



What responds research in the field of nanoscience and nanotechnology in Mexico?

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1. Introduction

With the emergence of nanoscience and nanotechnology, significant changes in research and technological innovation are occurring. In 2014, it is anticipated that the market for products made from nanotechnology will reach 2.6 trillion dollars (Lux Research, 2006) wherein a significant percentage owes to the micro-electronic products which are themselves the main application area of nanoscience and nanotechnology (NST).

In developed countries like France, major programs, in which technology transfer have an important role, have been launched (Robinson *et al.*, 2007). Nevertheless, the increase in the NST is not exclusive to developed countries alone, we observe that some developing countries are also participating in the race for development of these new sciences and technologies. China, for example, has a very strong growth in scientific research in this field (Guan & Ma, 2007) while in several other countries, Brazil, for example, national policies promote the development of the NST. Mexico, as an emerging country, has as yet neither any national program in this area nor does it have any industrial area of microelectronics likely to invest in the NST. However, as a starting point, research projects have already been carried out (Foladori & Zayago, 2007). With the arrival of these new sciences and technologies, important changes are expected in the economic and social sphere, as well as in scientific practices.

Studies of the dynamics of Sciences revealed that in developing countries scientific programs are set from external contexts, without necessarily responding to local needs (Kreimer, 2006). In Mexico, studies on the relationship between the private and public sector around the field of R&D, from a regional perspective (Casas, 2001) and social networks perspective (Luna, 2003), have analyzed the role of the government, academy and industry in the formation of networks of knowledge. On the other hand, a preliminary study on nanoscience in Mexico has shown us that the formation of collaborative networks is part of the strategies, of Mexican researchers in the field of the NST, for overcoming the lack of infrastructure. From this observation, this paper tries to answer the question “What responds research in the field of nanoscience and nanotechnology in Mexico?”. We propose four hypotheses to address this question: 1) The research themes are built in conjunction with Mexican industry, 2) These themes are defined from the concerns of international collaborative networks, 3) The research in the NST is the result of local political scientists’

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and entrepreneurs' institutional initiatives, and 4) The research in the NST is in response to the wave of the NST.

In this analysis, we will explore the four cases mentioned. For this, we will cite several examples of Mexican entities specializing in research on the NST, mainly in the field of advanced materials. To identify the centres and laboratories studied, we conducted an exploration of websites of major Mexican universities, our choice is therefore based on visible entities. The final list consists of four public research centres (INAOE, CINVESTAV, CIMAV, IPICYT) and four public universities (UNAM, IPN, BUAP, UANL).

The objective of the text is not to measure the importance of thematic the NST research with respect to the disciplines of origin but to reflect some out-standing elements (originally developed themes, for example) in order to understand the orientation of research in the field of the NST in Mexico.

The methodology of this study is based mainly on a series of interviews with researchers, students and technical and administrative staff of research entities visited. A total of 40 semidirective interviews were conducted based on a list of questions (an interview guide) on four axes: a) the functioning and structure of technology platforms, b) scientific collaboration, c) the rules of access and use of these platforms and, d) the dynamic themes and research activities. On the other hand, to represent the dynamics of research in the NST Mexico (cf. 2), we carried out a count of scientific papers published in this field (Kostoff *et al.*, 2007), between 1995-2007³. To complement our research, we also relied on the review and analysis of secondary sources: reports of activities of entities visited, websites of research centers, calls of projects, and statistical data on production scientist. Finally, this survey has enabled us to build case studies that will be used to test our hypotheses.

This study is a part of a project oriented toward understanding the dynamics of work being carried out in the field of the NST in Mexico.

First, we present a brief update on the progress of the NST in Mexico to make visible the context of this area in this country and the place of the entities studied in this context. Then, we present the results of our investigation, in which we explore several case studies to test our hypotheses. In the end, we present the conclusions of this research.

2. The context of the NST in Mexico and our case study

In Mexico several research centers, institutes, and university laboratories are developing research projects that correspond with the field of the NST. The collaboration with other national and international institutions is a characteristic of most of these research groups working in this field. During our investigation, we found the existence of at least four networks (formal and informal) which work around the NST: a) the International Center for Nanotechnology and Advanced Materials (ICNAM), b) the Network of Research Groups in Nanosciences and Nanotechnologies (REGINA-UNAM), c) the International Network of Nanoscience and Nanotechnology (REDINN, which is apparently going through restructuring) and, d) the network of laboratories of research and innovation working on Microelectronic and Mechanical Systems (MEMS, an initiative of the U.S.-Mexico Foundation for Science).

³ The data are obtained by consulting the *WoS* using the research equation proposed by Glänzel et al. (2003) which is constituted by the prefix "nano", as well as keywords to exclude documents that are not considered in the NST (i.e., "NANOGRAM") and other keywords to include texts that do not use the prefix "nano" (i.e. "MOLECULAR BEAM EPITAXY"). To focus our research on Mexico, we added to the initial equation the word "MEXICO" in the field "COUNTRY" (CU) of the *WoS*.

The training of human resources is another aspect of the development of the NST. At least fifteen Mexican entities (universities and research centers) offer programmes of studies at the doctoral level in the NST (Mendoza-Uribe & Rodríguez-López, 2007).

Concerning the National Policy on Science and Technology, the Special Program of Science and Technology 2001-2006 (PECyT) considers the NST field as a "strategic knowledge" (PECyT, 2002). It identifies ten scientific and technological areas that develop knowledge considered as parts of the world of the NST: catalyses, polymers, nanostructured materials, thin films, to mention only the first four. Despite the existence of a National Programme, the initiatives for the development of the NST, in terms of economic resources, are not significant enough to achieve the planned objectives⁴.

As we have already mentioned, to represent the dynamics of scientific production in the NST in Mexico, we counted the scientific articles published between 1995 and 2007⁵, in which we observed the growth of research activities in the NST in Mexico. Figure 1 below shows the trend. The periods of increase owe to, as we shall see later, the initiatives encouraged by different actors. We can see a constant growth (except in 2001 when there was a fall of 5 articles over the previous year), however, in comparison with China (Guan et Ma, 2007) and South Korea (Kostoff *et al.*, 2007, and 2008), countries included in the list of emerging economies like Mexico, this growth is relatively smaller. Moreover, in terms of public investment for R & D in the NST, according to estimates by the European Commission for 2004, Mexico occupies the 24th place (European Commission, 2005).

