PHYSICS ENGINEERING : A Career Created in Mexico to Improve the Coverage of Actual and Future Technological Needs.

J. Morales, M. Romero-Romo, R. Luévano-Enriquez and J. Granados-Samaniego.
Universidad Autónoma Metropolitana, Unidad Azcapotzalco,
División de Ciencias Básicas e Ingeniería, Area de Física,
Av. San Pablo 180., 02200 México, D. F., email: jmr@hp9000a1.uam.mx

Abstract. *In this work, we show the evolution of the Physics Engineering (PE) career offered by the Universidad Autónoma Metropolitana (UAM) in Mexico city. For that, we analyze its present and changing status which includes the fact that the scheme implemented by UAM has been taken as an example for the creation of the same career at other important Universities in Mexico such as the Iberoamerican University, the Monterrey's Technological Institute of Superior Studies, the University of Yucatan and the University of San Luis Potosí, for the time being. Also, we show how the Physics Engineering program, at undergraduate level, has played an important role in the creation of a postgraduate program in Sciences and Engineering Environmental and Materials, with the option in Physics of Materials, which cover the specialization, Master and PhD degrees and that will be promoted soon by UAM. Also, we give a special mention to the fact that Mexican PE program has been used as model of undergraduate proposals recently implemented in Latin America; particularly in Colombia and Chile where equal and equivalent undergraduate programs in Physics Engineering and Applied Physics have been created. Thus, the program of the Physics Engineering career is an interesting alternative in the formation of the new engineer as well as an effective strategy for inter-university collaboration at under and postgraduate levels.*

INTRODUCTION

The ever-accelerating pace of change in the modern world, driven largely by progress in science and technology, is creating benefits and challenges for the educational centers. On one hand, improved technology, originated in large part by university research, can provide new tools for teachers and students. On the other hand, the changes induced by such progress are at the root of major disruptive forces that put stress on universities and institutes or centers of research for which, it is important to know whether today´s university programs prepare graduates to perform effectively in our changing world.

Essentially, the most important output of universities is a cadre of people prepared to contribute to society and to lead. For that, it is necessary that under and postgraduate students must possess extensive knowledge in a special field as a consequence of high quality educational programs which should be in accordance with a world of constant, rapid, and to some extent predictable progress. Such condition, induces that the current research and development environment encourages industry to consider first planned projects. In fact, in developed countries, the fulfillment of high quality educational programs has made that policy makers and the general public responded with an unprecedented increase in support of scientific and engineering research. Specifically, governments proceeded to provide funds for extensive research and development in all areas propelling an increase in the number of projects. As a matter of interest, it should be remembered that by developed country it is meant here a scientific and engineering based country where information is extremely timely and informative, bringing together top consultants, leading-edge vendors, and pioneering information managers to show how technology is impacting business today and may transform yours tomorrow. Is for that reason that in first world countries, like USA, were created a long time ago undergraduate and postgraduate programs in Engineering Physics with the purpose to link applied physics and engineering.

In undeveloped countries, or countries in the way of being developed, as is Mexico, the above assertions just begin now to be recognized and appear explicitly considered in the "Education Sector Program" and in the "Science and Technology Program of Mexico for 1995-2000" (STP). In the first case, the chapter corresponding to "Middle and Superior Education" recovers the fundamental aspects of the "National Plan of Development of México" in educational matter when the government gives a high strategic value to the undergraduate and postgraduate studies [1]. Moreover, in the second case, the STP consider the importance to improve the competitiveness of science and technology in the country [2]. Consequently, in order to fulfill the objectives of both the above programs, many initiatives and different institutions are involved in a significant national effort where Universities and research centers play a very important role. Specifically, the Universidad Autónoma Metropolitana of México (UAM), which has a lemma that says *"House Open to Time"*, has implemented an organization system based on

the figure of Teacher/Researcher for the instructors. Accordingly, the UAM offers a variety of nine Engineering undergraduate programs focused to the application of scientific principles to solve practical ends, at undergraduate and postgraduate levels. Particularly, the Campus Azcapotzalco (Azc) of the UAM was the first (in the country) that implemented an undergraduate program of studies in Physics Engineering, which confer the title of Physicist Engineer.

