn in science finally came around 1870. By the end of the century Mexico was in the iron grip of the dictator Porfirio Diaz and for a time under the control of a group of men whose allegiance to Comte and Spencer led them to be called "los científicos."

A General Framework for Colonial Science

The foregoing pages provide a simplified chronological account of a brief episode in the scientific history of one country. In recent years, many such historical cases, representing great cultural diversity, have begun to emerge far from the European centers of scientific activity. If these cases, taken together and taken separately, are to be understood, the attempt must be made to formulate a general developmental model or comparative periodization scheme that will accord with accepted theoretical perspective's.

Of course, the division of Mexican history into discrete periods useful to the historian of science and technology is not a simple matter of discerning a factual or necessary pattern of development and giving names to successive stages of that development. The validity of the periods chosen will depend on the sorts of question historians wish to pursue. If, for example, they hope to facilitate cross-cultural comparisons or to explicate the diffusion and reception of European ideas, they should either stay with European periodization or else attempt to find a general model for colonial development. If on the other hand their aim is to see a science that is distinctively Mexican or to understand Mexico on its own terms, then historical analysis might be better served by a strictly contextual periodization scheme. In either case, finding a useful historical framework for colonial science is a problem shared by all those who study Australia, the United States, French and English Canada, or Latin America, and even by those who study colonial influences in the great cultures of Asia.

In sum, valid reasons for constructing a general analytical framework include the following closely related aims: one, to facilitate cross-cultural comparison of the many and varied social and intellectual environments in which "modern science" has come into being; two, to help understand the processes by which institutional accommodation has enabled modern science to prosper or has allowed it to fail; three, to clarify the nature of modern science itself- is it unitary and invariant or is it multifold and culturally derived; four, to identify the contribution to human intellectual advancement of particular cultural traditions; five, to understand the process of diffusion of ideas from one cultural setting to another.

In the remainder of this essay I shall explore three possible analytical schemes as they are related to the Mexican case and shall conclude with some general observations.

The Scholasticism Enlightenment Model

The European periodization scheme most widely applied to Latin American history-Scholasticism-Enlightenment-was elaborated primarily to discredit the old belief that the Spanish Empire remained isolated from the Enlightenment in Europe. Evidence was produced to document a revolutionary intellectual ferment that reached its high point in the reign of the Spanish King Charles III (1757-88).²⁰ The scholarly task of assessing the influence of Enlightenment thought on Latin America was one undertaken by a whole generation of historians, and their work has enriched our understanding-indeed transformed our perspective-of the intellectual history of that southern continent. They have convinced us that even in the far reaches of the Spanish colonial empire, literate individuals who cared to read were aware of the intellectual transformations occurring in Europe. Indeed, many intellectuals showed themselves to be well versed in the writings of French philosophers, and many cultural institutions in the New World were unquestionable products of European Enlightenment.²¹ Yet it is still open to question whether the Enlightenment is an appropriate explanatory device for any period of any country in the Americas.

Those historians who advocate the importance of the Enlightenment in Latin America rest their case heavily on the widespread dissemination of European books.²²

The full force of what is commonly referred to as "the French Enlightenment" reached a zenith in Mexico at the end of the eighteenth century. Evidence is voluminous. In 1795: no less than three sets of the Encyclopedie were revealed at one time to the Holy Tribunal, all owned by prominent criollos.²³

In these accounts much significance is attached to the discovery of private libraries, the size and quality of which would have been admired even in Paris.²⁴

Without doubt, the extensive book trade in various Latin America countries belies the solemn reputation of the Index as a great obstacle to the transmission of ideas.²⁵ The Index was ineffective for several reasons. Often the primary impact of a book preceded its formal prohibition. Frequently, detailed discussions of proscribed writings were readily available. Father Fejoo's popular discussions of Cartesianism, for example, were highly influential. The bureaucratic inefficiency of the Inquisition, moreover, has been well documented by historians.²⁶ In spite of intensified Holy Office censorship of French writings after the storming of the Bastille, knowledge of French authors was widespread among intellectuals in the capital, as Humboldt pointed out.²⁷ Although the "liberal" Viceroy Revillagigedo expressed confidence in the careful measures he had taken to prevent the discussion of French political ideas, he made no such attempt to discourage French scientific writings.²⁸

The majority of foreign scientific works found in the scholarly libraries of New Spain were French and English, sometimes in translation, sometimes in the original editions.²⁹ Members of the scientific community, with only a few exceptions, could read French. Jose Antonio Alzate, who in 1771 was named corresponding member of the French Academy of Sciences,³⁰ demonstrated in his *Gazeta de Literatura* an acquaintance with English and German scientific work, in addition to French. Jose Mariano Mocino began his study of European science by concentrating on the scientific writings of France and only later went on to those of England.

