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Foundations and philanthropic organizations in the development of new science and technology: the case of micro and nanotechnology in Mexico

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Introduction

The emergence of new science and technologies are accompanied by new dynamics in their production, use and dissemination of new scientific and technological knowledge. These new dynamics are reflected in the reorganization of scientific and technological activities, in the creation or reorientation of new research thematics, in the emergence of new concerns and debates on the risks and social implications, as well as in the participation of new bodies in the development of science and technologies, among other factors. These new dynamics are also seen in the processes of innovation, in which – through the processes of mutual learning – those involved learn to take on functions that previously were carried out by others. In studies on innovation the metaphor of a dance of the actors involved in innovation processes has been proposed to better understand these new dynamics (Kuhlmann et al., 2010). This chapter takes up the study of these new dynamics, where not only other actors are performing the roles, but we also find the presence of new actors who begin to assume central responsibilities in the installation and development of new technologies.

This chapter, then, focuses upon the study of the implementation and the development of micro and nanotechnologies (MNTs) in Mexico, particularly in the development of micro-electromechanical systems (MEMS), which have in a few short years developed scientific and technological capabilities, including the development of projects in partnership with industry and the creation of researcher networks. The growth in the development of these new technologies, which began to be emphasized at the beginning of this century, were accompanied by a series of technical and economic possibilities. These possibilities have caught the attention not only of representatives of the academic, governmental and industrial sectors, but also –through our research into the emergence of MNTs in Mexico – we have encountered organizations with 'philanthropic' origins. In this case, we refer to the Mexico-United States Foundation for Science (FUMEC), a non-governmental organization that has played important roles in the emergence and the development of these new kinds of science and technology in Mexico.

The presence of these organizations in the development of MNTs in Mexico draws our attention because they represent a kind of organization that is not taken into account by theoretical models on technological change and innovation processes. Essentially, in the social and economic sciences various studies have offered models on the relationship between organizations involved in the development of new scientific and technological knowledge oriented toward the study and understanding of technological change. The most frequently reviewed models within those studies are that of the Triple Helix (Etzkowitz and Leydesdorff, 2000), the innovation systems (Lundvall, 1992), the 'Mode 2' (Gibbons et al., 1994) and in lesser measure in Latin America, the Sábato Triangle (Sabato and Botana, 1971). One common characteristic to all of these models is that they focus on the relationships between agents from three sectors: university, government and industry. In our research on MNTs in Mexico, we have discovered that they have a limit, in that they do not consider actors coming from different sectors. In fact, in other research, the importance of taking into account new actors in these processes is important to better understand the new production and use dynamics of this new knowledge (Cozzens, 2010). These key actors with a significant presence in the processes of technological change are diverse and represent various social, economic and even political interests. It concerns organizations that are non-governmental as well as those of 'philanthropic' and multinational origins, such as the Inter-American Development Bank.

Our observations lead us to question how to model these relationships among different organizations involved in the production, use and dissemination of new knowledge. The hypothesis is that in these new dynamics of technological development, different organizations than those that traditionally participate, are fulfilling new functions in those processes. This results in a different arrangement among the organizations participating in scientific and technological systems, where each body fulfils one or a number of functions and this joint arrangement ensures the functioning of the system.

To undertake this study, in addition to a functionalist approach, the research characterizes and analyses the functions carried out by FUMEC in the development of MNTs in Mexico in its various dimensions: the installation of scientific infrastructure, the creation of scientific and technological networks, the training of human resources and the dissemination, transfer and commercialization of new knowledge. This research is based upon a series of interviews with scientists, representatives of FUMEC and the government, as well as on the analysis of reports and other documents related to projects involving the development of these sciences and technologies.

The results brought to light by this study show the different functions carried out by FUMEC at different stages and levels during the development of MNTs in Mexico. It shows that there are other organizations to be considered in research on the development of new technologies. Also, it places emphasis on the influence that philanthropic and non-governmental organizations can exert on scientific and technological systems, as well as in the public policies that regulate them.

Philanthropic and non-governmental organizations in scientific and technological development

In the academic literature, primarily in the field of the history of science, various authors have focused on the study of philanthropic organizations in the development of different fields of science and technology. Within that literature, we have identified two books that have been dedicated to the study of those organizations in science and technology (Arnove, 1980; Cueto, 1994). Moreover, articles in science and technology studies have also been published on case studies in Latin America (Vessuri, 1994;

Cueto, 1997; Harwood, 2009; Fitzgerald, 1994, Faria and da Costa, 2006; Solórzano, 1994), in Africa (Shrum, 2000; Toenniessen et al., 2008), in Asia (Brown, 1980) and in Europe (Stapleton, 2003; Buxton, 2003: Guilhot, 2007). Within this literature, the place occupied by philanthropic organizations in scientific and technological development shows them to be important actors in the periods during the First and Second World Wars, as well as during the Cold War (Abir-Am, 2002).

