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Analysis and Projections of Physics in Chile*

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Abstract. In the present work, an assessment of the Physics research capacity in Chile is presented. For this, the period between 2000 and June 2005 has been studied. In this period almost 200 physicists have contributed to scientific production in terms of ISI publications. Amongst these 200, ~160 correspond to theoretical physicists and only ~40 to experimental physicists; ~178 are men and only ~22 are women. A more detailed analysis shows that ~160 physicists have at least one appearance in ISI publications per year considering the last 3 years. Ten years ago, a similar criteria (at least one appearance per year in ISI articles, considering mobile three-year periods), the number of active physicists in the Chilean community was estimated at 70. Therefore, the Chilean active physicists' community has doubled in 10 years.

There exist 20 centres in which scientific research is developed: 18 university centres, a government institute and a private institute.
As regards scientific productivity, both as related to disciplines or research areas, and well as in relation to research centres, it is found that, generally, scientific production, in a particular area in Physics or in a research centre, is directly related to the number of corresponding researchers; that is to say, the percentage of the national productivity in an area or research centre corresponds to its share in the total number of physicists in the country. A geographical analysis shows that 50% of the productivity corresponds to Santiago and 50% to the rest of the country.
The impact of the different funds for research is assessed, also: FONDECYT, Presidential Chairs and large projects and centres of excellence.
According to Physics researchers opinion, *Fondo Nacional de Ciencia y Tecnología* (FONDECYT, National Fund fro Science and Technology) has become the best instrument to support researchi activities in Chile. However, the amount of projects awarded has practically

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not been increased, which is insufficient for a community that has doubled. Likewise, even 50% of the productivity corresponds to regional centres, only 35% of projects coming from FONDECYT are awarded to the regions (away from the metropolitan region).
Regarding experimental Physics, this represents 20% of the community in both, researchers and productivity of the community. However, in the regular FONDECYT contest in 2005, only 2 projects (10%) were awarded in experimental Physics, which is undoubtedly insufficient. The study also includes a brief analysis according to social appraisal of Physics, dissemination activities to other areas of national living, and relation of Physics with the productive sector. Finally, some recommendations are made:
- To create a special fund for experimental Physics in the regular FONDECYT contest. Complementarily, experimental Physics should be one of the priority areas for the technological and scientific development of the country.
- To duplicate the amount assigned to Physics in the regular FONDECYT contest.
- To create a system that allows increasing the salaries of the researchers in Physics so they could be assimilated to other professional salaries in our country or at an international level. Not only demands must be globalized but also the benefits.

1. Introduction

Even though there were former individual efforts, there exists a relatively general consensus that Physics research in Chile, as an organized activity was born five decades ago, around 1950. The first two publications in Physics of international level date from that time (1953); one of them from the group of Nuclear Physics and Cosmic Radiation, and the other from the group of Crystallography and Molecular Physics, both from Universidad de Chile. These two groups of experimental Physics set the beginning of the research in Physics as a professional activity. A subsequent major boost was the creation, in 1954, of the Laboratorio de Física Nuclear Pura y Aplicada, also belonging to the Universidad de Chile. During the next five years, 25 professionals, both researchers and engineers, joined that laboratory; all of them coming from the Escuela de Ingeniería, the Instituto Pedagógico of the Universidad de Chile, and the Universidad de Concepción. Together with those groups, there were also individual efforts from the P. Universidad Católica de Chile, Universidad Técnica del Estado (now Universidad de Santiago de Chile), Universidad de Concepción, and the Universidad Técnica Federico Santa María from Valparaíso. However, the real professionalization of Physics began in the decade of the 60's, at the time of the creation of Science Faculties with their respective Physics Departments at different universities of the country. On the same years, the Research Institutes of the Country grow stronger and the Comisión Nacional de Investigaciones Científica y Tecnológica (CONICYT), along with the Comisión Chilena de Energía Nuclear, are established; the latter one becoming a paradigm in the application and use of Physics.

The Sociedad Chilena de Física was born in 1965 with the aim of "stimulating the scientific research on the field of Physics and related sciences, the divulgation of this discipline, and the contact of the people whose main occupation is the practice of these sciences" (from the second article of the statutes). It is also by the end of the 60's when the first doctorate in Physics program is created at the Facultad de Ciencias of the Universidad de Chile. Thus, theoretical and experimental research on Physics becomes definitely consolidated, although not without obstacles, as demonstrated by the scientific publications on the field.

For around 25 years there have been postgraduate programs at the Doctorate level. The first programs were proposed at the Universidad de Chile and at Pontificia Universidad Católica de Chile. Recently, other three doctorate programs have been implemented, one at the Universidad de Santigo, another given by both the Universidad Católica de Valparaíso and Universidad Técnica Federico Santa María, and the third one by the Universidad de Concepción.

Although research on Physics in Chile has always been related to the experimental Physics, only one fifth of the professionals that have made a contribution to the research in Physics for the last five years are experimental physicists. The development of Physics has been directed towards pure research, with little or no incursion in the areas of application or productivity.