In the next paragraphs we show a synopsis of the PE undergraduate program of studies, its evolution and evaluation as well as the corresponding pursuit in the work market of the engineer physicists graduated. Briefly, we also mention the new postgraduate program in Sciences and Engineering recently created at the UAM-Azcapotzalco, as well as equivalent programs offered by other universities in Mexico and in Latin America.

UNDERGRADUATE PROGRAM IN PHYSICS ENGINEERING

As mentioned in the above section, the title deserved to students that complete all requirements of the undergraduate Physics Engineering career program is "Physicist Engineer" for which probably this title could be taken as synonymous of the "Industrial Physicist" used in the USA. Although industrial physicist is utilized to describe a physicist that works in industry under the title of engineers, in our case the PE program is focused to form professionals able not only to solve technical problems but essentially to contribute in the design of new capabilities for the industrial technological development by means of the use of the problem-solving skills and from the knowledge of basic physical principles acquired in the different levels of the undergraduate program. That is, the PE program has been created in order to break the well established Sickafus' statement : *a physicist can do anything but unfortunately a physicist is not trained to do anything* [3]. Thus, with the purpose to attain such a goal, it is necessary to give the students of the PE career the elements that permit them to develop key qualities and tools beyond their core of proficiency in order to compete effectively in the real world of most industrial corporations where success demands results. For that, the undergraduate Physics Engineering program, actually operating at UAM, have the distinctive characteristics shown in table I.

Table I. Features of the Undergraduate Program of the Career in Physics Engineering [4].

Level →	**General**	**Basic Professional**	**Research Area**	**Full Program**
Time elapsed (years)	1.3	1.4	1.3	4
Credits* to complete	131	223	159	513
Number of courses**	15	24	18	57
Type of subjects	Fundamental Sciences	Basic Engineering & Technology	Energy, Matter Equipment	Physicist Engineer

**). Credits are grosso modo equivalent to the number of hours of class per week.*
***). Estimate average by considering 9 credits by course*

This program remains under the responsibility of the Basic Sciences and Engineering Division (BSED) of the UAM-Azc. and is supported by an important number of professors assigned to five different departments of division. Also, the PE undergraduate program is divisional because it uses all capabilities of the BSED such as laboratories (electronics, physics, materials, chemistry and so on), computational resources that include two alpha D-3000 and one alpha Aspen Durango-Digital at 500 MHz, a Power Challenge and a Onix Silicon Graphics mainframes as well as workstations type Indigo and α-NT-Digital and more that 100 Pentium PC's and library facilities.

According to the above information, with the PE career it is intented to cover four important commitments:

a). Provide a more general and in depth instruction in aspects of fundamental sciences which are of major relevance in engineering : mathematics, physics and chemistry.

b). Acquire a strong preparation in basic engineering over all in those stages related with the classical or macroscopic treatment of the world around us; mechanics, electrical, thermic and systems.

c). To accede to an inter-disciplinary formation which incorporate those technical, economical and social aspects that are necessary to consider in the development of technology.

d). A sort of specialty in traditional and novel areas of engineering such as instrumentation, energy, advanced materials, equipment.

With all this characteristics, the PE program helps prepare, from the beginning, graduate students which are able to confront the real world because they are competitive and can be incorporated advantageously in the work market with increased certitude, pertinence and opportunity. In fact, it is expected that a Physicist Engineer graduate, thinks a situation differently and have the ability to synthesize concepts from a number of seemingly disparate pieces of information as result of a more fundamental understanding of the possibilities of solutions rather than the constraints pounded into our more pragmatic brethren in classical engineering. That is, the PE career aims to serve as bridge between the theoretical and practical (or applied) standard options.

In table II, we show statistics which recover the most important items of the PE program for the 1996 year. As can be appreciated, at the time there were 308 students registered in the Physics Engineering undergraduate career ; an average of a 7.5% corresponds to graduate students. Notice that, if we consider that the school services of the Universidad Autónoma Metropolitana in Mexico accept only 50 students in each registering term (six months after the previous one), the number of students that finish their program can be considered important. That is, there are 23 graduate students which correspond to almost 50% of the number of new students in the program. Also, as shown next, a very high percent of all this graduate students are working in industry in activities which are in accordance to their PE formation and not, as usually occurs with some careers, that graduate students work in activities far different to those in which they were qualified.