This seems to have been a typical progression in the scientific self-education of those Mexican scholars before the founding of the scientific schools.³¹

A second type of evidence used to demonstrate the penetration of the Enlightenment involves detailed analysis of the lives and the works of certain Latin American thinkers whose cardinal intellectual commitments were European and enlightened. No better examples of this need be cited than the personnel of the new scientific schools who formed a community of scholars with a set of common loyalties quite unlike any previously seen in Mexico or anywhere in Latin America. The community was composed of several dozen men in a population of perhaps 6 million. They were optimistic in the face of occasional hostility and continual financial distress. They were progressive in the most tradition-bound culture of the West. Their intellectual orientation was French in a land where the word European was almost synonymous with Spanish.³² Their familiarity with contemporary European thought cannot be doubted.

Finally, one of the strongest arguments for the influence of the Enlightenment is the School of Mines itself: boldly secular, fully committed to the need for experimental investigation, and wholly devoted to the promotion of useful knowledge.

These considerations are convincing evidence that Latin America was, at that time, no replica of medieval Europe; in an attempt to set straight this record, however, some historians have devoted themselves to searching out Enlightenment hues in the richly complex mosaic of Latin American history.³³ In this they have corrected one imbalance, but they have created another. To claim that the "Enlightenment in Spanish America, as in Europe, supplanted scholastic speculation by experimental investigation" is to misconstrue the evidence at hand seriously.³⁴ The statement that the Enlightenment "was well underway in America a half century before the wars of independence broke out" must be carefully qualified if misunderstanding is to be avoided.³⁵

In some of these historical studies, a tone of hyperbole, an almost defensive posture, can be sensed. This tone can perhaps be explained by the writers' awareness that, after all is said and done, the Latin American colonies were not notable exemplars of Enlightenment society. Mexico produced as few liberated philosophers as it did noble savages-which is to say, the Enlightenment was no more true than was the Black Legend. Among the tiny minority of Mexicans who cultivated book learning, many were aware of what was being said in Europe, but only a handful fully identified with the new philosophy. Indeed, the attitudes that characterise Enlightenment thought were scarcely relevant to the political and economic realities that prevailed in Mexico at the time. Finally, these interpretations usually do not take indigenous cultural influences into account at all, a grievous deficiency in any examination of the history of Mexican thought.

It is now generally acknowledged that political aspects of the Enlightenment lagged behind scientific aspects. Analysis of the revolution against Spain demonstrates the weakness, not the strength, of native agents of the Enlightenment. ^{3'} Independence came to Mexico in 1821, only after ten years of civil war and a generation of political intrigue operating in a maze of ill-defined cross-purposes. At this time the liberals were virtually powerless before the forces of reaction-the clergy, the military, and the propertied classes- who were the real mainstay of the revolution against Spain. Frightened of the prospect of social change instigated by the enlightened Spanish regime of 1820, Mexican reactionaries joined with Mexican liberals to bring about the existence of a separate Mexican nation. But Mexico had no bourgeoisie; Mexican liberals had no political or

economic base of support and no authoritative leadership until the coming of Benito Juarez thirty-six years after the war of independence.

In vivid contrast to the United States, which after 1776 was much freer of feudal institutions than either Great Britain or France, Mexico in the nineteenth century had military and clerical establishments as firmly entrenched as those of France and centralist and elitist factions as strong as those of England. Following the failure of the liberal thrust to power in 1833, under which major reforms were attempted by Vice President Gomez Farias, liberal sentiment grew steadily throughout the country, with the mestizos developing as an opposition force to the creole aristocrats. Finally after 1840, especially after the war with the United States, the conservative coalition began to weaken, leading up to the Reform of 1857 and eventually to the first noteworthy support of cultural and scientific institutions since the Spanish Viceroy Bucareli and Revillagigedo.

This lack of any political or economic foundation for liberal thought before Juarez has led Latin American historians to emphasise scientific, rather than political, aspects of the Enlightenment, especially with regard to "useful knowledge."³⁷ It is true that "useful knowledge" was often offered up by politically conservative groups for the purpose of strengthening the viability of the old regime. Indeed, it is precisely because of the many traces of scientific Enlightenment coupled with the absence of enduring commitment to scientific reform that it is finally necessary to conclude that the term Enlightenment is not entirely appropriate for this period.

Scientific periodicals were short-lived and of no fixed periodicity.³⁸ Some Mexicans did possess extensive collections of scientific treatises, but needless to say, the presence of scientific books in a private library does not always indicate scientific sophistication on the part of the owner. In any case, the best of the Mexican scientists would surely have made a more substantial contribution to European science had they lived in an environment that authentically reflected Enlightenment ideals.