It is interesting to point out that in the decade of the sixties the main activity of Physics research was the experimental area. However, from the seventies, even though there were new developments in experimental Physics with the setting up of a small cyclotron at the Facultad de Ciencias of the Universidad de Chile, the development of Physics was centred almost exclusively on theoretical areas, specifically in high energy and condensed matter Physics. Although this decay of the experimental Physics deserves a particular study, there were two events that influenced significantly its development: the expulsion of Argentinean scientists accused of espionage in 1969, and the Chilean military coup in 1973. Both events caused the abandonment of several laboratories

At the beginning of the 80's, a new impulse is given to experimental Physics, especially in the fields of plasma Physics and applied optics at the Pontificia Universidad Católica de Chile. In the 90's, laboratories of Physics of solids, condensed matter, and nonlinear Physics are established at Universidad de Chile, Universidad de Santiago, and Universidad Técnica Federico Santa María..

Nowadays, it can be said that even though the Physics activity in Chile counts on only a relatively small community (around 200 researchers) it is one of the high level disciplines in the country. The level of productivity of the community in the last decade outstands in both quality and quantity. The annual average of international indexed publications for each active member of the community is approximately 1.4 and the average impact factor per publication is estimated around ~1.8.

As regards the history and level of the development of Physics in Chile, the following sources can be consulted: "La Física en Chile hacia finales del Siglo XX" ("Physics in Chile at the end of 20th Century"), E. Vogel (Editions from Universidad de la Frontera, Temuco, Chile, 1996); Report of Sociedad Chilena de Física, June 2000 on the occasion of Encuentro Chile Ciencia 2000 (Chile Science Meeting); "Impact Factor and the International Collaboration in Chilean Physics: 1987-1994", E Vogel, Scientometrics, 38, 253-263 (2002), "Aspectos históricos del surgimiento y desarrollo de la física en Chile durante el siglo XX" ("Historical background in the arising and development of Physics in Chile during the 20th century"), E. Vogel, Rev. Mex. Fis. 48S3, 1-9 (2002), "Apuntes para una historia de la física en Chile" ("Notes for a history of Physics in Chile"), Claudio Gutiérrez and Flavio Gutiérrez (2005) in http://www.picarte.cl/historiaFisica.pdf.

This report attempts at assessing the current capacities of Chilean Physics as a discipline of scientific researching. For this, historical background available will be used, and mainly, data compiled specifically to accomplish this objective which correspond to the period from the year 2000 to the first semester in 2005. In order to analyze the state of development of the discipline, relevant data are: community size, contest funds availability, scientific productivity, existence of programs at the pre and post degree levels, concentration of the community and developed lines.

2. Size and characteristics of the community

For purposes of these studies, we have considered "active physicists" those who work in research and have appeared as author or co-author at least in one ISI publication during the 2000-June 2005 period (not considering pre and post graduate students in 2005). This has been the fundamental criterion to include them as researchers in Physics in the Board of the Academia Chilena de Ciencias (Chilean Science Academy) in 2005. It is worth mentioning that the Board includes those researchers that are authors of invention patents even though they have not contributed to ISI publications during the period, and those who have been distinguished because of their contribution to the formation of new generations of physicists or in the dissemination to other areas of national living even though they were active researchers before 2000.

We have identified 205 active physicists according to the established fundamental criterion (they have appeared as author or co-author at least in one ISI publication during the 2000-June 2005 period), plus a person from a private company who has produced 5 patents during the period. For purposes of statistical studies, we will use a universe of 205 researchers that appear in ISI publications during this period. At least 160 of these researchers have the Ph.D. degree.

From these 205 researchers, 165 correspond to theoretical physicists (~80%) and 41 of them are experimental physicists (~20%) (Figure 1). Only 23 of these 205 are women (~10%) (Figure 2). The

average age is 47 years. The average was obtained from a sample of 150 researchers who provided their age data among the 205 active; as there is a tendency from older people to refuse giving their age as data, this average could perfectly be higher. Figure 3 shows the distribution by age among the active researchers in Physics.

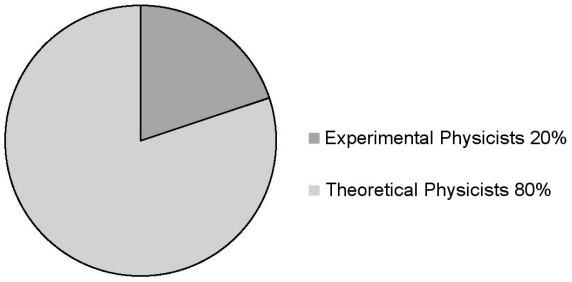

Figure 1. Percentage of theoretical physicists *vs* experimental physicists.