Undergraduate Program Assessment

When one compares the undergraduate programs of different Engineering with the PE career, it becomes clear that Physicist Engineer assimilate more rapidly the changes resulting from globalization and advancement of science and technology. Probably is for this reason that Physicist Engineers are accepted advantageously by industry : in the case of the UAM's graduate students, 94.7% found employment almost immediately after finishing their studies. In Table III we show some important data from which is possible to draw some conclusions about the type of work done by the graduate Physicist Engineer.

In fact, analyzing the type, size and sector of industry where graduates are employed, it becomes apparent that

Table II. Statistics of the PE program for 1996.

Staff of Instructors and their qualification (Physics area).	**45 Full time: 15 PhD, 20 Master and 10 B.Sc.**
Total students.	308
New addmision students *	46
Graduate students.	23

*) *According to the regulations established by school services, the UAM only accept 50 students each 6 months, after a selection exam.*

essentially they are working in large enterprises of the private sector which employ more that 2/3 of the graduate students of the PE program. This type of industry associated to the secondary and tertiary market, means that Physicist Engineers that work there are contributing in the development and advance of technology. In fact, according to the data of table II, almost 50% of the graduate students fall within the process industry and education institutions ; the former in development and the latter in research for advancement.

Another aspect that is important to emphasize, relates to the management level that graduate students perform in industry. Although the larger proportion of Physicist Engineers are part of the staff of researchers in engineering, actually it has been found that an important proportion (35%) of them are at head management ; as Director, chief of R&D/Engineering, group leader and responsible of project,

Table III. Comparative Data that show where graduate students are employed [5].

Type of Industry or Enterprise		**Size of the Enterprise**		**Industry sector**		**Contract Job (duration time)**	
Process	26.3 %	Large	70.8 %	Public	77.6 %	Undetermined	53.7 %
Education	27.5	Medium	18.0	Private	22.4	Determined	27.5

Professional Services 6.0 Transport & Communic 9.5 Government 9.5 Building/Construction 15.0 Other 6.2	Small 5.6 Micro 5.6		Open Project 4.8 Specific Project 10.0 Owner 5.0

section or department. Finally, respect to the PE graduates employed in education, some are engaged as teachers of medium and high level although an important proportion participate in activities of development and coordination of research projects. Thus, Physicist Engineers are well accepted in the market place with the same or better possibilities that other kind of engineers or graduates in pure sciences such as chemistry, mathematics and physics. To this end, it is important to notice that the UAM's PE undergraduate program is designed for a specific career (Physicist Engineer) conversely to other PE programs created to serve as option of regular Physics undergraduate programs currently operating at different universities as shown next.

Other National and Latin American undergraduate programs in PE.

As mentioned in the introduction above, the PE undergraduate program offered by UAM has been taken as a model for the creation of other similar programs in different Universities and Technological Centers at national level. Specifically, in the Mexico's metropolitan area there are two other equivalent programs administrated by private centers : one in the Iberoamerican University and other implemented by the Monterrey's Technological Institute of Superior Studies (campus Mexico state). Both PE programs are quite similar to the one offered by the UAM, although some minimal differences occur in the organization and number of subjects that are necessary in order conclude the total studies program. For example, the PE option of the Iberoamerican University is divided into 4 grouping levels instead of the three operated by UAM; basic (112), minor (54), major (190) and integrating (48) where the figures in parenthesis indicate the total number of credits of each level. However, the student requires to complete 436 credits to obtain the degree of Physicist Engineer which means that it is necessary to cover 16 additional credits to receive the corresponding title, as conferred by means of a written document, and 16 for social service.

