Early Patterns of Scientific Production by Mexican Researchers in Mainstream Journals, 1900–1950

Ma. Elena Luna-Morales
Centro de Investigación y de Estudios Avanzados del IPN, Unidad de Servicios Bibliográficos. Av. IPN 2508, Col. San Pedro Zacatenco, 07360, Mexico DF. E-mail: elena@csb.cinvestav.mx

Francisco Collazo-Reyes
Centro de Investigación y de Estudios Avanzados del IPN, Departamento de Física, Av. IPN 2508, Col. San Pedro Zacatenco, 07360, Mexico DF. E-mail: fcollazo@fis.cinvestav.mx

Jane M. Russell
UNAM (Universidad Nacional Autónoma de México), Centro Universitario de Investigaciones Bibliotecológicas, Ciudad Universitaria, 04510, Mexico DF. E-mail: jrussell@servidor.unam.mx

Miguel Ángel Pérez-Angón
Centro de Investigación y de Estudios Avanzados del IPN, Departamento de Física, Av. IPN 2508, Col. San Pedro Zacatenco, 07360, Mexico DF. E-mail: mperez@fis.cinvestav.mx

According to the bibliographical data included in the Web of Science, SCOPUS, Chemical Abstracts, and other specialized information services covering the period 1900–1950, the first publications in mainstream journals by Mexican researchers appeared only in the first decades of the 20th century. Contrary to expectations, we find that the academic community was not the protagonist in the early stages of Mexican scientific practices, but that there was a strong contribution coming from researchers associated with the public-health sector and the chemical and mining industries. We were able to identify in this half century four different modes of scientific production: amateur, institutional, academic, and industrial, which in turn correspond to distinct stages in the evolution of the Mexican scientific production. We characterize these modes of production with a variety of indicators: publication and citation patterns, author output, journal and subject categories, institutional collaborations, and geographical distribution.

Introduction

The availability online of the *Century of Science* initiative within the Web of Science, as well as the extensive coverage of services such as SCOPUS, presents us with the possibility of developing new perspectives on the growth and evolutionary paths taken by science during the 20th century. Previously, researchers had to search out relevant scientific texts of the time or rely on compilations and testimonies assembled by third parties. In the present paper we base our analysis of the evolution of the production of Mexican researchers during the first half of last century on the bibliographical data sets of their output in mainstream journals included in the Web of Science (WoS). Additional records were recovered from historic sources, as well as from SCOPUS, Chemical Abstracts (CA), and other specialist indexing services.

As pointed out by Shapin (1992) and Kragh (1987) this type of research data may be used to reexamine the history and sociology of science. Traditionally, in the field of science studies, the historical record, as a collection of personal and collective testimonies, has relied heavily on readings and bibliographical research, without the added advantage and insight that bibliometric data can provide. Bibliometrics has been used most often in the fields of library and information science. However, it can also be applied to learn more about the scholarly content of any discipline. For example, in the history of science, it has been used to elucidate the development of scientific disciplines by tracing the historical movements associated with results obtained by researchers (Okubo, 1997). While scientometrics and bibliometrics focus on the formal reporting of scientists, in contrast, we will use heuristic procedures typical of the field of historiography, to explain the formal on the basis of the informal (Edge, 1979; Martínez, 2003).

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The history of science was originally written by philosophers and by practicing and retired scientists (Christie, 2005) as a way to communicate the virtues of science to the public. In the 1930s, efforts were directed towards looking at the ways in which scientific practices were allied with the needs and motivations of society. By the 1960s, with the increasing importance of science and technology in modern life, the emphasis was on problematizing the scientific enterprise, thus making it difficult to reach consensus as to the best way to write its history (Suárez, 2005). The critical study of the history of science and its professionalization as the historiography of science during the 20th century, increasingly in the hands of the historians of science and now accepted as a legitimate field of academic study (Christie, 2005), brought with it a greater richness and variety of interpretations and viewpoints (Laudan, 2005) and an increasing demand for specialized documentary and other information resources. In 1963, Eugene Garfield, influenced by *Shepard's Citation Index* for legal cases, founded the *Science Citation Index* (SCI). Although bibliometric analysis predates it, SCI and its access to ISI's large datasets increased the popularity of bibliometric research, especially outside the field of information science. The SCI and more recently the Web of Science have become the most generally accepted basic source for bibliometric analysis. However, in the case of studies involving both historic and bibliometric analyses, it is necessary to compensate for the omissions found in certain periods covered by the WoS *Century of Science* and other information sources such as SCOPUS, with local sources of historical information. It is also convenient to consult recent online Web pages that include multidisciplinary or specialized information.

It is well established that the prevailing vision of the history of Mexican science has been written mainly by members of the national scientific community, through personal viewpoints, essays and monographs, some as eyewitness accounts of the period (Beltrán, 1952, 1970, 1989; Gortari, 1963), others as eminent saviors of our scientific past by way of general works (Moreno, 1986; Pérez-Tamayo, 2005), biographies of prominent scientists (Academia Mexicana de Ciencias, 2003; Coordinación de la Investigación Científica, 2003), and evolution of disciplines (García & Pérez-Angón, 2006; Pérez-Angón, 2006), as well as institutional histories. The emergence of the first studies by specialists in the sociology and historiography of Mexican science from the 1980s and 1990s (Casas, 2003; Saldaña, 1982; Trabulse, 1983) introduced new ways of documenting Mexican science: The questions asked were more diverse, as were the study objectives, and the diagnosis went deeper. Mexican science required a greater wealth of historiographic sources and interpretations (Trabulse, 1996, 2003) to complement the mainly descriptive and externalist approaches (Casas, 2003) and to strenghten conceptual study frameworks by incorporating both endogenous and exogenous factors to the analysis of the local maturing process of the sciences (Saldaña, 1994).