The point here is not to belittle the efforts of those hardworking gentlemen who identified progress with the importation of European science, but rather to highlight the difficulties that they faced. These same difficulties also plague any historian who describes this period as "the Enlightenment." Transplanting intellectual periods holus-bolus from one continent to another, and from one century to another, doesn't really work.

The complexities of Latin American culture defy the attempt to apply such fundamentally European concepts as the Enlightenment. The shoe doesn't fit.

Some historians seem to consider the Enlightenment a sort of moral standard against which the intellectual progress of any eighteenth-century country or even a nineteenth-century country can be measured. In my own work the question whether a Mexican Enlightenment took place has not seemed so important as have questions about the ends that such European ideas have been made to serve.

The Diffusion Phase Model

Clearly, individual ideas and sets of ideas do make their way around the world. Are patterns to be found in this "diffusion" process that provide a framework for understanding colonial science? A framework that will expedite the comparative analysis of science in different colonial contexts: Fifteen years ago George Basalla proposed such a model, which he felt was valid for describing the introduction of Western science into nonscientific countries, specifically, "Eastern Europe, North and South America, India, Australia, China, Japan and Africa."³⁹ While the model received mixed reviews on publication, during the last five years it has been uncritically applied in a number of studies. The model describes three overlapping stages. In chronological sequence these stages are phase one, in which the nonscientific society provides a source for European science through the medium of the scientific expedition; phase two, in which the colonial science begins to develop but is still "based primarily upon institutions and traditions of a nation with an established scientific culture"; and phase three, in which an independent and national science is established in the former colony.

Although the model purports to consider "the introduction of modern science into any non-European nation," during phase one scientific information is transmitted only in the opposite direction—from the New World back to Europe. Therefore phase one is utterly irrelevant to the diffusion vector that Basalla hopes to explain. Certainly the Mexican experience provides little justification for considering European expeditions as the first stage of its scientific growth or even as a separate phase at all.⁴⁰

European scientists did travel to Latin America during the sixteenth and early seventeenth centuries, but, as Basalla notes, the effect of these expeditions was limited almost entirely to Europe. No evidence has been produced to show that they had more than a negligible effect on the stimulation of scientific growth in the New World, and they therefore cannot be considered the first phase of that growth. During the seventeenth and early eighteenth centuries scientific expeditions did begin to function in a limited manner to encourage local scientific activity. Carlos Sigüenza y Góngora, for example, born in Mexico City in 1645, one of Mexico's first scientists of talent, established an international reputation by meeting all the distinguished scholars who came to Mexico, often corresponding with them after their departure.⁴¹ Later, during the first half of the eighteenth century, European expeditions to Latin America—especially that of La Condamine—brought about the election of seven Latin American scientists to the French Academy of Sciences.⁴²

Not until late in the eighteenth century did expeditions help the "spread of western science" by fostering the foundations of New World institutions. In Mexico, the Botanical Garden was established in 1788 by the Royal Botanical Expedition, and the School of Mines (1792) was part of a larger project, sponsored by Charles III of Spain, which included a mission of German mining experts.⁴³ Other Spanish expeditions functioned, in the same way and at the same time, to foster scientific growth elsewhere in Latin America.⁴⁴ During the nineteenth and even during the twentieth century, scientific expeditions and travellers continued to encourage scientific activity, though in a less substantial manner than in the late eighteenth century.⁴⁵ Thus, scientific explorations and expeditions, the signal for Basalla's phase one, have influenced the growth of Mexican science in all periods of its history except the earliest.

In Mexico, the first phase of Basalla's model best describes the last two decades of the eighteenth century, precisely the years of the founding of the first Mexican scientific institutions—the hallmark of his phase two. Furthermore, this same period, 1788–1811, also seems to mark the

transition to national science, or to phase three.

Thus, in Mexico, the three phases of the Basalla model are seen to be so much intermingled as to be of little value in analysing scientific growth. Other problems with the model remain. Natural science, for instance, does not completely dominate the "colonial" period in Mexico. The studies of early Mexican scientists, like those of seventeenth-century Europeans, tended to be eclectic, showing lively interest in astronomy, mathematics, engineering, and botany. The tendency for colonial scientists to favour the natural sciences over the experimental is to some extent a reflection of similar European predispositions during much of the eighteenth century. Since the Western Hemisphere was, in a sense, the world's laboratory for natural sciences, the scientists living in its midst might be expected to confine themselves almost exclusively to problems of taxonomy and natural description. As a matter of fact they did no such thing. Early Mexican scientists drained swamps and observed astronomical phenomena with as great enthusiasm as they named new plants. By the time the founding of the School of Mines was under way, the focus became social utility, whether in the natural or the physical sciences.