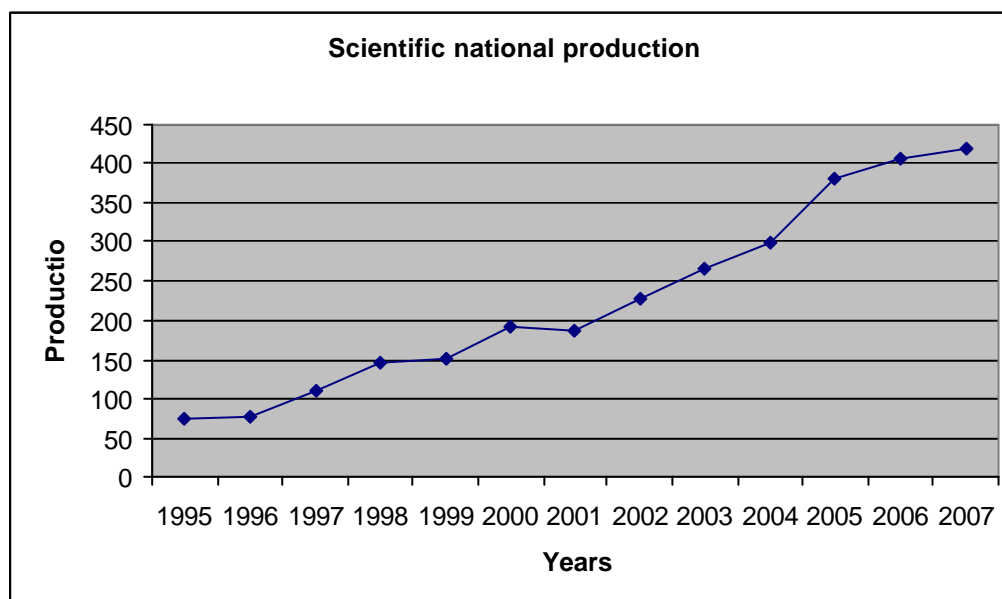


Figure 1: national scientific production

The scientific production of entities that we visited represents 61% of the national total, which corresponds to 1801 out of 2944 articles published between 1995 and 2007 in the domain of the NST. The share of each entity appears in Figure 2 showing that UNAM is the entity most productive. In terms of international colaborations, the countries with which

⁴ For a more detailed study of the status of the NST in Mexico, see Foladori & Zayago (2007) and Mendoza-Uribe & Rodríguez-López (2007).

⁵ See notice 1.

Mexico has the highest number of collaborative projects is the USA, followed by Germany, France being the third in line, while Japan fills the fourth place (Guan et Ma, 2007).

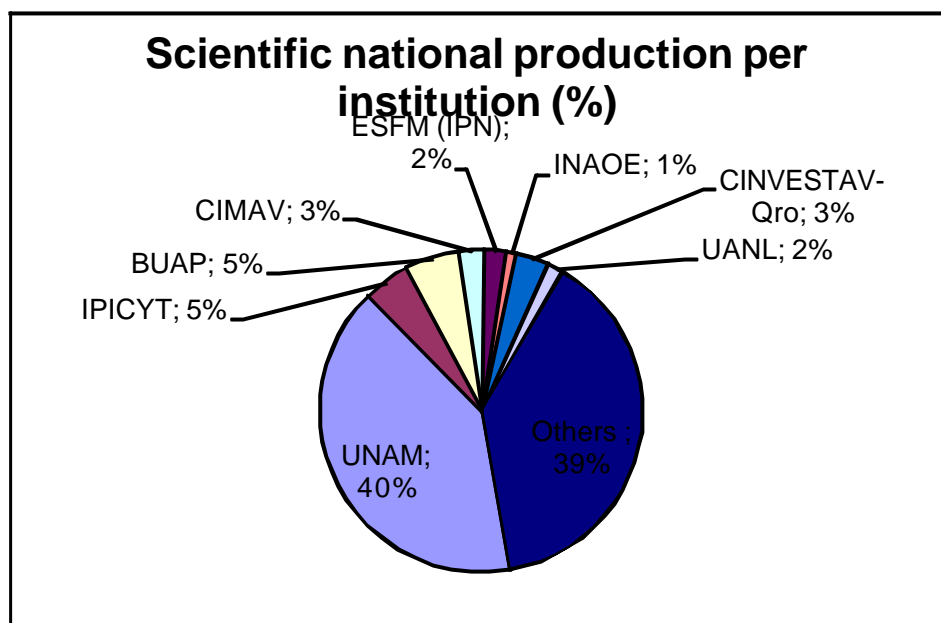


Figure 2: Domestic production for each entity studied.

Figure 3 shows the first ten disciplines in which Mexican researchers published more frequently their NST research. The discipline “Materials Science” is the most important (16.88% of total published articles)⁶, following are the disciplines “Chemical, Physical” (15.65%), and “Physics, Condensed Matter”, “Physics, Multidisciplinary”, “Chemistry, Multidisciplinary”, “Physics, Applied” and “Chemistry, Inorganic & Nuclear” with more than 100 articles each: 7.81%, 5.84%, 5.57%, 5.43 % and 3.46% respectively.

⁶ The discipline “Materials Science” is divided into ceramics, biomaterials, characterization and testing, coatings & films, composites and paper and wood.

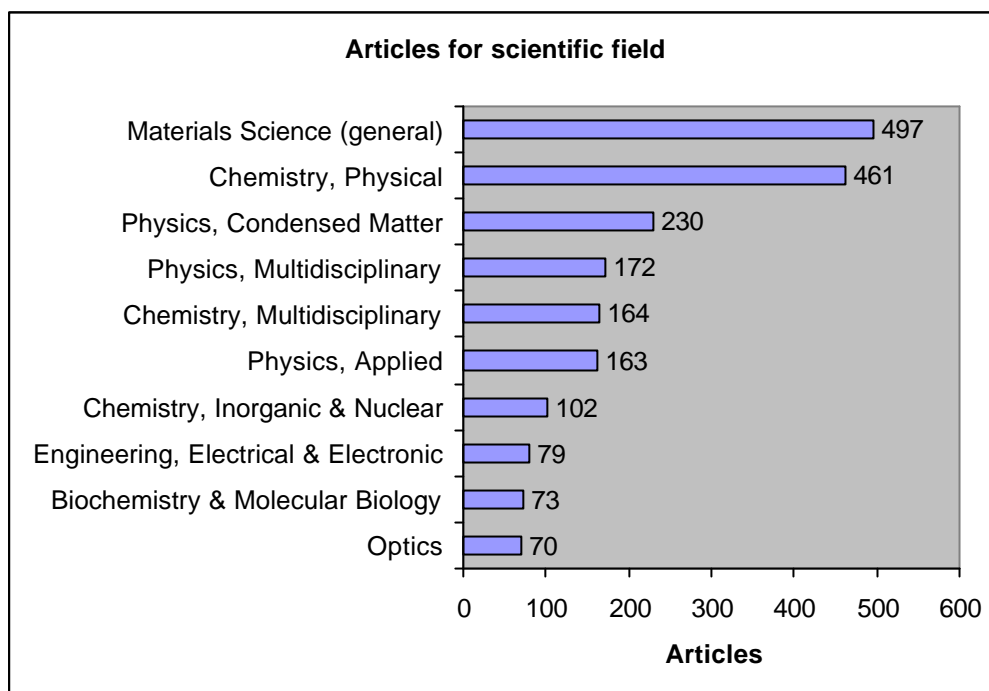


Figure 3 : Distribution of articles by scientific field (tops 10 fields)