The present study, therefore, puts a different perspective on the history of Mexican science by identifying four distinct knowledge production modes characterized as amateur, institutional, academic, and industrial. The application of a heuristic procedure as used in the historiography of science, which recognizes the presence of different practices and traditions in the evolution of the sciences (Martínez, 2003), was complemented by analyzing the relevant production and communication patterns during the first half of the 20th century. We were especially interested in mapping the organizational and disciplinary structures that emerged over this period, as well as publication patterns that characterized knowledge production during this time. We also hoped to identify aspects that help characterize the process of transition and rupture between knowledge production based on immediatist intentions, centered on specific regional developments and applications (Pérez-Tamayo, 2005) and the new mode of production of knowledge that started to gestate within the public-health institutes as well as in the academic and industrial sectors during these phases of development. In order to achieve this goal, we used historical bibliometrics (Hérubel, 1999) combined with social-network analysis (Molina, 2001), which allowed us to identify the coauthorship patterns of each knowledge-production mode and to characterize the first genuine efforts in scientific collaboration in the areas of public health, infectious diseases, clinical and general medicine, biomedicine, industrial chemistry, and physics. This new phase of scientific collaboration was gradually incorporated into the traditional way of doing science in Mexico (which by this time had outlived its usefulness), thus enriching the organizational structures, scientific communication patterns, research methodologies, orientations, and customs of the amateur and individual modes.

Material and Methods

Mexican science published in mainstream journals during the first half of the 20th century, besides being sparse, is only partially retrievable using the international bibliographic databases available online nationally, due to lack of information with respect to country and author affiliations, and missing records. In other words, more work was published than that readily retrievable. In order to correct these omissions, we resorted to complementary procedures involving four different search strategies, three of which involved using the term *Mexico* in WoS, in SCOPUS, and in CA. A fourth search was carried out in the WoS on author names identified in a historical archive constructed after consulting different documents on the history of Mexican science from 1900 to 1950 (Beltrán, 1952, 1970; Gortari, 1963; Pérez-Tamayo, 2005). Outcomes of the different search strategies are shown in Table 1. We also analyzed 639 additional papers, 45 of which met the criteria for this study, present in specialized services such as BIOSIS, GEOINFO, and PyscINFO, but which we were not able to access from academic institutions in Mexico. These correspond to the period from 1941–1950. Apart from increasing author, institutional, and

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TABLE 1. Coverage of Mexican science in international indexes, 1900–1950[a].

No.	Index	Search strategy	No. retrieved records	Duplicate records	Final no. records
1	WoS	Mexico not New Mexico	85	0	85
2	SCOPUS	affil (Mexico and not New Mexico) and pubyear aft 1899 and pubyear bef 1951	83	13	70
3	CA	Mexico Refine: Year and Company/organization	62	46	16
4	WoS	Individual searches on names of 280 authors	126	0	126
		Totals	356	59	297

[a]Sources: Web of Science. Retrieved May–November, 2007, from http://apps.isiknowledge.com/WOS_GeneralSearch
SCOPUS: Retrieved May–November, 2007, from http://www.scopus.com.pbidi.unam.mx:8080/scopus/search/form
Chemical Abstracts. Retrieved May–November, 2008, from http://134.243.85.3:210

journal-production levels already identified as Production Mode 2, this further group of papers was found not to add any new qualitative insights into our original data.

We took as our baseline the 85 records originally retrieved using the country name of *Mexico* in the WoS, not including the period 1945–1950 when records did not contain information on countries or author affiliations. The subject areas best covered by this search strategy were geophysics, civil engineering, metallurgy, health and public hygiene, and general medicine published in *Transactions of the American Geophysical Union*, *Transactions of the American Institute of Mining and Metallurgical Engineers*, *Physical Review*, and the *Journal of Infectious Diseases*.

As shown in Table 1, the coverage of SCOPUS and WoS are very similar in terms of numbers, but very different with respect to publication years, research themes, institutions, and journals used. Eighty-five percent of documents were published at the end of the 40s in the field of pharmacological chemistry, carried out by industrial laboratories and published principally in the *Journal of the American Chemical Society*, the *Journal of Organic Chemistry*, *Mikrochemie Vereinigtmit Mikrochimica Acta*, the *Journal of Chemical Education*, and *Science*. With SCOPUS we were able to recover other documents by the second institutional address and others published as letters, notes, news, abstracts, scientific apparatus, and laboratory methods, as happened with 16 contributions to *Science*, none of which we had been able to retrieve from the WoS.

Most of the 62 documents retrieved for Mexico in CA were duplicates of those recovered using Search Strategies 1 and 2 in Table 1, or had been published in journals not covered by the WoS. The 16 documents included in the final analysis were published in the period from 1946–1950 on topics in the field of chemistry, carried out in academic institutions or hospitals and published mainly in *Analytica Chimica Acta*, *Archives of Biochemistry*, *Nature*, and the *American Journal of Physiology*.

The 126 documents recovered by Search Strategy 4 were the result of separate searches carried out on the names of 280 authors; none of these records had been retrieved by our previous three searches using the name *Mexico*. Seventy-seven percent were published from 1945–1950, the period for which the WoS does not include author addresses; the remaining 23% fall outside this period but again were not retrievable for the same reason. The corresponding institutional affiliations of the authors were added to our data for each record. To do this, we went directly to printed or online sources and to author and institutional biographies. In each case we confirmed that at least one Mexican institution was involved. Documents identified using this procedure were in different subject fields and published predominantly in the following journals: *Physical Review*, *American Heart Journal*, *Proceedings of the Society for Experimental Biology and Medicine*, *Journal of Immunology*, and *Transactions of the American Institute of Mining and Metallurgical Engineers*.