The activities of philanthropic organizations are carried out at different levels and in various dimensions. In fact, the studies on the understanding of this historic importance of these organizations in science and technology have revealed that their key functions concern the funding of research activities, such as the financing of new infrastructure and the training of human resources. In some cases, their presence has given rise to the creation of new fields, with one of the more remarkable cases being the development of the 'green revolution' and its emergence in peripheral countries (Losego and Arvanitis, 2008), where the Rockefeller Foundation has been a significant player in the implementation of these technologies. Another interesting case involving the same foundation is the emergence and development of molecular biology (Abir-Am, 2002). In some of the studies that we have reviewed, the fields where philanthropic foundations intervene are seen to have great potential and where the knowledge produced shows a high degree of discipline. Furthermore, political and social changes in the contexts of action are elements that also must be taken into account by those organizations when arriving at definitions and making adjustments to support strategies relevant to the development of new sciences and technologies (Arnove and Pinede, 2007; Faria and da Costa, 2006). Two other interesting points we have already mentioned are in regard to the implementation of new institutional science models (Fitzgerald, 1994) and the construction and maintenance of hegemony over less developed countries (Parmar, 2002a and 2002b; Cueto, 1994).

Moreover, the book edited by Cueto (1994) focuses on the implication of philanthropic foundations on the scientific development of Latin America. One of the hypotheses of this chapter is that science promoted by these organizations in Latin America has been based upon 'an elitist vision of the history of science and of U.S. society'. Cueto argues that the representatives of the U.S. philanthropic foundations share this elitist vision through the definition of their programmes of action. Later we will return to a discussion on this vision of philanthropic organizations for science and their influence on science and technology political systems.

Today, the field in which philanthropic organizations are present cover practically all sectors and these organizations – as mentioned previously – are not new and they have an international presence. The foundations and other non-governmental organizations carry out their activities in the fields of agriculture, health, biology and even in the social sciences, such as political science and economics, for example. From the beginning of what we know today as philanthropy, which started in the 1920s, foundations like Rockefeller, Carnegie and Ford stand out, and most recently on the international scene we see the Bill and Melinda Gates Foundation, just to mention a few.

The studies we have previously mentioned show the importance of philanthropic organizations to science and likewise reveal various important elements that allow us to better understand the dynamics of science and technology where these organizations are active. Before we move on to the case study in our research, it is pertinent to review the concepts of a philanthropic organization and of a non-governmental organization. There is an ambiguity to both, which makes a qualification of their actions challenging, and we believe for that reason it is important to examine them in our study.

So far we have used the terms 'philanthropic foundation', 'philanthropic organization' and 'non-governmental organization' to refer to the social entities that we analyse in this chapter that do not belong to the institutional spheres of industry, academia nor the government. Here it is important to note that we use all of these terms conscious of the fact that ambiguity exists in their definition and for this reason we will clarify their use. First, the term 'foundation' is commonly used to refer to philanthropic foundations, which are non-profit organizations and are economically, politically and organizationally independent of other institutional spheres. We have also introduced the presence of 'non-governmental organizations' in scientific development. In this second term, the academic literature commonly classifies philanthropic foundations as 'non-governmental organizations'. However, not all organizations known as 'foundations' are 'non-governmental', since there are, in effect, governmental organizations that make use of this term in their name. For example, the 'National Science Foundation' in the United States, which is the state agency whose responsibility it is to 'promote the progress of science; advance national health, prosperity and well-being'. Finally, we view 'philanthropic foundations' as those organizations that carry out, in various sectors, initiatives and activities for development with an aim to improve the conditions of life for humanity.

The definitions of the terms that we mention here have been the basis for our qualifications of FUMEC, the organization that we examine in this chapter, as an organization with 'philanthropic origins', but that has changed over time and whose philanthropic principles that were so visible at the moment of its creation are today scarcely visible. In the following section we discuss the origins and the present-day nature of FUMEC, in which we attempt to show the evolution of this organization that today plays an important part in the development of diverse sectors in science and technology in Mexico.[1]

The Mexico-United States Foundation for Science: philanthropic origins and its evolution

The FUMEC was created in 1992 as a non-governmental organization. The driving force behind the creation of the foundation has been attributed to the American Congressman George E. Brown Jr., who had proposed the creation of a foundation that would encompass all of Latin America.

This implied the participation of various countries, however, the conditions for an initiative of that scope were not favourable and the only country with which the initiative proved to be possible was Mexico.

We characterize FUMEC as a philanthropic foundation since the motives for its creation are characteristic of philanthropy. This is reflected in the 'guiding principle' of the foundation expressed in the second activity report of FUMEC by its president: 'a spirit of cooperation and of participation in science and technology can, and will, help the international human effort to improve the quality of life in the United States as well as in Mexico' (FUMEC, 2000). Furthermore, the first programmes and initiatives of FUMEC likewise confirmed this philanthropic character: in the activities report of the foundation's first five years, the three priority areas were environment, public health and socioeconomic problems resulting from the integration of both societies (FUMEC, 1998). This principle that guided the foundation has seen significant changes. In effect, FUMEC today follows a strategy that is focused on the development of specific projects that respond to windows of opportunity that have been identified through feasibility studies. The projects that are currently developed are organized in three strategic areas that are different from those defined at the creation of the foundation: (1) economic development based upon technological innovation, (2) human resource development and (3) environment and health. This change or adjustment of strategic areas takes form in the development of initiatives in fields where the knowledge produced shows a high degree of discipline, a characteristic mentioned earlier.

Furthermore, at the moment of FUMEC's creation, its operational area was limited to the border region between Mexico and the United States. However, the face of FUMEC took a few years to change, as the foundation today extends its activities throughout Mexico, on the one hand, and changed as we mentioned earlier its strategic areas to include a field with wider socioeconomic impact for North America. It is within this new logic that FUMEC sees the development of micro-electromechanical systems (MEMS) and the aerospace and automotive industries as priority areas (FUMEC, 2010).

