Factors Affecting the Functionality of Postgraduate Programs in Natural Sciences and Engineering in a Northwest State in Mexico

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Abstract

From the researchers' perspective, the study aimed to identify factors affecting the functionality of postgraduate programs in natural sciences and engineering in a north-western Mexican state. Through the typical cases method, 25 researchers who worked in six doctorate programs in the region were selected. From the perception of these participants, the functionality of the postgraduate program is affected by external factors, such as the weakness of other participants' actions in the scientific and technological innovation system in the region; and internal factors, in particular, difficulties concerning the formation processes and strategies for academic training and technology transfer into the region.

Keywords: functionality, innovation, postgraduate program, transfer

1. Introduction

In the state in which the study was conducted, the postgraduate programs began to take place in the seventies of the last century, when the Sonora Institute of Technology (1975), the University of Sonora (1978) and the Monterrey Institute of Technology (1980) opened master's programs. The development stage of these programs, which covers from 2000 to date, is distinguished by an accelerated growth in the number of programs and students as well as an increase in the participation of private institutions, which already possess more than 50% of the enrolment at this level of study (Rodríguez, Urquidi, & Pérez, 2011).

In 2010 there were 25,035 alumni statewide with postgraduate studies, which ranks the region in the fifth national place in proportion with those of similar studies within the economically active population. However, this growth has not been balanced in the various school disciplines, but it has happened primarily in the areas of social sciences and education-humanities, which in 2008 possessed 86.7% of the total number of graduate students in the state (Foro Consultivo Científico y Tecnológico [FCCyT], 2011).

Moreover, it should be noted that 32 out of the 100 postgraduate programs in the state, (representing the 32% of the programs) are registered in the National Postgraduates Quality Program [NPQP] (Consejo Nacional de Ciencia y Tecnología [National Council of Science and Technology, CONACYT, Spanish abbreviation], 2012) and only one program had received the international competency certification that this agency gives. In addition, only five institutions in the region, all of them being public, have postgraduate programs recognized as a quality program by CONACYT.

Studies in the region relating to postgraduate programs are scarce, as only five publications focused on the topic were identified from 2002 to 2012 (Mungarro & Montiel, 2011; Rodríguez & Pérez, 2009; Rodríguez et al., 2011; Valdés, Vera, & Carlos, 2012; Valdés, Vera, & Estévez, 2012). No investigations were found, prior to the present, where the functionality of the postgraduate programs that are taught in the region and the role they play within the regional system of technological innovation are directly addressed. It is evident a vacuum of knowledge with regard to the development of competencies of graduates of such programs, and its integration in the work place

and the linking of research with the needs of the region.

This study analyzed the functionality of doctorate programs in natural sciences and engineering in a north-western Mexican state, which were registered in the NPQP of the National Council of Science and Technology. By adopting the perspective of a comprehensive evaluation proposed by Stake (2006), the study identified aspects that affect the functionality of these programs through the inquiry into perceptions.

In Mexico it is expected that postgraduate programs contribute decisively in the consolidation of Higher Education Institutions (HEI) within the scientific and technological systems of innovation, it is expected they support the creation and transfer of knowledge and technology to their regions. Functions are assigned to postgraduate programs such as: (a) encourage the scientific and technological development through supporting research, (b) stimulate links between enterprises and institutions of higher education, and (c) promote innovation in enterprise and the training of human resource of high scientific quality (CONACYT, 2012).

The fundamental strategy followed in Mexico for the development and strengthening of this level of training of human resource was the creation of the NPQP, which is administered in coordination with CONACYT and the Secretariat of Public Education through the Undersecretary of Higher Education. The NPQP proposes that the country have institutions that offer national and international recognized quality postgraduate programs, which are characterized by attending the social and productive needs through the creation and application of knowledge. In this way it promotes researchers and graduates of these programs to contribute to the achievement of greater autonomy, competitiveness, and therefore growth and sustainable development of the country (CONACYT, 2012). It is expected that the programs included in the NPQP develop a high level of scientific competency in its graduates, all of which are currently at the top of the pyramid of the required competencies in the labor force in learning communities (Lanvin & Fonstad, 2009).

