Science in Brazil

ORGANIZED BY
Antonio Carlos Campos de Carvalho
Diogenes de Almeida Campos
Luiz Bevilacqua

Science in Brazil

Science in Brazil

ACADEMIA BRASILEIRA DE CIÊNCIAS

Rio de Janeiro

2002

Brazilian Academy of Sciences
Rua Anfilófio de Carvalho, 29/3° andar
Rio de Janeiro, RJ, Brazil
CEP 20030-060
Phone: +55 21 2220 4794
Fax: +55 21 2532 5807
Email: abc@abc.org.br
http://www.abc.org.br

Editors:	*Bruno Barreto de Góes*
	Marcos Cortesão Barnsley Scheuenstuhl
Translators:	*Bruno Barreto de Góes*
	Derrick Guy Phillips
	Marcos Cortesão Barnsley Scheuenstuhl
Graphic Design:	*Inventum Design*
Films:	*Ingrafoto Fotolito*
Printed by:	*Gráfica MCE*

S416 Science in Brazil. – Rio de Janeiro : Academia Brasileira de Ciências, 2002.

320 p.

ISBN: 85-85761-23-7

1. Ciência – Brasil. 2. Ciência – história. I. Academia Brasileira de Ciências

CDD 509.81

Referência bibliográfica:

SCIENCE in Brazil. Rio de Janeiro: Academia Brasileira de Ciências, 2002. 330 p.

Contents

Science in Brazil: the state of the art

This publication intends to present a brief overview of some important aspects of mathematics, natural sciences, social sciences and engineering sciences in Brazil. It is not the purpose of this report to be complete or to explore all the possible roles played by the different private and public institutions involved in the process of scientific research and development in the country. We here draw an outline of the research and capacity building in some of the key fields of knowledge, such as: mathematics, physics, chemistry, earth sciences, biology, biomedical, health sciences, agrarian sciences, engineering and human sciences. This will provide, we hope, a guide for the foreign scientists that are not familiarized with the Brazilian academic activities, helping them to identify possible themes of common interest.

The first edition of this report was organized in 1997, by professor Luiz Bevilacqua, being reedited in 1999 with a few inclusions and modifications. Professor Antonio Carlos Campos de Carvalho coordinated an edition, in Portuguese, of the report, presented as a contribution of the Brazilian Academy of Sciences to the National Conference on Science, Technology and Innovation, organized by the Brazilian Ministry of Science and Technology in September of 2001. This present English version constitutes the third edition of this publication, and was coordinated by Professor Diogenes de Almeida Campos.

Although the present volume represents a third edition of *Science in Brazil* (previous editions were published in 1997 and 1999), we are aware that the texts here published are still subject to criticism from the different sectors of the academic community. We will be pleased to, once again, collect all the suggestions and comments that will certainly complement this report, making it even more precise and complete in future editions.

However, we do believe that the contents of the present edition will be extremely helpful to foreign scientists, for whom this book has been primarily written. We hope that our initiative stimulates a more effective interaction among scientists willing to engage in collaborative enterprises. Enjoy your reading.

Eduardo Moacyr Krieger
President of the Brazilian Academy of Sciences

Science and Technology in Brazil: Current Situation and Future Perspectives

I was much honored to assume the task of coordinating the third edition of "Science in Brazil", which presents the current status and the future perspectives for science and technology in the country. When initially discussing the report with the Brazilian Academy of Sciences, it was decided that the document should contain an evaluation of the various areas of S&T in which the Academy is active. A coordinator was chosen for each one of the areas and these coordinators, with the aid of colleagues, were responsible for the elaboration of the present analysis. The product of this effort is here presented as follows: each area constitutes a chapter where the current state of the art and the perspectives for the development of the area in the next ten years are appraised.

The model adopted to structure the report and the short period of time available for its development resulted in an inevitable heterogeneity, which also reflects the diversity among the areas. Nevertheless, the reader will perceive a high level of convergence that is briefly highlighted in this introduction.

Initially, the fundamental role of graduate education in the expansion and consolidation of the S&T system in the country is unanimously recognized. The model worked very efficiently, allowing the training of human resources and the insertion of national scientific production in the international statistics. The average number of PhDs trained per year in Brazilian graduate programs reached 5.000, and the indexed production of complete articles surpassed 8.500 on the ten thematic areas, in the year 2000. The growth is substantial and is due to a quality increase; the citation impact of the publications has continuously increased, reaching in 1998 the mark of 2.67 citations per published article. However, the great success of the current model should not cloud our vision to the necessity of its continuous evolution, both quantitative and qualitative.

Another point of consensus is the need of improving our primary and secondary educational systems, guaranteeing special attention to the area of science education. The necessity to cultivate young talents and to improve the scientific basis of our secondary school teachers is beyond question, and the willingness demonstrated by various scientific societies, among which the Brazilian Academy of Sciences, of getting involved in large-scale projects on science education, should be enthusiastically supported by all levels of government. In summary, science and technology will not become a part of the country's agenda if we have a scientifically illiterate society.

With regards to undergraduate education, the convergence of opinions about the increasingly urgent need of integrating education and research is very prominent, due to the overwhelming process of knowledge accumulation. It is necessary to teach and to learn; and there is nothing more appropriate than the scientific method to train a professional to face an ever changing job market. The paradigm bequeathed to us by our fondly remembered masters, like Carlos Chagas Filho, remembering that we teach because we research, is even more current and, as a matter of fact, has become an imperative.

The importance of a multidisciplinary approach on scientific research was another point commonly indicated in all areas. The urgency of going from words to action should make us rethink the structure of our entire higher education system, which is still based on the classic thematic divisions based on exact, biological and human sciences. The possibility of educating with a strong emphasis on all three areas would allow a significant advance on the multidisciplinary approach in the research developed in our country. It would also allow a fast expansion of the public university system, which is necessary due to the growing number of high-school graduates.

Another point that is common to most analyses is the identification of the high level of regional concentration of our S&T system. This concentration is recognized as highly prejudicial to our system as a whole, and the initiatives of the Ministry of Science and Technology to reduce the problem are recognized and stimulated in all area documents. An integrated policy with the Ministry of Education, responsible for the federal higher education system, where a significant percentage of the national scientific capacity is concentrated, could rapidly transform this reality, helping to diminish the socioeconomic disparities that divide our nation.

Finally, the challenge of linking our scientific and technological development to an industrial policy is considered a fundamental factor for sustaining and expanding not only the S&T system, but also the country's progress. It can be noticed that the lack of a national (and not nationalist) development policy constitutes an unsurpassable obstacle for the S&T system and even for socioeconomic development. The small number of patent registrations in comparison to the expressive production of scientific articles cannot be associated to problems in the S&T system, but instead it should be attributed to the lack of industrial policies. Without a national development agenda, there will be no space for the PhDs trained by the S&T system to develop patents in the national, multinational or transnational industries. In the same way, there will be no means for science to aggregate value to Brazilian exports, perpetuating the shortages on our balance of payments and increasing our national debt. The harmonious development of the production and S&T systems is necessary and sufficient to create a virtuous cycle that will allow us to reach the level of socioeconomic development that we expect to extend to our people.

At last, I could not end this presentation without thanking the colleagues that accepted to share responsibilities with me, contributing in a decisive manner to make possible the fulfillment of the task that was delegated to me by the Brazilian Academy of Sciences. The coordinators that made this report viable were: José Roberto Postali Parra (Agrarian Sciences); Henrique Krieger (Biological Sciences); Walter Araújo Zin (Biomedical Sciences); José Augusto Penteado Aranha (Engineering Sciences); Carlos Alberto Aragão de Carvalho Filho (Physical Sciences); Elisa Pereira Reis (Human Sciences); Aron Simis (Mathematical Sciences); Angelo da Cunha Pinto (Chemical Sciences); Marco Antonio Zago (Health Sciences); Roberto Dall'Agnol (Earth Sciences).

Antonio Carlos Campos de Carvalho
Member of the Brazilian Academy of Sciences

Science and Technology in a Developing Country: The Brazilian Case

JOSÉ ISRAEL VARGAS

Modern science in Brazil started mainly under the influence of the Brazilian Academy of Science (from 1916 on)[1] and afterwards, particularly in the fourth and fifth decades of last century, under the spell of a group of brilliant young researchers trained at the University of São Paulo. This institution counted with a good number of high-level European scholars as teachers. Nuclear experimental and theoretical physics in particular were, then, at the forefront of world's science, and locally they were aptly explored under the leadership of G. Wataghin and G. Occhialini, both ex-members of Fermi's group, in Italy.

