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Enriching knowledge production patterns of Mexican physics in particles and fields

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Abstract A detailed analysis of the research carried out in Mexico in the physics specialty of particles and fields (MPPF) reveals the way the current production and citation patterns evolved over a period of 60 years. The basis for the analysis were the publications and citations registered in the *Stanford Public Information REtrieval System—High Energy Physics* (*SPIRES*) from 1970 to 2007. The historical coverage afforded by the *Science Citation Index* provided supplementary data from 1948 to 1979. Papers were classified into five research types: theoretical, phenomenological, experimental, cosmological, and other, while citations were identified as coming from: published or unpublished sources. Results show that the development of MPPF emerged from traditional theoretical and phenomenological research and that the most notable changes taking place in production and impact are associated with the community's involvement in more productive and more internationally visible research practices, characteristic of large international collaborations, leaders in experimental physics and in the authorship of review papers.

Keywords Mexican physics · Physics particles and fields · Big science · Scientific communication patterns

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Introduction

Mexican research in the physics area of particles and fields (MPPF) has evolved by diversifying ways of generating knowledge and thus enriching organizational, production and scientific communication structures. This field of research began in Mexico at the end of the first half of the 20th century as an isolated scientific practice. Its first significant achievement was to gain continuity in the production of results, coupled with the institutionalization and professionalization of the discipline in the country. This was accomplished on the basis of theoretical research and to a lesser extent, phenomenological, steadily showing more consistent scientific practice which served as a basis for the formation of new research groups and the development of other types of research within the discipline. The most important changes in the scientific production and impact occurring in the history of the discipline, are related to the opening up of this community and its participation in other types of research, such as experimental and others like gravitation and quantum-cosmology which emerged as the result of an environment more propitious to cross disciplinary influence and fertilization of ideas.

Physics in particles and fields (PPF) is a scientific discipline that attempts to understand the most basic components of the universe. In order to achieve its goal, experimental research in the area requires large scale technology involving huge multinational collaborations. Sometimes, experiments in this field entail the work of more than 1000 physicists from more than 100 collaborating institutions located around the world (Iribarne and Gadille 1999). Although these types of experiments are usually split into smaller subgroups (single detector, single process subgroups), the collaborating physicists are not allocated to individual projects that produce and publish separate experimental results, but rather they publish collaborative papers with a large number of authors. In this sense, the big accelerator laboratories, sometimes called the new horse powers (Lincoln 2004), constitute modern factories for the production and appropriation of new knowledge (Knorr-Cetina 1999). These laboratories have evolved as epistemic centers of elevated (scientific) culture with a rather effective machinery that is a guaranteed source of new social and technological knowledge (Konnigsberg-Levy 2005).

Evolution of the experimental type (EPPF) has been characterized by the continuous scaling of technological developments and increasing levels of energy in the particle accelerators and detectors. However, there is a component in the research practice of the PPF community that has distinguished this field from others in modern science: this community has designed and built, as a part of its scientific practice, the electronic and computational instruments that are used in its communication collaboration models (Ginsparg 2000). In particular, it has been very efficient in handling e-prints as a self-regulating network that distributes and organizes research papers in a speedy and economical way (Cronin 2004). The SPIRES database (Stanford Public Information REtrieval System in High Energy Physics) has become one of the most competitive networks that have transformed the process of producing and distributing new scientific information through electronic files, which, in turn, operates independently of the traditional system of scientific journals (Cronin 2004; Langer 2000; Brown 2004; Russell 2001; Hurd 1996; Harnad 2003; Gentil-Beccot et al. 2009b). Besides the old functions associated with the traditional publishing system of scientific journals, such as legitimacy, reliability and recognition, the new e-print servers provide wider accessibility and visibility to PPF research work. In addition, the SPIRES network provides automatic follow up of citations and a series of bibliometric indicators which are very useful in evaluating research performance: average number of citations per paper, the now famous h index, the rate of self-citations. This model of scientific communication has remained true to its original principle of open access to information, with improvements to its service being made with the development of INSPIRE (http://hep-inspire.net/). For authors such as Aymar (2009), Gentil-Beccot et al. (2009a) the future for this type of communication is to join innovative Open Access initiatives, a case in point is the Sponsoring Consortium for Open Access Publishing in Particle Physics (SCOAP3). This consortium which aims to convert to Open Access the HEP peer-reviewed literature while continuing to administer peer-review of the highest standard from journals which have served the field of decades, may possibly provide a blueprint for the way Open Access could live side-by-side with a continuing presence of the traditional services provided by the prestigious publishing houses. As Gentil-Beccot et al. (2009a) point out, the HEP field is uniquely placed to answer recurrent questions raised by the current trends in scholarly communication and we might add, also to pave the way for more sweeping changes in the way knowledge production in all fields is disseminated, validated and accessed.