The study accepted as a theoretical base, the quality evaluation model of HEI developed by De la Orden, Asensio, Biencinto, González, and Mafokozi (2007), who argue that the quality of the institutions is the result of a relationship of coherence between three closely interrelated dimensions: *functionality*, *efficiency* and *effectiveness*.

Particularly, the dimension of functionality was considered in this study because it plays a central role in the quality of the HEI (De la Orden et al., 2007). Functionality expresses the level in which HEI get their targets to respond to social needs and how they manage to satisfy them. This congruence between objectives and the results of the HEI with the social demands are expressed in four forms: (a) the input from the institutions, (b) the organization and its function, (c) the outputs and outcomes of the programs, and (d) the objectives and targets in relation to the human capital formation.

The functionality of the postgraduate programs from the perspective of the *Triple Helix Model* lies in their ability to be integrated in the interaction of three broader institutional areas: government, business/industry and higher education (Etzkowitz, 2003). This allows the HEI to integrate important elements within the Systems of Scientific and Technological Innovation (SSTI) and contribute to its effective performance through the elaboration of theoretical development models based on science and technology, the development of policies regarding science and technology, the management of resources for the development of projects of scientific-technological innovation, promotion of relationships between the various players in the innovation system and the formation of qualified human capital (FCCyT, 2008; United Nations Organization for Education, Science and Culture [UNESCO], 2009; Organisation for Economic Co-operation and Development [OECD], 2007).

The studies regarding the training of scientists in Mexico can be divided into three main groups: the first is integrated with those who have addressed the topic from an educational policy perspective and its impact in the scientists' training (Basulto & Grediaga, 2011; Díaz, 2006; FCCyT, 2011; Rivas, 2004; Rodríguez, 2009; Sánchez, 2008; Tinajero, 2006); the second refers to studies regarding the sociology of the professions (Didou, 2009; Ibarra, 2000); and a final group-which is part of this study-, that addresses the problem with a more focused approach in education, taking a specific interest in the training processes (De la Cruz, Díaz-Barriga, & Abreu, 2010; García & Barrón, 2011; Moreno, 2007; Luna, 2008; Reynaga, 2002).

Considering the importance of the postgraduate programs in the promotion of the regional development based on knowledge, the present study aimed to investigate, from the researchers' perspective, the factors that affect the functionality of these curricula. The results will provide information to implement improvement strategies to the curricula. The study was conducted with a qualitative and phenomenological approach which assumes the supposition that individuals, through their interactions with the objects, events, and people form beliefs that are influenced by the way they experience and act within their social contexts (Creswell, 2009; Mertens, 1998).

The topics of the study were: (a) mechanisms that are used for the training of scientific competence in students, (b) difficulties that are identified in the training of scientific competence, (c) perspectives on the impact of the postgraduate program and its graduates in the regional development and (d) opportunity scenarios to strengthen the training in the postgraduate program and the regional development.

2. Method

2.1 Participants

Using the key informant method, researchers who worked in six natural sciences and engineering doctorate programs from three public HEI in the state and registered in the NPQP, were selected. The participants of the study were part of the basic academic group of the program and had more than five years of experience in the program. The sample size was determined by theoretical saturation criterion, i.e. when new interviews ceased to provide relevant information to the study.

Based on the above criteria, 25 professors with an average age of 53 years old were included in the study, 14 of them (56%) were male and 11 (44%) were female. All of them had a doctorate degree in sciences, with full-time permanent contracts as researchers, and belonged to the National System of Researchers in Mexico.