It is in this context that we find the eight entities that we visited during our investigation. Geographically, four of these entities are located in central Mexico whose laboratories of the UNAM (the Institute of Physics, the Faculty of Chemistry and the Institute of Materials Research) and the Ecole Superior de Physique Mathématique of the Polytechnic Institute National (ESFM) are in Mexico City, the National Institute of Astrophysics, Optics and Electronics (INAOE) and the Autonomous University of Puebla (BUAP) are in the state of Puebla. The Research and Advanced Studies Centre campus Querétaro (CINVESTAV-Qro) and The Institut for Scientific and Technological Research of San Luis Potosi (IPICYT) are situated in the region of the “Bajío”. And to north of the country, the Centre for Research on Advanced Materials (CIMAV), in the State of Chihuahua, and the Autonomous University of Nuevo Leon (UANL), in the city of Monterrey, are located, both near the border with the USA.

At last, it is important to note that a characteristic shared by entities in our study is the fact that everyone (except INAOE) conducts research in the field of advanced materials.

3. Results

We will now test our four initial hypotheses to see if these answers can explain the dynamics of thematic research developed in Mexico.

3.1 The relationships with the industry

The interest of industry to collaborate with academia lies primarily in solving punctual technological problems. These relationships can be based on two kinds of activities: the use of scientific equipment to conduct tests or measures intended to control quality, and the realization of research projects in the broadest sense. This is the latter type of relation we want to analyze, because we believe that a research project corresponds to a thematic research, which is co-defined between a group of research and industry.

Several papers published about the development of the NST in Mexico, as well as reports on activities in this field, have already reported the interest of national and international companies in research in the NST (Mendoza-Uribe et Rodríguez-López, 2007, PECyT, 2002). For example, the firm "Industrias Peñoles" has an R&D centre that conducts research on nanoparticles of silver (Ag), in collaboration with several public research centers. Another indicator shows the interest of the industry on the NST in Mexico: the participation of ten companies in "the consortium for nanotechnology projects" which is an initiative created in 2004, with the support of CONACYT, in which are also involved several Mexican research centres and the University of Texas in Austin and El Paso (CIMAV, 2005). Another example of industrial participation in the development of the NST is the program *Latinchip* by company Motorola, which has contributed to the construction of the National Laboratory for Nanoelectronics that is currently under construction in the INAOE. Despite the industry's interest in the NST in Mexico, cases of academy - industry rapprochement leading research and innovation are still very few: in the three public research centers of CONACYT that we analyzed, only 35 projects out of a total of 122 are implemented in partnership with industry in 2006⁷.

During our investigation, we found that research projects in the NST industry are rarely developed in research centres in Mexico. The actors in the research, interviewed during our investigations, are hardly likely to be involved in projects carried out in collaboration with industry. About academy - industry rapprochement, one of the researchers interviewed told us: "*in Mexico we have not a culture of working with the industry*". It was supported by an interviewee in another research centre saying: "*Academy - industry relations in Mexico were set aside*".

In addition, academic works about academy - industry relations in Mexico have shown that the centres and universities that are the most dynamic in terms of near relationships with industry are located in the north of the country (Casas et Luna, 2001). We find the same panorama in the case of the NST. Indeed, it is in the northern region of Mexico that are two research centers engaged in the largest number of research projects in partnership with industry. The other area where research projects with industry are frequent, but to a lesser extent, is the "Bajío" (Querétaro and San Luis Potosi). In central Mexico, the centres visited (except the INAOE) rarely have research projects in the field of the NST with industry.

Also, to reflect the involvement of industry at the definition of research projects in the NST, we will focus on the case of CIMAV, a public research of CONACYT known for its relations with industry (in 2006, 51 research projects in partnership with industry were being developed, of which 31 were related to the NST⁸). It is, furthermore, an entity which has an important productivity of patents in the field of advanced materials.

We noticed that various projects have been carried out in collaboration with industry. The origin of these projects is asymmetrical: some come up at the academy⁹ and, later, raise the interest and support from industry, while others come directly from industry needs. In the latter case, the industry visits the research centres to find a solution to a technological problem timely, thus giving origin to a research project funded for the industry (in some cases, funding for the project is done with the participation CONACYT). We will now briefly describe two cases to illustrate how collaborative projects initiate with industry that we have just mentioned.

⁷ The information was obtained from reports of activities of these research centers: www.conacyt.mx

⁸ *ibidem*.

⁹ We mean by "academic" any production that comes to the concerns of researchers and not the needs of industry.

The first case involves a device for producing carbon nanotubes (CNT) on a large scale. Actually, the manufacturing (or synthesis) of CNT is well known at the CIMAV, as well as in many other laboratories of advanced materials (nowadays, it is difficult to design an advanced materials laboratory that has not experienced the manufacture of CNT). One of the actors interviewed says that the idea was born because they have realized in the academic literature that, with the equipment available at their center, they could make CNT: so, they decided to embark on the manufacturing to be self-sufficient in the availability of CNT, increasingly demanded by researchers and which represents a considerable expense. The first device designed in the laboratory allowed a daily production of slightly more than 3 grams of CNT. This quantity is sufficient for the needs of the centre, but one day the director of the center commissioned scientists to improve the manufacturing method because a company had expressed its need for large quantities of CNT to test in its production site. Researchers worked, and with economic aid of CONACYT and the Government of the State of Chihuahua and with the association of a center for engineering and innovation, they managed to design a device that allowed fivefold production of CNTs, thus providing the required amount and awakening the interest of a company determined to invest capital. As we write these lines, in the new laboratory of CIMAV in Monterrey, a third device is being installed. It will serve as a pilot site where transfer of this technology to company is being negotiated.

Our second case arose from a need for the local mining industry: it is to develop an expansive product, a chemical powder, which is used for demolition. In the form of a mixture it is poured into holes drilled previously in rocks and after a few hours, the product spreads and fractures rocks (or concrete). This avoids the use of explosives. The company proposed this idea to scientists who accepted it. This company brought in financing, CIMAV was involved for its knowledge in chemistry materials, and the project was lead by a researcher who works in the line of catalytic nanostructured materials. The project objective was to formulate the expansive agent using local materials. To achieve this, not only materials were synthesized and characterized for the product, but also measurement tools and knowledge for testing mechanical expansive agent were developed.

These two examples of projects developed in the CIMAV are based on two distinct forms of technological production: one is part of a need for basic science and the other depends on the needs of local industry. The budget provided by industry, in most cases, is devoted to the acquisition of scientific instruments, purchase of raw materials (pure minerals, for example) and to cover travel expenses of participants (actors involved are not in the same region). Finally, these relationships with industry are important (or strategic) for research centres as CIMAV, insofar as they can ensure not only the transfer of knowledge, but also the availability of resources for activities for the “scientific credibility” (Latour et Wollgar, 1996), acquisition instruments, procurement of pure materials, finance travel, presentation of work in workshops and conferences, writing articles, among others.