Funding and institutional independence

In order to fund the creation of FUMEC, an initial proposal was to follow the model of *debt-for-science swaps* proposed by Brown and Sarewitz (1991), which involved a model inspired by *debt-for-nature swaps.*[2] That proposal was not embraced and in the end, the economic fund that provided for FUMEC's creation was provided in equal parts by the governments of Mexico and the United States in 1992. For the United States, the Agency for International Development (USAID) provided $2 million. For Mexico, the National Science and Technology Council (CONACYT) provided matching funds. Two years later, USAID provided an additional $150 thousand (FUMEC, 1998). These contributions made up the organization's operating fund, the economic base to ensure its operation. In fact, the operating costs for FUMEC are financed by the interest obtained by the investment of this fund. This method of financial operation gives FUMEC economic independence when dealing with public and private institutions. It is important to note that the fund has continued to increase its capital worth, starting with around $4 million at its creation and reaching $13.9 million by the end of 2009.

Moreover, the projects undertaken by the foundation are financed for the most part with resources provided by public institutions. FUMEC retains a percentage of that funding as the managing organization. Those resources are so significant, for example, that López et al., in a report on the Small and medium-sized enterprises Funds of the secretary of the economy, revealed that FUMEC in 2006 was the top-funded organization within that governmental programme. In this document, it reported that between 2004 and 2006 the foundation received a total of 328.445 million Mexican pesos (approximately $29.8 million) in funding for various projects, including microsystems technology in the case we present here.

The board of governors and its political network

Within the foundation, decisions are made by a body known as the 'board of governors' which is made up of 16 people: eight Mexicans and 8 Americans. Its members are drawn from academia, governmental institutions and industry. It is a group that is considerably heterogeneous and that represents diverse interests. Notwithstanding the origins of these members, FUMEC is presented as an organization that is independent of the spheres of government, private institutions and academia. The label 'independent', which takes us back to the term 'non-governmental', confers upon the foundation a certain legitimacy in its interactions with other institutions, as FUMEC is not seen as a potential adversary. This legitimacy is confirmed during an interview with a representative of FUMEC in which he responded to a question regarding the foundation's positioning with respect to other institutions:

> So, we are an entity that belongs to no particular sector and this neutral character gives us a great deal of value for those institutions, since we are in competition with no one and in reality our function is to promote and assist the in bringing their projects to fruition (Avendaño, 2009)

Moreover, the members from those three sectors that make up the board of governors represent the basis of a network of contacts among various public and private institutions that are mobilized to the task of forming alliances and seeking useful information that helps to implement programs. This network, which we label as a 'political network', since it is based upon political relationships, represents an important social capital to the foundation. This importance is reflected in the fact that FUMEC has succeeded in delivering its programmes with public financing despite the discontinuity in science and technology policies, as well as those of economic development, throughout different presidential administrations.[3] Also, the importance of this political network to FUMEC and its activities is reflected in the following quote from the president of the board of governors which we have taken from one of the foundation's reports on activities:

> Another significant strategic effort in the period was the renovation and strengthening of our network of relationships with the two key federal agencies relevant to our mission, the Secretary of the Economy (SE) and the National Council for Science and Technology (CONACYT), once Mexico's change of Federal Public Administration was complete in 2006. These two agencies are not only the Mexican contributors to our endowment fund, they are also our biggest clients and sponsors of our programmes. This solidified a very close and effective relationship with the key officials of those agencies (FUMEC, 2008).

FUMEC in the emergence and development of microsystems technology in Mexico

The emergence of MEMS

MEMS are devices that have a length of less than 1 mm and greater than 1 micron, combining both electrical and mechanical components and are manufactured using technologies of integrated circuit processes (Gad-el-Hak, 2011). The term microsystems technology is also used to refer to these kinds of devices that are evermore present in our daily lives. In fact, this presence is due to the large quantity of applications of these devices which utilize advances in nanotechnology and advanced materials to increase the ability to miniaturize electrical and mechanical components. For this reason, microtechnology advances are strongly tied to scientific and technological advances at the nanometric scale. One of the first applications of these devices was in integrated accelerometers in automobile security systems, which activate air bags at the instant of a collision. We discovered another example in portable telephones or digital cameras that orient themselves automatically to the horizontal plane when rotated to maintain a stable image on their screen.

In the academic literature, the first scientific articles date from the 1960s (Flores-Herrera, 2007). The manufacture of the first MEMS devices appeared in the 1970s, however, the first MEMS on the market appeared in the 1980s (automobile air bags). Today there are public and private research and development centres working with these devices, mainly in the countries that lead in technological advances, with one of the most important centres situated in the state of New Mexico, United States. The Sandia Laboratories – a research centre specializing in weaponry – housed a total of 500 researchers and engineers in 2000 who were working on MEMS development (Freiburghouse, 2001). Also, in the academic field, the progress of these technologies is reflected in the proliferation of specialized journals in this field that appeared beginning in the 1990s, as well as in the growth of publications in the field (Vinck and Robles-Belmont, 2011).

Beyond the academic world, publications on microsystems technology have also seen a significant growth, especially those covering the latest developments in those technologies. Some of these journals are the communications channels for companies dedicated to technological monitoring, preparing reports and feasibility or marketing studies regarding MEMS development.