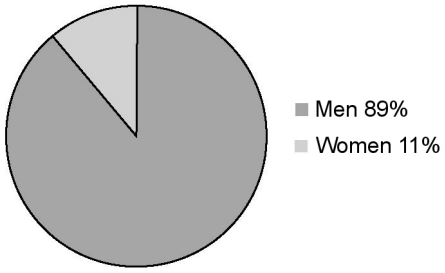

Figure 2. Distribution by gender of the researchers in Physics.

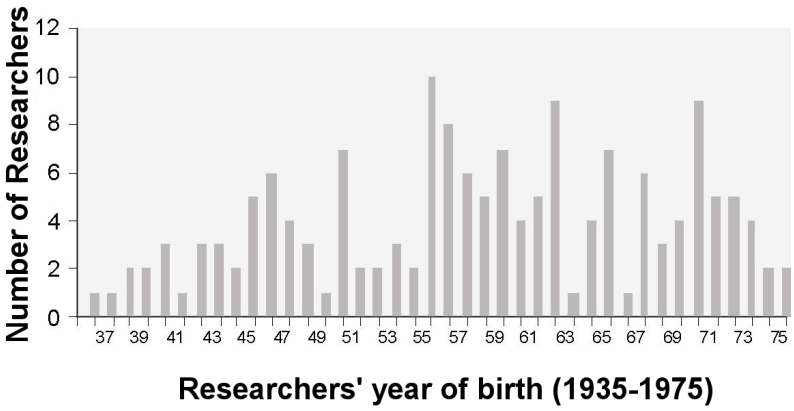

Figure 3. Distribution of active physicists per year of birth.

3. Measured productivity in terms of ISI articles

From compiled information for the 2000 - June 2005 period, it is concluded that the total productivity of the discipline is of the order of 100 to 120 ISI articles per year. Each article has 3 authors on average. Figure 4 shows the presence of researchers in Physics in ISI publications during the 2000 - June 2005 period.

From the data, it is concluded that the average presence of a researcher in Physics, as author or co-author, in ISI journals is 1.45 per year. A more detailed analysis of the information shows that, approximately:

10% only has one article in the last 5 years
12% only has 2 articles in the last 5 years
15% only has 3 articles in the last 5 years
37% only has between 1 and 2 articles per year
13% has between >2 and 3 articles per year
4% has between >3 and 4 articles per year
5% has between >4 and 5 articles per year
2% has between >5 and 6 articles per year
2% has 7 or more articles per year

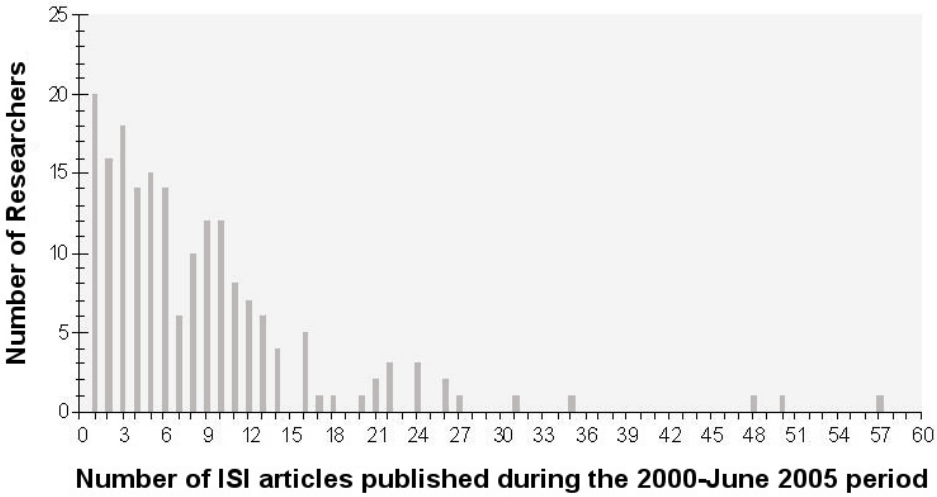

Figure 4. Presences of researchers in Physics in ISI articles during the 2000-June 2005 period.

That is, considering the last ~5 years, 63% of active physicists has at least one presence in ISI articles per year, which corresponds to ~130 physicists. It is important to mention that in the study of Vogel published in 1996 ("La Física en Chile hacia finales del siglo XX", E. Vogel, Universidad de la Frontera Editions, Temuco, Chile, 1996), an active physicist was considered that who had at least one presence on average in ISI articles per year, considering mobile three-year periods. With this criterion, and considering the last two mobile three-year periods, Vogel determined that in 1995 there were 70 active physicists in Chile. In order to give the chance of including those recently doctorate physicists, we can add those who have 3 ISI articles in the last ~5 years, which add up to a total of 15%, i.e. a total of 160. This is, using a similar criterion to the one Vogel used a decade ago, there were between 130 and 160 productive physicists in Chile. Therefore, we can state that, in Chile, the amount of researchers in Physics has doubled in one decade.