Finally, a limit on the hypothesis of the definition of research thematics with industry is that this hypothesis is based almost exclusively on a case study, the CIMAV. Indeed, technological production in Mexico in the NST is asymmetrical: on the one hand we have a research centre with a rate of sizable technological production and on the other hand we have research centers that have a very limited technological production.

3.2 The networks of scientific collaboration

The multidisciplinary is a remarkable characteristic of the NST. The studies of matter at the nanoscale require the involvement of scientists from various disciplines: for example, in laboratories where nanocomposites are being synthesized and characterized, it is common to

see physicists, chemists and materials engineers all of whom work together. The research groups in the NST are increasingly heterogeneous. Today, the creation of networks of scientific collaboration is part of the research strategies of researchers and research centres, as well as of research policies in this field.

This form of network organization in Mexico is not new. Santos et de Gortari (2003) have studied the formation of networks of collaboration in the field of materials, discipline closely linked to the NST. The first network of scientific collaboration in the NST in Mexico is REGINA of the UNAM, founded in 2003. Later, international networks have emerged, the ICNAM in 2004, the REDINN in 2005 and the NanoforumEULA in 2007.

On the other hand, in the field of the NST, the question of scientific instruments is central, since the study of phenomena of matter at the nanoscale, as well as the synthesis and characterization of new nanostructured materials, require powerful microscopes and other instruments which are not only important but also very expensive (equipment X-ray diffraction and RAMAN, for example). In the case of Mexico, researchers have not an easy access to these instruments. Thus a solution for researchers was to integrate into networks of scientific collaboration (Robles, 2008). The networks most attractive are those that include developed countries, because it is in research centres in these countries that the presence of these instruments is most common.

Kreimer (2006) characterizes the integration of Latin American researchers on "the international scene" as "subordinate", insofar as the choice of research fields and the vision of all the problems along with their real or potential benefits are concerned, with a heavy dependence on the reference centres, located in more developed countries". It is in this context that we wanted to check how far relations with the international community have an impact on research topics of Mexican researchers.

To tackle our second hypothesis, we focus on the network of the ICNAM because this is an initiative in which all the entities that we study have participated.

The ICNAM is an initiative created in late 2004 with the main objective of promotion of scientific collaboration between UT Austin and major research centers and universities of Mexico (UT-Mx). It is an initiative coming from UT Austin and the Mexican Government (i.e. CONACYT) with the participation of CIMAV. To achieve its objectives, each party participates equally in financial terms for research projects. The conditions for obtaining this funding is that projects must be submitted by at least one researcher on each side of the border, and that resources allocated should be used to cover the costs of travel and use of scientific instruments. The centres or Mexican research institutes who have participated in the initiative of the ICNAM are: IMP, CIQA, ITESM, UANL, CCMC-UNAM, CINVESTAV-Qro, CICY, CIO, IPN, UASLP, IPICYT, CIMAV, CIE-UNAM, UMSNH et UDLA.

Within the framework of the ICNAM, 59 projects were funded between 2005 and 2007¹⁰. Analyzing of the titles and objectives of projects, we have four different types of projects. In Table 1, it shows the number of each type of project per year. The most frequent type of projects (25 projects) corresponds to the use of scientific equipment to characterize or study the properties of materials, and these activities are often developed by PhD students.

The projects that involve "scientific activities" (24 projects) are as important as precedents. These are not limited to the use of scientific equipment, but include visits for the advancement in research being conducted within medium to long term research projects. The two other types of projects are less frequent. They involve either academic activities such as

¹⁰ Source : <http://www.engr.utexas.edu/icnam/>

meetings, courses, symposia, etc or activities of promotion of scientific collaboration (laboratories presentations, groups and fields of research). From the above discussion, we may conclude that the use of instruments has a considerable significance.

Type de projet	2005	2006	2007	Whole
Use of instruments	7	9	9	25
Scientific activities	7	5	12	24
Meetings, courses...	1	2	0	3
Activities of promotion	5	1	1	7
Whole of activities	20	17	22	59

Table 1 : Projects of the ICNAM.

In addition, in the presentation of the ICNAM, available on their website, we see that the ICNAM gives quite an importance to its aspect regarding the access to the instruments by saying “it provides the possibility to use world class research equipment at UT and at Latin American institutions”. It is clear that the mobility of researchers from South to North is much larger than the reverse.

To check the impact of these relations on the Mexican research, we developed the graphic 4, which shows the dynamic collaborations UT-Mx during the period between 2000 and 2007. In the curve, we can see two important periods of growth. The first increase occurred after the arrival of a renowned Mexican researcher, in physics and microscopy, in the Department of Chemical Engineering at the University of Texas at Austin in 2001. He is a key actor in the ICNAM because he participated in the creation of this network and is director of the ICNAM. The part of the curve that we are particularly interested lies in 2005, when research projects started under the ICNAM. In 2007, the important increase observed is due to the collaboration initiated two years earlier with the creation of the ICNAM.

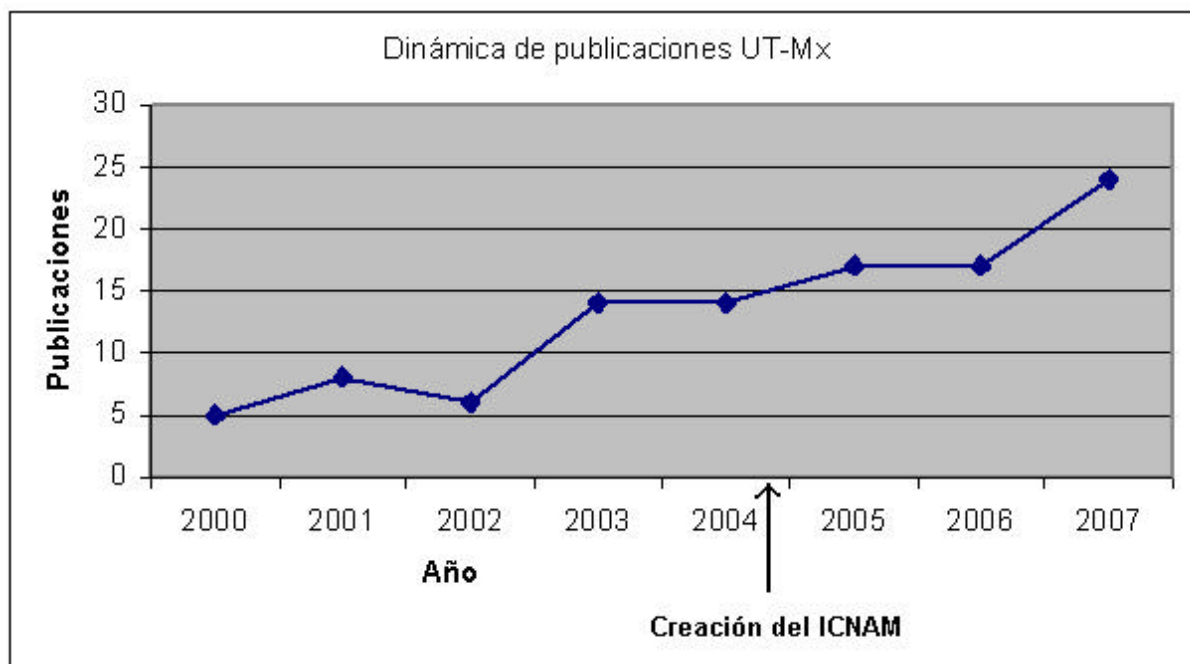


Figure 4. Dynamics of articles published by network UT-Mx.