2.2 Techniques

An in-depth interview was utilized as a technique for achieving a more complete description about how they perceive the teaching aspects relating to the postgraduate program. The interview with the professors began by asking the following opinion questions: What mechanisms do you perceive are used for the training of scientific competencies in the postgraduate student programs? What are the difficulties that researchers identify in teaching the scientific competencies in postgraduate student programs? What are your perspectives regarding the impact of the postgraduate program and its graduates in the regional development? What opportunity scenarios do you visualize to strengthen the impact of the postgraduate program in the regional development?

2.3 Procedure

First, the directors' informed consent of the postgraduate was requested to obtain access to the field study. Subsequently, the selected researchers were contacted for conducting the interviews, to whom the objective of the study was explained as well as their voluntary participation and permission to record the conversations was requested. Interviews were carried out in spaces verified with the necessary privacy to safeguard the information given by the researchers; the interviews' duration ranged between three and four hours, and it was conducted in two different sessions according to the researchers availability of time.

For the analysis of the information the inductive approach proposed by Thomas (2006) was used, generating initially 50 analytical categories that were reduced to 30 in a subsequent analysis. The ATLAS.ti 5 software was used as support for the analysis of the information.

2.4 Ethical Aspects

The ethical aspects of the research were verified to ensure the informed and voluntary participation of the professors (researchers) in the study. In addition, initiatives were taken to guarantee the confidentiality of the information obtained and to increase the analyses' validity and credibility.

2.4.1 Measures to Strengthen the Validity and Credibility of the Study

The credibility and validity of the findings were strengthened through strategies such as the use of a theoretical sampling and the triangulation of techniques of data collection and researchers participating in the analysis. A coherence verification was realized by asking to some researchers unaware of the thematic that, based on the analysis of the categories, identify the parts of the text that exemplify them. Finally, a credibility control was performed at the moment to discuss with the participants the analyses.

For the data analysis, two external researchers with ample domain of the thematic and experience in conducting the technique were involved in the project.

3. Results

3.1 Practices of Postgraduate Programs for the Formation of Competencies in the Students

The content analysis of the speech on this subject was performed from the implicit and explicit categories of the curriculum. Within the explicit category were included all those practices that had been formally defined as competencies, activities and forms of assessment associated with them. On the other hand, those teaching activities where there are not established clearly purposes, teaching strategies and assessment forms were included in the implicit category (see Figure 1).
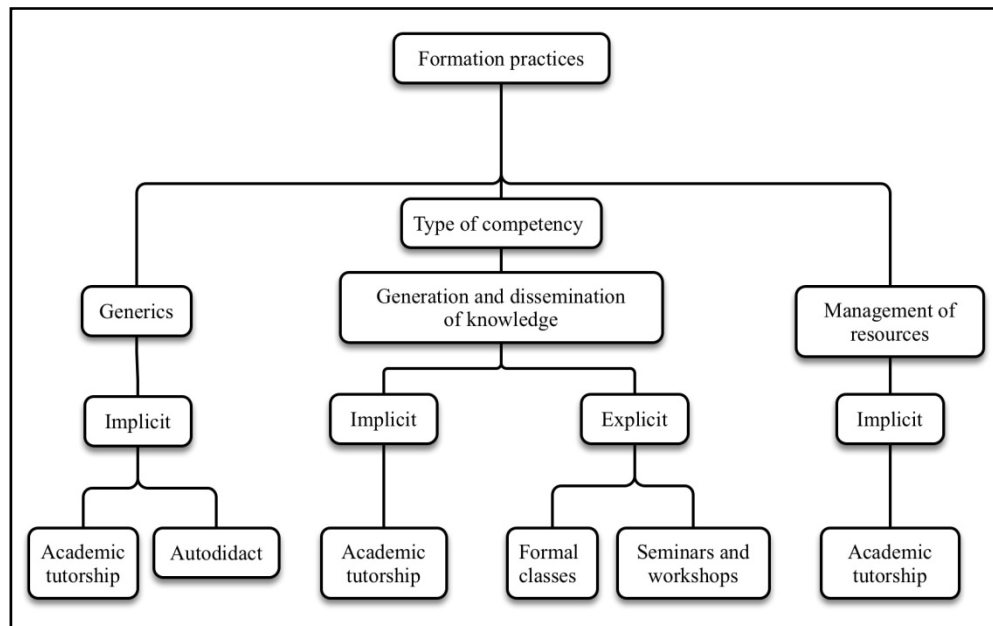
Figure 1. Researchers' beliefs in relation to the mechanisms of formation of scientific competencies in postgraduate students