4. Institutions carrying out research on Physics

Twenty institutions have been identified, in which research in Physics is carried out in our country. Table 1 lists the institutions and details the amount of active physicists in each, as well as an estimate of their measured productivity in ISI articles, in affiliation with the corresponding institution. It is worth mentioning that an article may have more than one institution as sponsor. To determine the amount of physicists related to an institution, the affiliation the researcher declared in his publications was considered, apart from the existence of a formal contract.

In the last decade, chances have been given to researchers in regional and private universities, and in Comisión Chilena de Energía Nuclear, increasing the number of institutions in which research in Physics is carried out.

From Table 1, it is observed that a direct correlation between the amount of active physicists and the productivity of the institution exists. A singular case is the one at Universidad Técnica Federico Santa María, with only 8.7% of the active physicists in the country, which contributes with about 20% of the publications in Physics in Chile. A more detailed analysis shows that the group of particle Physics and high energies from that institution is the one that greatly contributes to that singularity.

The 20 institutions are: 18 universities, a private institute with public and private funding, and a state institute. From universities, 3 of them are private. Half of the active physicists are in regions and the other half in the Región Metropolitana. 50% of the national productivity is originated in regions and the other half in the Región Metropolitana. A decade ago, only 35% from productivity was originated in the regions and 65% in the Región Metropolitana.

Table 1. Institutions in which research in Physics is carried out*			
Institution	**Region**	**Amount of active physicists (% approximated from the total)**	**ISI Articles in affiliation with the Institution (% approximated from the total)**
Universidad de Tarapacá	I Región	8 (3.9%)	2.4%
Universidad de Antofagasta	II Región	2 (1%)	0.4%
Universidad Católica del Norte	II Región	5 (2.4%)	1.9%
Universidad Técnica Federico Santa María	V Región	18 (8.7%)	20%
Universidad Católica de Valparaíso	V Región	17 (8.2%)	4.8%
Universidad de Santiago	Región Metropolitana	26 (10%)	10%
Universidad de Chile	Región Metropolitana	39 (19%)	21.5%
Pontificia Universidad Católica de Chile	Región Metropolitana	24 (11.6%)	14.3%
Universidad Diego Portales	Región Metropolitana	2 (1%)	0.3%
Universidad Nacional Andrés Bello	Región Metropolitana	5 (2.4%)	1%
Universidad de Los Andes	Región Metropolitana	2 (1%)	1%
Comisión Chilena de Energía Nuclear	Región Metropolitana	8 (3.9%)	4.3%
Universidad de Talca	VII Región	2 (1%)	0.3%
Universidad Católica del Maule	VII Región	1 (0.5%)	0.3%
Universidad de Concepción	VIII Región	15 (7%)	6.2%
Universidad del Bío-Bío	VIII Región	2 (1%)	0.7%
Universidad de la Frontera	IX Región	13 (6%)	3 %
Universidad Austral de Chile	X Región	4 (2%)	1%
Centro de Estudios Científicos del Sur	X Región	7 (3.4%)	3.5%
Universidad de Magallanes	XII Región	4 (2%)	0.5%
Private Sector		2 (1%)	
TOTAL		**206**	

* Productivity estimations are based on the number of presences of a researcher as author or co-author in ISI articles; in the same way, productivity in a sector or an institution is given by the number of presences in ISI articles. The data gathered did not contain detail enough for an analysis of the impact of the productivity.

Table 2. Physics Research Areas in Chile.

Area	Institutions	Number of researchers (approximate % of the total)	Approximate relative productivity (%)
Condensed Matter Physics, Materials Physics and Statistical Mechanics	Pontificia Universidad Católica de Chile, Universidad de Chile, Universidad de Santiago, Universidad Técnica Federico Santa María, Universidad de la Frontera, Universidad de Tarapacá, Universidad Católica del Norte. Comisión Chilena de Energía Nuclear	51 (25%)	25
Physics in High Energies, Particles, Gravitation and Cosmology.	Pontificia Universidad Católica de Chile, Universidad de Chile, Universidad de Santiago, Universidad Andrés Bello, Universidad Técnica Federico Santa María, Universidad de la Frontera, Universidad de Concepción, Universidad del Bío-Bío, Universidad Católica de Valparaíso, Centro de Estudios Científicos del Sur.	48 (23%)	27
Nonlinear Physics and Fluids	Pontificia Universidad Católica de Chile, Universidad de Chile, Universidad de Santiago, Universidad del Bío-Bío, Universidad Católica de Valparaíso.	16 (7.8%)	10
Quantum Optics	Pontificia Universidad Católica de Chile, Universidad de Santiago, Universidad de Concepción, Comisión Chilena de Energía Nuclear.	8 (4%)	4.5
(a) Atomic and Molecular Physics	Universidad de Chile, Universidad de Concepción.	7 (3.4%)	4
(b) Plasma Physics	Pontificia Universidad Católica de Chile, Universidad de Chile, Universidad de Santiago, Universidad de Concepción, Comisión Chilena de Energía Nuclear.	14 (7%)	8.6
(c) Nuclear Physics	Universidad de Chile	5 (2.5%)	1
Other specialties in Physics, or not declared		56 (27%)	19.9

5. Physics research areas in Chile

Table 2 shows Physics research areas in Chile, including institutions, the number of researchers and relative productivity.