In recent years, the MPPF community has been involved in large experimental collaborations using the big accelerator centers, such as CERN, Fermilab and DESY. This practice has modified its publication and citation patterns in such a way that the average numbers of publications and citations are well above those found for Mexican scientists working in other fields. In the present paper, it is assumed that this change (Collazo-Reyes and Luna-Morales 2002; Luna-Morales and Collazo-Reyes 2002; Collazo-Reyes et al. 2004) cannot be explained solely as a natural consequence of the increase in resources and economical support to the PPF area, but rather it is inherent to the evolution of this scientific field: the new e-print culture developed through the SPIRES system has boosted new ways of scientific production from which the Mexican PPF community has benefited. In order to examine this change, we analyze in detail the scientific mainstream production of this community in the period 1948–2007 through two different but complementary bibliographic systems. We take the total production in SPIRES from 1970 to 2007, plus additional papers found in journals in the physics, particle and fields category in the Science Citation Index Expanded (SCIE) from 1948 to 1979. We then look for citations to each of the papers recovered from the two systems. Results show that the MPPF achieved its maximum state of growth as reflected in the bibliometric indicators of production and impact, when it was able to form new research groups, provide continuity in results and create the circumstances necessary to carry out different types of research: theoretical, phenomenological, experimental and cosmology. This upscaling of the discipline to a more productive organizational structure can be interpreted as a general process of enrichment of a research field and above all, as a response directed towards improving the growth dynamics of a saturated mode of knowledge production (Ziman 1994). There is another scientific field in Mexico, astronomy and astrophysics that publishes in a free online repository, the Astrophysics Data System (http://adswww.harvard.edu/). However, as far as we know, its publishing-citation pattern has not been studied in full (Sierra-Flores et al. 2009).

Materials and methods

The basic set of 5,739 published and unpublished Mexican papers in PPF area was recovered by searching under "*find country Mexico*" in the Stanford Public Information REtrieval System—High Energy Physics (SPIRES) corresponding to the period 1970–2007. These were supplemented with a further 120 papers resulting from searches on the names of individual authors taken from an historical catalogue of Mexican scientists (Luna-Morales et al. 2009), in combination with the term "*Mexico not New Mexico*" in the Web of Science's (WoS) Century of Science (Science Citation Index Expanded, SCIE). The 120 records are related to the first papers in the field published between 1948 and 1979, not covered in SPIRES as can be seen in Table 1, all having at least one author affiliated to a Mexican institution.

The 5,739 papers retrieved from SPIRES were classified into three types: (a) 3,278 found to be present also in SCIE, (b) 677 published but not covered in SCIE (c) 1,784 unpublished. Of the 3,278 papers in SCIE, approximately a third (35%) was published in journals classified in the subject category of Physics, Particles and Fields (PPF), according to the Journal Citation Reports (JCR). The remaining 65% also correspond to studies undertaken in PPF but which are linked to other areas of physics and published in journals in other categories of the JCR, mainly General Physics, Astronomy and Astrophysics, and Nuclear Physics. For instance, *Physics Letters B* and *Physical Review Letters*, two of the preferred journals for publication by the MPPF, are in the category of General Physics.

Citations

Table 2 shows the retrieved citations organized in the following way. The 120 papers and the 793 citations found in SCIE, were used to complete the analysis of the period not covered by SPIRES, corresponding to the general history of the discipline and shown in Figs. 1 and 2 of the results.

The 3,278 papers found in both databases received, 33,387 citations from published papers and 21,803 citations from unpublished work in SPIRES and 40,942 citations in SCIE. The 1,784 unpublished papers in SPIRES received 2,894 citations from published sources and 2,185 citations from unpublished sources.

The 677 papers identified in SPIRES published in sources not covered by SCIE, generated 1,315 citations from published sources and 712 from unpublished sources.