3.1.1 Teaching Practices of Explicit Nature

It was observed that few teaching practices directed to the formation of competencies related to the generation and dissemination of knowledge are addressed explicitly in the curriculum of the postgraduate programs. Within these training strategies the professors mentioned formal materials, workshops and seminars.

Researcher 12 "there are courses with certain approaches, for example, students studying milk products, those who take courses that they will use for their experiment..."

Researcher 8 "in the first semester they are given basic research courses…"

Researcher 4 "a significant factor in the formation of postgraduate students is the research seminars, where progresses of their thesis project are presented…"

3.1.2 Teaching Practices of Implicit Nature

An important part of the teaching practices referred by the researchers as used in the programs can be classified as implicit (academic tutoring with its supervisor, academic visits and meetings with groups of researchers).

Of the various strategies that were grouped in this category the researchers mentioned the academic tutoring as the most important, especially the one that the student receives by the supervisor.

Researcher 3 "a large part depends on the supervisor who teaches them to establish a research problem and formulate their hypotheses…"

Researcher 12 "the supervisor is who should guide the student in terms of the courses that must be taken and the competencies in which must be working on to develop its project…"

However, taking in consideration that many aspects of these practices are not being clearly defined, the student formation depends on the beliefs of each supervisor about the aspects relative to its function and the competencies that the student must acquire as a result of this formative practice.

Researcher 1 "the supervisors perform an important role in the formation of the student and each one carries out this function in the way in which it is estimated convenient for the student and even according to their attitudes and personal characteristics…"

Researcher 7 "supervising is a job in which everyone performs it in the way it considers convenient, that is why some students learn more or less than others and advance at different rhythms..."

3.2 Difficulties Identified by the Researchers in the Formation of the Scientific Competencies in Students

The analysis of what was expressed by the researchers in this thematic axis allowed to group into three categories the difficulties related to the formation of the scientific competencies in postgraduate students, which are relative to: the economic resources, the student or the teachers themselves (see Figure 2).
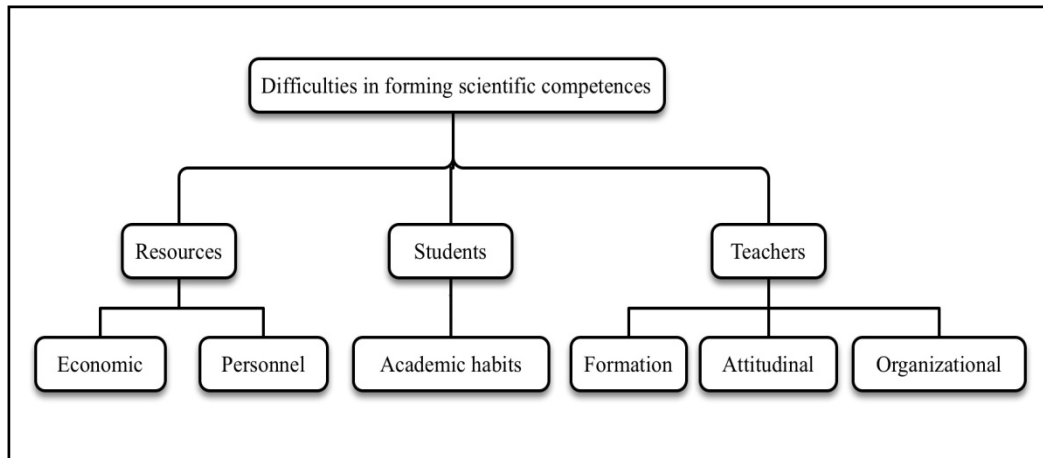

Figure 2. Difficulties perceived by researchers in training scientific competencies in the students

3.2.1 Relative to the Lack of Economic Resources

In this section the researchers mentioned deficiencies in the physical infrastructure, which make it difficult to provide students a proper workplace, presence of outdated laboratory equipment and delays in the acquisition of materials and products necessary for the work in the research projects.