The development of these technologies is mainly concentrated in the United States. China, Japan and the European Union countries are also important to MEMS development. In Latin America, the country where the most advances in the field have been made is Brazil. Mexico holds second place in the region. The emergence of these technologies is practically new in Mexico, because a scientometric study has shown that the first publications dating from 2002 (Robles-Belmont, 2011).

The FUMEC Microsystems Programme

Our analysis of scientific publications shows that microsystems technology in Mexico is in its early stages. Currently in Mexico, there are at least 14 research centres and educational institutions carrying out activities to develop these new technologies. These activities are directed toward the training of specialized human resources, the installation of new scientific and technological infrastructure, as well as the development of programmes in design, manufacturing and the characterization of MEMS devices. Throughout our investigation, we have found that many of these initiatives are part of FUMEC's Microsystems Programme.

FUMEC's MEMS development programme began in 2000 following a series of workshops it hosted on MEMS technology in cooperation with the Sandía Laboratories and the University of Texas at El Paso (FUMEC, 2002). In this workshop, MEMS technology was identified as a window of opportunity for the border zone between Mexico and the United States. The context analysis of this area indicated the presence of businesses based on those technologies on the United States' side of the border, but it also indicated a lack of scientific and technological capabilities on the Mexican side. However, this deficiency did not represent a significant obstacle to FUMEC, since the foundation was already convinced of the potentials of these technologies and had created a program dedicated to MEMS development. In the beginning, two goals were identified within the framework of this programme: the training of specialized human resources in the MEMS field and the construction of scientific and technological infrastructure for device development.

This programme is made up of various initiatives, and throughout its evolution we identify two phases. In the first phase, we see two initiatives oriented toward addressing the lack of human and infrastructure resources. The first initiative, launched in 2002, had the aim of installing infrastructure for the conceptualization of MEMS devices; it involved the National Network of MEMS Design Centres (CD-MEMS). Parallel to the creation of this network, FUMEC also coordinated the integration of a group of specialist researchers with the aim of developing human resource training and promoting the development of this technology in Mexico. Later, in 2004, with the goal of completing the remaining stages of MEMS device development, FUMEC promoted and supported the construction of three laboratories for the manufacture and characterization of those devices. This second initiative, also focused on infrastructure, was known as the Network of MEMS Innovation Laboratories (LI-MEMS).

The second phase that we identified in FUMEC's Microsystems Programme is constituted by three initiatives oriented toward the integration of various sectors with potential for the development of MEMS and the commercialization of those devices. The first initiative was the creation of the Centre for MEMS Productive Chain (CAP-MEMS) in 2004. One year later, the Mexico Microsystems Consortium (CMM) was created. The third initiative was the formation of the MEMS Strategic Alliance and Innovation Networks (AERI-MEMS) created in 2008 within the framework of a CONACYT programme to create national innovation networks in strategic areas.

These five initiatives shape the emergence of microsystems technology in Mexico. In our research, we have noted that these initiatives are cross-linked. These relationships are based on the arrangements that FUMEC's Microsystems Programme has made, based on its experience with the evolution of each initiative. For example, the bases for creating the CMM were the CAP-MEMS, the CD-MEMS and the LI-MEMS. Beyond these initiatives, FUMEC undertakes other parallel activities promoting them, as well as dissemination of MEMS developments and the potential uses of this technology. These activities are carried out in academic and industrial environments, allowing the foundation to identify new potential scientific and economic actors for the development of these new technologies. The initiatives that we have outlined above are represented in the following image and are developed in the following sections:

[INSERT IMAGE 1 HERE]

Image 1. Initiatives within FUMEC's Microsystems Programme and key dates in the development of MEMS in Mexico. Source: Author's creation.

Installation of scientific and technological infrastructure in Mexico

The development of these kinds of technologies requires considerable resources for the installation of scientific and technological infrastructure for the training of human resources and for the development of research projects and MEMS devices. Funding for the installation of this infrastructure is traditionally provided by the state, via policies oriented toward the development of new science and technologies. However, in the Mexican case, as we have mentioned there is no national programme or plan for MNT development. Despite this, the two initiatives for the installation of infrastructure were carried out thanks to public financing provided by FUMEC.

A first step was gaining the attention of political policymakers with regard to MEMS development; this occurred in 2003 during an event organized by FUMEC, CONACYT and the transnational company AMD, attended by the president of Mexico and the SE, both of whom showed particular interest in the development of microsystems technologies. In the same year, a series of meetings with representatives of the SE took place, with the result being that the project would create the CD-MEMS Network.

The response to the convocation was significant, with a total of 12 academic entities responding, of which only ten successfully installed infrastructure. It is important to note that the funding of these design centres was not covered in full by the SE: support from the institutions where it was installed was one of the requirements of the convocation. The part covered by the SE went toward computing equipment and into conceptualization and simulation programs, and the adaptation of the areas where the CD-MEMS were installed was covered by the academic institutions.

These ten centres are distributed primarily in Mexico's central zone, from Bajío northward. In the centre-south of the country, five CD-MEMS centres have been installed: in Mexico City within the Faculty of Engineering at the Autonomous National University of Mexico (UNAM); in the State of Puebla at the National Astrophysics, Optics and Electronics Institute (INAOE) and in the Autonomous Popular University of the State of Puebla (UPAEP); in the State of Morelos at the Institute of Electric Research; and in Veracruz within the Faculty of Engineering at Veracruz University. Three more centres were installed in the Bajío region: one in the Centre for Research and Advanced Studies (CINVESTAV – Guadalajara campus); the second in the University of Guadalajara (Ciénega campus); and the third in this region, in the Irapuato Institute of Higher Studies, in the State of Michoacán.