Similarly, there are in the country two other universities which have implemented a PE undergraduate program [6] : The Autonomous University of San Luis Potosí and the Autonomous University of Yucatán. In the first case the PE program is considered not as specific as in the UAM, but as a terminal option of the Physics career existing at that university. In that case, in order to access to the PE program, students originally interested in Physics choose a certain number of optional subjects in order to complete the Physicist Engineer formation. Conversely the Yucatán's PE career is very close to the UAM´s offer.

Finally, as far as we know only very few countries in Latin America have implemented a similar or equivalent program to the one of the UAM-México. For example, in Colombia the PE undergraduate program is offered by two Universities. One of them is the Universidad Tecnológica de Pereira [7] where the PE program is of recent creation (1996) and it was founded with the purpose to have a near collaboration with the University del Valle in order to complete the formation of pure and applied physics.

Another country with an specific PE career and equivalent PE programs is Chile [6]. The specific one occurs in the University of Santiago de Chile and one of the equivalent PE programs is in Applied Physics under the responsibility of the Universidad de la Frontera in Temuco. It should be noticed that this last program consider as research areas X ray spectroscopy, solid state physics, applied optics, sismology and remote perception for which the program is closest to physics programs rather than to engineering ones. In a similar way, other equivalent PE program is in Physics Education put in charge of the Universidad Metropolitana de Ciencias de la Educación, in Santiago, Chile. This program consider as research areas those related to teaching physics ; didactics, media, and so on. In short, the two latest programs existing in Chile can be considered as particular cases of the PE undergraduate program offered in Mexico.

POSTGRADUATE PROGRAM IN MATERIAL PHYSICS ENGINEERING.

With the purpose to form high qualify researchers able to generate new knowledge which will contribute to the scientific and technolgical development of Mexico, recently (March 1998) the UAM's Academic College approved the creation of a three level postgraduate program titled "Specialty, Master and PhD Degrees in Sciences and Engineering; Environmental, Materials". Concerning the second option, the first degree (specialty) was conceived with the aim to generate options of development for sciences graduates that would come from several other institutions, and our own engineering graduates interested in increasing and deepening their cognition level on specific aspects related to materials; Chemistry, Physics and Engineering of Materials. Although each level or degree of the program possess its corresponding objective, in general the postgraduate studies have as purpose to form professionals in pure and applied research. With the intermediate level

(Master) it is also aimed to improve the degree of qualification of teachers for the undergraduate programs offered by UAM; materials engineering, physics engineering, environmental engineering and chemical engineering. In short, the postgraduate program in sciences and engineering created by UAM can be considered as a new option to enable Engineers to carry out research and development in order generate knowledge that can be used in the advancement and assimilation of technology.

In the specific case of the Postgraduate Program (PP) that considers the option in Material Physics Engineering, the basis of the PP are taken from the undergraduate program of Physics Engineering. That is, the PP accept students that come from the PE career and it have the following distinctive characteristics.

According to above table, the postgraduate program permits to complete each degree by means of the fulfillment of the corresponding requirements at each level or it is possible, according to preferences, to proceed straight to the top level of PhD without having to fulfill particularities or requirements to get certification for the intermediate ones. In this respect, it is important to notice that the PP has been designed without requisites in the presentation of research results for the students in the specialty level in order to open the program for people interested in deepening their academic skills but not interested in research from a formal point of view. On the other hand, with the Master level the PP considers enough a suitable communication of research results in order to permit that students interested in PhD level, write only one Thesis. However, the main requirement for justifying one thesis is : it is demanded a high quality for the research work as reflected in two published papers in journals of wide international diffusion as well as refereed.

With these improvements, the program can be completed in a very short time for each level.

Table IV. Features of the Postgraduate Program in Materials Physics Engineering [8].

Requirements	**Specialty Level**	**Master Degree Level**	**PhD Degree Level**
Credits	81	225	360
Normal Elapsed Time*	1	2	4
Additional Requirements	None	Suitable communication of research	Thesis +2 published papers
Type of School Program	Traditional teaching.	Half tutorial	Full tutorial
Staff Teaching/Research Qualification	PhD & Masters	PhD & Masters	PhD

**) The maximum elapsed time permitted to fulfill the level is double the normal one.*

CONCLUDING REMARKS.