Researcher 3 "sometimes the research projects and in particular the work of the students is delayed by difficulties in the acquisition of products and other inputs by absence of resources..."

Researcher 7 "our students sometimes do not have adequate workspaces where they can write and work in peace. On occasions I don't have where to locate my students..."

Within this category are also mentioned the lack of institutional support to enable students to develop their projects when they do not obtain external financing on the part of the supervisors.

Researcher 6 "the supports with which we account almost always come from external resources, and that when our projects are not approved, we do not receive any support from the institution to continue with the works where the students are involved, so that the formation of these is affected..."

Researcher 11 "it is impossible to do research in the sciences without money because the products cost much money, who has no money does nothing. That should be required, the researcher should have money to be able to have students…"

3.2.2 Relative to the Students

In particular, they mentioned the partial dedication to the program and the little development of habits of academic work and methodological competencies that facilitate them to respond efficiently to the academic requirements of the postgraduate program.

Researcher 2 "sometimes the same student comes with a mentality that is not suitable to work in the postgraduate program and is reluctant to change it..."

3.2.3 Relative to the Teachers

Responses from researchers about the difficulties they perceive in the teachers to facilitate the development of scientific competence in the students were grouped into: (a) little pedagogical formation of teachers, (b) lack of commitment to the students formation from some teachers, and (c) organizational aspects of the educational institutions.

With regard to the formation, they mention that in general the researchers responsible for the students have no training as teachers, therefore they conduct its practices based on their empirical experience without the proper

theoretical basis that justifies them.

Teacher 20 "most of us don't have formation in education, we teach in the way they did so with us. We are not aware of the new models like that of competencies and in fact do not know what it is about..."

They also point out that the lack of commitment from some researchers with the formation of students also affects the development of competencies. They argue that these do not show a disposition to support students in the conduct of their tasks and even sometimes are not treated with the respect they deserve.

Researcher 21 "there are researchers very dedicated to their students, however, there exist others that do not provide them attention, do not review their projects and works. They even come to show negative attitudes towards the student that affects the willingness of students to learn..."

The organizational practices of the institutions cause that the researchers are subjected to demands of various types. They mention that in many cases serve in various educational programs and perform administrative functions which make them have less time in the attention to the students that they supervise, and even in teaching their classes.

Researcher 15 "the time for researchers must be distributed with the assistance to meetings; the researcher has to be dealing with them, as: What should I do first? Because there are a million things to do..."

3.3 Perspectives of the Researchers about the Impact of the Postgraduate Program and Its Graduates in the Regional Development

To present the information recovered from the researchers in this thematic axis, the information was divided in regard to the contributions of the postgraduate program and its students in the region, and on the other hand information related to the difficulties that appear for a more important impact in the regional development.

Researchers emphasize that postgraduate programs tend to impact positively on the development of the region since they form specialized human capital that is going to locate in the HEI within the state and in companies where they put into practice their knowledge, possessing the competencies to meet the needs and demands of the regional companies.