The most developed areas are Condensed Matter Physics, Materials Physics, and Statistical Mechanics, and Physics in high energies, particles, gravitation and cosmology, which cover 48% of researchers and 52% of productivity.

There is a direct relation between the size of the community in each area and its productivity.

Table 3. Institutions in which research in experimental Physics is carried out, development areas, number of researchers and related productivity regarding total productivity in experimental Physics.

Institution	Area	Nº of researchers (% regarding the total in experimental physicists)	Relative approximate productivity in relation to the total productivity in experimental Physics
Pontificia Universidad Católica de Chile	Condensed Matter Plasma Physics	3 (5%) 4 (10%)	9% 13%
Universidad de Chile	Condensed Matter Nuclear Physics Crystallography Nonlinear Physics***	4 (7.5%) 3 (7.5%) 2 (5%) 2 (5%)	10% 5% 19% —
Universidad de Santiago	Nonlinear Physics Materials Physics and Semiconductors* Quantum Optics*	4 (10%) 3 (5%) 1 (2.5%)	6% 5% 0.3%
Comisión Chilena de Energía Nuclear	Materials Physics * Plasma Physics*	3 (7.5%) 4 (10%)	3% 17%
Universidad Católica del Norte	Materials Physics**	1 (2.5%)	0.5%
Universidad Técnica Federico Santa María	Material Physics*	2 (2.5%)	7%
Universidad Católica de Valparaíso	Optics**	2 (2.5%)	2%
Universidad de Concepción	Thermo-opto-acoustics and Materials Physics **	2 (2.5%)	0.7%
Universidad de la Frontera	Optics* Fluorescence of X Rays**	1 (2.5%) 1 (2.5%)	1% 1%
Universidad Austral de Chile	Instrumentation	1 (2.5%)	1%

* Laboratories created in the last decade

**Laboratories created in the last 5 years

*** Laboratory created in the last year; therefore, there is no data during the ~5 years of the statistical study. Its researchers are incorporated to the Universidad de Chile during 2004.

6. Experimental Physics

From these 205 active researchers, only 41 declared themselves as experimental physicists; this is only 20% of the total and its contribution to the total national productivity is 18%. The average presence from Chile of a researcher in experimental Physics in articles published in ISI journals is 1.28 per year, whereas the presence of a researcher in theoretical Physics 1.5 per year. This means that the average number of publications from an experimental researcher in Chile, in 10 years, is 13 ISI articles, while in the case of a theoretical physicist this number is 15.

Table 3 lists the institutions in which research in experimental Physics is developed, work areas, number of researchers and an estimate of the related productivity regarding total productivity in experimental Physics. The presence in ISI articles of experimental physicists has been used for the estimate of the productivity in the respective areas during the 2000 - June 2005 period.

It is important to point out that, of 18 existing laboratories, 11 have been created in the last decade. Moreover, the creation of a laboratory in quantum optics has been recently initiated in the Universidad de Concepción.

The crystallography group is the most productive with 19% of the total in national production, and only 5% of experimental physicists in the country. The Plasma Physics group of the Comisión Chilena de Energía Nuclear stands out among groups created in the last decade with 17% of national productivity and 10% of experimental physicists in the country. This group is a real singularity since it was not developed in a university environment.

It is quite interesting to notice that, with the efforts in the 50's, in less than one decade, it was possible to gather a total of 25 professionals, around a pure and applied Physics program (experimental and theoretical physicists, and engineers). Unfortunately, its development was negatively affected because of the historical background pointed out in the introduction. The country has not made an effort of such importance in experimental Physics; i.e., an effort that not only allows for equipments and infrastructure investments, but also increasing significantly the number of researchers dedicated to experimental Physics and preparing professionals and highly qualified technicians who directly support this activity. Since there exists a knowledge in the role of experimental Physics in developed countries, and also the intention of the state in the creation of a knowledge based economy, experimental Physics should be one of the priority areas for the technological and scientific development in the country. Experimental Physics is an absolutely abandoned area in government policies of scientific development over the last decades, at least in practice and in the criteria for project selection. Also, it is possible to see how difficult it is to be competitive with projects within the experimental Physics area. In the regular FONDECYT contest, for instance (see later), when an important part of the budget in a project is assigned to capital investment (which provides only for minor laboratory equipment), it is a fact that the proposals are considered feasible from the scientific point of view, but not from the economical.

7. Pre and post degrees formation

There exist 9 institutions which offer a Physics degree program equivalent to a Bachelor degree in the country. Three of them have been created in the last decade in regional universities (Table 4). The number of admissions per year can be estimated at 220, and the number of graduates is 34 per year.