The early contribution of the new Brazilian school to cosmic rays physics and of new associate nuclear physics instrumentation[2] (Ref. 6) with the concomitant discovery of penetrating showers (Ref. 7 and 8) and to astrophysics (Ref. 9 and 10) soon met with international prestige, later consolidated through investigations made in Europe (Cambridge, Bristol, Liverpool, Paris and Rome) and in the United States (Chicago, Princeton and Berkeley). The striking discovery of the meson by Powell and Lattes (Bristol) (Refs. 11 and 12), and by Burferming, Lattes and Gardner (Berkeley) (Ref. 13), did exert everywhere great influence, not only because it was taken as a confirmation of early theoretical work by Yukava – which has motivated long, fruitful and still ongoing co-operation between Japanese and Brazilian scientists in the field of high energy particle physics. It also seemed likely to offer, a so far, unimagined approach to nuclear energy production, *via* meson-catalysed fusion of hydrogen- deuterium nuclei, which (Refs.14, 15 and 16) received extremely wide press coverage, but revealed itself to be unfeasible, as shown sometime later by Zeldovich *et al*. and Alvarez. It was thus shown not capable to compete (Refs. 15 and 16)[3] with the newly established uranium fission, that had just achieved the

1. *For ample information on Brazilian science see Ref. 1 which includes earlier contributions on all fields and References 2,3, 4 and 5.*
2. *The described coincidence circuits were ten times faster than any other then existent and allowed for the penetrating shower and other fundamental works on muons that were carried out.*
3. *Because of a too small «sticking probability» of muons to 3He, produced in the muon fusion reaction p+d= 3He+5.5Mev.*

fantastic feat of, so to speak, literally "unplugging" humanity from our sun, the single energy source available to men since immemorial times.

For people of my own and of the preceding generation, the future was considered to be extremely promising. Cheap and abundant nuclear energy would – forever – free mankind from the burden of necessity.

These conquests have thus everywhere induced dedicated men of science, such as Bahba and Menon, in India; Abdus Salam, in Pakistan; Alcina and Sabato, in Argentina; Lattes, Souza Santos, Schemberg, Leite Lopes and Tiomno[4], as well as representatives of the older generation, like Costa Ribeiro, Magalhães Gomes, Bernhard Gros, and Álvaro Alberto[5] in Brazil – both well known to this house - to direct their efforts, at home and at the international arena, to set up institutions dedicated to the fostering of scientific research. In Brazil a National Council for Research, as well as an agency (CAPES) – dedicated to recycling and post-graduate training of university personnel, both in Brazil and abroad - were established in 1951, immediately after the founding of the Brazilian Centre for Physics Research (CBPF), in Rio, by these pioneers. Their statutes were inspired by those followed by the very prestigious British research establishment. In fact, many of the new Brazilian research leaders were trained in England – perhaps in recollection of the still prevailing reputation justly enjoyed by Lord Rutherford's Cambridge School.

Another important initiative was taken with the creation of a science and technology Financing Agency (FINEP) with a view to distribute grants for the implantation of major university equipment as well as of soft (low interest) loans for science and technology development in industries. It also launched the development of Brazilian

4. *Lattes, Leite Lopes and Tiomno are founders in Rio de Janeiro (1951) of the Centro Brasileiro de Pesquisas Físicas (Brazilian Center for Physics Research). Assisted by an international commission, sponsored by Unesco, whose creation was inspired by Paulo Carneiro, constituted by the following scientists: Giuseppe Occhialini, former participant of the Physics Department of USP, crated by Wataghin in 1933; Ugo Camerini, of Italian origin, participant C.S. Powell's group and later Professor at University of Wisconsin; Gert Molière, German theoretical physicist from Heisenberg's group; and Gerhard Hepp, Dutch electronics technician from Philips.*

5. *The first is the discoverer of the thermo dielectric effect (electrets); the second, as the founder of the second Brazilian Centre dedicated to the research of nuclear science and technology (IPR), now CDTN – Centro Brasileiro de Desenvolvimento de Tecnologia Nuclear, the third created an important physics research group on the theoretical aspects of cosmic radiation, on detectors of nuclear radiation, on rheology and dielectrics materials, the last was the founder and first chairman of the National Research Council.*

consulting firms with a view to foster the autonomous development of innovative projects. It has had important impact in many fields, notably in the area of new materials, nuclear science and the aeronautics. The last sector resulted from a close association with the Massachusetts Institute of Technology scholars and that, later on, was engaged in space research, mostly with French institutions, with NASA in the USA, and more recently with China. The local production of middle jet planes by EMBRAER - an off shot of the very modern Aeronautics Technological Institute (ITA), also created in the fifties - led it to become the third supplier of middle range jet and conventional training planes in the world. Its success can be judged by its current backlog of aircraft orders, which totalled US$ 23.5 billion in June 2001 (US$ 10.7 billion in firm orders and US$ 12.8 in options). The Brazilian policy, which more modestly is parallel to those of India and China, resulted in the production and orbit placing of two homemade data collecting satellites and another remote sensing and also data collecting satellite in association with China (CBERS - China-Brazil earth research satellite). Brazil is also the only developing country participating albeit in a small scale in the construction and future exploitation of the International Space Station.

In spite of these laudable efforts, along more than 50 years, science (and technology) has still to face and overcome the vagaries of Brazilian history, that have shaped its socio-economic relative retardation. Some years ago, an Admiral, ex-chairman of the Brazilian National Atomic Commission used to state (and not in jest…), that Brazil was the only country in the world that had Brazilian problems. To my mind he was, of course, equally right and wrong. He was right because a good share of the startling Brazilian problems results from the heritage, up to a point unique, of the past colonial system established by Portugal, as well known in our historiography. The Portuguese colonial system, although set up by an European nation, had been bypassed by the Industrial Revolution and by its "Illuminist" source, the originator of modern western science.[6]

In contrast with the Spanish colonies where, in spite of a domineering obscurantism by the same causes, early illustration started already in the XVI century at universities and publishing houses; in Brazil the printing press was only introduced in 1808, and a conglomerate of a few professional schools – albeit of high quality – came to light under the guise of an university only in 1922, after more than

6. *See however William Joel Simon, «Scientific Expeditions of the Portuguese Overseas Territories (1783-1808), Instituto de Investigação Científica Tropical, Lisboa, 1983.*

four centuries of intellectually dreary circumstances. However, in truth, during the colonial period, a considerable number of outstanding young Brazilian intellectuals were trained in Coimbra University and in some other European learned institutions. They were sent to work mostly to Freiburg, Edinburgh, Paris and Montpellier. The most distinguished of them all, José Bonifácio de Andrada e Silva, worked with Fourcroy in Paris and Werner in Freiburg (Germany). A member of several most distinguished European academies, he was a precursor in the discovery of lithium, served as professor in Upsala, and for many years was the perpetual Secretary of the Portuguese Academy of Sciences. Finally, upon his return to Brazil, he became the Patriarch and key personality of Brazilian political independence. The dismal evolving situation, that has however anticipated these felicitous developments, resulted, to a large extent, also from the socio-economic activities that along large periods pulsated, upwards and downwards, along at least three economic cycles to obviously attend the necessities of the colonial powers: - at first, in the early colonial days, the predatory extraction of red wood pigments was followed, subsequently, by extensive well known sugar cane plantation-style sugar production, and later on, by gold mining and coffee growing. Almost exclusively slave work and the concomitant lucrative human trade, lasting practically up to the last decade of the XIX century, sustained all these phases. The "modern" African slave exploration, admittedly, was a common feature of the colonial system used by many Western countries, such as Holland, France, England and Belgium, for example.

Our Admiral was nevertheless wrong because, apart from the aforementioned unique cultural traits, just pointed out most Brazilian problems may be found to be similar to those facing some of the largest existing developing countries, such as, among other limitations: lack of local savings and generally rather limited risk capital investments; uneven geographic distribution of economic development as with the consequent inequities in the regional and personal incomes distributions; the frequently wide ranging climatic variations, extending over large semi-arid, tropical and temperate areas (Figure 1) and therefore often demanding widely different technologies. All these factors, one way or another, compose the extreme diversity of features displayed in the pertinent socio-economic indicators, as shown in the 1998 data reported for Brazil, as a whole, to some of its states, and for China, India, Mexico, etc. displayed in Figure 2. (Ref. 17).