The reasons which researchers attributed to the limitations mentioned above were grouped into four types, according to whether they referred to structural aspects of the state, attitudes of the companies themselves, deficiencies in the formation of students and lack of efforts of the postgraduate programs to communicate with the companies (see Figure 3).
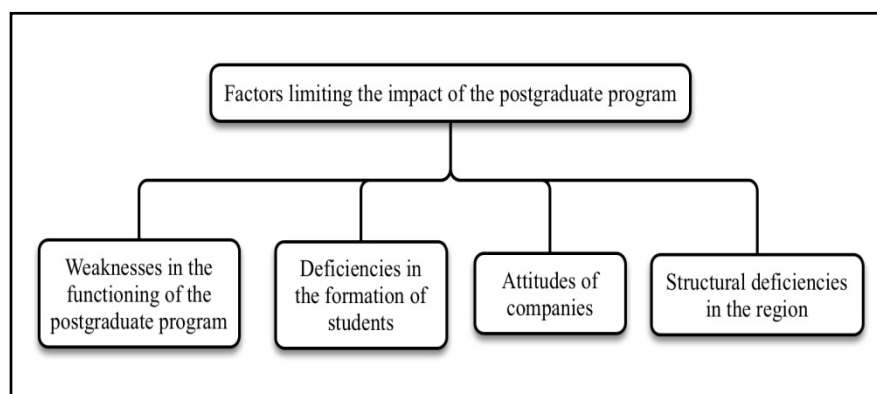

Figure 3. Factors limiting the impact of the postgraduate program in the region

3.3.1 Structural Factors

Within the structural factors are mentioned the little presence of companies in the state that need and/or require graduates of postgraduate programs, the lack of permanent jobs for academic research in institutions of higher education and in the public sector in general.

Researcher 5 "there are few academic opportunities for a doctoral graduate... For those who fail in obtaining a permanent job like researchers, there exists the food industry as an alternative option, but in this state is non-existent..."

3.3.2 Attitudes of the Companies

Researchers point out that even though companies approach postgraduate programs looking for solutions to some of their problems, they are very reluctant to invest in research projects, they practically want all services given to them. The same thing happens with the graduates since many companies are not willing to spend on hiring them for research and technological development activities.

Researcher 4 "with the companies the relations are good, but we don't have enough resources to meet their needs, because they want everything to be free; most of the requests that come here are: 'we need to tell us how to do'... then they bring a big problem and don't want to invest..."

3.3.3 Relative to the Formation of the Students

With regard to the formation of the students, researchers admit that the postgraduate programs are not being transformed into the reality that many of its graduates will not find employment in the HEI or state enterprises.

Although researchers know that one of the solutions to this problem is to create in students the necessary competencies to establish their own businesses and create businesses based on the knowledge that they have acquired, the postgraduate programs do not include the development of these competencies in its curricula, which puts the graduates of the same in a clear disadvantage.

Researcher 1 "There are some students with the idea of developing a business, but they do not have any formation to do it; I think that they could do it and easily, there are many things that can be done and that would work very well..."

3.3.4 Relative to the Functioning of the Postgraduate Program

Researchers recognize that in the majority of postgraduate programs are lacking efforts to establish better communication with the companies and, in particular, to sensitize them regarding how graduates of the same can support them to improve their competitiveness.

Researcher 8 "we do the job bank in an informal way due to the requests of universities or companies; it is assumed that this is a function of the department of exchange. I assure you that many researchers are not interested in linking with the businesses, they see it wrong, criticize it; so with this formation the student is not going to do it…"