Furthermore, if we look at the authors of articles published by entities of the network UT-Mx between 2006 and 2007¹¹, we see that in the 70.73% of articles (29 out of 41 documents), researchers from the UT appear as the last signatory of the articles. Based on this observation and the fact that the last to sign the articles are generally scientists that facilitate access to instruments, we can conclude that the majority of UT-Mx relations is mainly around the question of access to instruments and not necessarily thematic research. However, it is important to underline the fact that many of these relations are recent and that they can be starting points for future relations that can develop new fields of research.

Finally, the case of the ICNAM does not correspond to our hypothesis on the construction of thematic research from inserting the international research networks, because this network is based principally on the question of access to instruments. In addition, here it is important to emphasize on the fact that Mexico currently does not maintain much of the formal networks of this type with other countries (the other two networks have been identified are REDINN and NanoforumEULA, that have just been created).

3.3 The role of institutions

In this section, we analyze the role of institutional actors in the development of the NST in Mexico: Mexican Political science and technology, entrepreneurs and scientists and institutions. Firstly, we will explore how the NST has gained recognition as a strategic area in the National Development Plan of Mexico. Then we will analyze initiatives of the CONACYT and entities that we visited.

The NST in the national policy on science and technology

To our knowledge, the first proposal of a national initiative for the NST took shape in 2002 in a document entitled "National Programme of Nanoscience and Nanotechnology to Develop New Technology Bases" (IPICYT, 2002). This document was the result of the "Second Meeting of Nanoscience and Nanotechnologies: Towards a National Programme ", during which a group of 31 researchers from national and international institutions met at the ICIPYT. In the aim formulated in this document, the foundations of the programme can be seen.

“Establish a National Program for Nanoscience and Nanotechnology, which supports and convenes the groups that already conduct research in this field, and which also promotes the formation of new groups and human resources, so that through joint and articulated efforts, through multidisciplinary projects, both basic research as products and processes may be developed, which culminates in new technologies to contribute to the solutions of national problems in areas such as energy, medicine, communications, agriculture, education and so on.” (Objectif the proposition of «Programme National des Nanosciences and Nanotechnologies »)

In this document, the scientific actors, in view of the promises of the NST, emphasize the importance that “the Government of Mexico supports the Nanotechnology through projects in the short, medium and long term”. The proposal suggests investing in “infrastructure, human resources and groups of basic research and technology” so that Mexico should not be too late in the race for development of the NST. In addition, the proposal identifies studies of catalytic materials as a niche opportunity for Mexican research.

¹¹ This period was chosen taking into account the fact that the first research projects under the ICNAM were driven in 2005 and that, consequently, the results of these collaborations have not been published before 2006.

The Mexican Academy of Sciences also considers the NST as a priority. It proposes to “promote the creation and participation in international research laboratories, on regional or global topics of interest or the projects which require large investments (e.g. Genomic sciences, nanotechnology)” (Paredes, 2006). In addition, the Fund of Science and Technology for Economic Development considered in 2005, nanotechnology as a field of knowledge priority (FCCyT, 2006). Finally, the demands made to the state so that the NST should be deemed as priority had an impact in the Special Program of Science and Technology 2001-2006 (PECyT), where we consider advanced materials, biotechnology and genomics as strategic areas of knowledge. This means that the State of Mexico has integrated the NST in its national policy on science and technology.

However, we have already mentioned, the actions of the Mexican state carried out until now do not appear sufficient to consolidate a genuine development initiative of the NST (Foladori et Zayago, 2007, et Delgado, 2007). Indeed, as we shall see later, in Mexico there are important initiatives aimed at improving the infrastructure for the NST, but the budget earmarked for it is not sufficient enough to cover the needs of research in this field.

CONACYT initiatives in the development of the NST

Funding for most of the initiatives of the NST executed in Mexico come from the government through CONACYT which is the institution in charge of distribution and control of resources allocated. It launches calls for the financing of research projects. In considering projects in 2006¹² in two research centres (CIMAV et IPICYT), we observed that in the case of CIMAV the financing (total or partial) of 17 of 24 projects identified in the field of the NST comes from CONACYT. In the case of IPICYT, all projects (20) were funded (totally or partially) by CONACYT. The funds obtained for these projects are mainly used to cover expenses for travel by researchers and / or their students, for the acquisition of equipment, inputs for experiments and scientific instruments priced relatively low. The way to manage these resources is heterogeneous and depends on the internal policies of each research center. When CONACYT provides partial funding, the other part comes from regional governments (in the case of Mixed Fund), industry (for the case of consortium) or foreign governments (in the framework of bilateral cooperation programmes that Mexico has signed with other countries).

In 2006, CONACYT launched a call for supporting the construction of “National Scientific Laboratories or Technological Development Infrastructure”, addressing to the Institutions of Higher Education and / or research centres in four areas, including nanotechnology. This tender was an initiative that was part of PECYT.

It is an initiative designed to respond to the demand of technological infrastructure and whose ceiling is set at 20 million of pesos (about 1.17 million euros) for each project accepted. However, to be eligible for this funding, the interested research centre must first arrange on its own at least the same amount demanded from CONACYT. This condition poses a big hurdle for the interested research centres.

The rules for operating expenditures of scientific equipment are set in advance:

“The costs related for the operation and maintenance of equipment will be paid by the institutions and may be covered with profits from services offered. Maximum 5% amount of the budget assigned by CONACYT will be used for the following expenditures:

¹² Source : http://www.conacyt.mx/Centros/Centros_Publicaciones.html

- Training of specialized technical personnel
- Maintenance
- Accommodations of research participants
- Visiting research fellows' stay
- Specialized subcontracting services for 3 foreigners
- Specialized subcontracting services for 3 Mexicans
- Specialized software (Point III 2 of call)

This means that recipient centres must assign a share of their resources for running costs of new equipment installed, which is not new for them. The solution to generate such resources is to open labs to companies. In this case, it is logical but important to remember that the time devoted to companies is time not devoted to research. However, the decision to offer or not this type of service is up to the concerned research centre. There is a boost from institutions, but its effects are limited because of certain procedures in place.