By analyzing the common elements of the retrieved bibliographical records (such as author, title, journals, addresses, numbers of references and citations, document type, and categories) and the application of quantitative, desegregation, and word-frequency techniques, we were able to identify important differences between the institutional structures, forms of organization, and scientific communication patterns present during the period analyzed. This allowed us to identify four knowledge-production modes: amateur (Saldaña & Azuela, 1994), institutional, academic, and industrial, each one with its own mechanisms for incorporating the standards of publication of international science, which we were able to characterize with the help of nine different bibliometric indicators.

The characterization of scientific practices was carried out by applying social-network analysis to the coauthorship structures found for each production mode (Molina, 2001). Networks were developed using special software for the exploration of social networks (Nooy, Mrvar, & Batagelj, 2004) based on a matrix where the social actors or nodes are the authors of the scientific papers and the relations are represented by the coauthored publications involving two or more authors (Newman, 2001a, 2001b). This procedure alerted us to the absence of collaborations in the amateur mode and to the appearance of the first authentic scientific collaborations of researchers from Mexican institutions: initially during the institutional mode in the areas of public health and biomedicine, and subsequently within the academic and industrial modes, in cosmic ray physics and steroid chemistry, embodying the first contributions by Mexican science

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to the international scientific arena by way of the mainstream scientific literature.

Results

We recovered a total of 297 mainstream publications spanning the years from 1900 to 1950: 10% corresponded to 1900–1925 and 90% to the second quarter of the century 1926–1950. More important than the actual numbers of papers in the first quarter of the century is the fact that Mexican science showed a continuous, albeit small, presence in the international databases during this period of the greatest political instability in the history of the country, caused by the revolution of 1910–1920.

Figure 1 shows the general distribution of scientific production from 1900 to 1950 according to the four different patterns of knowledge production and communication. Two distinct periods are apparent: The first covers the long period of reliance (1900–1930) on the customary ways of doing science, based mainly on a single type of scientific practice. Other patterns evolved during the second period, from 1930 to 1950, such that towards the end of the period we see four different knowledge-production modes coexisting.

One quarter (73) of the papers correspond to the amateur mode, which exhibits a static form of production, suggestive of precarious scientific activity related to limited organizational structure and isolated scientific practices. In contrast to the other three modes, the amateur mode is present during the greater part of the 50-year period and represents the most established way of doing science in Mexico during this time. The institutional mode is responsible for the largest part of the production, 32.5% (97) appearing in the second quarter of the century (1925–1950); this is an emergent form of production that is consolidated during the last 10 years of the period under study. The studies undertaken in the academic environment correspond to 23% (68) of the total and are concentrated in the final decade of the period. These represent the first international publications produced by the newly established research institutes and are mainly physics papers authored by the National Autonomous University of Mexico (UNAM). The last mode to be consolidated was that developed in the industrial sector, with a share of about 20% (59) published mainly in the last four years of the period under study.

Each of the production modes was sustained by distinct circumstances, and organizational structures and resources that replicated clearly differentiated patterns of publication, citation, and information usage as characterized in Table 2 for Modes 1 and 2 and in Table 3 for Modes 3 and 4.

The amateur or individual mode occurs throughout the period, but mainly from 1900–1940, associated with poor, nonprofessional scientific practice, principally the result of the individual effort of authors, accomplished locally in isolation from peers and with immediate utilitarian objectives in mind. A variety of different research topics were undertaken, within subject areas related mainly to the mining, oil, railway, and health-industrial sectors, which showed little continuity and connection between authors. With the notable exception of A. Medina, the most productive researcher during this period, who published results on the characteristics and progress of geodetic work in Mexico in the 30s, the majority of authors published only one paper and very few

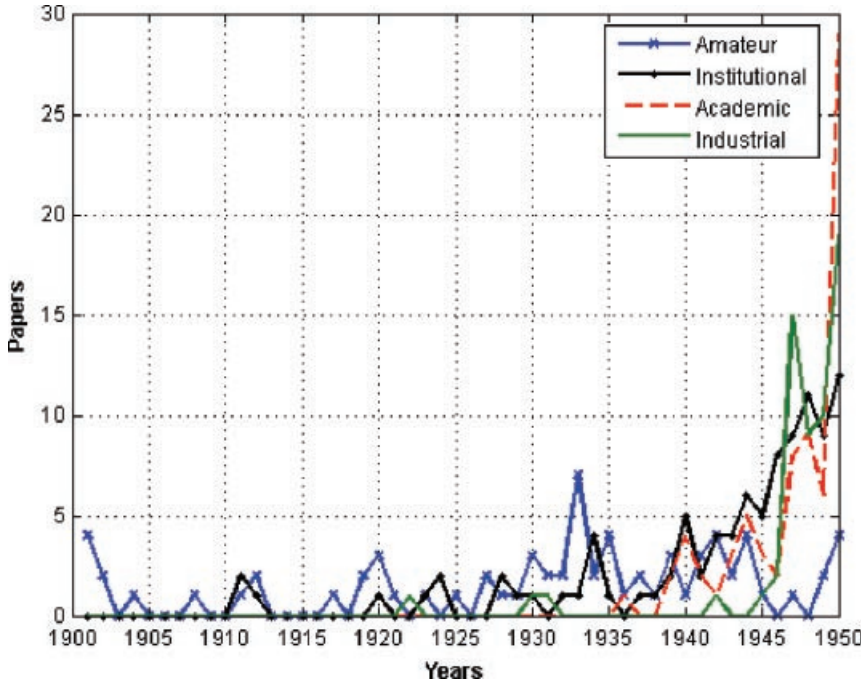

FIG. 1. Scientific production modes of Mexican science during the first half of the 20th century.