The diffusion-phase model makes dubious assumptions about the nature of science, history, and culture. It is a strictly linear analysis of extremely varied and complex cultural and scientific matrixes. Science is everywhere the same, an unproblematic given, a positivist conception that fails to make accurate distinctions among sciences and technologies. The model is presumed to have universal application, relating similarly to cultures as varied as Mexico and India, Australia and Japan, Africa and Quebec. The model is blind to time, with the same phase occurring hundreds of years apart in different locations. The so-called phases of the model make sense only when seen as interactive processes, not separate periods, as reflexive patterns, not chronological stages.

Finally, on close examination Basalla's diffusion model is found to be simply a special case of the colonial-national model. Phases one and two are clearly seen as stages of colonial development, which overlap with phase three, denoted by increasing national independence.

The Colonial-National Model

The conventional periodization of Latin American political history is, for the most part, unrelated to the history of science in those countries. These divisions were drawn by political historians with exclusive regard to political hegemony; thus we are told that the indigenous period ends in 1492, while the colonial phase lasts until the inauguration of the national period in 1824. Since the only two transition points in this model are the making and breaking of Spanish power in the New World, it is not surprising that the periods defined correspond reasonably well to European history and are roughly applicable to all Spanish American countries. Although such simplistic periodising provides mnemonic aid to students of political development, it may actually obscure the analysis of social, economic, and intellectual history. If the concept of colonialism is considered to include economic criteria as well as political, for example, it becomes necessary to extend the colonial period into the twentieth century, or at least until late in the nineteenth, when the forces of nationalism began to develop.⁴⁶ In other words, colonialism is peculiar to no one historical period but has been a dominant force in Latin America since the consolidation of

Spanish power in the sixteenth century.⁴⁷ Furthermore, the majority of terms that have been employed to designate narrowly defined periods-Spanish, colonial, patrimonial, national, independent-have been vaguely and inconsistently applied.

If the historical perspective is broadened so as to include the periods of colonial science histories in other parts of the world, the terms Federalist, Republican, Jeffersonian, Age of Jackson, Banksian, Baconian, emergent, antebellum, and so on are encountered.

Needless to say, cross-cultural comparisons of diverse provincial traditions are made more difficult by such a bewildering array of periods. In other words, without a more general framework, we sink into a sea of local histories.

It was suggested earlier that distinguishing colonial and national periods of a scientific tradition is often of doubtful validity. Not only is there usually a considerable overlap between the supposedly colonial institution and the supposedly national institution, but also colonial science is seldom in any significant sense transformed into national science. (The United States, the Soviet Union, and Japan are exceptions that show how it is done.) Today, European and American journals are the world repositories of scientific information, no less than were the museums of Europe during the eighteenth century. Colonial science remains colonial even in politically independent nations.

Colonial institutions remain on the periphery of international science, which is often focused on problems of great interest to the dominant scientific powers but of much less interest to economically developing countries. The relations of center to periphery are those of status and access, of power and control.⁴⁸ Even when internationally recognised institutions emerge in a geographically provincial setting, they usually remain subject to most of the restraints imposed by their peripheral location, and they certainly remain Eurocentric in orientation, at least in the absence of an effective wedding of the production of knowledge with the production of goods and services in the peripheral country.

This Eurocentric orientation in fact becomes vitally important in the examination of certain questions concerning the uses of science in the colonial setting. It may even be important for the understanding of scientific developments in the center. Is it possible, for example, that the history of continental drift theory would have developed very differently had not much of the supporting evidence been located in the periphery and supporters of the theory dispersed in such places as Tasmania and Canada: On the other hand, when internationally recognised scientific institutions appear in a former colony, they may be said to illustrate the growing ability of the center to appropriate knowledge-as well as primary resources and staple commodities-from the economically dependent nation.

A colonial scientific institution becomes national not just when it is financed by the national treasury and staffed by its own citizens, but rather when it is economically and politically integrated into the national interest. The United States, the Soviet Union, and Japan may be cases in point. Most Latin American countries are not.

It might be suggested that the Mexican scientific schools of the eighteenth century simply provide a contrast between two varieties of Spanish colonialism: the university symbolising Hapsburg rule and the School of Mines symbolising the "enlightened" Bourbon approach. The

intellectual, economic, and sociostructural foundations of the scientific institutions, however, complicate the case.