Table 1 Papers and citations in SCIE and SPIRES

Paper type	No. of papers[a]	No. citations in SPIRES			No. citations in SCIE From published papers
		From published papers	From unpublished papers[b]	Total SPIRES	
Available in SCIE	120				793
Available in SCIE and SPIRES	3278	33387	21803	55190	40942
Unpublished papers SPIRES	1784	2894	2185	5079	
Published not covered in SCIE	677	1315	712	2027	
Totals	5859	37596	24700	62296	41735

Sources: I. SPIRES-HEP: http://www.slac.stanford.edu/spires/ (retrieved: September, 2008). II. Web of Science: http://apps.isiknowledge.com/ (retrieved: September, 2008)

[a] Papers resulting from search on individual authors

[b] E-prints, conference, papers, conferences, these

Table 2 MPPF: papers, citations and averages in SCIE and SPIRES

Spites/SCIE	Theory	%	Phenomenology	%	Experimental	%	Cosmology	%	Others[a]	%	Total
Papers: 1971–2007	1370	41.8	868	26.5	527	16.1	483	14.7	30	0.9	3278
Citations SCIE											
Citations	11353	27.7	3838	21.7	10328	25.2	4211	10.3	6162	15.1	40942
Average	8.3		10.2		19.6		8.7		205.4		12.5
Citations SPIRES											
Total citations	11323	20.5	11246	20.4	19746	35.8	5265	9.5	7610	13.8	55190
From published papers	8595	25.7	6560	19.6	9950	29.8	3716	11.1	4566	13.7	33387
From unpublished papers	2728	12.5	4686	21.5	9796	44.9	1549	7.1	3044	14	21803
Total average	8.3		13		37.5		10.9		253.7		16.8
From published papers average	6.3		7.6		18.9		7.7		152.2		10.2
From unpublished papers average	2		5.4		18.6		3.2		101.5		6.7

[a] It includes related research to areas of computational, lattice, instrumentation, nuclear physics and review papers