After this long digression on national misfortunes, perceived as usual only much later as past history, one should not however loose sight of the considerable economic growth undergone by Brazil, notably during and subsequent to the last two World Wars and along the cold war. In fact, during these and along the intervening periods extending up to the eighties, an induced or deliberately established internal market protection policy, alongside with the intense political competition that prevailed during the Cold War period, the national economic expansion was considerably stimulated, which benefited also other regions. According to the OCDE, during half a century, lying between 1937 and 1987, Brazil's GNP underwent a 13.6 fold growth (Ref. 17). This should be compared to a growth factor of 19 for Japan and 8 for Germany, along the same period. A conventional explanation of this process, generated mainly at CEPAL (United Nations Latin American Economic Commission) and widely accepted in many quarters, considers this policy as to observe a so called "import substitution model", which however in our view would rather be better defined as consisting of a massive "technology importation model", and whose virtues, were undeniable under the prevailing circumstances.

The last conceptualization entails a better understanding of the paradoxical role played by human capital in Brazilian development. Education is justly recognised as a key factor for the understanding of the process, and it may be considered as one of the main facets responsible both for the relative success, and the limitations of the "model" that, ultimately, came to affect negatively the very adopted policies. In fact, the policy has, for some time, enjoyed a major success in so far as it permitted the system to train a labour force almost exclusively only prepared for the absorption and utilisation of imported technology. This aspect may be taken as one of the pillars of the protected market model. However, as anticipated, ultimately, it has at least in part failed, because the traditional educational level revealed itself incapable of responding to the needs that would be later demanded by the more advanced educational standards, deemed to be indispensable for the insertion of Brazil in the new knowledge geared and extremely competitive international economic environment. Consequently, as elsewhere in the developing world, the local industry participation in science and technology and on their applications, within a market newly oriented to the appropriation and creation of highly innovative processes, was extremely limited. Industry's complacency fed by this policy has therefore alienated universities and the scientific community from the pivotal role they had to play in the generation of new high technology based services and products. It should be noted that the science actors, in turn, were unfortunately not as vocal as they should have been on the importance of their alliance with industry. Therefore, by the eighties, Brazil found itself as a minor participant of the new emerging global economy. This unsatisfactory situation was therefore composed, for example, by the losses incurred in the use of a profoundly inadequate patent legislation, and is further illustrated by a misguided concentration of efforts almost exclusively on the development of a purely autonomous production of hardware. This approach was further aggravated by the decision to extend only negligible attention to the development of the more easily manageable, dynamic and cheaper software sector of I.C.T. These are instances that illustrate some of the misbegotten policies that at least in part led to the final collapse of the “import substitution model”, which were of course “added” by some inevitable impacts of the “open market” global policies adopted more successfully in regions such as Southeast Asia. These lessons are now well taken by the Brazilian Government. It has started, in the beginning of the nineties to pay increasing attention to those science and technology policies conducive to the creation of more competitive enterprises. They have already led to a 36.6% participation of the productive sector in science and technology and research and development expenditures. To that effect, all along the decade and particularly in the last three years, a number of incentive laws have been enacted to promote the integration of science with the entrepreneurial sector. They consist basically in directing part of the incomes resulting from the concessions during the privatisation programme to R&D. To this objective, a list of these legal instruments may be found in Annex I to this paper. It is to be expected that this legislation shall soon induce S&T and R&D investments to globally reach at least the magic 2% participation in the GNP.

In spite of the previously considered shortcomings, Brazil now still ranks among the world’s top ten countries in economic size, as shown in Table 1 (Ref. 5). To have reached and observe upgrading from this rank, heavy investments in capital intensive infra-structural facilities and in human resources had to be made and must be further accelerated. The results of this new policy may also be made apparent by a number of interesting indicators. Among them, stands out the obvious correlation between the attained GNP and energy consumption, as shown in Figure 3. After all, energy is just the capacity to do work, and consequently investment in energy, thanks to its strong participation in – among other fields – the important industrial transformation sector, it is still deemed to be indispensable for development and must continue to be so for a long time to come. Figure 4 displays the evolution of the installed hydroelectric potential that has been steadily pursued from 1910 to 1998 (Ref. 19). The rates of

GNP growth and of energy consumption have thus been practically the same: they have reached 4.6% per annum, and 4.4% per annum, respectively. The ordinates displayed in Figure 4, as well as in others to be shown later in this paper (Ln F/1-F), represent elements of a solution (logistic) of Volterra-Lotka equation, summarised in Annex II and in Ref. 20 and 21. It has frequently been utilised by Cesare Marchetti, at the International Institute for Applied System Analysis, to describe a large number of evolutionary phenomena (Ref. 22). The good fitting of the observed data by the logistic equation is so impressive that it is claimed to allow for rather reliable predictions on the future evolution of many systems under scrutiny (Ref. 21). Figure 5 displays on this representation the generation of Electricity from 1940 to 1998.

Deviations from the secular logistic equation, displayed in its linear (Fisher-Price) format, are found to present oscillatory behaviour, describing cycles of economic growth, depression and/or stability (Ref. 23). This pattern is displayed in Figure 6, relative to the deviation of the installed hydroelectricity production, highlights the evidence of an ongoing Brazilian energy supply crisis. This situation originates from unforeseen recent climatic anomalies – the most severe draught in 70 years – that have forced the system to work at exceedingly high “charge factors”. It has also been provoked by the exaggerated present share of 92% of hydro-electricity in the Brazilian electricity generation (Ref. 24). This graph also indicates that Brazil probably should not be able to revert to a “normal” situation – an economic growth of about 4% a year – described by the secular strait line and presented in Fig. 6, before the years 2004-2005. This crises scenario is already exerting a negative impact on the national economy. In fact, such gloomy predictions have already been conjectured through the previously described modelling carried out back in 1992. Energy is of course essential for the quality of life and hence to life expectancy itself, as shown in Figure 7. This graph relates the per capita electricity used per annum in 127 countries, assembled in groups of 10, with life expectancy, as presented by the World Energy Conference in 1992.

While energy is thus undoubtedly a good general indicator of all socio-economic activities, it can only be produced, managed and widely applied by educated human beings. As you may remark from the previous illustrations, energy production and use constitute a surprisingly steady and long-range phenomena, which consumes large amounts of both time and money. So does education, as can be judged by Figure 8, where it is shown that it took over 120 years for Belgium, England and Italy, and 95 years for Japan to reduce their population’s illiteracy from 90%

to 10% (Ref. 25). Interestingly enough Brazil has taken about the same span of time to reduce illiteracy, in its above 15-years-old age group, as shown in Figure 9. A similar behaviour has been observed for most Latin American countries (Ref. 25). In Brazil fortunately, thanks to large recent governmental efforts, 97% of the children aged between 7 and 14 years are now attending school and, likewise, vocational training has, for decades, been meeting with considerable success, as shown in Figure 10 (Ref. 26). SENAI and SENAC have, between 1942 and 2000, trained 61 million secondary level technicians. The parents enrollment (2000) reaches 4.7 million of there students for both intitutions. On the other hand, the total of enrollments in secondary tecnical education for 2000 reached 2,859,135 students, which is similar number to the 2,694,245 university enrollments.

Development however, demands not only continuous efforts to promote general education but it critically also calls for intensive training in science and, of course, in applied science – for “there is no applied science without science”, a phase framed and repeatedly invoqued by the late Abus Salam. Science and technology consequently imply considerable and steady investments. Awareness of the inevitable problems posed by the new globalised and politically altered environment, has led Brazil’s public and private sectors to devote, as already mentioned, an increasing share of their resources to this end, as illustrated in Figure 11 (Refs. 3, 4 and 5). Figure 12 and Table 2 show that, in spite of successive severe economic crises that have affected the country, the concession of scholarships to train scientific personnel has not been reduced. Thus the number of university students has been multiplied, from 1937 to 1998, by a factor of 85, to reach, at present, more than two million students; the number of doctorate diplomas conferred at home and abroad has increased from 1994 to 2000 by a factor of more than three. This expansion has led to an increased participation of Brazilian scientific papers indexed in the international literature. Figure 13, as indicated by the Institute for Scientific Information, displays the percent participation of a selected number of countries in the world’s scientific production. As can be seen, the developing countries participation is still rather meagre. Brazil participates, in 1996, with about 1% of the publications, following India and the Republic of China. However, as far as the quality of the papers is concerned, as measured by the citation impact – the average number of citations induced by the published papers – Brazilian performance, as shown in Figures 14 and 15, ranks better than those of China, India and South Korea (Refs. 5 and 27). In fact Brazil’s rank has advanced from the 28th place in 1981 to the 17th last year. An equally relevant data on the country’s development is the number of PhDs and engineers actually working in science. For Brazil, it amounts to 3% of slightly more than 90,000 participants assembled in a survey carried out by the National Science Foundation, the OECD and the Brazilian Ministry of Science and Technology. Brazil ranks reasonably well as compared to other developing and even some major industrialised countries. Its position compares well with that of Spain (2.8%); of South Korea (2.4%); of Canada (2.4%) and of Italy (1.8%). It is inferior to that of China (5.9%); of India (4.4%) and of Japan (6.8%) (Ref. 5). It is no surprise that the United States ranks first with 30% of this kind of the world's qualified personnel. In Brazil, whenever all research fields are considered, it is found that 70% of the practising scientists are involved with the natural sciences (Ref. 5). These figures should not obscure the fact that Brazil's position is much more precarious when counting is done on a per capita basis.