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TABLE 2. Publication and citation patterns of knowledge-production Modes 1 and 2.

Bibliometric indicator	Denomination	Mode 1: Individual or amateur	Mode 2: Institutional
1	Type of research	Isolated, local, utilitarian, private, and public funding	Institutional, professional with continuity in the production, topics, authors, and institutions. Utilitarian
2	Reference and citation patterns (WoS)	Avg. no. references: 2.1 Avg. no. citations: 0.1	Avg. no. references: 10.7 Avg. no. citations: 10.4
3	Document type	– Articles: 85% – Letters: 10% – Abstracts: 2.5% – Notes: 2.5%	– Articles: 82.5% – Abstracts: 12% – Notes: 3.5% – Reviews: 1% – Letters: 1%
4	Language	– English: 98.6% – French: 1.4%	– English: 93% – French: 6% – German: 1 %
5	Preferred journals	– *Trans Am Geophys Union* – *Trans Am Inst Mining Metall Eng* – *Science* – *J Chem Ed* – *Am Midl Nat*	– *Am Heart J* – *P Soc Exp Biol Med* – *J Immunol* – *J Infect Dis* – *Compt Rend Sci Soc Biol* – *Science* – *J Cell Comp Physiol* – *Am J Hyg* – *Am J Trop Med* – *Arch Biochem* – *J Lab Clin Med* – *Press Med*
6	Categories (WoS)	– Geochem & Geophys; Metallurg & Metallurg Engin; Engin Civil – Multidisc Sci – Chem, Multidisc – Med,Gen & Intern – Ecology – Biodiversity & Conserv	– Med, Research & Experiment – Med, General & Internal – Cardiac & Cardiovascular & Systems – Immunology – Multidisc Sci – Infect Diseases – Biology – Pathology – Public, Environm & Occupational Health – Physiology – Microbiology – Biochem & Mol Biology – Trop Med
7	Geographic distribution by state	– Mexico City: 64 % – Sonora: 5% – Hidalgo: 5% – Coahuila: 5% – Sinaloa: 4% – Chihuahua: 4% – Zacatecas: 4% – Other: 9%	– Mexico City: 94% – Yucatán: 3% – Other: 3%
8	Institutional structure	– Directorate of Geographic, Meteorological and Climatic studies – Mining companies – Agricultural Department – Mutada Herbarium Escuincla – National Observatory of Astronomical – National School of Medicine	– Institute of Tropical Diseases – General Hospital – National Institute of Cardiology – Public Health – Hospital Laboratories America – Pediatric Hospital – Horan Hospital
9	Word frequency	Mexico, geodetic, Mexican, mining, mine, methods, Pachuca, cyanide, ore, geology, gravity station, Fresnillo, oil, plasmogenesis	Typhus, Mexican, brucellosis, heart, fever, infection, Guinea pigs, immunological, blood, treatment, virus, human, vaccines, clinical, epidemic

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TABLE 3. Publication and citation patterns of knowledge-production Modes 3 and 4.

Bibliometric indicator	Denomination	Mode 3: Academic	Mode 4: Industrial
1	Type of research	Professional, institutional, and independent, public funding, theoretical	Corporative, industrial funding, applied research
2	Reference and citation patterns (WoS)	Avg. no. references: 4.4 Avg. no. citations: 4.5	Avg. no. references: 3 Avg. no. citations: 7
3	Document type	– Abstracts: 42.4% – Articles: 37% – Letters: 8.5% – Notes: 8.5% – Editorial: 1.8% – Reviews: 1.8%	– Articles: 81% – Notes: 10% – Letters: 7% – Abstracts: 2%
4	Language	– English: 92.5% – German: 6% – Spanish: 1.5%	– English: 88.3% – German: 8.3% – French: 3.3%
5	Preferred journals	– *Phys Rev* – *J Pharmacol Exp Ther* – *Science* – *Rev Mod Phys* – *Nature*	– *J Am Chem Soc* – *J Org Chem* – *Arch Biochem* – *Mikrochem Vereing* – *J Biol Chem* – *Nature* – *Protoplasma* – *Science*
6	Categories (WoS)	– Phys Multidisc – Multidisc Sci – Chem Multidisc – Pharmacol & Pharmacy – Med, Gen & Internal – Psychiatry – Chem Multidisc	– Chem Multidisc – Bioch & Mol Biol – Chem, Organic – Multidisc Sci – Chem Analytical
7	Geographic (distribution by state)	– Mexico City: 94% – Puebla: 3% – Nuevo León: 3%	– Mexico City: 100%
8	Institutional structure	UNAM-Institutes – Physics – Pharmacology – Geophysics – Mathematics – Chemistry – Medicine – IPN	– Industrial laboratories – Syntex – Hormona Laboratories – Hotel Geneve, Mexico – Forsch Lab Org Chem
9	Word frequency	Cosmic, radiation, fields, gravitation, magnetic, Birkhoffs, rays, fields, energy, magnetic, spectrum, orbits, particles	Sapogenins, steroidal, steroids, ketosteroids, synthesis, Mexican, apogenins, plants, fat, bromination, biogenesis

published three papers on different subjects. Such is the case of E. Ordóñez, who published on the Mexican railway system, the mines from the Pachuca district, and oil in the south of the State of Tamaulipas. Another example is P.C. Sánchez, who wrote about earthquakes, the history of geodesy in Mexico, and volcanoes.

This production mode replicates the publication patterns of a sole author with no references and no citations. The papers are typically reports, classification studies, descriptions, technical research reports, implementations of solutions, clinical methods, and studies, written in English by researchers, such as engineers and physicians, affiliated mainly to foreign companies established in Mexico from the mining, oil, and railway sectors, and to a lesser extent, from national institutes in the fields of geography, geology, and private hospitals.