In the northern region of the country, two CD-MEMS centres were installed, both in the border zone with the United States. The first CD-MEMS centre was installed in the Autonomous University of Ciudad Juárez (UACJ) and the second in the Monterrey Technological Institute of Higher Studies (ITESM). It is important here to note that at the beginning of FUMEC's Microsystems Programme, only the border zone was under consideration for the development of this technology, but the response to the convocation also included institutions in other parts of the country. Furthermore, one of the conditions of support by the SE to the CD-MEMS Network was to develop this initiative beyond the border zone.

The second initiative pursued in the installation of infrastructure was launched once the CD-MEMS Network had been consolidated. At that point FUMEC broadened its strategy for the remaining stages of MEMS development: manufacture and characterization. The key objective of this second network was to make available the infrastructure necessary for the manufacture of specific applications in three niches of opportunity: biomedical micro-electromechanical systems (BioMEMS), MEMS for the automobile industry and MEMS for telecommunications. It is interesting to note that these three windows of opportunity were identified by FUMEC through feasibility studies and technological monitoring performed by other groups, among which were the Micro and Nanotechnology Commercialization and Education Foundation (MANCEF).

Also with the support of the SE, in 2005 FUMEC launched the initiative to create the LI-MEMS Network. The first laboratory was built on the grounds of the INAOE in the State of Puebla. This laboratory is in fact part of a broader project in this institute called the National Nanoelectronics Laboratory (LNN), a project where in addition to the SE and FUMEC, the secretary for economic development of the State of Puebla also participates. This presence of the local government is due to the fact that in the city of Puebla a Volkswagen factory is located, which generates significant economic incomes for the region and as a result, the economic policy in the region is oriented to support the automotive sector, which is a significant consumer of MEMS devices. In this laboratory the scientific and technological infrastructure necessary for the fabrication of certain MEMS prototypes based on microelectronics has been installed. In fact, the LNN initiative arose within the INAOE due to the need to renovate the institute's microelectronics laboratory infrastructure that had originally been installed in the 1970s. Also, part of this infrastructure came as a donation from Motorola under the framework of the *LatinChip* initiative a few years earlier.

The second laboratory has been installed in the Faculty of Engineering of the UNAM and the available infrastructure is dedicated to the fabrication and characterization of MEMS devices. The LI-MEMS and CD-MEMS installed in this university are part of a wider project called UNAMems. This is a MEMS development centre, which pursues activities for the development of radio frequency identification (RFID) antennas, fibre-optic sensors, MEMS for magnetic resonance systems and BioMEMS for medical applications. The SE (via the CD-MEMS and LI-MEMS initiatives) and UNAM financed the construction of this centre. Currently, the UNAMems centre is capable of conceptualizing, simulating and manufacturing MEMS devices, with this centre oriented to lending its research efforts to the development of MEMS based on more economical biocompatible materials.

The third laboratory in the LI-MEMS Network has been installed in the UACJ, in the border zone between Mexico and the United States. This laboratory is located close to the key MEMS development centres in the United States and in an area where the economic activities surrounding MEMS manufacture are very important, mainly due to the automotive *maquiladora* industry. The infrastructure was installed in this LI-MEMS primarily for the packaging of MEMS devices. This laboratory was also supported by the local government, and – with the CD-MEMS centre at this university – forms part of the Centre for Applied Research in Science and Technology (CICTA). Currently, this centre has the capability to cover all of the stages in MEMS development.

The construction of the CD-MEMS and LI-MEMS centres therefore represents the basic infrastructure for the development of MEMS in Mexico. These installations also serve for the training of human resources in the field, a point we take up later in the chapter. On the matter of infrastructure, another important point for the development of MEMS is the mass production of those devices. FUMEC has also prioritized efforts in MEMS mass production, however, none of the laboratories mentioned previously are equipped to do so. The laboratory with the greatest capacities is that of INAOE, where the second stage of the LNN, still under development, plans for a dedicated laboratory for the miniaturized manufacture of MEMS devices.

The organization of research and development activities surrounding MEMS in the form of collaboration networks has been promoted by FUMEC, with the objective of confronting the lack of available material resources. In effect, this means rationalizing the few available resources and putting them to common use by the entire scientific community. This experience of the constitution and reorientation of scientific networks in the development of MNTs has been analysed in a previous work (Robles-Belmont, 2009). Another influencing factor was the conditionality of the SE for 'no duplication' in infrastructure within the LI-MEMS framework. In fact, it is for this reason that each of the three LI-MEMS centres is specializing in different stages and techniques for MEMS development.

In the process of installing infrastructure for the development of microsystems technology in Mexico, FUMEC has obtained the necessary financial resources and managed laboratory construction projects. Within this process, FUMEC's political network has played an important role in connecting, persuading and opening negotiations to support these developments with policymakers, in which FUMEC has made available information on the economic and social potential of microtechnologies. Moreover, the particular economic and social dynamics of the local contexts where the laboratories have been installed were considered by the foundation under the terms of the Microsystems Programme and its justification. Here we can see the articulation of the global with the local, as FUMEC succeeded in calling the attention of key economic and political actors to achieve the first steps toward the development of microsystems in Mexico, an achievement attained without there being an explicit policy in the country covering these kinds of technologies. In Image 2 we show the different institutional actors identified in the study and their relationships with the diverse initiatives carried out by FUMEC and other institutions for the development of MEMS technology in Mexico:

[INSERT IMAGE 2 HERE]

Image 2. Relationships between the diverse actors in the process of installing and developing MEMS technology in Mexico.