The transformation of scientific knowledge into services and products, *via* technology, constitutes a long and complex chain of events. Development implies, starting at basic research, a complex sequence of actions involving pre-competitive R&D, applications experiments and trials up to the product, followed by the development engineering phase and the corresponding market trials and product improvement, as summarised in Figure 16 (Ref. 28). It displays the increasing cost of the sequence basic science, experimental development, model testing until finally the market introdution of the new product. It shows that the cost of the last phase is easily ten times bigger than the investment spent in the basic scientific research.

The modern economy is frequently characterised almost only by the indication of the explosive growth of the number of registered patents, as shown in Figure 17 (calculated with data supplied by the WIPO, ref. 29). From about half a million demands registered in 1995, the corresponding number reported for 1999 attained the staggering level of 7 million of registered demands. The number of patents applications in Brazil in 1999 reaches nearly 16,000 (Ref. 5).

The corresponding figures for a selected number of countries describing patent registered in the all important American market, from 1977-79 to the year 2000, varies from 66 to 113 for Brazil; from 67 to 63 for Argentina; from 113 to 100 for Mexico and from 25 to 3,472 to South Korea. These figures are sufficiently eloquent for me to refrain from further comments (Ref. 5).

It is however worthwhile to recall that in many cases the patent laws, resulting from the Uruguay Rounds (TRIPS) agreements, are relatively new and the preceding legislation, as happened for Brazil, often did not involve more dynamic fields such as modern food technology, pharmaceuticals, microelectronic and computer sciences.

Despite the fact that the role of patents as indicators of technological intensity is undeniable, one should not forget a whole range of other broader, perhaps more meaningful indicators – such as the ones adopted by OECD countries, which comprise up to 82 evaluation categories. Perhaps for the evolution of technological density more meaningful is the technological balance – an indicator describing how much is spent and how much is gained by a given country in its technology international transactions. A careful study conducted for Brazil's case, is shown in Figure 18. In 1999, it has attained 4.3 billion US dollars, exports reaching almost 50% of the imports value. This result is better than the performance of Spain (46%) and slightly worse than that observed for Italy (51%) (Refs. 5 and 30).

So far the beacon of the new age is considered to be information and communication technologies. The Brazilian situation in these fields is rapidly evolving. For Internet use, it represents more than the double (in fact, 61%) of Latin American clients.

Figure 19 shows de recent evolution of telecom. It can be noted that the number of fixed telephones was increased by 25% in 1999, while the number of mobile phones has grown, in the same period, by 83%. 3.4 billion US dollars have been invested in the national optical fibre network.

The personal computers' market is also fast growing. It is foreseen that, for the same period, it will rise from the present 10.5 million to 25 million units (Figure 20, ref. 28). This expressive growth in PC utilisation may be anticipated to be observed for China, India, Southeast Asia and Latin America in the near future, which however are all still relatively much smaller than the presently saturated American and European markets. It remains to be seen whether the emerging market shall be sufficient to counter the present ongoing "new economy" I.C.T. crises. Cheap computers have been reportedly developed both in Brazil and in India shall probably respond positively to governmental intentions to connect most of the households of those countries. If this comes through and considering growing demands from China and Russia, it may contribute to reduce the present ongoing I.C.T. crises.

Brazil's Internet coverage is also still modest and there remains a relatively large potential for further growth. However, the last few years extremely fast evolution of mobile telephone terminals and Internet hosts are displayed in Figures 21 and 22. Despite the ongoing previously referred to world wide collapse in the expansion of the I.C.T technologies, the number of installed mobile telephones shall attain in Brazil over 40 million units in the next 5 years.

With the anticipated saturation of the information and communication technology market, it might be surmised that the next wave of applied science market penetration will continue to emerge from the extraordinary - both recent and also not altogether new - discoveries in the life science field, in particular from molecular biology. Additional progress may be achieved in the applications that might result from the development of more ductile and higher transition temperature super-conductors.[7] Quantum computers might constitute good candidates to join these new and exciting future achievements. The utilisation of nuclear research reactors for assaying and evaluating environmental problems (health, agriculture and pollution) supportive of sustainable development policies, exemplified by the outstanding work conducted by the International Centre for Environmental and Nuclear Sciences, in Kingston, Jamaica, emphasized the important contribution and the novelty of a multidisciplinary approach to solve complex phenomena with rather traditional techniques. They may also still generate meaningful results in basic science. Time limitation does not allow me to dwell in more speculations, which are, after all, “the bread and butter of scientists”.

Let me finish with two remarks. The first one is that nuclear energy is bound, everywhere in the near future, to undergo considerable expansion. If it succeeds in so doing, it shall fulfil, at least in part, the youthful dreams of my generation. But it has first to show itself capable of finding acceptable solutions to the radioactive waste disposal problem. Thanks to its characteristics, it will certainly contribute to reduce the impact of the greenhouse effect. (Incidently, let me recall that the Brazilian contribution to the global emission of greenhouse gases is rather limited (Table 3, ref. 17), renewable energy responding to 68% of its energy matrix.) Nuclear energy has to be cheaper than other existing alternatives. Projections on the future cost of energy seem to confirm its cost wise potential for wider utilisation (Table 4). An optimistic vision of such future expansion has already sometime ago been expressed by Marchetti and is summarised in Figure 23, taken from ref. 31. As far as Brazil is concerned, the complete command of the nuclear fuel fabrication using its locally produced enriched uranium will certainly induce it to join, in the future, the new nuclear band-wagon of the peaceful users of nuclear energy. Under these circumstances, it shall expand its

7. *While finishing up this paper, J.H.Schön, C.H.Cloc and B.Batlogg reported the existence of a new organic material super conductor reaching a transition temperature of 117ºK, Science, 30th August 2001.*

presently modest installed potential (2 million kW), profiting from its rank as the fifth depository of the world's uranium reserves. This policy would also open the opportunity to employ a considerable number of highly trained specialists who have, in fact - due to the observed general ongoing almost worldwide mitigation of nuclear energy utilisation – played important roles in improving the quality and the design and construction of a wide-range of industrial equipment. The Brazilian sugar cane based alcohol fuel program - the largest renewable energy project in the world – constitutes a good example of this past contribution.

The expected renewal of nuclear energy utilisation shall naturally take place under the aegis of the International Atomic Energy Agency, that Brazil has helped to create. It is our hope that not only non-proliferation of mass destruction weapons, but also effective general abolition of all nuclear weapons shall finally take place. It will eventually allow this Agency – on behalf of the international community – to fulfil its lofty and unique objective of promoting peace and also contribute to curtail terrorism originating mostly from the lesser developing. Brazil and Argentina pride themselves of having created a mechanism of mutual inspection of their nuclear activities, under the supervision of IAEA, which impedes a nuclear arms-race in our southern continent. The roles of both national scientific communities nurtured by this Agency is well recognised. May this example stimulate others to adopt similar initiatives. This attitude is coherent with the Brazilian stand, having lived peacefully for the last hundred and fifty years with all its neighbours. In fact our Constitution limits nuclear applications exclusively to peaceful use (Ref. Article 21, paragraph 23, indented line a).

It gives me great pleasure and honour to recall that the chairmanship of the very first, still interim Board of Governors of this novel international organisation, whose fourtieth anniversary was commemorated in 2000, was exerted by a Brazilian, the late ambassador Carlos Alfredo Bernardes, to whose memory I wish to pay a most respectful tribute.