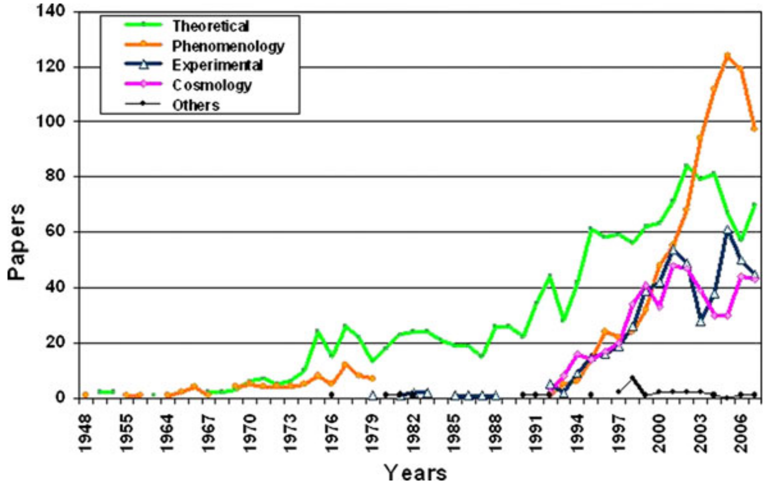

Fig. 1 MPPF: production by research type

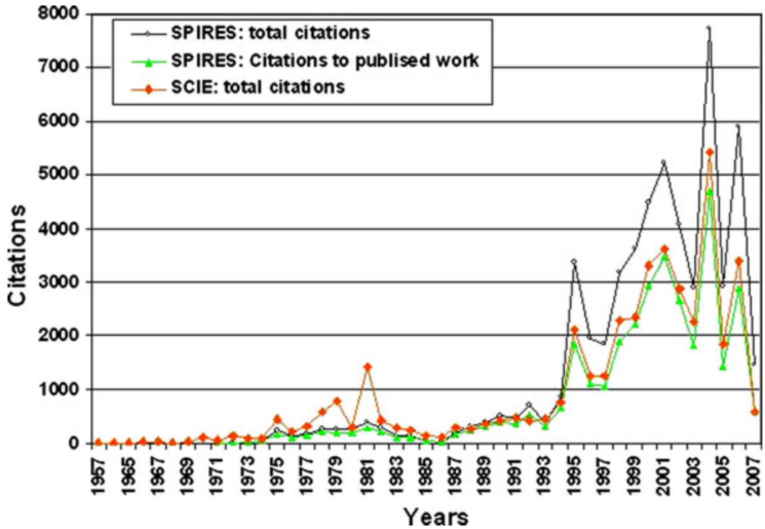

Fig. 2 MPPF: citation comparison SPIRES vs. SCIE

Categorization of papers for the information analysis

In order to identify the determining factors which influenced publication and citation behaviour, the 3,278 papers found in both databases were disaggregated into five distinct types of research taken from the SPIRES classification system: (1) theoretical, (2) phenomenological, (3) experimental, (4) cosmological and (5) other. In addition to the traditional types of research methodologies (theoretical, phenomenological and experimental), we incorporated papers on gravitation and quantum cosmology as new research types due to their influence during the stage of major growth of MPPF. In the category of "other" are included a variety of different types of recent studies and those with only sporadic publication related to areas of computational, lattice, instrumentation, nuclear physics and review papers, but which show important differences in citation patterns. The publications and citations retrieved from the SPIRES database system were classified into three types: (1) published in journals also covered by SCIE, (2) published in sources not covered by SCIE, and (3) unpublished.

This approach allows us to explore all the different combinations possible among the different types of research paper, citations and publications which resulted in the indicators shown in Table 2, in terms of how much they contributed to the production and impact of each type of research and to each of the two database systems.

Results

Scientific production

Figure 1 shows the total MPPF production for the period 1948–2007 classified according to the type of research involved: theoretical, phenomenological, experimental, cosmological, and others. The first MPPF research papers were published in the late 1950s, most of them by single authors. It took almost 20 years to reach steady production.

The first publications involved theoretical and phenomenological studies in the 1970s, but in the 1980s most of the publications were only on theory, with about 20 papers published per year. This pattern changed in the early 1990s with the incorporation of the first experimental high energy physicists to the Centre for Research and Advanced Studies (Cinvestav). The MPPF community diversified production modes when the experimental groups started their involvement in various international collaborations, principally D0, E791, SELEX, FOCUS, ALICE and CMS.

In recent years, MPPF production has stabilized with an impressive growth of the phenomenology papers, reaching a maximum of about 120 papers in 2005 (Fig. 1). As far as the number of citations received by the MPPF papers is concerned (Figs. 2, 3, 4), while the experimental papers got the largest number of citations in the period 1995–2007, the phenomenology and theory production received a steady number of citations. We classified