The specialized journals used are in the subject categories of engineering—geochemistry, geophysics, mining, civil and chemical engineering—and general, internal, and clinical medicine, in journals that are no longer covered by the SCI, such as *Transactions of the American Geophysical Union*, *Transactions of the American Institute of Mining and Metallurgical Engineers*, and the *Journal of Industrial Engineering Chemistry*. An interesting feature of this mode of production is that unlike the institutional, academic, and industrial modes**,** research is much less centralized within Mexico City.

The institutional Mode 2 of production begins towards the end of the period 1910–1919, and corresponds to scientific practices that share the characteristics and circumstances of local and external development of Modes 1 and 3 throughout the period analyzed. Nonetheless, it also presents important

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differences with respect to communication, publication, and citation patterns as shown in Table 2. This mode is developed mainly in the institutions of geology, geography, general medicine, public health, and hygiene, and biomedical research, astronomy, and biology, created by the state under varying names beginning in the 19th century. It is manifest in the international, mainstream literature in a more marked and continuous way in the 1930s by the attention given to the topic of typhus as a particular local public-health problem, written about by different specialists, with MD degrees, such as G. Varela, M.R. Castañeda, H. Mooser, J. Sozaya, and N.P. Hudson, affiliated to institutions of public health and hygiene, such as the Institute of Hygiene, the Institute of Health and Tropical Diseases, and the General Hospital, which created a laboratory specialized in typhus research, as well as private laboratories and hospitals. This environment, created as a result of typhus research, produced the first instances of national and international scientific collaboration centered around a local problem, in addition to the first Mexican papers to receive more than 10 or 20 citations.

Mode 2 emerged under different local, social, and political circumstances and with changes in the authors and in their professional profiles with respect to Mode 1. In the 40s, new specialists joined the researchers studying typhus; among them were exiles from the Spanish Civil War and Mexican researchers who were trained abroad. For instance, I. Chávez, B. Sepúlveda, A. Rosenblueth, I. Costero, F. Giral, J. Romo, G. Haro, and F. Gómez, among others, attached to the Institutes of Cardiology and Pediatrics, and institutions from the chemical and pharmaceutical industry, created new openings in the relationship with international science, which translated into the consolidation of new patterns of scientific production and communication. These were associated with the adoption of scientific practices involving coauthorship with peers in both national and international scenarios, diversification of languages and research methods, the presentation of papers in international meetings, which were reviewed in mainstream journals, as well as the publication of short communications in the form of notes and letters.

In Mode 2 efforts were directed along different paths towards insertion of Mexican science into the international standards of publication and citation, as is evident in Table 2, by an increasing average number of references cited in the papers accompanied by a rise in the impact of local studies through citations given by peers in the international scientific community. The average of 10 citations per paper is in keeping with present-day average numbers of citations for Mexican science. These characteristics are associated with changes in the objectives set by scientific practices, above and beyond utilitarian considerations, as shown by basic research of a theoretical and experimental nature, which has guaranteed the continuity of the new topics studied and has allowed access to different journals with the highest impact factors in their respective areas, such as the *American Heart Journal*, *Proceedings of the Society for Experimental Biology and Medicine*, *Science*, the *Journal of Immunology*, the *Journal of Infectious Diseases*, and the *Journal of Cellular and Comparative Physiology*, where the first studies were published; these studies received more than 50 citations. The *Journal of the American Chemical Society* had the highest average number of citations (79 citations per paper) and the paper with the highest number of citations (154) for the period analyzed. Mode 2 was developed in a centralized manner in Mexico City.

The academic Mode 3 begins towards the end of the 1930s; it corresponds to professional research carried out within institutions and linked to academic topics. This implies greater freedom in the choice of research topics and greater independence from considerations related to the solution of local problems than with respect to Modes 1 and 2. Its origins lie in the incorporation in the period 1930–1950 of the Institutes of Geology and of Biology, the National School of Medicine, and the National Astronomical Observatory, among others, to the National Autonomous University of Mexico (UNAM) as well as the creation of the Institutes of Physics and Mathematics and the Faculty of Science within the UNAM. It initiated its development in a strongly centralized way, 90% concentrated in the UNAM, particularly in the Institute of Physics and within Mexico City.

The academic mode is the least present and appears only at the end of the period analyzed. The production mode and communication patterns, identified in Table 3, correspond principally to the physical sciences and, in particular to the area of cosmic rays, the theoretical research topic with most influence among physicists at that time. Mexican scientists working on this topic disseminated their first studies internationally in the *Proceedings of the American Physical Society*, principally in the meetings celebrated in 1947 in Houston, Texas and in 1950 in Mexico City. This communication channel guaranteed the publication of papers in the *Physical Review*, the main international journal in the field, in the form of meeting abstracts. This type of document represented 50% of all contributions made under Mode 3 and were generally written by a single author, with few references and citations. These conditions were a fundamental influence on the overall characteristics of the academic mode, identified in Table 3, which refer to publication patterns exemplified by individual authorship and low average numbers of references and citations.

The industrial Mode 4 emerged at the end of the period under study, principally as a result of the interest of the industry associated with steroids research. In a relatively short time, a rather important research group in this applied area developed a new pattern of publication involving production and citation averages somewhat higher than those characteristic of the other three modes. Furthermore the average number of authors was smaller and associated with only two industrial laboratories: Syntex and Hormona. The laboratories, both located in Mexico City, published about 75% of their papers in four journals, mainly in the *Journal of the American Chemical Society*, (subject category: chemistry, multidisciplinary) and about 30% of the words used in the respective titles were related to the terms sapogenin and steroids. It is

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also relevant to mention that both research groups included foreign researchers among their members.