3.4 Opportunity Scenarios for Strengthening the Formation of the Postgraduate Program and the Regional Development

In this thematic axis researchers mentioned some areas of opportunity in terms of possibilities for strengthening the impact of the postgraduate program in the regional context, such as: (a) build on the experience and increase the link with the graduates of the same that are inserted in the business sectors and government in the state, (b) enhance the relations of the postgraduate program with the business sectors and government, (c) encourage the creation of an entrepreneurial spirit in teachers and students, and (d) promote the participation of teachers and students in interdisciplinary groups (see Figure 4).
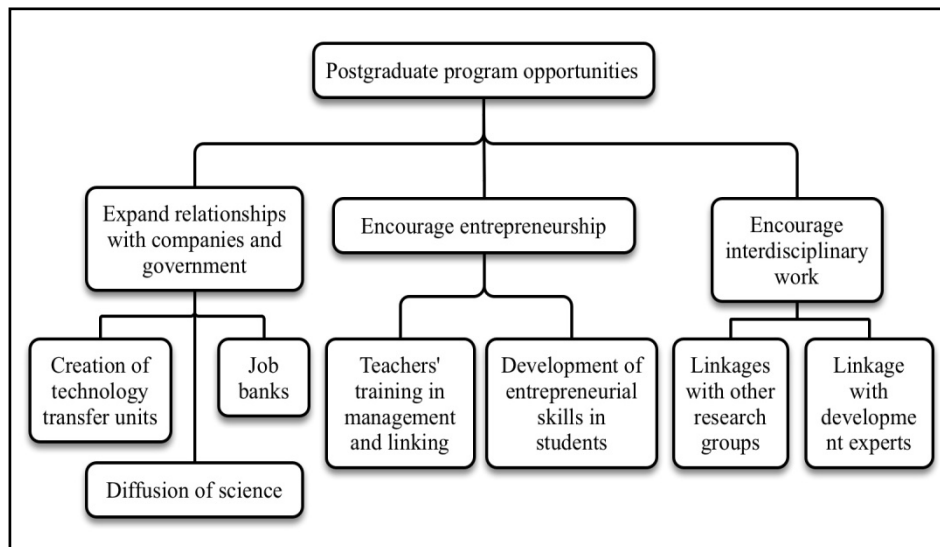
Figure 4. Perception of the researchers about the opportunities of the postgraduate program to impact the regional development

3.4.1 Take Advantage of the Experience and Increase the Link with the Graduates

With regard to this point, the researchers mentioned that it is necessary to strengthen the ties with the graduates who are working in various private and public companies in the state, to take advantage of their experience and the possibility of carrying out joint projects.

Researcher 11 "it is necessary to know exactly what they are doing and where our graduates are located to promote the realization of projects, especially when they are working in the public and private sector…"

3.4.2 Expand the Relationships of the Postgraduate Programs with the Business Sectors and Government

Researchers recognize that to increase the impact of the postgraduate programs it is necessary to strengthen relations with the business sectors and government. For this purpose they propose actions such as the creation of units to transfer innovations, labor exchanges where the students' services are offered, in general a wider diffusion towards the community, and in particular toward the companies, regarding investigations and projects carried out in the HEI.

Researcher 5 "We must establish connections with the government and the few companies of technological base that exists in the region so they can know what we can offer them as well as our graduates to improve its productivity and competitiveness …"

3.4.3 Promote the Creation of an Entrepreneurship Spirit in Researchers and Students

The researchers noted that it is necessary to change the conception of the traditional formation which prepares students as future employees, and instead of it develop in them an entrepreneurial spirit that allows them to possess the skills to create their own businesses. They recognize that this possibility would be more effective if included the formation of the teachers.

Researcher 3 "first it is necessary an enterprising culture in the researchers and only then can be transmitted to the students..."

3.4.4 Strengthen the Intra- and Interdisciplinary Work

Researchers report that it is important, given the complexity of science and current demands, to promote work with other colleagues in the same areas and point out the importance that students visit other national and international institutions.

In this section they also emphasize the need for students to participate in interdisciplinary groups, especially with researchers in the social areas that have greater knowledge and skills with respect to the associations with the actors of the social and economic development of the state.

Researcher 19 "transdisciplinarity, we need to get together with economists, we need to make increasingly transdisciplinary projects, not to say: technology is this... and there I leave it, we need an economist integrated in

the same project, who sees where this technology is needed, in addition to know where it can be accommodated better…"

4. Conclusion

It can be concluded that from the perspective of the researchers the functionality of the postgraduate programs is affected by external and internal factors of the programs themselves.