The second remark is that our dreams of using science and technology to promote human peace and progress, to alleviate misery and its trail of disease and famine, are on the march. This can be judged by the data contained in Figure 26. It summarises the continuous growth of the so called human «development index» for some representative countries, both rich and poor (Ref. 32).

Admittedly, much remains to be done to alleviate the pangs of sorrows that still affect many human beings, thriving that they remain with incomes that are scandalously laying bellow the poverty line (Figure 27, ref. 32).

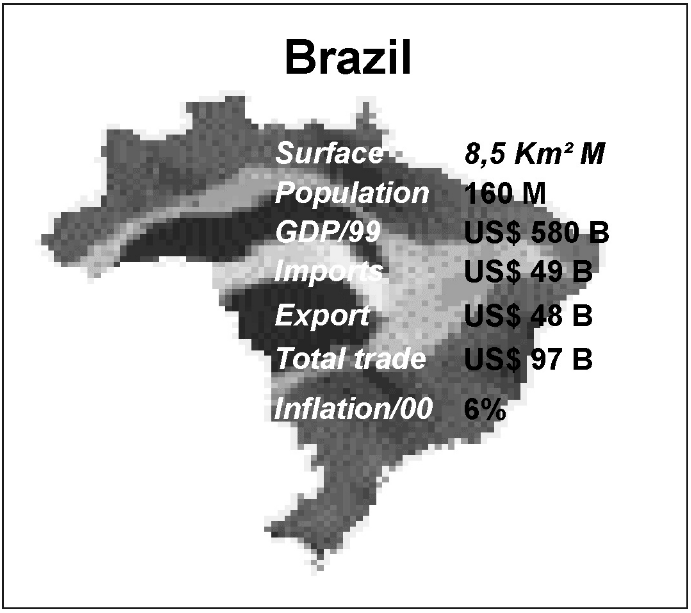
I am however proud of the Brazilian progress in agricultural technology, in genomics, in molecular biology (Figure 24, ref. 19) and in reducing AIDS provoked mortality, which would have attained more than 15 thousand deaths per annum, in the absence of the use of good science, originated everywhere and of a high quality national management. Figure 25 indicates that this scourge will shortly revert to its 1983 value, when the disease started (Ref. 33).

Finally, as you all know, scientists constitute a lucky lot, for they are all engaged in and benefiting from the happiness of pursuit; let us now all – poor and rich – strive for the establishment of a new social contract that shall make science contribute to the pursuit of happiness for all humanity, and never forget the most pertinent reflection by one of the founding fathers of modern humanism, François Rabelais: «La Science sans conscience c'est la ruine de l'âme».