Never a purely colonial establishment, the School of Mines drew not upon the Spanish scientific tradition, but rather upon educational precedents in northern Europe. This fact, combined with substantial Mexican contributions, both financial and intellectual, produced an institutional order more closely aligned with the later national models than with the medievalism of the original Spanish institutions. And yet even in a country as steadfastly independent as modern Mexico, scientific institutions are often marginal in the setting of the Mexican political economy. Such institutions may be said to serve as colonial outposts for dominant American and European interests.

Conclusion

In summary, the three models considered have several common characteristics that severely limit their explanatory power. First, they are Eurocentric in conception. While to some degree inevitable, this has the effect of minimising local contributions, trivialising distinctive aspects of local development, and focusing the discussion entirely on science and technology to the neglect of other social values and cultural products. Furthermore, science itself is seen as inevitably and monolithically European in format, a dubious assumption, especially for the long run.

Second, the models are all chronologically linear and progressive; that is, they pass through a series of stages which move not only from then to now, but also from darkness to light, from error to fact, from poverty to wealth, from wrong to right. Such naive assumptions ignore modern understandings of the nature of science and the nature of culture, which are both complex and interactive matrixes, not one-dimensional unidirectional strands. In short, the models use positivist theories of science and imperialist theories of development.

Third, the models pretend to be universal in their applicability. This feature seems highly desirable, if it can be achieved. Not surprisingly, pressure for universality often stems from social and economic aspirations in the former colonies. What does the third world want from case studies of scientific development? A guide to modernisation. Why do they seek to modernise? Put in the simplest terms, they seek greater wealth-or higher standards of living and they seek positions of greater power and independence in the world, but not at the cost of cultural integrity.

Historians of science and technology wishing to serve such aspirations must attempt to understand the development of scientific and technological institutions in a rich diversity of cultural settings. They must seek neither to force this diversity into a single acultural mode or to deny the possibility of patterns of regularity.

It is still too early to delineate the fine structure of such patterns of regularity. But it is clear that a satisfactory approach to the problem must derive from, and successfully account for, a multitude of case studies, most of which remain undone. Such an approach will highlight whatever natural groupings and patterns emerge in these case studies and will also include consideration and disposition of the differences that emerge from diverse cultures, diverse geographic locales, and

diverse economic structures. Cultures will be seen as interactive, not merely receptive. Science and technology will be seen as a complex of ideas and processes, not just staged development.

Thus, the final significance of the Mexican case considered here must await detailed research in other colonial settings. Mexico, may after all, appear to be atypical and unique; or it may manifest a pattern most common in the Spanish New World; or it may represent one in a series of possible patterns of cultural and economic response to the explosion of ideas and developments that is often called Western science.

Even in its current limited form, the Mexican case reveals that any account of colonial science which sees the generation of scientific culture purely as the delayed importation of European institutions and ideas-or which sees it as an earlier, more primitive form of what was later to turn into European science-cannot be presumed to hold any general validity because it fails to accord specifically with what is already known about Mexico.

FOOTNOTES:

1. I do not know who originated this term, but I have seen it used by Everett Mendelssohn, in "The Emergence of Science as a Profession in Nineteenth-Century Europe," in *The Management of Scientists*, ed. Karl Hill (Boston: Beacon Press, 1964), p. 4, and ten years later by Arnold Thackray, in "Natural Knowledge in Cultural Context: The Manchester Model," *American Historical Review* 79 (1974): 674. 2. For a detailed treatment of this question with reference to China, see Peter Buck, "Science, Revolution, and Imperialism: Current Chinese and Western Views of Scientific Development," *Proceedings of the XI V International Congress of the History of Science* (Tokyo, 1974~; see also D. W. Chambers, *Red and Expert: A Case Study of Chinese Science in the Cultural Revolution* (Geelong, Victoria: Deakin University Press, 1979~). 3. For a useful survey of Mexican science, see Eli de Gortari, *La ciencia en la historia de Mexico* (Mexico, D.F.: Fondo de Cultura Economica, 1963~). For a brief review of science in Mexican education before 1800, see D. W. Chambers, "Two Stages in the Development of Science in Mexico" {Ph.D dissertation, Harvard University 1969~; J. T. Lanning, *Academic Culture in the Spanish Colonies* (New York: Oxford University Press, ~1940~; E. Beltran, ed., *Memorias del primero coloquio mexicano de historia de las ciencias*, ~ vols. (Mexico, D.F.: Sociedad Mexicana de Historia de Ciencia y la Tecnologia, 1964). 4. Bernabe Navarro, *La introduccion de la filosofia moderna en Mexico* (Mexico, D.F.: El Colegio de Mexico, 1948); for comparison, see J. T. Lanning, *The University in the Kingdom of Guatemala* (Ithaca, N.Y.: Cornell University Press, 1951) and *The Eighteenth Century Enlightenment in the University of San Carlos de Guatemala* (Ithaca, N.Y.: Cornell University Press, 1956~). The latter suggests that "students . . . droned out [Newton's! laws in the Schoolman's singsong Latin." 5. For a general introduction to Alzate's work, see Rafael Moreno, "Alzate, educador, ilustrador," *Historia mexicana* 7 (January-March 1953~: 371-89. On the founding of the Botanical Garden, see H. W. Rickett, "The Royal Botanical Expedition to New Spain," *Chronica Botanica* 11 (Summer 1947): 1-86. On the opening of the School of Mines, see Chambers, "Two Stages in the Development of Science in Mexico." Walter Howe, *The Mining Guild of New Spain* (Cambridge: Harvard University Press, 1949), gives the best general account of mining education, emphasizing matters of administration. J. J. Izquierdo, *La primera casa de las ciencias en Mexico* (Mexico, D.F.:

Ediciones Ciencia, 1958), gives the best treatment of curriculum, facilities, and students. The summary description of the Mining School that follows is based on these three works and on my dissertation, "Two Stages." 6. In their Representacion to the Spanish king, Velazquez de Leon and Lassaga, the founders of the school, point to German and Swedish mining schools as exemplary. Elyuhar and del Rio received their technical training at Freiburg, later touring other parts of Germany, the Scandinavian countries, and England. The writings of Duhamel, professor at l'Ecole des Mines and later at l'Ecole Polytechnique, are occasionally cited in Mexican scientific treatises; no reference is made, however, to the format of French technical education. Humboldt had visited l'Ecole Polytechnique before his arrival in Mexico in 1803, where he was in close touch with Elyuhar and the faculty of the mining school, but by this time the Mexican school had been in operation for eleven years. 7. Alexander von Humboldt, *Essays on the Kingdom of Mexico*, 2d ed., trans. John Black, London: Longman, 1822, vol I, p 22. This work, originally published in 1805, received a mixed critical response. In particular, several doubted the validity of Humboldt's assessment of the scientific institutions he visited. This matter was treated in detail in D. W. Chambers, "Centre Looks at Periphery: Foreign Accounts of Mexican Science in the Nineteenth Century," *NIS* submitted for publication; an earlier version was presented to the Midwest Joint of the History of Science Society in 1977. 8. My knowledge of European technical schools is based on such monographs as that of E. B. Artz, *The Development of Technical Education in France, 1800-1870* (Cambridge: MIT Press, 1966), and on discussions with Alexander Osipov at Oklahoma State University. 9. *Gazeta de Mexico* (29 November 1797). 10. Antoine Lavoisier, *Tratado elemental de chimica* (Mexico, D.F., 1797). 11. For further discussion of the admissions policy, especially with regard to the relaxation of race and caste restrictions, see Chambers, "Two Stages," pp. 81-89. 12. Bernard Cohen, *Some Early Tools of American Science* (Cambridge: Harvard University Press, 1950), p. 63. The fact that the collection included apparatus—such as orrery, reflecting telescope, camera obscura, and Nollet apparatus—of little use in mining education or research indicates the depth of the commitment to the establishment of a comprehensive instructional base in the physical sciences. The original list of instruments ordered is given in full in Howe, *Mining Guild*, pp. 501-8. 13. This journal, edited by Jose Antonio Alzate, was published at least once a month for more than seven years. It and the *Gazeta de Mexico* are the most important sources of information about certain scientific controversies that stirred the scientific community during these years. *Registro Trimestre*, published 1823-33, was associated with the name of the scientist and politician Pablo de la Llave, who contributed more than half the papers. *Boletin de la Sociedad Mexicana de Geografia y Estadística*, published in 1839 and from 1853 to the present, is the oldest continuously published scientific journal in Mexico. 14. Most of the early records of the school have disappeared; useful primary materials, however, are collected in Santiago Ramirez, *Datos para la historia del Colegio de Minería* (Mexico, D.F., 1890), including a list of professors, pp. 187-91. 15. None of the founding generation of distinguished Mexican savants—Bartolache, Alzate, Leon y Gama, Montana—was offered a professorial position in any of the new institutions; young graduates of the technical schools, once the schools were under way, were given preferential treatment, illustrating the professional character of the training. An analysis of the social origins, education, and scientific contributions of the twenty persons who constituted this first scientific community is given in Chambers, "Two Stages," pp. 31-49. 16. Among the political groupings there was no firm ideological base for opposition to the School of Mines. Anticlerical liberals would not wish to destroy the most important school that was free of the authority of the church. The royalists would presumably not wish to do away with that which they had created. The aim of the third important group, the Creole moderates, was not to destroy the institutions of the country but to