In this work we have presented an innovative full program in Physics Engineering for undergraduate and for postgraduate students. As shown, the undergraduate PE career has proved to be pertinent as a new option to the standard programs in Engineering. Two facts support the above assertion ; the program has been used as basis for the creation of other similar undergraduate alternatives in some universities and the graduate students of the PE career offered by UAM have been well accepted by society and are working advantageously in industry. Besides, the PE undergraduate program has be used as platform to launch the postgraduate program in Sciences and Engineering, with an option in Materials Physics Engineering, which will start next September at the UAM-Azc facilities. With that, we have a program of ample coverage which can be used for students with different preferences. Besides, the program promotes the participation of an important nucleus of teachers in order to bring in a fuller benefit for the formation and integration of various *academic corps* as well as the feedback of human resources necessary. That is, the total PE program, undergraduate and postgraduate, can be considered as an effective element used to improve the research cadre available at the Basic Sciences and Engineering division of the UAM-Azc-Mexico.

In short, we have presented a PE undergraduate program which gives priority to form students with skills according to

the advance of the basic sciences that are at the origin of the notable technological changes that occur day after day in the modern world. For that, the PE career integrate basic sciences and engineering under the philosophy of a form of perception in order to form students that can be incorporated into the market work as designers or researchers able to solve and create new technological advances. This kind of conception makes a fundamental difference respect to other standard engineering programs which have as purpose to form high level technicians due to the fact that basic sciences are incorporated in the scheme of studies as tools of work.

Finally, it is important to point out that, as mentioned in the introduction section of this work, many undergraduate and postgraduate programs in "Engineering Physics" are offered in various Universities of the United States. Although the purposes of the various programs are quite different, as far as we know, the Engineering Physics major in the USA are focused for students who plan a career in an applied science or engineering field. That is, generally this programs consider *specific* engineering developments for which are closest to the undergraduate programs in applied physics; for example, the University of Virgina uses without distinction the names "Engineering Physics" and "Applied Physics" for the same undergraduate program [9].

In the case of the present work, we prefer to call "Physics Engineering" to our undergraduate program because we want to emphasize the purpose of the program to provide an *ample* basic sciences and engineering knowledge content, to engineering students and also physics students. Probably, the UAM's Physics Engineering undergraduate program is similar to the program in Engineering Physics at Princeton University (USA) which provides students with a fundamental knowledge of physics, together with problem-solving skills, and an understanding of engineering, is designed to address the needs of students seeking innovative careers in today´s technological age [10]. With that, both UAM's and Princeton's undergraduate programs allow students to keep their options open between physical sciences and engineering. In any case, due to the fact that there is a considerable number of programs in engineering physics in various USA universities and in the rest of the world, as for example in the University of Saskatchewan as well as Alberta University in Canada, it would be very useful to analyze the similarities and differences among different Engineering $\leftrightarrow$ Physics undergraduate programs conception. Such a comparison is out the scope of this work and deserve publication by its own.

Bibliography

[1]. Mexico : Plan Nacional de Desarrollo 1995-2000, www : http/rtn.net.mx/PND/

[2]. Mexico : Programa de Desarrollo Educativo 1995-2000., *Univers. Futura* **7**, 19 (1995).

[3]. E.Sickafus, *The Industrial Physicist*, **2**, 22, 1996.

[4]. *Undergraduate program of Physics Engineering*, Divisional Council, UAM.

[5]. G.Valanti, Empleo y desempeño de egresados de la UAM, *Informe Ing. Física*, (1995).

[6]. Catálogo Latinoamericano 1998 de Programas en Física, *Mexican Physics Society, Bulletin* (1998).

[7]. L. E. Llamosa and R. Ramírez, *Scientia et Technica*, **2**, 137 (1996).

[8]. Postgraduate program in Sciences and Engineering, UAM-Azc., *Academic College UAM - Mexico* (1998).

[9]. Engineering Physics (Applied Physics) at the University of Virginia, *http://bohr.ms.virginia.edu/ep/*

[10]. Engineering Physics at Princeton, *http:/www.ee.princeton.edu/eng-phys/intro.html*