As can be seen in Figure 2, coauthorships links differ considerably between the four distinct modes. The amateur production Mode 1 displays scientific practices carried out in an unstructured and isolated environment with no collaborative links between authors, their institutions or research interests. Coauthored work is the exception in this mode and occurred only with respect to two authors publishing together on one occasion. The most productive authors, M. Medina and A.L. Herrera in amateur research, showed the greatest continuity with no apparent links or influence on other authors. The configuration of Figure 2 suggests that 89% of the papers correspond to single authorships whose production is dependent on individual efforts developed in isolation making only occasional contributions and on a variety of topics. In networking terms, all authors play marginal roles; mediation, cohesion, and centrality features are nonexistent as are linkage and influence structures, indicating an absence of established relationships between actors.

The institutional mode produced the richest and most elaborate structure with about 60% of collaborating articles. This set of publications included collaborations even among authors appearing in the other production modes. The institutional mode also covered interdisciplinary subjects with authors involved in all three modes of production.

The network for the institutional mode is the first example of an authentic associative network of Mexican scientists collaborating on local problems (Figure 2). The first coauthorship structure developed in the period 1928–1940, and as mentioned previously, focused on local hygiene and public-health problems related to typhus, a subject that incorporated important characteristics of international scientific practice into the development of the incipient local scientific effort such as continuity in research on a specific topic; participation of a considerably sized group of 14 researchers; distinct organizational forms that involved from 2–3 coauthors forming interrelated groups; application of distinct research modalities (clinical, experimental, and applied); and participation of researchers from both national and international institutions. Findings attained the same level of importance as those reported in the scientific literature by international groups working on the same subject, helping to sustain interest in this research field. The research on typhus began with the individual efforts of H. Mooser and J. Zozaya, who were affiliated with a private hospital and with the Mexican Institute

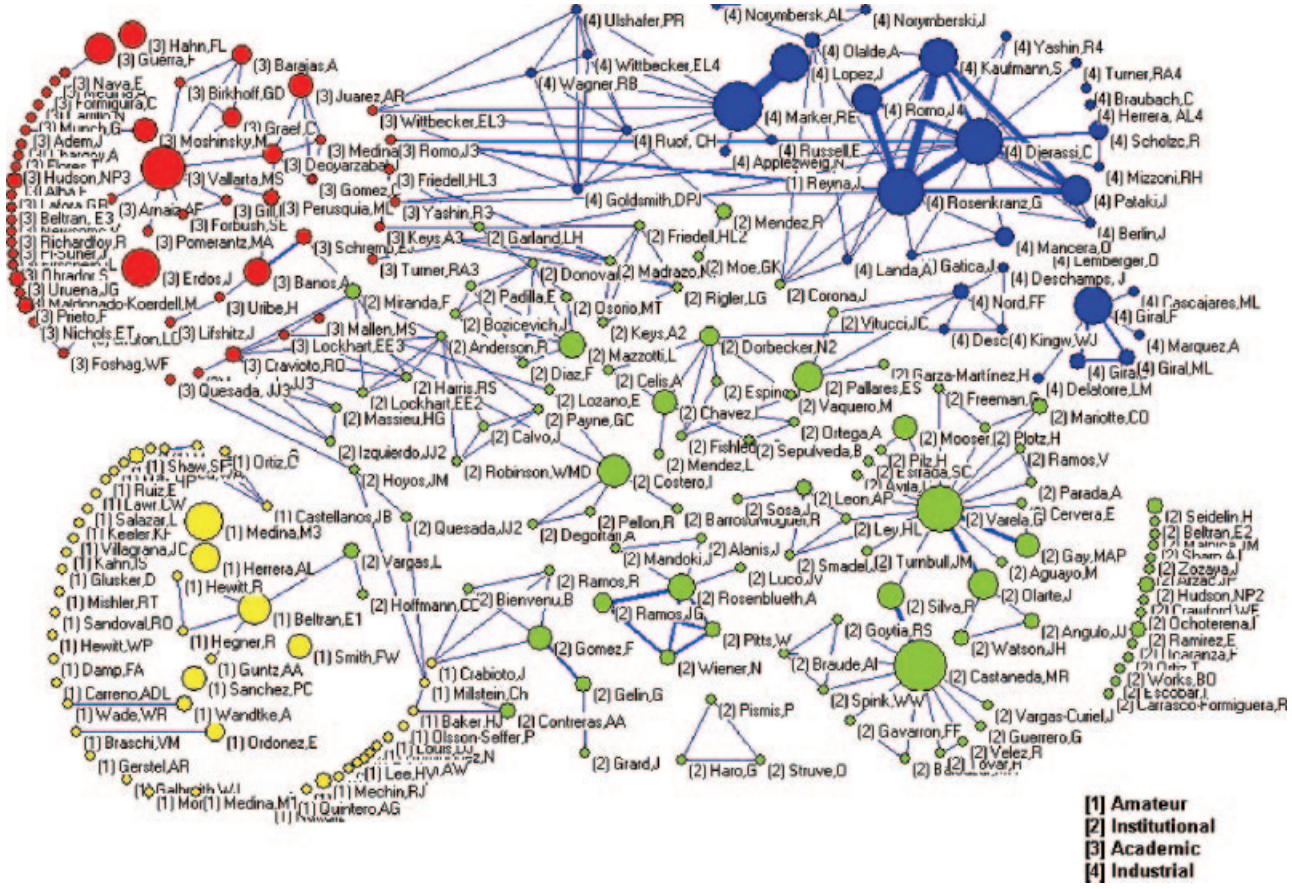

FIG. 2. Modal representation of the coauthorship network of Mexican research, 1900–1950. Authors are represented by the nodes, the publications by the lines and coauthorships by the relations between nodes. The size of each node relates to the production of each author and the thickness of the lines, the collaboration between authors.