Human resources training for the development of microtechnologies in Mexico

Recall that at the beginning of the Microsystems Programme, FUMEC identified the training of specialists as one of its challenges. However, the training and accumulation of specialist human resources in this field was not the goal of initiatives. The training of human resources was carried out within the different initiatives of the Microsystems Programme. Within the framework of this programme, the activities identified to address the lack of human resources were developed mainly at two levels: scientific training and professional training.

In regard to scientific training, the first steps took place in the context of the creation of the CD-MEMS network. In 2002, within the project to create this network, a program specializing on MEMS technology was put in place by FUMEC. This program of specialist training consisted of a series of courses and workshops on these technologies that were delivered to researchers from the institutions selected at the convocation of this network. This initial specialist training was delivered by researchers from the top U.S. universities in the field of MEMS: the University of Texas and the Sandia Laboratories. These scientific training initiatives focused on aspects of different theoretical techniques for the manufacture of MEMS and on the design and computer-assisted simulation. With the intention of promoting CD-MEMS and the collaboration between the different scientist participants, the courses and workshops were delivered at the different institutions where the CD-MEMS centres were set up and on four occasions in the U.S. institutions from which the educators were drawn.

Later, within the CAP-MEMS initiative, this training of scientists continued. The project was funded by the SE with the aim of strengthening the capabilities of the CAP-MEMS and FUMEC. In the latter case, it involved technical courses offered by members of the two networks and from two other external educational and research institutions. In the framework of CAP-MEMS, we identified five courses and workshops carried out in 2004 (see Table 1) that reflect the dynamic of the specialist training in MEMS within the foundation's programme.

[INSERT TABLE 1 HERE]

Table 1. Specialist scientific training activities in MEMS in Mexico within the framework of CAP-MEMS, FUMEC.

These kinds of training courses for researchers were held during academic and professional events in the MEMS field. For example, the 'MEMS – CAD course – Coventor & SoftMEMS' was organized by FUMEC within the auspices of the COMS 2008[4] conference activities in Mexico. In the initiatives of the networks and of CAP-MEMS that followed, they continued to offer MEMS specialized training activities. In the last FUMEC initiative, the CMM, one of the objectives was 'training and strengthening high-level human resources'. It was in this context that a 2010 course on FPGA (Field Programmable Gate Array) device design techniques was organized by FUMEC with the support of the SE.

Regarding the training oriented toward professionals that has taken place within the FUMEC initiatives to develop MEMS technology, one part of this kind of training was carried out in the educational and research institutions where CD-MEMS and LI-MEMS laboratories were set up. The infrastructure that was put in place served laboratory activities for various courses in engineering that have included in their subjects of study the development of MEMS. In some of the training offered by FUMEC, professionals who were already working in the industry participated. Such is the case of six people who received grants to receive FUMEC training on the design of FPGA devices that we have just mentioned. Another example is the workshop on MEMS packaging organized in 2004 in Ciudad Juárez with Delphi Corporation.

The human resource training provided by FUMEC is not solely concerned with technical issues, but also with training on topics such as administration, offered within the framework of the Microsystems Programme. This kind of professional training has taken place in different participant institutions from the MEMS networks. One of these activities was organized, for example, by the UPAEP in 2005 in the form of a diploma directed toward researchers and students as well as business leaders and engineers. The diploma title was 'Business Training for MEMS Technology'. This training was offered over several weeks and was intended to inform participants about the development and applications of MEMS devices, about commercialization and protection of innovations in this field, as well as an analysis of opportunities for Mexican companies in the development of these technologies. The educators who delivered the diploma were researchers in the area of Mexican MEMS, and some who came from the University of Texas and from MANCEF. The seminar received economic support from the SE and FUMEC. Another example of this kind of training is a workshop that was recently organized by FUMEC on these technologies in the context of the MexEEdev 2010 event[5] at the Pan-American University in Mexico City. The objective of this training was to communicate the business opportunities that were available to Mexican companies through the use of microtechnologies.

The examples that we have provided on the human resource training within the context of the Microsystems Programme show that FUMEC performs functions in the funding and organization of activities oriented toward the specialist training of scientists and professionals. This training offered and directed by FUMEC covers all of the steps necessary for the installation and development of MEMS technology in Mexico. Another function that we have identified on the part of FUMEC in the training of human resources is the mobilization of specialists in the microtechnology field. This involves co-financing with other participating governmental institutions to bring in specialists, coming principally from the United States, to impart cutting-edge knowledge on MEMS development to Mexican researchers. In some cases, FUMEC also provides funding to support doctoral student or researcher visits abroad in the field of MNTs.

Promotion, dissemination and commercialization of microsystems technology

With its Microsystems Programme initiatives, FUMEC developed a variety of activities aimed at promoting, spreading and commercializing MEMS technology in Mexico. These activities, as in the case of human resource training, have been cross-connected through various projects and initiatives.