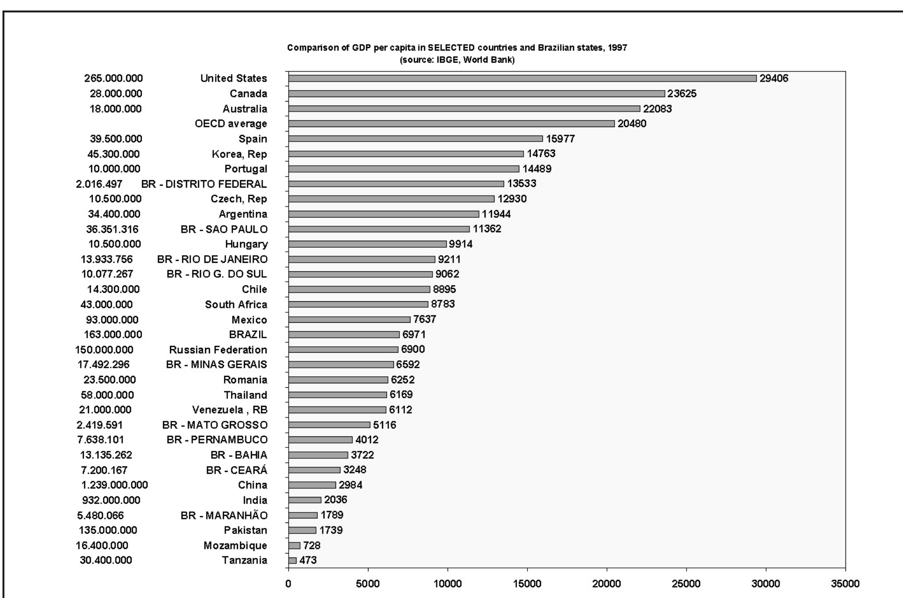
FIGURE CAPTIONS

TABLES

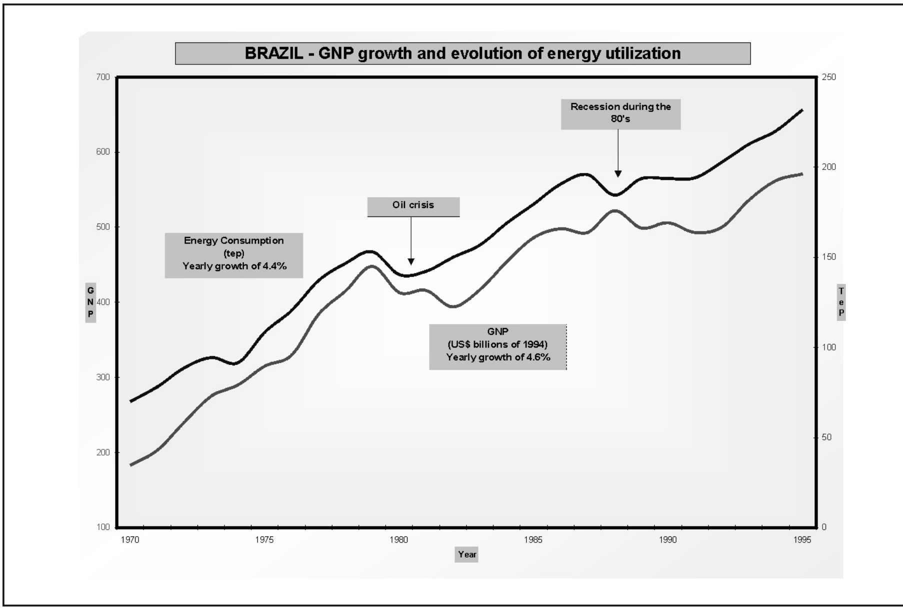
■ FIGURE 1



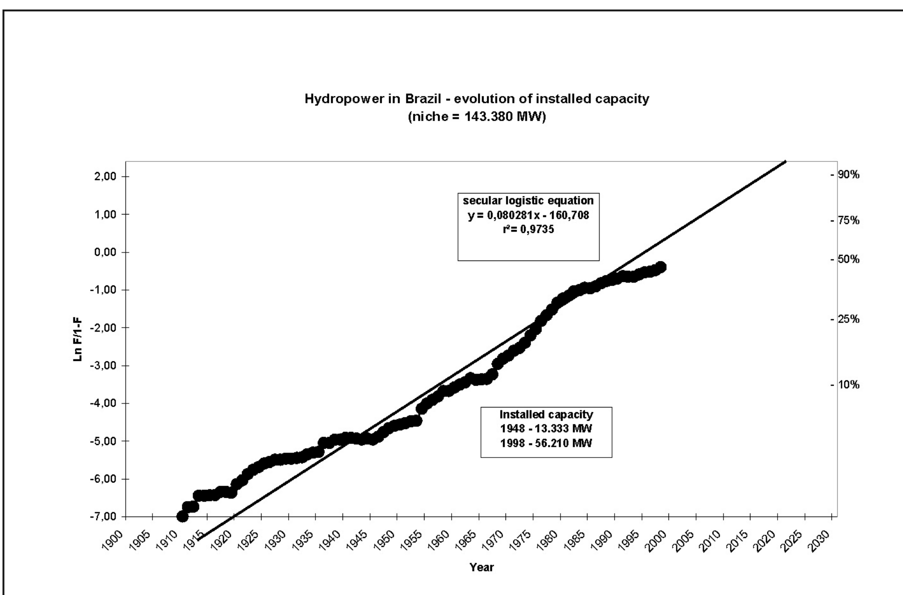
■ FIGURE 2



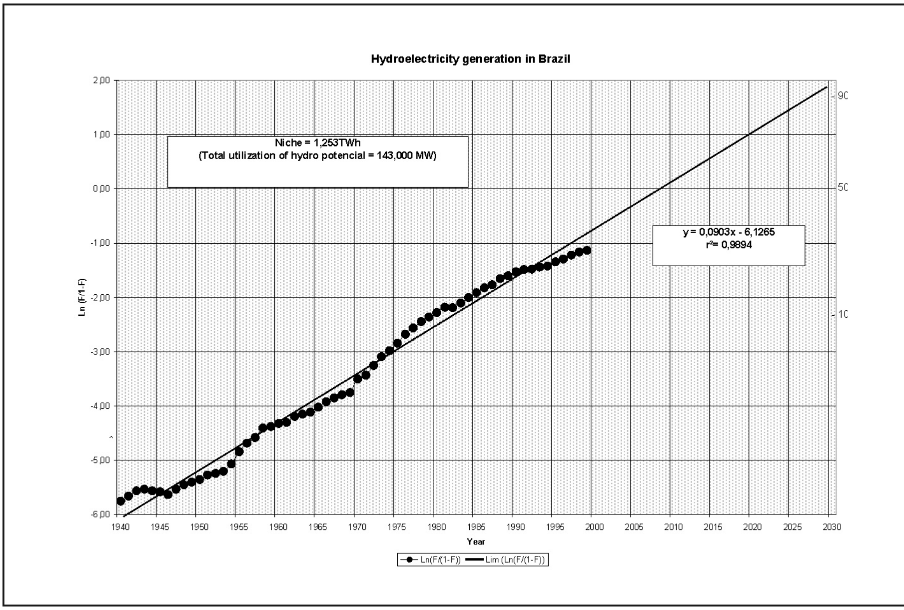
■ FIGURE 3



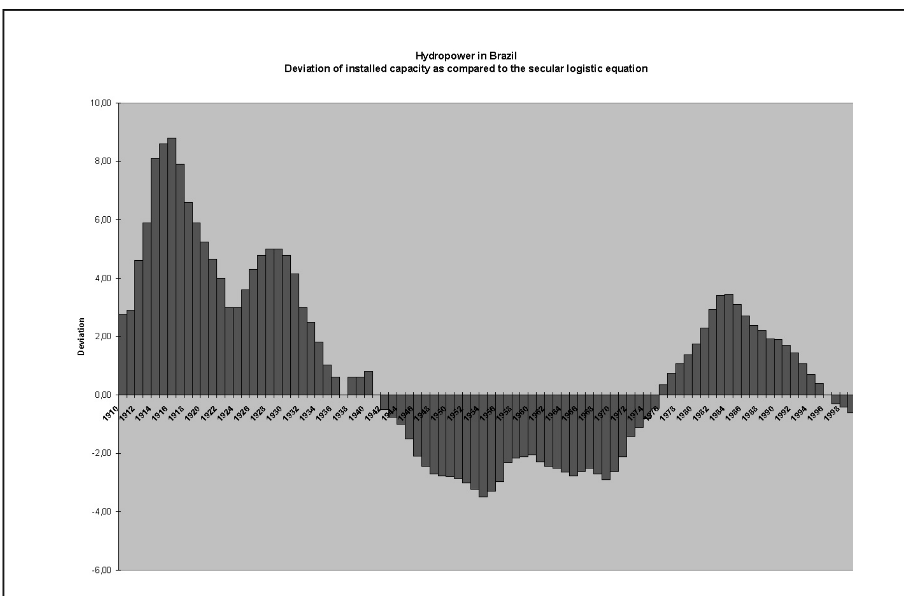
■ FIGURE 4



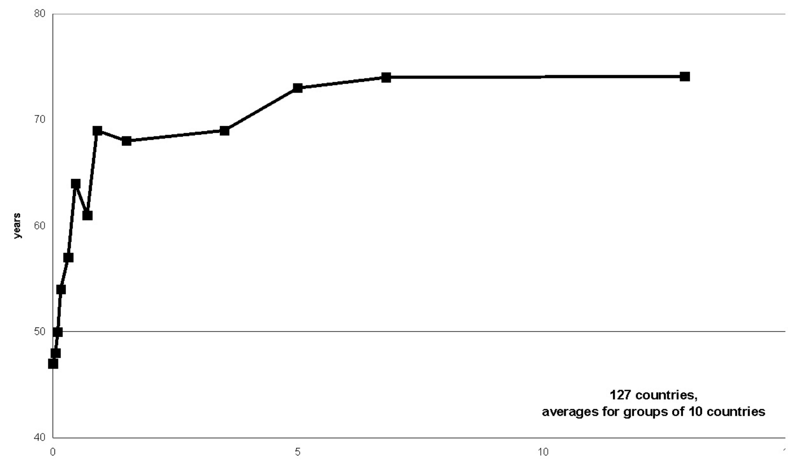
■ FIGURE 5



■ FIGURE 6

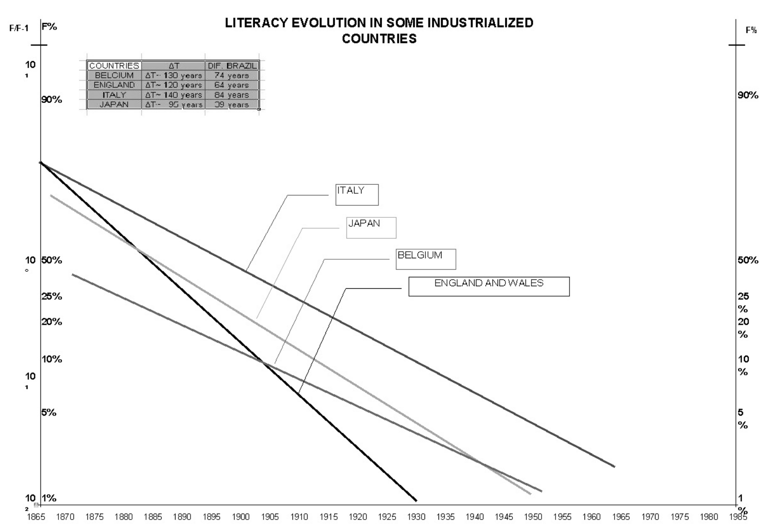


■ FIGURE 7



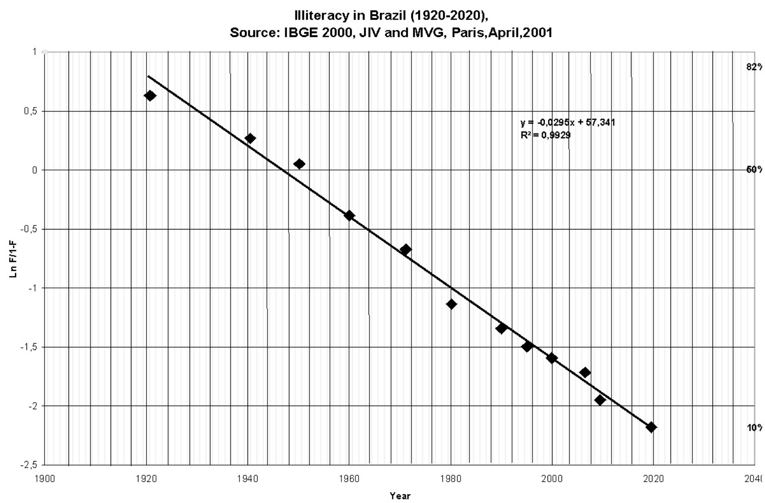
Life-time Expectancy vs Eletricity Use

■ FIGURE 8



COUNTRIES	ΔT	DIF. BRAZIL
BELCIUM	ΔT~ 130 years	74 years
ENGLAND	ΔT~ 120 years	64 years
ITALY	ΔT~ 140 years	84 years
JAPAN	ΔT~ 95 years	39 years

■ FIGURE 9



■ FIGURE 10

VOCATIONAL TRAINING IN BRAZIL

(two major professional training institutions in Brazil)

Source: Ministry of Education (www.mec.gov.br)