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of Hygiene; this collaboration continued up to the late 20s with the appearance of research groups headed by G. Varela and M.R. Castañeda, and collaborative group research under the leadership of G. Varela; these were the most influential and best-connected researchers in Mexican science at the time, and they formed associations with emerging groups in other areas of biomedical research of the period. On his return to Mexico at the end of the 30s, M.R. Castañeda, who formed a small research group that did not coauthor with Varela's established group, strengthened Mexico's participation in the field with the development, improvement, and distribution of the vaccine against typhus, for which he achieved important international recognition. In the late 40s, interest dwindled in typhus among Mexican researchers, who started to publish on related subjects. It is not known just how much the success of the typhus vaccine was responsible for this but it certainly was a contributing factor. From 1940–1947, L. Mazzotti also carried out research on infectious diseases in public-health institutions in collaboration with five other authors and with minimal production during the eight years.

At the same time as production dwindled on this first research topic developed in coauthorship, other biomedical research groups began to emerge in public-health institutions as small collaborative groups under the leadership of different researchers. The first coauthorships were produced in the Institute of Cardiology by two cohesive groups centered around two authors: I. Chavez and N. Dorbecker. The two groups were linked by the close collaboration of their leaders. The second set of coauthorships started in 1948 in the field of physiology with the publication of the first scientific papers written by A. Rosenblueth on his return to Mexico, in collaboration with other authors, giving rise to a coauthorship subnetwork comprising six authors. The third set of coauthored papers corresponds to a research group associated with I. Costero, a Spanish researcher exiled in Mexico and comprising five other authors but with no ties to the other two groups from the Institute of Cardiology. In the institutional mode the most productive authors also have the largest numbers of collaborative relations. We could identify two other groups, one comprising three authors and the other four authors, each linked through the publication of one paper on topics in general medicine mediated by F. Gómez.

The academic mode had 54% of articles with a sole author. Some of the most productive authors in this mode, such as J. Erdos, A. Guerra, and F.L. Hahn, never developed collaborations that resulted in publications during this period. Figure 2 shows the initial structure of the coauthorship relations in research carried out in academic settings, corresponding to a scientific practice based principally on individual publication accompanied by the emergence of the first working ties, occuring in the field of physics, where two groups are significant for work carried out in the same subject areas but without coauthorship links. The first association resulted from the research published between 1939 and 1941, by A. Baños, on his return to Mexico as the founding director of the Institute of Physics at the UNAM, where he continued work on cosmic rays started in collaboration with M. Vallarta abroad, but now in local collaboration. Here he published the first research papers of that period in theoretical physics authored by a Mexican institution that had been created expressly to carry out scientific research. The second group corresponds to the most structured subnetwork of Mode 2, involving more authors in two groups working also on the nature of cosmic radiation (Mondragón & Barnés, 1978). This topic gave international recognition to M. Vallarta and he continued this line of research on his return to Mexico during the final stage of his productive academic life, in collaboration with local and foreign scientists. In Figure 2, he appears as the most productive author with more links and with the greatest capacity of mediation in this first expression of Mexican academic science.

Other linked groups, such as those of A. Keys, H.L. Friedel, L.H. Garland, L.G. Rigler, and M.F. Madrazo in the field of cardiology and E.T. Nichols, L.C. Graton, and W.F. Foshag in research on the Paricutín volcano, were short-lived as manifest by a sole publication. In general terms, the least productive authors showed less tendency towards collaboration, with the exception of F. Guerra and M. Moshinsky who are among the most productive but have the smallest number of relations.

The industrial mode generated publications that involved strong commercial interests in steroid research. The respective research groups were the most productive in this period: the collaboration between R.E. Marker and J. Lopez, for example, were the most productive for two-author papers, while the research group based in the Syntex Laboratories was the most productive for a relatively large set of authors (G. Rozenkranz, C. Djerassi, J. Romo, S. Kaufmann, and J. Pataki). This group also developed collaborations with scientists in the biomedical area. On the other hand, there was a research group led by F. Giral with no connections with the Syntex group and that also produced a large set of publications in the areas of biochemistry, molecular biology, and pharmacology. In summary, the industrial mode involved the smallest number of publications with a single author.

Discussion

When we consider that, on the one hand, the records identified in SCI and SCOPUS represent 28.6% and 23.5%, respectively, of the total encountered using our methodology, and on the other, the 45 papers identified that meet the criteria for our study present in databases not accessible in Mexico (BIOSIS, GEOREF, and PsycINFO), we can appreciate that SCI and SCOPUS are not reliable sources for the retrieval of the overall scientific production of Mexico during the last half of the last century. We need, therefore, to consult additional specialist sources that complement the data for this period in Mexican scientific history.

The variables identified in our bibliometric analysis allowed us through the application of desegregations techniques, quantification, analysis of word frequency, as well

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as network analysis for coauthorship, to identify the main subject areas of Mexican scientific production in the first half of the 20th century, namely, geophysics, cosmic radiation, typhus, and steroid chemistry. All research areas emerged with production and citation patterns related to strong industrial interests, like the mining-metallurgy and steroids industries, or the public-health and academic sectors.

Using the same bibliometric approach, we were able to uncover the process by which the local scientific community incorporated into the global scenario by adopting the international standard of publication in mainstream journals. This process evolved by documenting the construction of new ways of knowledge production that occurred and complemented each other throughout this period. In each of these stages favorable local conditions were created for a closer relationship with international scientific culture.