Promotion of the development of MNTs (and MEMS among them) has been undertaken in practically all academic and professional fora where FUMEC has participated as an organizer or where it has been invited to present its programme for MEMS development in Mexico. From early in this century, the development of MNTs has been one of FUMEC's strategic areas. The foundation decided to embrace MEMS development following a meeting with specialist MNT researchers in the United States, recognizing the technical and economic potential that were heralded with the emergence of these new technologies. In the presentations that agents of the foundation use when participating in events, we find the arguments in favour of these potentials, primarily economic. As we have previously mentioned, FUMEC initiated the Microsystems Programme at first along the border area, and quickly extended it to the rest of Mexico – apparently following the realization that the development of these technologies could be inserted into the race to develop nanotechnologies, which are seen as an opportunity to overcome the shadow of underdevelopment.

It is not easy to stay abreast of the latest in new technologies. During our research on the development of MNTs in Mexico, one case caught our attention. It involves a small, specialized footwear producer with a line of shoes for diabetics. The company delivered a presentation in an academic forum on nanotechnologies in Mexico in 2008. Its interest was in an innovative modification of the shoes through the introduction of silver nanoparticles in the sole with the aim of avoiding foot infections among persons afflicted by that illness.[6] The initial idea to apply nanotechnology to the shoes came up in a discussion shared by FUMEC on the development of nanotechnology a few months earlier. The person in charge of the diabetic shoe project attended that event and came away convinced of the technical applications of nanotechnology: his presentation in 2008 caught the attention of researchers in the nanotechnology field. The company, in partnership with researchers from various research centres, began researching in this area with funding from CONACYT. In this process, FUMEC performed the role of a channel of information in the promotion of the potentials of nanotechnologies. That role has proven to be important in the dissemination of these technologies.

With regard to the development of microsystems, we have discovered MEMS courses on offer in various educational institutes that have not participated in FUMEC's initiatives. One of these cases is the Microtechnology and Embedded Systems Laboratory (MICROSE) at the National Polytechnic Institute, a laboratory that currently undertakes activities involving MEMS and the training of human resources in that field. In an interview, the director of this laboratory explained that the reorientation of the research in this laboratory to MEMS development occurred in a context in which the emergence of microsystems in Mexico was in full swing and the discourse focused on promoting the development of these technologies as a window of opportunity for the country. In the process of integrating MEMS as a research line in the laboratory, a key agent was the director himself, who was already familiar with MEMS technology since he had participated in at least one event at the Mexican Petroleum Institute organized by FUMEC. In fact, during the interview, the director of the laboratory made reference to FUMEC as the agency that had, from the beginning, driven the development of MEMS microsystems technology in Mexico.

We put forth these two cases in this chapter in an effort to better consider the spread of new technologies. We find it interesting that within the theory of technology change and innovation systems it is widely recognized that the spread of technology moves with the flow of information among different actors (OCDE, 1997) and that these technological changes occur in discontinuous processes (Pérez, 2004). In both cases, the flow of information among actors and the complexity of the processes of technological change is confirmed, with FUMEC playing the role of producing certain information and then conveying it. In some cases, the efforts taken in relation to the spread of this new technology we identify as a 'latent function' (Merton, 1949) since it is not a role that FUMAC seeks to fulfil.

On the matter of the commercialization of products based on MEMS technology, we have already noted that the initiatives of CAP-MEMS and CMM have this point within their objectives. CAP-MEMS, created in 2004, is a spin-off of FUMEC whose main goal is 'to facilitate linkages between businesspeople, academics and decision-makers with the aim of forging broad collaborations that allow for the development of new products and business' (FUMEC, 2006). In the case of CMM, created in 2006, in one of its stated objectives it specifies the 'assistance and promotion of courses, diplomas, fora and specialized events of technological visioning and management, intellectual property protection, high technology business, commercialization, etc.'.

Another initiative for the commercialization of products based on MEMS technology is the AERI-MEMS, created in 2008. We mentioned earlier that this initiative, led by FUMEC, operated within a CONACYT programme. Within this, initiative activities were undertaken to link entities principally in the productive and academic sector, with the goal of development projects of MEMS application in the health, food, automotive and energy sectors. The projects that have been supported within the framework of this initiative are required to include the participation of companies that produce products related to the field. A total of three projects have been put into operation within this framework, the first being a 3D video camera currently on the market that has been developed by Prefixa. FUMEC supported and guided this small business through the presentation of its video camera project to CONACYT and the SE, to seek funding for manufacture. The second project is a joint development between UACJ and Team Technologies for the production of a switch based on radio frequency micro-electromechanical system (RF-MEMS) technologies with application in portable telephones. A patent has been filed and the project has been partially funded by CONACYT. Team Technologies is currently listed as a technology-based business that specializes in significant innovation capabilities that have been acquired thanks to the public funds obtained with the support and guidance of FUMEC. The third innovation project is the development of MEMS-based biomedical systems for neonatal respiratory flow monitoring. This is a project developed by the small technology-based business Biomedical Integral, which specializes in the manufacture and commercialization of prenatal incubators, with funding coming from CONACYT, while the MEMS aspect is provided through the UACJ and FUMEC supports the creation and monitoring of the project.

Discussion and conclusions

Over the course of this chapter we have traced the emergence and development of MEMS technology in Mexico from the beginning of the century, when FUMEC began playing a central role in the promotion of these technologies as a window of opportunity for Mexico to the development of prototypes and its link with potential users of these technologies. Indeed, the history of the emergence and installation of microtechnologies in this country confirms that its emergence had its origins in the initiatives carried out, in various stages and at different levels, by FUMEC.