The results of the call, however, have been favourable for two projects in the field of the NST: the first was the National Nanotechnology Laboratory of CIMAV (the budget for this laboratory is 30 million pesos, consisting of 20 from CONACYT and 10 from the Government of the State of Chihuahua). The second project accepted came from the IPICYT. It was the construction of the "Research Laboratory in Nanoscience and Nanotechnology" (LINAN) for which the budget was 40 million pesos, in which the CONACYT provided 50% and the rest of 50% was provided by the Government of the State of San Luis Potosi.

On the other hand, in 2006, CONACYT launched another call for mega-projects of scientific or technological research. This initiative was far more ambitious than the first because it was funding up to one billion pesos.

The project selection process was supposed to take place in three phases. Given the magnitude of the budget, competition was strong: 81 proposals passed the first phase, including 5 projects in the field of the NST ("National Laboratory of Nanoelectronics", of the INAOE, "Development of nanoscience and nanotechnology in Mexico as a catalyst to encourage science and industry with a significant impact on society" of the IPICYT, "National Nanotechnology Initiative" (NANOMEX), of the CIMAV, "National Nanotechnology Initiative", of the UNAM, "Plataforme full research and technological development for the pharmaceutical industry Mexican using instruments of bio-technology, nanotechnology and pharmaceutical engineering", of the ITESM).

This call aroused unprecedented enthusiasm in the scientific community¹³ but the disappointment was too of the same magnitude. The funds promised for these mega projects were never released and hence the initiative failed. To fill the gap, CONACYT decided to create a National Network of Nanosciences, Nanotechnology and New Materials Research Groups. It was a thematic network in the field of the NST that would integrate into already existing initiatives of the National Groups Network and Research Centers (RNGCI). This confirms that in the case of Mexico, networks of scientific collaboration "have also become instruments of scientific policy, more flexible than the creation of large specialized laboratories" (Vinck, 2007). However, this initiative is not yet in operation.

Initiatives by universities and research centres in the development of the NST

Another institution that plays an important role in the development of the NST is National Autonomous University of Mexico (UNAM), with several centres and institutes

¹³ One of the people we interviewed, who was involved in a project, comments: "This initiative megaprojects launched in 2006 we took a breath".

working in the NST. The first among them is the Institute of Physics (IF), founded in 1938, and which gave birth to the Institute of Materials Research (IIM), the Centre for Applied Sciences and Technology Development (CCADT), The Science Centre of Condensed Matter (CMAC) in 1997, the Institute of Physical Sciences (ICF) in 1998 and the Centre for Applied Physics and Advanced Technology (CFATA) in 2002. In 2003, in the IF, the Network of Research Groups in Nanoscience and Nanotechnology (REGINA) was born. A year later, it spread to other centres and institutes of the UNAM. It is worth mentioning that in a previous study, we showed that the creation of this network has had a significant impact on scientific production in the NST of the UNAM (Robles, 2008). At the end of 2004, the Rector of the UNAM created the Project University Nanotechnology (PUNTA), oriented to research in nanocatalysts for environmental protection. Finally, just a few weeks ago, the CCMC changed its name to "Center of Nanoscience and Nanotechnology" (CNN). This shows that in UNAM, there is a tradition of research in the field of physics and that their recent initiatives are trying to boost the NST. It has recently been confirmed by the announcement of the initiative NANO UNAM aiming to combine the past initiatives to help ensure that the NST becomes the "engine of national development" (DGCS, 2008).

The second largest university in Mexico also wants to be an actor in the progression of the NST in the country. In fact, the National Polytechnic Institute of Mexico in December 2006 announced an "agreement wherein the networks of nanoscience and micro nanotechnology, biotechnology and environment of the National Polytechnic Institute (IPN) were established" (IPN, 2006). This initiative was launched in response to the creation of the National Groups Network and Research Centres, which we have already mentioned, which is driven by CONACYT. The objectives of the IPN with this initiative are "to promote the training of human resources of academic and professional excellence, and the generation of new scientific knowledge and their transformation into useful applications for society". The entities of the IPN where work is being carried out in the domain of the NST are: Superior School of Physics and Mathematics, Professional Interdisciplinary Unit of Biotechnology, the Department of Physics of CINVESTAV-México, the Department of Applied Physics of CINVESTAV-Merida and the Department of Materials of CINVESTAV-Queretaro. In addition, in 2008 on the campus of Zacatenco (Mexico City), the IPN is building a nanotechnology laboratory that will be equipped with installations dedicated only to research in the NST.

In the State of Puebla, a university and a research institute are working on research projects in the NST. The Autonomous University of Puebla has an Institute of Physics (IFUAP) which consists of an infrastructure of 16 laboratories where researchers and students are conducting projects in the NST. The most important projects being developed in this institute are on nanocomposites and semi-conductors. There are three sources to finance these projects: external financing (CONACYT, interinstitutional or bilateral agreements), financing VIEP-BUAP (Vice-President of Research and Graduate Studies University) and internal funding (BUAP). The first source is the most important. The research groups at the university maintain collaborative relationships with major research centers in Mexico including IF-UNAM, CCMC-UNAM, the University of Sonora, CICATA, ICE and the IPICYT, among others. At the international level, key relationships are with the USA, Japan and France. In 2006, IFUAP hosted the 3rd International Topical Meeting on Nanostructured Materials and Nanotechnology (NanoTech06) and the 1st Mexican Workshop on Nanostructured Materials (this event was repeated at the same place in 2007).

On the other hand, in the same state of Puebla, the INAOE distinguishes itself from other entities as it is dedicated to the research in the field of microelectronics. We have already mentioned that the INAOE is currently constructing the National Laboratory of

Nanoelectronics (see 3.1), and that this project has been realized through the gift of the company Motorola. This donation consisted of a production line of microchips that the big company was not using anymore because of its relocation in Argentina¹⁴. The construction of building for the laboratory was conducted in two phases: first, which has just been concluded, is designed to install a portion of the manufacturing line of chips, to host the “innovation laboratory of MEMS” (LIMEMS) and to establish a cleanroom class 10 and 100. The second phase foresees the construction of a building of 2000m² with an investment that amounts to 18 million. The budget for the construction of premises comes mainly from the Ministry of Economy, the Office of Economic Development of the State of Puebla and the Foundation Mexico - USA for Science (FUMEC) that also participated in the framework of LIMEMS. The case of the construction of the National Laboratory of Nanoelectronics clearly shows the existence of a regional policy for the development of the NST.