wrest control of them from the Spaniards. All political parties, moreover, recognized the usefulness of trained engineers in an independent republic. For further discussion of the politics of Mexican science during this period, see Chambers, "Two Stages." 17. See, for example, the profound influence of World War I on every phase of U.S. science, as described by A. Hunter Dupree in *Science in the Federal Government* (New York: Harper & Row, 1971), pp. 51-55. By comparison the U.S. war for independence was almost insignificant. In *Early Tools*, pp. 51-55, CoLien retells the charming story of the expedition of the Harvard Hollis Professor of Mathematics and Natural Philosophy into British-occupied territory to observe an eclipse of the sun. The good professor felt that the period of safe conduct given to him by the British was "wholly inadequate." In Mexico no such incidents seem to have occurred. No such expeditions were organized, and it is not likely that they would have been respected either by the plundering guerrilla chieftains or by such vicious Spanish generals as Calleja. 19. Ramirez, *Datos*, pp. 217-219. 20. See especially Jean Sarrailh, *L'Espagne eclairée de la seconde moitié du XVIII siècle* (Paris: Imprimerie Nationale, 1954); Richard Herr, *The Eighteenth Century Revolution in Spain* (Princeton: Princeton University Press, 1958); and Arthur Whitaker, ed., *Latin America and the Enlightenment*, 2d ed. (Ithaca, N.Y.: Cornell University Press, 1961). 21. Though now dated, the best historiographical discussion of the Enlightenment in Latin America is Arthur P. Whitaker's "The Intellectual History of Eighteenth Century Latin America," reprinted in *Latin American History*, ed. Howard Cline (Austin: University of Texas Press, 1967), vol. 1, pp. 723-32. Whitaker believes that the Enlightenment "was the central theme of the most significant thought of [the eighteenth century] both in and about Spanish America." He makes an excellent case for the proposition that "changing attitudes towards [the Enlightenment] have been a major factor in the interpretation of the intellectual history of Latin America." I question, however, his notion that the Enlightenment forms a natural or even a useful periodization of Latin American development. Whitaker himself states that "there is some reason to suspect that the importance of the [Enlightenment] may be found to diminish rather than increase as the problem is subjected to the more systematic and discriminating study which it still sorely needs." See the various essays in *Latin America and the Enlightenment*, ed. Whitaker. 23. Hugh M. Hamill, "The Mexican Criollos and the Hidalgo Revolt of 1810" (Ph.D. dissertation, Harvard University, 1956); p. 15. 24. See, for example, Lawrence S. Thompson, "The Colonial Libraries of Latin America," in *History of Latin American Civilization*, ed. Lewis Hanke (Boston: Little, Brown and Company, 1967), pp. 36-46. 25. See Jefferson R. Spell, *Rousseau in the Spanish World before 1833* (Austin: University of Texas Press, 1938), p. 40, for the frequent evasion of the Index. Jose Torre Revello, *El libro, la imprenta y el periodismo en América durante la dominación española* (Buenos Aires, 1940) indicates the near impotence of the censors. Irving A. Leonard, *Books of the Brave* (Cambridge: Harvard University Press, 1949), and Monelisa Perez-Merchand, *Dos etapas ideológicas del siglo XVIII en México* (Mexico, D.F., 1948) offer interesting accounts of the book trade. 26. Richard E. Greenleaf, "The Mexican Inquisition and the Enlightenment, 1763-1805," *New Mexico Historical Review* 41 (July 1966): 181-91. 27. Humboldt, *Political Essay*, p. 110. 28. Revillagigedo to Valdes, 14 January 1790, *Archivo General de la Nación*, Mexico City, p. 111. 29. See, for example, the libraries catalogued in Navarro, *La introducción de la filosofía moderna en México*, pp. 305-8. In these and other colonial libraries the names most frequently encountered are Bacon, Boerhaave, Newton, Nollet, Lescartres, Luchamel, Fontanelle, Gassendi, and Pascal. Indeed, these are precisely the names most frequently cited in scientific treatises and journals in eighteenth-century Mexico. 30. Institut de France, *Index géographique des membres correspondants de l'Académie des Sciences de 1666 à 1939* (Paris: Gauthier-Villars, 1939), p. 31. *Gazeta de literatura* (Mexico City,