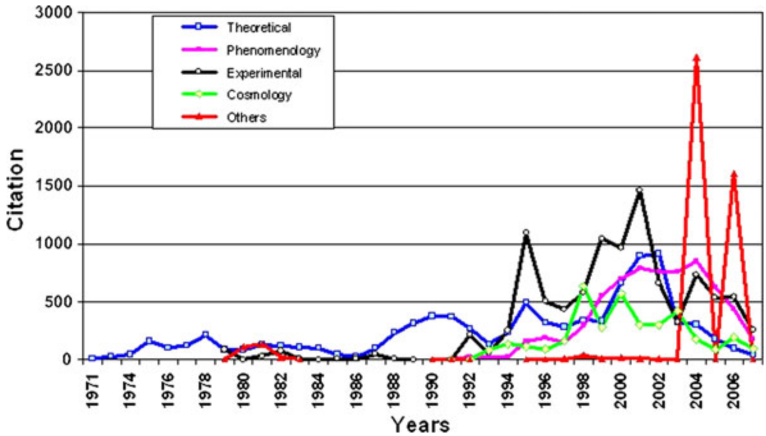

Fig. 3 MPPF: citations in SPIRES by research type

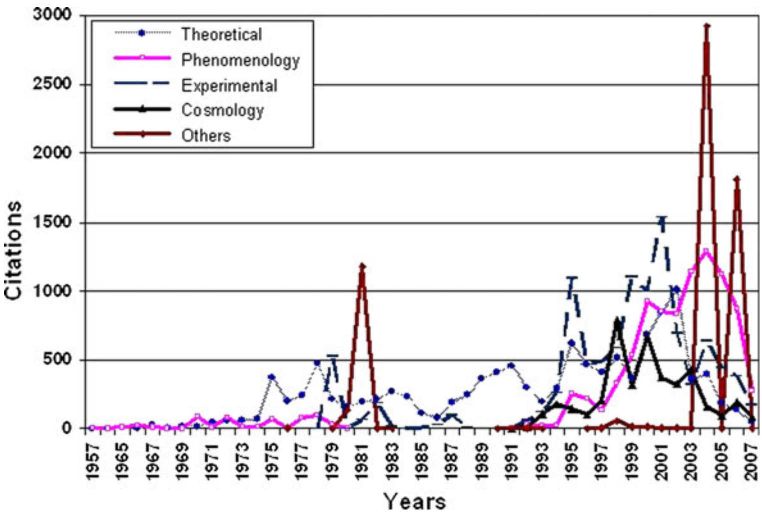

Fig. 4 MPPF: citations in SCIE by research type

in the category of "others", research related to aspects of computational, lattice, instrumentation, nuclear physics, two review papers published in 2004 (Eidelman et al. 2004) and 2006 (Yao et al. 2006) by the Particle Data Group (PDG) which stand apart from the general pattern of MPPF production and which received more than 2500 and 1500 citations, respectively, in a short period of time (Fig. 3). These papers that pull together experimental data and phenomenology results, are updated every two years and constitute a required reference for a large number of PPF papers.

Citation patterns

The first citations received by MPPF papers appeared in 1957 and 1963 but it was not until the late 1960s that the flow of citations to MPPF papers became steady. The evolution of the number of citations to the MPPF production is depicted in Figs. 2, 3, and 4 for the period 1957–2007. We have used both SPIRES and SCIE data in this analysis. The years from 1957 to 1994 are characterized by a rather small number of citations for theory and phenomenology papers. Three papers published in 1975, 1979 and 1981 received a number of citations larger than 100. The first which received more than 100 citations, reports on a specific type of solution to the equations of general relativity (Plebanski 1975). The second acquired more than 500 citations for a study on observational astronomy (Lequeux et al. 1979), and finally, the third received more than 1000 citations for a review on PPF (Brody et al. 1981). These papers constitute isolated events in MPPF production according to both the SCIE and SPIRES files.

With the advent of experimental physicists involved in large international collaborations, both the production and the number of citations increased impressively from 1995 to 2007. In this period the experimental papers dominated the number of citations generated by the MPPF production. In particular, the papers published by the D0 Collaboration in Fermilab that reported the discovery of the top quark (Abachi et al. 1995), are responsible for the large number of citations registered in 1995. The H1 collaboration from DESY also produced an important number of citations in 1999 as did the D0 collaboration which produced eight papers in 2001 that generated over 100 citations each.

Citations by type of research

The 3,278 papers generated 40,942 citations according to SCIE and 55,190 according to SPIRES. Table 2 shows the distribution of these papers and citations by type of research and the respective percentages. We have included both SCIE and SPIRES citations to each type of research. In the latter case we have considered also the citations given in sources not included in the SCIE. The theoretical papers represent the largest share in production but they acquired only 27.7% of the SCIE citations, while the experimental papers represent only 16.1% of total production but received 25.2% of the SCIE citations. On the other hand, "other" papers generated 15.1% of the SCIE citations with just 0.9% of the production. This pattern reproduces in other areas of Mexican science, where several review papers have generated over 100 SCIE citations each. With the sole exception of the theoretical papers, publications received more citations in SPIRES than in SCIE.

Discussion and conclusions

Results from both databases show a marked shift in both publication and citation behaviour at the halfway point of our study, indicating a clear division between two evolutionary states which developed under distinct knowledge production structures. The stabilization of the production in the first stage had to do with the conditions surrounding the saturation of the traditional mode of knowledge production in the decades of the 1960s, 1970s and 1980s, linked to the scientific practice of employing only one type of production mode characterized by institutions, academic profiles, financing, professional training, research interests and teaching programmes, all operating within a theoretical and phenomenological research culture. In addition, this research environment isolated itself from the influence of other types of approaches present in its own scientific area, such as the experimental approach and others related to gravitation, quantum cosmology and instrumentation.