There exist 5 accredited post degree programs in the country, and they offer the Magister and Ph.D. degrees (Table 4). In the last 5 years, 37 Magisters and 29 Ph.D.'s have been graduated, that is an average of 5 to 6 doctors per year. These programs have been awarded by MECESUP projects from Ministerio de Educación (Ministry of Education).

8. Scientific dissemination activities for the community and the school sector

All institutions in which Physics research is carried out develop dissemination activities to the school sector. Also, there are extrainstitutional efforts for example the PROFISICA group.

Four years ago, the Olimpíadas de Física, historically organized by a group of good willing physicists, were assumed as an official activity of the Sociedad Chilena de Física. Yearly, about 1,500 high school students from the entire country participate in the Olimpíadas de Física, who take theoretical and experimental tests. About 85 students of the national final participated. Since 2003, the winners participate in the Olimpíadas Iberoamericanas obtaining a distinguished place in two opportunities.

There exist two big initiatives of scientific dissemination at national level. One of them is the Museo Interactivo Mirador (MIM), of which the original creation and scientific direction was in charge of a full time physicist researcher with a Ph.D. (L. Huerta) for 5 years, until little after its inauguration in the year 2000. The other initiative is the EXPLORA program of CONICYT. Both initiatives have played a fundamental role in the dissemination of Physics to the school sector and the community in general. It seems necessary for these two initiatives to grow stronger in the future. It

would be important, also, to implement policies that encourage institutions and people to submit dissemination and social appraisal of science projects, guaranteeing clear and equal access to the resources that CONICYT assigns for this purpose.

Table 4. Institutions with pre and post degree (or both) in Physics

Institution	**Pre degree admissions offered (March 2005)**	**Graduates in Physics**		
		Pre degree Total Nº during the 2000-June 2005 period	Magister Total Nº during the 2000-June 2005 period	Doctorate Total Nº during the 2000-June 2005 period
Universidad Católica del Norte*	40	without graduation yet	NA	NA
Universidad Técnica Federico Santa María[1, 4]	~20 of 200 from common plan with Engineering	~5	4	3
Pontificia Universidad Católica de Valparaíso	20 (common plan between pedagogy and Bch. degree)	5		
Universidad de Chile (Fac. of Science)	25	25	4	4
Universidad de Chile (Fac. Physical Science and Mathematics)[1]	~20 of 540 from common plan with Engineering	25		
Pontificia Universidad Católica de Chile	20	54	25	15
Universidad de Santiago de Chile	55 (Physical Engineering)	46	No info	7
Universidad de Concepción[2, 4, 5]	100 (common plan between Physics Bch degree and astronomy Bch degree)	23	4	0
Universidad de la Frontera*[, 3]	Special admission	3	NA	NA
Total	**-**	**186**	**37**	**29**

***** Programs created in the last decade.

[1] Data from students that, after starting the common plan, continue in the Bch. degree, were not given at UTFSM and Faculty of Physics Science and Mathematics at UCh; in both cases we could consider that vacancies are about 20. For example, the students registered in Physics at FCF and M-UCh were 28 in 2000, 40 in 2001, 48 in 2002, 54 in 2003, 68 in 2004; students are registered semester by semester (in this sense the given number would be accumulative), desertions and changes of careers are not specified. If the registration is repetitive in three consecutive times, the admission in Physics would be a third of the given number; that is about 20 students.

[2] There are no differences in admission for specialties (pedagogy and Bch. degree in Physics and astronomy, as appropriate).

[3] Bch. degree in Applied Physics at UFRO was created in 1991, students can enter to this career via transfer from another career or via professional title (currently, there are six students who are distributed in different levels). From its creation, 4 students have been graduated, three of them during the 2000-June 2005 period.

[4] With post degrees of creation and recent accreditation (2000-2001).

[5] Post degree program in Physics include invited proffesors coming from Universidad La Frontera, Centro de Estudios Científicos del Sur and Comisión Chilena de Energía Nuclear.

9. Physics social appraisal and researchers' salary

Along with the results that science produces, the other element that is closely related to the social appraisal of science is the place that scientists occupy in society regarding salaries. The average salary of a scientist is much lower than the average salary of other professionals from the country. This situation is not the same in developed countries; in most of them the salaries are similar, and even in some cases the average salary of scientists is higher. Physics researchers in Chile have reached a competitive level internationally and it is the time for salaries to have a competitive level as well, similar to that of other professions in the country and to that of researchers at international level. Not only demands must be globalized but also the benefits.

10. Connection to the productive sector

The so-called basic science connection of the productive sector is one of the unsatisfied fields of Physics in our country. There exist efforts to satisfy this connection at some institutions where special pre degree programs have been created. For example, the program of Ingeniería Fisica of the Universidad de Santiago intends to link Physics and Engineering. Unfortunately, no isolated experiences of physicists in development projects of private companies have been consolidated. To satisfy the connection of basic research in Physics to the productive sector requires a substantial growth of the community and the implementation of State policies to promote the generation of technology development projects in private companies. An important observation is that in developed countries that have reached a high industrial level, there exist from 3 to 4 experimental physicists for every theoretical physicists; in our country the proportion is the other way around: one experimental physicist for every four theoretical physicists.