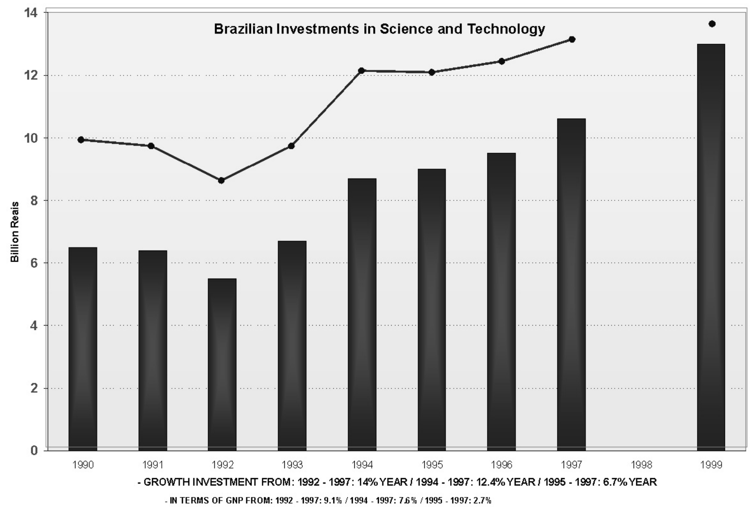
Brazilian Confederation of Industry and Commerce Institutions	SENAI	SENAC
Inception date	1942	1946
Enrollment – 2000	2.9 million	1.8 million
Training courses	342	514
Graduated students	30 million	31 million

Total of enrollments in the 3 levels (*) of professional education for 2000 in 5,451 public and private courses (**)	2.8 million

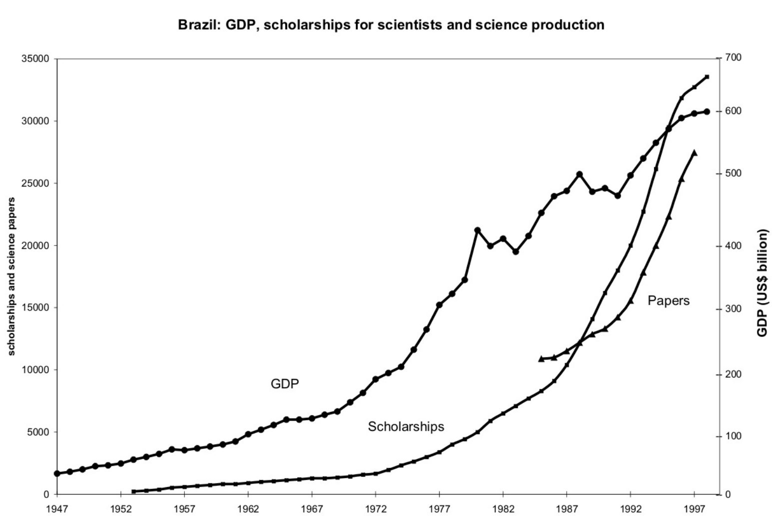
(*) Basic, technical and technological

(**) Traditional primary, secondary and university education excluded.