The second stage shows a contrasting state of growth with respect to the first, is witness to a long period of expansion of the organizational, subject and cognitive boundaries of the scientific practice of the first period. The MPPF found in this diversification process of its knowledge production modes, the components necessary to free itself from the limited circumstances that surrounded a stationary production state (Ziman 1994). These new circumstances enriched the organizational structure of institutions, research programmes, training profiles, topics and research approaches which, according to the results, constituted a more productive and receptive organizational environment functioning internally and externally in harmony with international scientific practices and the dual modality of publication-citation characteristic of the scientific communication model of the area. Within this environment, the rapid adoption of the e-print represents the assimilation by the MPPF, of a set of rules and procedures (Luna-Morales and Russell 2009) for the incorporation of pre-publication, pre-citation and pre-peer review into its local patterns of scientific communication, as the preferred form of disseminating research results.

This shift in the production and citation patterns seen at the beginning of the 1980s, coincides with an increase in resources, implemented via a noteworthy decentralization process of research and teaching programmes in favour of the universities and research centres in the interior of the country. This initially served to supplement and strengthen theoretical and phenomenological research groups and topics within the National Autonomous University of Mexico (UNAM), the Centre for Research and Advanced Studies (Cinvestav) and National Polytechnic Institute (IPN). Secondly, it led to the formation of the first experimental physicists and later, to the incorporation of attendant research interests. These circumstances opened it up to influences between the different subject areas (Collazo-Reyes 2002) and to cross-topic research (Kostoff and Del Río 2001), giving rise to more productive cognitive and organizational structures.

These determinants help to understand the evolution undergone by theoretical and phenomenological research; nonetheless, the growth of experimental research and the citations associated with review papers have other components. The difficulties of developing experimental research using only the resources routinely allocated to local groups, led Mexican physicists to seek out partners and to establish international alliances (Subotzky 2005). This resolve has allowed them access to one of the most powerful contemporary apparatus for knowledge production, expanding their cognitive learning boundaries, and knowledge appropriation and production. A strategy known as the internationalization of the benefits of scientific work (Autio et al. 2003; Wagner 2004) has proven to be an effective learning mechanism to gain access to new areas of scientific practice and to environments favourable to the acquisition of knowledge and to the expansion of scientific and technological capabilities (Casas et al. 2000; Wagner 2004). The incorporation of elite, multi-institutional groups (Jones et al. 2008) into experimental physics and the event of review papers such as those published by the Particle Data Group (PDG) involves interaction between highly prestigious researchers, access to experimental equipment, more productive organizational structures and greater international visibility, all these factors decisive in the process of the consolidation in the growth of papers and citations from the 1990s onwards. This situation has allowed the introduction of scientific practices into the MPPF as new modalities in the organization of more productive and internationally more highly visible scientific work, circumstances that are modifying the organizational structures of production, citation and scientific collaboration of the physical sciences in Mexico, as reflected in the historic period of greatest growth of Mexican science from 1994 onwards.

On the one side, the average of 14.8 citations reported by Lehmann et al. (2003) for this area, is intermediate between the general averages of 12.5 and 16.8 found in our study for SCIE and SPIRES, respectively. On the other, the difference of 14,248 citations obtained by the same papers covered in SPIRES and SCIE, represent 25.8% more citations for the first with respect to the second. This can be related to data reported by Gentil-Beccot et al. (2009a) who estimated that 20% of citations from articles in PPF during a two-year period occur before publication in peer-reviewed journals. These similarities indicate just how far the local scientific community has gone towards adopting the publication and communication practices of their international colleagues.

In the national environment, the collaborative practices of the new generation of Mexican experimental physicists during the different stages that conform the life cycle of experimental research projects (data collection, information analysis, publication of results, software development, design and construction of detectors, renovation of deteriorated and outdated research material artifacts) have permitted them to assimilate the identity and fundamentals of the international PPF epistemic culture (Knorr-Cetina 1999). In this way, the Mexican scientists reaffirm the set of values and beliefs intrinsic to the internal dynamics of this culture which has permitted them to recreate themselves, with every new scaling up of scientific-technological machinery, on the basis of their own resources, intellectual capacity and accumulated knowledge and experience. These same dynamics have enabled the Mexican experimental physicists to construct their own accelerators (Herrera-Corral 2005) thus allowing them to replicate the basic principles and values of the epistemic culture which creates and certifies knowledge from local or regional settings. An example of this is the design and construction of synchrotron light accelerators for multidisciplinary research, as has happened in several countries with similar characteristics to Mexico, such as the world class National Synchrotron Light Laboratory in Brazil (Brum and Meneghini 2002).

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