In connecting to the productive sector, institutes from the State could play a fundamental role, for example, the Centro de Investigación Minera y Metalúrgica, Institutos CORFO, Comisión Chilena de Energía Nuclear. For this, the number of active physicists in their payroll must increase. The Comisión Chilena de Energía Nuclear is the only Institute of the State that has incorporated active physicists in the last decade and has succeeded in consolidating a group in experimental Physics.

11. Funding for research

FONDECYT: In the opinion of the physicists' community, the regular FONDECYT program has proven to be the best instrument supporting the research activities in Chile. Around 20 projects are approved each year. Until recently, projects were approved by a maximum of 3 years, so there were about 60 projects in execution each year at a stationary regime, but for some years now projects may last up to 4 years, so, today, in stationary regime, there can be 80 Physics projects in execution per year, which would imply an increase of 33%. That is certainly not enough for a community that has doubled its population in the last decade (from around 70 reasonably productive physicists to 145). On the other hand, despite the fact that the productivity between the Metropolitan Region and the rest of the country has become uniform, this has not mirrored the ratio of projects approved at the rest of the regions of the country. Currently, only a 35% of the regular FONDECYT projects are carried out outside of the Metropolitan Region.

Regarding experimental Physics, it represents a 20% of the community both in the quantity of researchers and with respect to its productivity. At the regular FONDECYT contest for the year 2005, only 2 projects (10%) were assigned to experimental Physics, which is no doubt insufficient.

Scientific Presidential Chairs: The Presidential Chairs were projects given directly by the President of the Republic to prominent researchers (according to an international panel of judges of renowned merits). Their annual funds were equivalent to the average fund of 2 to 3 FONDECYT projects in Physics, and were provided for up to three years. They were given four times from 1995, and 48 researchers obtained the benefit of this initiative, 7 of which are physicists. The areas of Physics that obtained the benefit were: mathematical Physics, Physics of continuous media, Physics of systems out of equilibrium, high energy Physics, experimental nonlinear Physics, condensed matter Physics and experimental plasma Physics. An evaluation of the program has not been carried out so far. However,

it can be said that the awarded researchers kept or increased the productivity and impact. Moreover, the freedom that they could give to their projects allowed them to, in some cases, explore new lines of research. Two cases that set a qualitative difference between "before and after" of the Presidential Chair can be mentioned; the first one is the case of the high energy Physics of the Universidad Técnica Federico Santa María, where the productiveness of the area increased significantly. The other one is about experimental plasma Physics, which allowed consolidating an active and productive group of experimental Physics at the Comisión Chilena de Energía Nuclear.

Large scale projects and Centres of Excellence: Among these we can find the projects of the Fondo de Areas Prioritarias FONDAP, the Institutes, and Núcleos Milenio, and recently, those associated to the Programa Bicentenario en Ciencia Tecnología (anillos, consortia, etc.). Physics projects have been awarded with:

- A FONDAP project in *Material Sciences*, with an assigned fund that corresponds to the average of 30 FONDECYT projects in Physics. They are awarded for 5 years and can be renewed for up to 10.
- An Instituto Milenio in *Biology, Physics, and Glaciology*, Centro de Estudios Científicos del Sur, CECS. The annual funds given correspond to the average funds of 30 FONDECYT projects in Physics or 20 FONDECYT projects in Biology. They are awarded for 5 years and can be renewed for up to 10.
- A Núcleo Milenio in *Condensed Matter*. The annual funds given correspond to the average funds of ~10 FONDECYT projects in Physics. They are awarded for 3 years and are renewable with the presentation of a new project.
- A Núcleo Milenio in *Quantum Information*. The annual funds given correspond to the average funds of 10 FONDECYT projects in Physics. They are awarded for 3 years and are renewable with the presentation of a new project**.**

The FONDAP in Material Science began with the participation of material, biomaterial, and continuous media researchers as well as advanced material researchers such as ceramics and thin films researchers. The project was recently renewed. By their own decision, the experimental researchers in ceramics and thin films are currently not taking part in the second stage of the FONDAP.

When the CECS became Instituto Milenio, it was moved to Valdivia city and its researchers put an end to their contractual commitments with the universities. In the area of Physics, they focus on Gravitation and Cosmology, and on the new stage, they have kept or increased their productivity standards. Their funding was recently renewed.

The Núcleo Milenio in Condensed Matter was established as a national level collaboration, with researchers in the cities of Antofagasta, Valparaíso, Santiago and Temuco. They have developed pure and applied Physics and have given support to young researchers. The Núcleo Milenio was recently renewed for three years.