Another research center that plays an important role in the field of materials science is the IPICYT. Its importance is reflected in its scientific production (5% of national production) and its visibility in the international scientific community. The IPICYT is a young public research center of CONACYT¹⁵, created in 2000, wherein the research is organized into five divisions: applied mathematics, advanced materials, environmental science, applied geosciences and molecular biology. Molecular biology and advanced materials are the divisions in which projects of the NST are developed. We'll, therefore, concentrate our analysis on the division of advanced materials. The IPICYT includes the “Research Laboratory in Nanoscience and Nanotechnology” (LINAN), infrastructure project which is not yet concluded and that provides an investment of 40 million pesos (2.48 million euros), funded for the CONACYT and the Government of the State of San Luis Potosi. An important part of the equipment in the laboratory is completely new. The policy of using scientific equipment of IPICYT gives priority to research work, which allows groups of local research (from UASLP, for example) to have access to instruments. The use of instruments is open to industry; however, IPICYT requires that it should be done within the framework of research projects. Although the research relationship with industry is not evident in Mexico, the IPICYT has developed projects with Hitachi (Japan), "Industria Peñoles" (Mexico), and currently the division of materials is working on a research project with a big Mexican company: MABE. In this project, the IPICYT is participating with the knowledge of advanced materials and the company is funding a portion of the project (the other part is financed by CONACYT through a consortium for research). In addition, a new laboratory was established for this project (called “laboratory MABE”) and PhD students from the company are working on the project. Some academic activities such as meetings of the Mexican Association of Physics on the NST, took place in the premises of the IPICYT. The international visibility of IPICYT is explained for the scientific relations with others countries, between 2001 and 2007, IPICYT has co-authored 58 articles with the USA, 39 with Japan, 36 with Germany, 19 with England, and so on. Another fact which reinforces its international visibility is that the IPICYT is the Mexican reference in the NanoforumEULA, European initiative which has carried out a mapping of the NST in Mexico in 2007. The aim of this initiative is to establish research relations in the World of the NST between Latin America and Europe¹⁶.

Finally, all these initiatives we have just mentioned illustrate the importance of the roles of national and regional institutions in the development of the NST. On one hand, some

¹⁴ The creation of the initiative LatinChip by Motorola was just to transfer this production line of chips. In the same initiative, another production line was sent to Brazil.

¹⁵ The INAOE and CIMAV are also public research centers of CONACYT.

¹⁶ The NanoforumEULA has also conducted activities to promote scientist collaborative relationships at Brazil and Argentina. See: <http://www.mesaplus.utwente.nl/nanoforumEula/>

of these initiatives (mainly those driven by CONACYT) are the sources of funding for research activities in the NST. On the other side, initiatives such as PUNTA or Innovation Laboratory of MEMS (INAOE and FUMEC) are crucial in defining research subjects, as their strategies are focused towards research areas well defined (the first on the catalysts and the second on MEMS), when other initiatives are focused towards broader fields (for example, nanostructured materials). In addition, we also saw some initiatives promote the creation of networks of scientific collaboration. It shows that the creation of these networks is part of strategies for the development of the NST.

3.4 Face to the wave "nano"

We are trying now to understand the extent to which research groups in Mexico guide their lines of research in response to the emergence of the NST. We analyze, on one hand, the growth of basic research projects, and on the other, the reorientation and creation of study programs in the NST.

First, it should be noted that the announcement by the international scientific community of this emergence and these promises related to the NST has quickly attracted huge investments for their development in the world. To some extent this has accounted for both scientists for the institutions, an opportunity to get funding to continue their research activities. On the other hand, products made with the NST increase beyond forecasts (Lux Research, 2006), this implies an impact on the organization of the industry. With the advent of these new technologies, more human resources with new skills will be required. It is in this context that we analyse the basic research projects funded by CONACYT and the arguments justifying the changes and creation of study programs in the NST.

The orientation of lines and research projects towards the NST in Mexico

We said before that an applied research project developed in a laboratory corresponds to a thematic research (cf. 3.1). In this respect, we consider the same thing for basic research. In addition, we also talked about the importance of CONACYT in the funding of infrastructure in Mexican laboratories (cf. 3.3). The same importance we find financing for projects of basic research: for example, in 2006, CONACYT has financed 100% of projects in IPICYT and 83% in CIMAV.

On the other hand, analysing scientific publications, we found that the first article of Mexico which contains the prefix "nano" was published in 1991, and that from 1995 the curve of publications with the same prefix reveals a constant growth¹⁷. However, preliminary studies of matter at the microscopic scale have developed in Mexico before the use of the prefix "nano". When we asked a Mexican researcher about the birth of the NST in Mexico, he replied that "we have been working on nanoscience for many years in this country". In fact, during the years 1980, the Institute of Physics of the UNAM developed research in catalysts (CIC, 2007). According to the researcher interviewed at that time one of the terms used to refer to infinitesimally small particles was, for example, "sub-micron particles". For this researcher, the point from which the progression of the NST had a great impulse in Mexico was after 2000. This can be seen in the Mexican scientific production, within 3 years (2001-2004) the scientific production in this field had almost doubled (see figure 1).

¹⁷ In this case, for research on WoS has only used the word "nano": TS = (NANO *) = CU AND MEXICO. The results show an increase which has not ceased to increase, but this growth is not so important as in the case of China (Guan and Ma, 2007).

An analysis of titles of projects funded by CONACYT in the NST during the period 2002-2006¹⁸ reflects the thematic lines. The results of this analysis are shown in Table 2: The first column shows the growth of funded projects and the second column contains the words and terms representing the field (keywords) that were used in titles.

The first column shows that in an interval of 4 years the number of projects had duplicated, this number of projects increased from 59 in 2003 to 111 in 2004. So if each project was proposed by a research group that works on a thematic set, these results suggest the increase of research groups who devote their scientific activities to the NST.

The second column of Table 2 shows the increased use of the prefix "nano", in 2006 the use of the prefix is three times greater than in 2002. However, the use of other terms such as "thin film", "catalysis", "synthesis and characterization", does not present significant changes. This shows the increasing integration of prefix "nano" in the scientific language in Mexico. Indeed, terms like "nanoparticles", "nanoclusters", "nanocomposites", "nanomaterials", are increasingly present in demands for funding. These results show the appropriation of the prefix "nano" in the scientific community in Mexico. It seems that the use of compound words with this prefix is part of the strategy of some research groups to make visible their research topics, and thus attract funding.

Year / number of projects	Words and terms used in titles
2002 / 59 projects	Nano* : 14 Thin films : 6 Microscopy and RAMAN : 4 Synthesis and characterization of materials : 14 Catalysis : 7 Electrical, chemical and optical properties: 7 Atomic and electronics structure: 7
2003 / 59 projects	Nano* : 27 Thin films : 5 Synthesis and characterization of materials (polymers, ceramics, ...) : 22 Catalysis : 5
2004 / 80 projects	Nano* : 34 Thin films : 14 Synthesis and characterization of materials: 27 Catalysis : 4 Composites : 1
2005 / 84 projects	Nano* : 37 Thin films : 6 Propriétés structurels : 13 Synthesis and characterization of materials (polymers, ceramics, ...) : 17 Catalysis : 8 Composites : 3
2006 / 111 projects	Nano* : 47

¹⁸ The analyzed data were obtained of results of tenders for basic research projects in the period 2002-2006, which are available from the website of CONACYT.