The international collaboration of Mexican researchers in the mainstream literature showed a healthy transition from the rather low levels found in the period from 1900 to 1950 (Collazo-Reyes, Luna-Morales, Vélez-Cuartas, & Pérez-Angón, 2008) to levels as high as 60% in certain research areas such as physics and biology in the period 2000–2005 (Russell, Madera-Jaramillo, Hernández-García, & Ainsworth, 2008). In the latter case, the US was the major partner with a rising European presence but with little coauthorship with other Latin American nations.

The presence, under local conditions, of new scientific practices during the period analyzed was observed using bibliometric methods involving the tracking and quantification of common biographical elements (authors, journals, topics, institutions, references, and citations) for the identification of changes occurring in institutional structures, forms of organization, and patterns of scientific communication. These biographical elements laid down the evolutionary pathways and other testimonial elements sufficient for the characterization of the development of Mexican science during this period, tracing its journey through four distinct stages for the generation and publication of knowledge in the international environment.

The structures resulting from the analysis of the coauthorship relations allowed us to come closer to defining the circumstances surrounding the emergence of modern scientific communities in Mexico and the shaping of their traditions, through the identification of the distinctive transitional events and the continuity in and among the distinct scientific practices seen during our study. Mode 1 appears as a depleted scientific practice for individual work with its methodologies focused mainly on the characterization of the national geography and geodesy; the identification, information gathering, and generation of inventories of natural resources, such as flora, fauna, and minerals, as well as the development of methods, techniques, and other aspects associated with their exploration.

With the first research developed with the funding and interest of foreign firms established in Mexico and published internationally during the initial decades of the 20th century, a process was begun that led to continuous efforts to adopt the conduct and procedures associated with research methods and publication standards used internationally. This paved the way for the consolidation of the first scientific practices involving collaborations of two or more authors, giving rise to the first research subject structures or relations occurring primarily in health and hygiene, in the area of infectious diseases, such as in the case of typhus, and later in research on cosmic-ray physics, steriod chemistry, biomedicine, cardiology, and physiology, principally. In Mode 1, an event was described in the history of science as a passage from the private to the public modes (Saldaña, 2005), which referred to a change in the origin and funding sources for research work from the mining and petroleum sectors to public institutions. The result was a progressive decline in the contribution made by the mining and petroleum-extraction companies and an increase in the role played by the Mexican State in the funding and development of research infrastructure, principally from the 30s onwards. Under these conditions corporative scientific practices emerged in institutions in different sectors, but mainly in public health: the Institute of Hygiene, the General Hospital, the Pediatric Hospital, and the National Institute of Cardiology.

Between Mode 1 of scientific practices of the first three decades of the 20th century and the formation of the first true research relationships developed mainly from the beginning of the 30s as part of Mode 2, an important transitional process occurred in Mexican science, forewarning a modification in its publication and citation patterns and communication structures. During this time Mexican science entered a period of expansion with respect to its limits of growth, leaving behind its dependence on a depleted, single way of producing knowledge. One of the mechanisms developed to incorporate new scientific practices into the local environment took advantage of the incorporation of researchers trained aboard, the increase in the number of local researchers, and of external factors involving the participation of foreign researchers with interests in the pressing problems of the time: typhus in national hygiene and public health; cardiology and physiology in biomedicine; cosmic rays in physics; and steroid production in chemistry, among others. The high incidence of typhus fever in Mexico, also a subject of interest in international science, had already been written about in Mexico but on isolated occasions and not as a consequence of public policy. Subsequent collaborative research allowed greater continuity in the research effort, which culminated in the production of a vaccine to combat the disease. These shared scientific practices were carried out for the first time within the research institutions of Mexico as an emerging research mode based on relations of mutual interest among scientists, and accomplished in accordance with genuine principles of information and knowledge exchange.

The expansion of these practices to other research areas of biomedicine and industrial chemistry at the end of the period, and their changing publication and communication patterns, confirm the presence of developing research structures with more productive organizational formats and with greater international visibility. The emergent processes in

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each of these evolving areas developed their own system of internal relationships, making it possible to document the different variants seen in the efforts made towards the co-opting and adoption of modern Mexican science, such as in the case of industrial chemistry, seen only in the final years of our study period.

The publication and citation patterns of the scientific literature on typhus disease are the clearest indication of the dividing line of Mexican science during the 20th century, in terms of changes in communication patterns between the amateur and the institutional modes. It is also the first example of the internationalization of a local topic that attains wide impact, carried out by Mexican researchers affiliated to institutions in the area of public health and using resources of their home institutions.

As expected, the academic mode flourished in institutions directly associated with basic research and formal education. The respective research groups enjoyed more freedom in their choice of research topics and were far removed from influences directed towards the industrial, commercial, and health application of results compared to the other three modes. This mode was initiated by the first research groups of physicists with PhDs educated abroad, with experience in publishing in mainstream journals. M. Vallarta created the first successful group of physicists working in cosmic-ray research, which in turn constituted the first research subject that prospered due to its permanence and international visibility. M. Vallarta was a well-known physicist internationally and he used his contacts to promote the training of young Mexican physicists in some of the best universities in the USA.

The findings of the present study suggest that the least productive state of Mexican science is associated with scientific practices adopted during times of greatest social and political instability, within a single production mode, carried out principally in amateur form, isolated from the influence of other scientific practices and aligned with utilitarian objectives, and which experience the most difficulty in matching standards of international scientific publication. The phase of greatest growth, at the end of the period analyzed, is the prime result of changes in local conditions, and the convergence and complement of the amateur, institutional, academic, and industrial modes.

We consider that the historical bibliometric approach used in the present study, made possible by the online availability of mainstream production records from the beginning of the last century, has proved a valuable adjunct in the description of the development of Mexican science from 1900–1950 and particularly for the identification of the mechanisms that were instrumental to the integration of Mexico into international scientific community standards during that period.

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