It can be seen that the area of materials science and condensed matter has received a considerable support via large projects; however, the productivity of the area has not shown a qualitative change in comparison to other areas. Their productivity has been more proportional to the number of researchers than to the assigned funds (See Table 2). The previous remark is an indicator that in order to improve the productivity in Physics, it could be more efficient to invest in human resources than in large scale projects, or that these projects must be oriented to increase the amount of active researchers. By the way, it is worth noting that the results and impact of that sort of projects go beyond their productivity and it is expected that the productivity will be reflected in the next years.

The Núcleo Milenio de Información Cuántica was recently approved and it is located at the Universidad de Concepción.

A deep and serious program evaluation is recommended, such is the case of Iniciativa Milenio that distributes significant resources. This evaluation should compare the results obtained to those from other programs, as in the case of the regular FONDECYT program. The evaluation should also consider the selection process, the regulation of the periodic renewal of experts as members of the

jury, and the separation of the technical judgement, with regard to projects, from the decisions about the program policies.

The Programa Bicentenario en Ciencia y Tecnología has been implemented by the current State administration. Its orientation is based in how to connect the scientific activity with the productive activity of the nation. Although we share this objective, a higher discussion with the scientific community is missing in the creation of new instruments. The Proyecto Bicentenario has created special programs oriented to universities, to regions and private companies. The lack of a program directly orientated to the State Institutes is evident; especially for the insertion of Ph.D.'s that allow creating competitive groups of research and taking advantage of their internal resources for the carrying out of scientific research and technological development.

12. Conclusions and recommendations

The number of active physicists that have figured as author or co-author with at least one ISI article in the last ~5 years has been estimated at 205 (at least 160 of them have the degree of doctor). Of these 250 physicists, there are 160 that have at least 3 presences as author or co-author in the last 5 years. Likewise, there is a group of 130 physicists that have, in average, at least one publication as author or co-author in an ISI article per year (considering the last 5 years). A decade ago, using as criteria an average presence over a mobile three-year period as an author or co-author of 1 article per year, it was determined that there existed approximately 70 physicists that comply with this requirement. We may conclude that in a decade the amount of productive physicists of the country has doubled from 70 to 140.

Physics in Chile is mainly carried out in universities but other sectors should be explored: industry, armed forces and state institutes. Particularly, starting from the infrastructure and technical qualification of the State Institutes, it is recommended to fully incorporate a competitive system of scientific and technological research, providing them with sufficient qualified researchers and removing the bureaucratic and administrative restrictions that preclude its development.

Only one out of every five active physicists in the country develops experimental Physics as its main research activity. In developed countries the proportion is the converse, 1 theoretical physicist out of every 4 experimental physicists. Efforts and special programs must be carried out oriented towards increasing the community of experimental physicists and thus reverting this proportion in the next years. Complementarily, it is recommended to create a program, of major equipment for laboratories. On the other hand, as certain, 20% of the community corresponds to experimental Physics and its productivity corresponds to 18%. However, only 2 of 20 projects, *i.e.* 10% was assigned to experimental Physics in the last regular FONDECYT contest. The different nature of experimental work, as opposed to theoretical work, imply higher costs in the development of experimental projects (infrastructure, technical support, operational expenditure) and does not allow an fair competition within the same group of study with a common fund to be distributed among theoretical and experimental physicists. It is recommended to create a special fund for experimental Physics in the regular FONDECYT contest. Furthermore, given the role that experimental Physics plays in developed countries, and the governmental intent of creating an economy based on knowledge, experimental Physics should be one of the priority areas for the scientific-technological development of the country.

The amount of FONDECYT projects approved by year has stayed fixed at approximately 20 projects in the last 10 years. However, 5 years ago the duration of projects has increased from 3 to 4 years, making the amount of projects in execution on stationary regime increased from 60 to 80. This means an increase of 33% in the number of projects in execution, which is insufficient for a community that has doubled in size and productivity. Currently, there are 45 projects presented to the regular FONDECYT contest. In the opinion of the researchers that have participated from the groups of study, approximately 40 of them comply with the quality standards to be approved, but there are not sufficient funds. Being FONDECYT the most successful instrument in the development of Physics research, it is recommended to duplicate the amount assigned to Physics. With the duplication of the

fund it will be possible to satisfy the demand of the new researchers that have been incorporated and will be incorporated to the system whether it is in traditional, private or regional universities or state institutes.

Large fund programs are welcomed as long as they do not affect the growth of the regular FONDECYT program and as long as they demonstrate a multiplication of the productivity and scientific impact, in science as much as in other sectors of Chilean work.

Regarding the social appraisal of Physics, along with disseminating the results that the science produces, the economical conditions of the physicists must be improved. The average salary of a scientist is much below the average salary of other professionals from the country. This situation is not the same in developed countries, in which they are equivalent and even in some cases the average salary of scientists is higher. Physics researchers in Chile have reached an international and competitive level, and it is the time for salaries to have a competitive level as well, comparable to the one of other professions in the country and also to researchers' salaries at international level. Not only demands must be globalized but also the benefits. It is recommended to create a national system that allows for duplicating, on average, the salary of the researchers that have reached productivity and international quality standards.

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