	Thin films : 7 Sol-Gel : 1 Microscopy (AFM...) : 2 Composites : 2 Synthesis and characterization of materials (polymères, céramiques, ...) : 19 Composed and hybrids materials : 17 Optical, catalytic and structural properties: 16
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Table 2. Analysis of titles of projects CONACYT in the NST.

Reorientation and creation of study programs

Another indicator that reflects the emergence of the NST is the reorientation and development of study programs. It exists in Mexico within some twenty research centers and institutes, the study programs of PhD¹⁹, in which students develop research topics of matter at the nanometer scale. In addition, and like other countries that invest in the NST, we begin to see the emergence of study programs of PhD and engineering in the NST. An example of these programs is that proposed by the IPICYT: This is the PhD program with an option “Nanoscience and Nanotechnology”. The PhD program began in 2002 under the label “PhD in materials”, which was changed in 2004 for “Nanosciences y Nanotechnologies”. This change is part of the strategy of the center to respond to the emergence of the NST:

“We want to further strengthen the program in function of the natural evolution of nanoscience. We are convinced that this program is like the molecular biology program. If molecular biology is a discipline considered as a strategic science, then nanoscience can be also considered as vanguard. Both are emerging. The biology is old and recent in same times, because today it is placed on a very important part of development. [The field of] nanosciences is completely new, [it] is emerging, it is something that just arose. Obviously, it must be separated [of other programs]. This is how we see and that the evaluation committee saw” (interview with the head of the PhD program).

The program in question is proposed in two ways: the PhD (traditional) in Applied Sciences and the Direct PhD in Applied Sciences. The difference between the two lies in the admissions process: for the Direct PhD, it is not necessary to have a Master’s degree Research. This allows professionals to do a PhD on a research topic in the industry, alternating with their professional activities. To some extent, the objective of such programs is to train human resources according to demand from industry²⁰.

On the other hand, the University of the Americas (UDLA) in the State of Puebla, is the first that created the first graduate program in NST in Latin America: a degree in Nanotechnology and Molecular engineering. The decision to create this study program was taken in 2005 during the “evaluation academic” of study programs of the university. The objective of this license is to train human resources in the field of the NST, taking into account the interdisciplinarity of these new technologies. The creation of this engineering program is part of a strategy for the university to train experts that the labour market will require in short-term:

¹⁹ It is study pograms specialist in materials, physical chemistry, applied physics, molecular biology, polymers, biotechnology, among others.

²⁰ For a detailed analysis of this type of study programs in Mexico, see the work of Santos and de Gortari, in which they are studying the production of knowledge through training of human resources in response to demand from industry specializing in materials and lasers in Mexico (Santos y de Gortari, 2003).

“Every five years, the university takes time to conduct a review of all study programs, we call it an academic review, and to an analysis of the characteristics of existing programs to see if they meet the needs of labour market. It was during this period we also explore the possibility of changing the programs or create them. We do this every five years, and it was in 2005 that we take the decision to create this degree” (interview with the head of the engineering program).

These two examples that we have explicated show that decisions to reorient these study programs are based on forecasts of labor market that the field of the NST will require. But in view of the lack of a genuine national policy that not only creates the impulse of the NST in research centres but also includes the transfer of technology to domestic industry, the question that arises is: “if domestic industry is far from innovative products with the NST, who took advantage of highly trained human resources? We can already find an answer by observing the case of INAOE, institution which trains human resources in the field of microelectronics, which, face the absence of a national labour market, finally leaving to work in foreign enterprises.

Finally, the growing use of the prefix “nano” in the titles of projects and increased funding for these clearly show the progressive interest of Mexican research groups to the NST, but these results do not provide sufficient evidence to qualify if research of the NST is developing as a response to the wave of these new sciences and technologies. Concerning the shift (and creation) of study programs to the NST, we see that the speech to justify these changes are based on promises of these new sciences and technologies.

4. Conclusion

The exploration of case studies for the development of the NST in Mexico, detailed in the text, is not exhaustive. Nevertheless, examples presentations allow us to advance some answers to the initial question of this study. Analysis of our case studies leads us to the following conclusions.

The first hypothesis “influence of industrial demand” explains well what is at stake in the case of the CIMAV, an entity that maintains the highest relations with industry in the context of research and technological innovation projects. The knowledge produced in research centres in terms of the NST call for the attention of some national and international industries. However, the expressions of interest from the industry that materialize in technological research projects and innovation are very few. Of course, other studied entities have also the experiences of this type, but projects in partnership with industry are sporadic. The case study shows that the CIMAV research relations with industry support the passage of nanoscience to nanotechnology, but it also shows that these relationships provide resources for activities of the “edge research” in the NST. On the other hand, the analysis shows that technological research projects in the NST can arise both from the industry's needs and concerns of the academy. However, generally speaking, projects with industry remain insignificant if we compare with the number of purely academic projects (i.e. basic research).

As far as the role of collaborative networks is concerned, analysis of these with foreign partners reveals that this form of organization of the science is part of science and technology policies, and strategy of researchers to gain access to scientific instruments. Here, it is important to emphasize that the initiatives which plan the installation and construction of important infrastructure for the development of the NST, will have an impact on this technological dependence. On the contrary, the guidelines of research of the entities have their integration into national networks (such as REGINA, PUNTA and the network of laboratories

of innovation in MEMS) rather than their individual initiative or promotion of institutions initiatives, especially as Institutions are driving the creation of networks and these networks have an important weight on institutions.

Concerning the analysis of the roles of institutions in the development of the NST in Mexico (third hypothesis), we found that, in terms of funding, the CONACYT is the main provider of funds, but this actor is not decisive in definitions of thematic research (RNGCI initiative which intends to organize research on topics was not feasible). Indeed, the main economic sources for research projects, basic and applied, are public. However, we also saw that all initiatives fail to see the day: some remain in the field of discourse. These facts help us understand why some government actions in the field of the NST are classified as “tasteless” (Barrañón, 2007).

Finally, this panorama of the NST in Mexico shows that research in advanced materials occupy an important place in the progression of these new sciences and technologies. Our research also shows that researchers do not expect a Mexican national policy as the engine of growth in the NST. The creation of collaborative networks, increasing of the number of groups that are heading towards the NST, the reorientation of PhD programs around the NST and the creation of academic degrees of the Nanotechnology and Molecular Engineering constitute a group of local and international initiatives, that intertwined with each other, are beginning to sketch the dynamics of the NST in Mexico.

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