17911, vol. I, p. 285-31. Humboldt speaks of meeting Mexican citizens in the 'remote parts' who were shocked to learn that some Europeans did not speak Spanish; such ignorance of their language the Mexicans presumed "to be a mark of low extraction." Humboldt, *Political Essays*, vol. I, p. 33. Arthur Whitaker, ed., *Latin America and the Enlightenment* (New York: Appleton, 1941), offers the best example of this one-dimensional approach to the eighteenth century. No one can deny the heuristic value of the book nor its solid grounding in primary research; its publication stimulated such a vast quantity of scholarly research emphasizing the strength of Latin American Enlightenment, however, that the proper proportions have been lost. In Mexico City in 1863, for example, thirty-two papers were presented at a symposium on the general topic "La ilustración en la América Latina." Twenty-six of these were subsequently published in *Memorias del primer coloquio mexicano de historia de la ciencia*, ed. Beltrán. Though many of the investigations presented are extremely useful, when taken together the essays paint a distorted picture of Mexican reality. 34. Harry Bernstein, "Some Inter-American Aspects of the Enlightenment," in *Latin America and the Enlightenment*, ed. Whitaker, ed. ea., p. 53. 35. J. T. Lanning, "Reception of the Enlightenment," *ibid.*, p. 76. 36. Charles Griffith, *ibid.*, pp. 43-44, questions the simplistic notion that the European Enlightenment was, in some manner, causally related to the wars for independence. Historians now reject that idea. 37. See, for example, the commentaries on the paper by Eli de Gortari, "La ilustración y la introducción de la ciencia moderna en México," in *Memorias*, ed. Beltrán, vol. ~, pp. 48-49. 38. *Mercuro volante* 1771-731, edited by José Bartolache, is of some interest. Bartolache held that physics, medicine, and logic were all alike when considered as sciences. *Gazeta de literatura* 1778-95, edited by Antonio Alzate, is the most interesting scientific journal of the period. 39. George Basalla, "The Spread of Western Science," *Science* 156 (5 May 1967): 611-11. 40. The first natural history expedition to Mexico was commissioned by Philip II in 1570. Francisco Hernández had close contact with many Mexican doctors, but this was in his capacity as a medical examiner, not as a botanist. See his *Obras completas*, ed. German Somolinos d'Ardois, 3 vols. "Mexico, D.F.: Universidad Nacional de México, 1959-60." The first volume contains a comprehensive biographical study. 41. For biographical information, see Irving A. Leonard, *Don Carlos de Sigüenza y Góngora* (Berkeley: University of California Press, 1919). 42. V. W. von Hagen, *South America Called Them In* (New York: Alfred A. Knopf, ~, pp. 1-85; Institut de France, *Index biographique*. 43. The definitive study of the garden and the expedition is Rickett's "Royal Botanical Expedition to New Spain." A good account of the mission is to be found in Clement Mottet, *Mexican Silver and the Enlightenment* (Philadelphia: University of Pennsylvania Press, 1950). 44. See Federico A. Gredilla, *Biografía de C. Mutis* (Madrid, 1911), and A. R. Steele, *Flowers for the King* (Durham: Duke University Press, 1964). Steele's delightful account of the Ruiz and Pavón expedition to Peru includes an excellent discussion of the interactions of scientific travelers and Latin American scientists, pp. 1-11. 45. In this respect, the Humboldt expedition in 1804 was the most successful. After Humboldt, Darwin, Spruce, and other scientific travelers seem remarkably in different to the prospect of communicating with Latin American scientists. 18-82 Alexander Agassiz, for example, who had traveled at least twice to invest in the exploitation of Mexican mineral resources found it "appalling what barbarians the Mexicans still are, at least a hundred years behind the age." After being generously entertained by a former student at Harvard, Agassiz wrote to his mother, "How anybody who has spent four years in the United States and subsequently studied eight years more in France, can have gone back to this semi-barbaric state passes my comprehension." Utterly ignorant of the archeological investigation being conducted by Mexicans, Agassiz thought it a pity that the ruins are not in a civilized country where they could be studied and preserved." Unfortunately,

Agassiz's attitude seems to have been fairly representative, both of European attitudes and those of "los norte americanos" who traveled to Latin America in the nineteenth century. See G. R. Agassiz, ed., *Letters and Recollections of Alexander Agassiz* (Boston: Houghton Mifflin Company, 1913), pp. 100-101. 46. Richard M. Morse, "The Heritage of Latin America," in *The Founding of New Societies*, ed. Louis Hartz (New York: Harcourt Brace, 1964), p. 165, suggests that the "colonial period" should extend from 1760 to 1920. 47. See Mario Gongora, *El estado en el derecho indiano, epoca de fundacion, 1492-1570* (Santiago, 1951). Gongora presents a convincing case for extending the end of the indigenous period to 1570. 48. Access to funds, to journals, and to the best laboratories, the best teachers, and the best students, and so on. Interesting studies of these relations include those of Ben-David, Shils, Schon, and von Giza.