From an external point of view there are mentioned the limited and little synergistic actions of the various actors of the SSTI (HEI-Companies-Government), which are necessary to strengthen the impact of the postgraduate programs in the development of the regions (Carlsson, 2005; Yusuf, 2006). This agrees with the findings of other studies, which reported little investment in science and technology in the state, little development of enterprises of technological basis and difficulties in the coordination of the various actors of the SSTI (FCCyT, 2011).

However, the social value of these programs is limited also by actions relating to its own processes of formation and the absence of clear strategies to link and transfer knowledge and technology to the region. This conclusion involves a significant degree of displacement of the functionality of doctorate programs in science and engineering in the state in terms of the congruence between its results and the demands of the regional development (De la Orden et al., 2007).

Internally, the functionality of the postgraduate programs is affected in a negative way by the predominance of teaching practices that do not have defined explicit objectives, means and even their forms of evaluation. This makes it difficult to achieve a homogeneous graduate profile of the students (Posner, 2005; Zabalza, 1997) and explains to some extent the differences in the levels of development of the competencies of graduates that have been reported in other studies (Valdés, Vera, Carlos, & Estévez, 2013). This type of formative actions is guided by the customs, interpretations and attitudes of each researcher, which gives rise to a large difference in the formative opportunities for the student (De la Cruz et al., 2010).

The limitations found in the teaching practices for the formation of scientists can find an explanation in the undesirable effects that have been produced by the public policies for higher education in recent decades; paradoxically, those policies have promoted the investigation but neglected the teaching and academic formation (Estévez & Martínez, 2011; Estévez, Arreola, & Valdés, 2014). In their research on Mexican academics, the authors mentioned above conclude that those who dedicate more time to research that teaching, are less interested in improving their teaching methods.

Another aspect that makes the functionality of the postgraduate programs difficult and that is associated with the processes of formation of the same, it is that there is maintained a traditional vision of the investigators' training where there are not included formative aspects directed to the development of the necessary competencies for the transference of knowledge and the development of companies of technological base, which is related to the current vision of the scientist and its role in learning communities (Vera & Valdés, 2013; Yusuf, 2006).

These covered aspects relating to the creation of stronger alliances with other actors of the regional development as well as changes in the way of conceptualizing the formation of the student of such programs, which in general is realized in a traditional way because it focuses on the creation of competencies in students to be employed and not in those who help them to undertake on the creation of their own companies of technological base, which has already been proposed in the policies of higher education in Mexico (Arredondo, Pérez, & Morán, 2006; Asociación Nacional de Universidades e Instituciones de Educación Superior [National Association of Universities and Institutions of Higher Education, ANUIES, Spanish abbreviation], 2000).

These findings suggest the need for revision of the training practices, and strategies that are developed in the postgraduate programs in natural sciences and engineering in the region, so they will allow increasing the functionality of such programs and thus its impact on the development of the region. However, it also shows that it is necessary to carry out actions to improve the efficiency of the SSTI of the state so that they could take it as an advantage, according to the regional development, the knowledge, the technologies and the human capital that are developed in the postgraduate programs in these areas.

Without these changes the scientific and technological research compromised with regard to the postgraduate programs under study, would hardly be in a position to participate in the creation of regional poles of investigation, proposal released by the ANUIES (2012) in response to "a global movement, especially in countries that are transiting from emerging to economies based on knowledge and technology, as there are the cases of Brazil, Russia, India and China (BRIC)" (p. 49).

This recommendation is of great importance in countries such as Mexico, where the universities have had -and they must continue to do so- a fundamental role in the research and development and can contribute to "the

creation of better living conditions and better jobs from the utilization of the economic and social scientific research and the university technological development" (Organización de Estados Iberoamericanos para la Educación, la Ciencia y la Cultura, 2012, p. 55).

It is important to specify that a limitation of this study is that the analysis of the functionality of the postgraduate programs was conducted only from the perspective of researchers, which makes necessary further studies that address the problem from the perspective of other actors involved.

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