The characterization and qualification of the roles played by FUMEC provides clues to better understand the place it has occupied and occupies today in the dynamics of the installation, development and spread of MNTs in Mexico. In the first section, we saw that the formation of the foundation’s governing board conferred a degree of prominence to the organization. In effect, what we have characterized as a ‘political network’ allowed the foundation a certain mobility through other institutional spheres as it formulated and implemented programmes without being significantly affected by the changes in political power in the country. FUMEC is positioned to work with different government levels (local, regional, national) and, through the information that it produces and acquires, the foundation builds knowledge in local and regional contexts. This reflects a process of learning for the organization that allows it to construct social capital and have influence on the scientific and technological systems at different levels throughout the country, either by participating in its own project convocations or as a member of evaluating committees.

With respect to the roles carried out by the philanthropic and non-governmental organizations in scientific and technological change, the academic literature that we have briefly presented in this chapter distinguishes at least seven functions: (1) funding research activities; (2) infrastructure installation; (3) promotion of new science and technologies; (4) application of new technologies; (5) creation of scientific networks; (6) policy formation; and (7) changing institutional models. Through our analysis of FUMEC's Microsystems Programme, we have seen that this organization has carried out activities in these areas. This includes a role in the training of human resources, as well as in the production and flow of information on new technologies for their promotion, dissemination and commercialization. The study of the installation and the development of MEMS technologies in Mexico has provided indicators that enable us to understand the new dynamics in the development of new science and technologies. We see that organizations different from those traditionally studied are fulfilling roles that previously were performed by other agencies in the institutional spheres. These changes in the roles of different institutional spheres require further empirical study to examine those new dynamics.

Moreover, the FUMEC case study and the development of MEMS in Mexico show how these kinds of organizations, which are not normally considered as part of the institutional spheres of academia, government and industry, can perform key roles in the processes of the installation and development of new technologies. Here it is important to note the profile of FUMEC as a transnational organization, operating between Mexico and the United States, has been created and moulded by the context of the complex relationships between those two countries.

The importance and centrality of this foundation in the development of these technologies in Mexico, as we mentioned in the introduction to this chapter, puts into question the modelling of the relationships between different organizations that have been proposed in the academic literature, models that are typically represented by a configuration of actors and their relationships in the form of a triangle. Further, we note the presence of these organizations, which we characterize as 'philanthropic' and 'non-governmental', among others, has already been the subject of various social science investigations. Drawing from our observations of the case of MEMS in Mexico and supported by other research on these organizations, we propose extending the range of entities to be taken into account within these kinds of studies. To include these organizations as a fourth sphere in the relationship models, we propose the figure of a tetrahedron, where each vertex represents each of the spheres and the edges represent the possible relationships in the processes of production use and dissemination of new knowledge (see Image 3). It is worth mentioning that this representation of relationships does not imply that it is necessary to unite the four institutional spheres to achieve the production and application of new knowledge.

[INSERT IMAGE 3 HERE]

Image 3. Tetrahedron of the possible relationships in the production, use and dissemination of new knowledge.

Furthermore, we emphasize the policy implications of the models of production and application of new knowledge, because these theoretical models are conveyed by practitioners and decision makers (advisors, consultants, politicians, etc.) as models for technological development that should be reproduced. This has significant economic and social implications, since it is from these models that science and technology policies are created that are strongly tied to policies for economic and social development. Considering that philanthropic, non-governmental and other organizations provide support for development, they could be useful in the formulation and application of science and technology policies, above all in contexts where we are seeing new dynamics in technological development.

Finally, this leads us to highlight the importance of these new actors in the processes of the installation and technological change in several contexts and in the dynamics of different stages of those changes (from the promotion through to the commercialization of new technologies). The actions and initiatives that shape these changes may originate in global dynamics (such as the development of micro and nanotechnologies, and other emerging technologies) and the progress of the installation process may adapt in response to the dynamics of local contexts.

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[1] FUMEC operates a number of programmes in the health, education, and scientific and technological sectors in Mexico.

[2] The *debt-for-nature swaps* model consists of reserving a part of the foreign debt of a country in exchange for its cooperation in conserving its own environment (González-Fernández and Pérez-Ímigo, 2008).

[3] The lack of continuity in science and technology policies, as in other areas, is one of the characteristics of Mexico's political system. On this point, Casas and Dettmer (2007) have noted that this discontinuity is an obstacle that impedes the definition of a consistent paradigm in national science and technology policy.

[4] In 2008, FUMEC's CMM in coordination with the MANCEF foundation, the Science and Technology Board of the State of Jalisco (COECYT-Jalisco) and the National Chamber of Electronics Industry and Information Technologies (CANIETTEI) organized the COMS international conference in Puerto Vallarta, México, with the principal goal of bringing together the scientific and economic sectors involved in the field of MEMS technology.

[5] The *MexEEdev* is a forum that is held at least once per year in Mexico, dedicated to the developers of electronic systems and embedded programs (FPGA), which are the technologies tightly tied to MEMS. In fact, FUMEC's Microtechnologies Programme encompasses these technologies.

[6] A quarter of the people afflicted by this disease have complications of 'diabetic foot', which is characterized by foot infections that can lead to the amputation of extremities (Bogdanchikova et al., 2009).

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