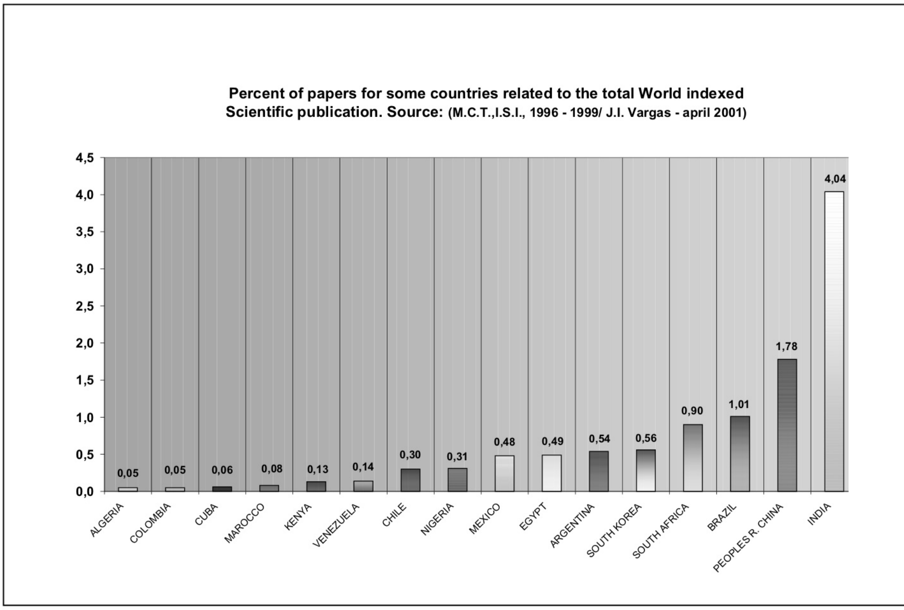
■ FIGURE 11



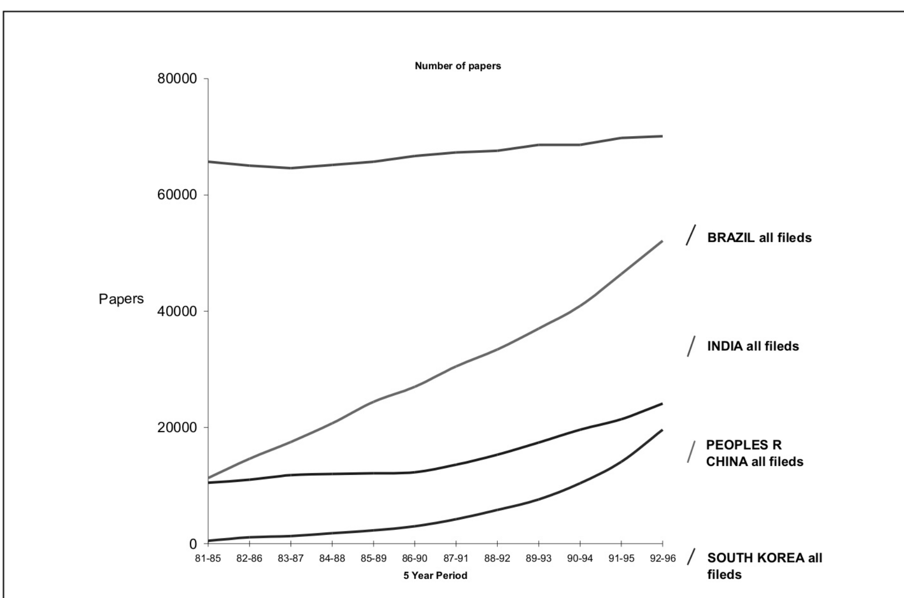
■ FIGURE 12



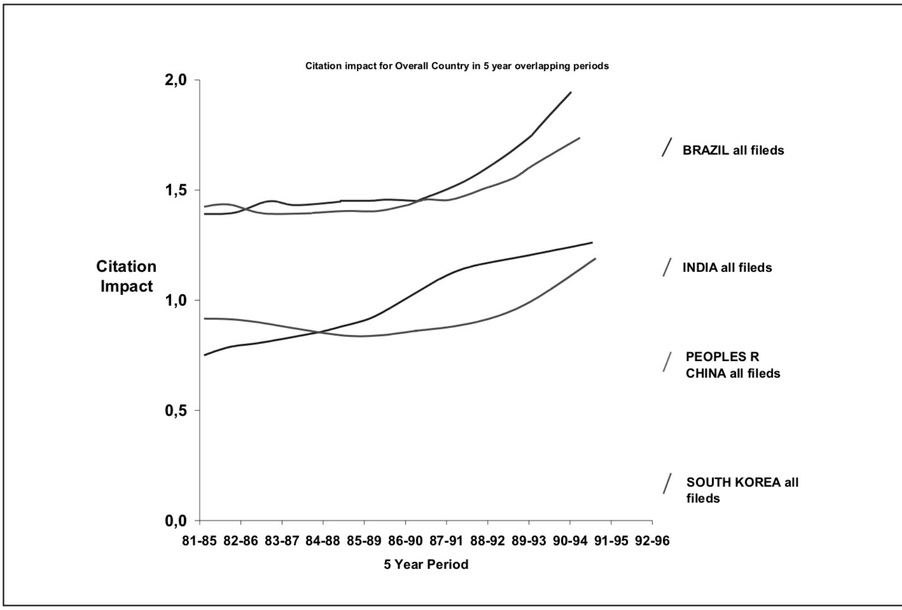
■ FIGURE 13



■ FIGURE 14



■ **FIGURE 15**



■ **FIGURE 16**

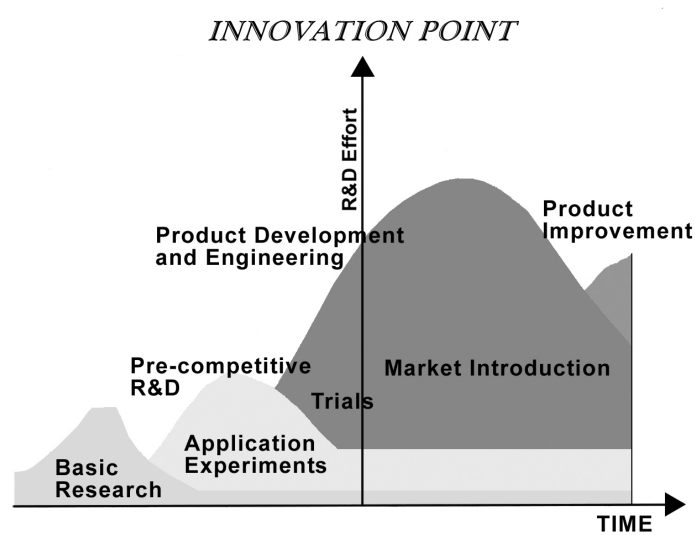
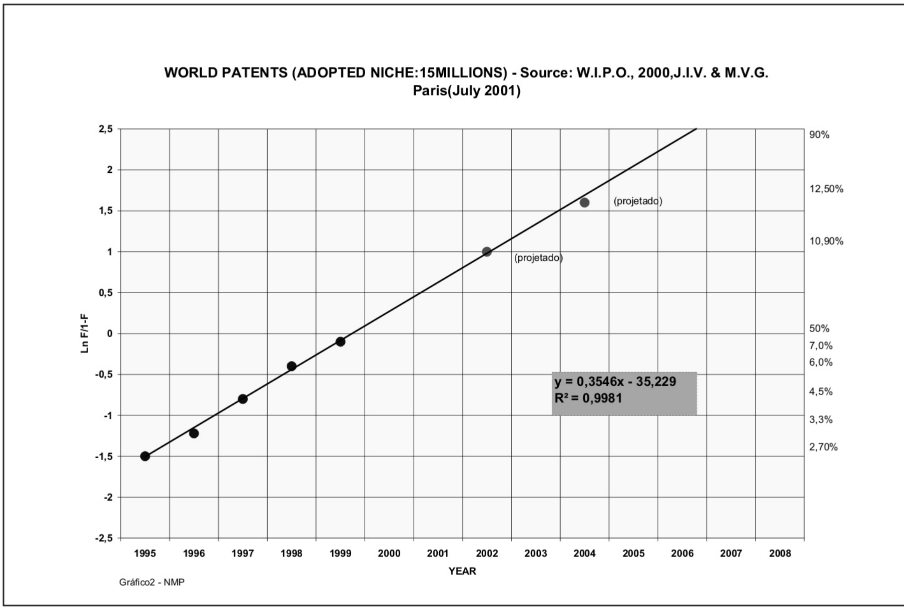
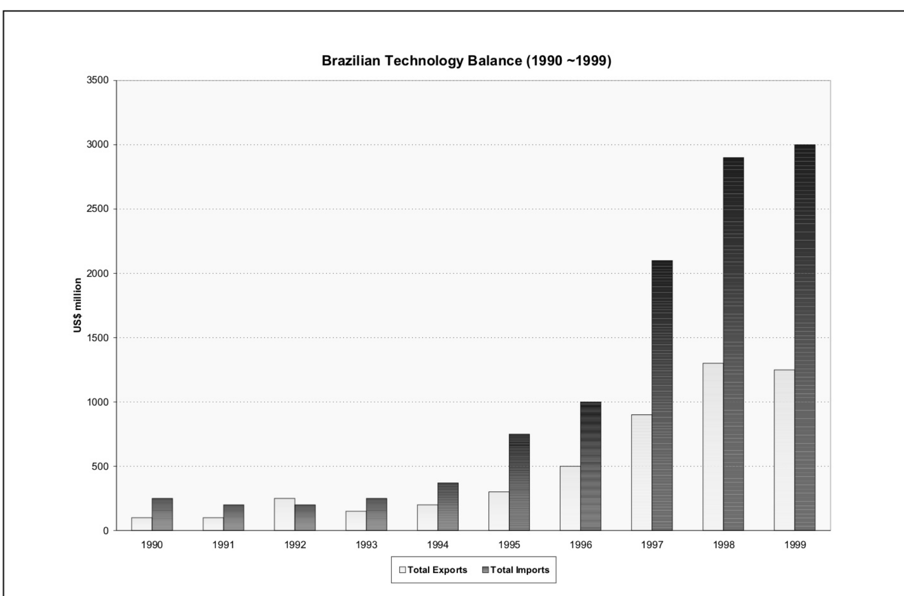


Figure 16

■ FIGURE 17



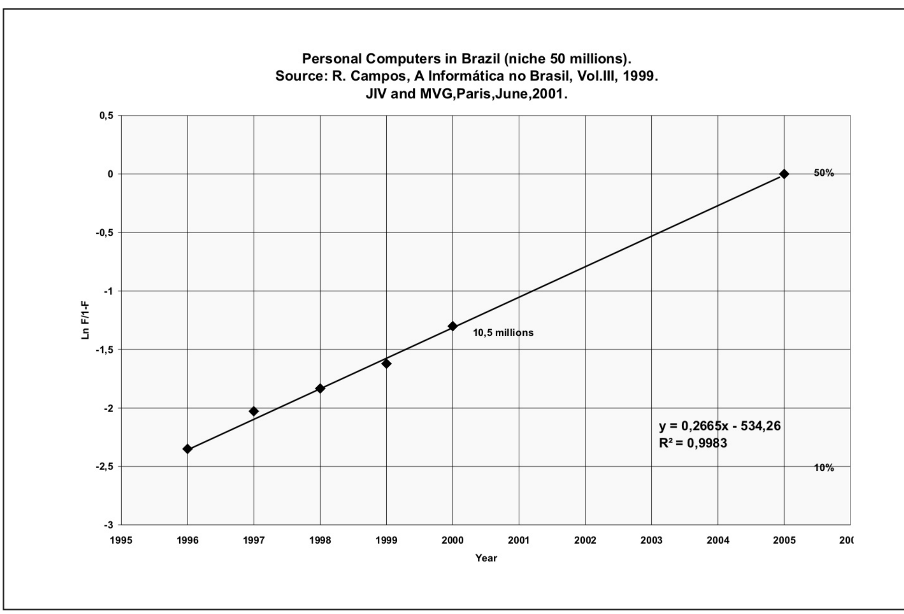
■ FIGURE 18



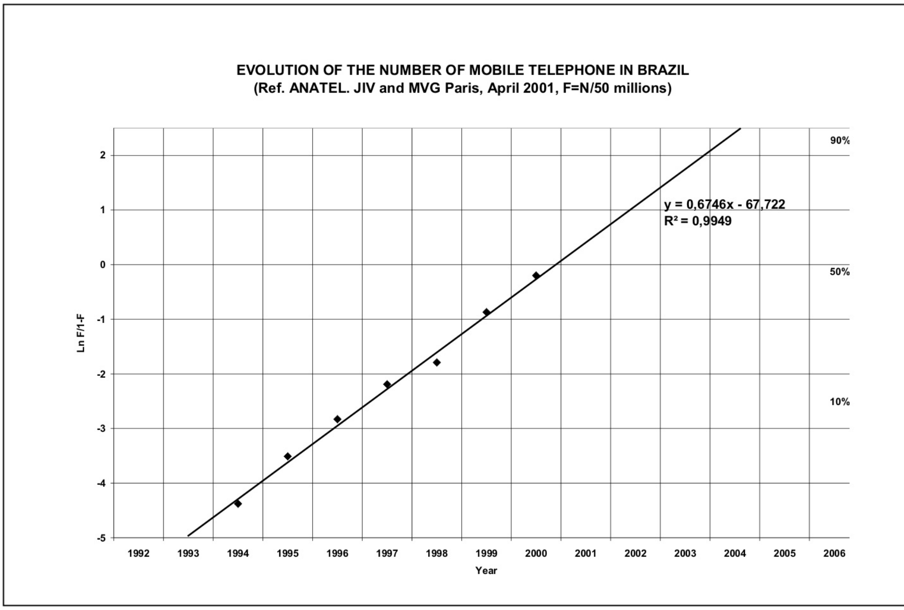
■ FIGURE 19

☞	OPTICAL FIBER - 3.4 US$ BILLION INVESTMENT
• **HFC Networks and Internet Connection**	
☞	Cable TV - 115 authorized providers
☞	MMDS - 33 authorized providers
☞	Up to 478 tows covered

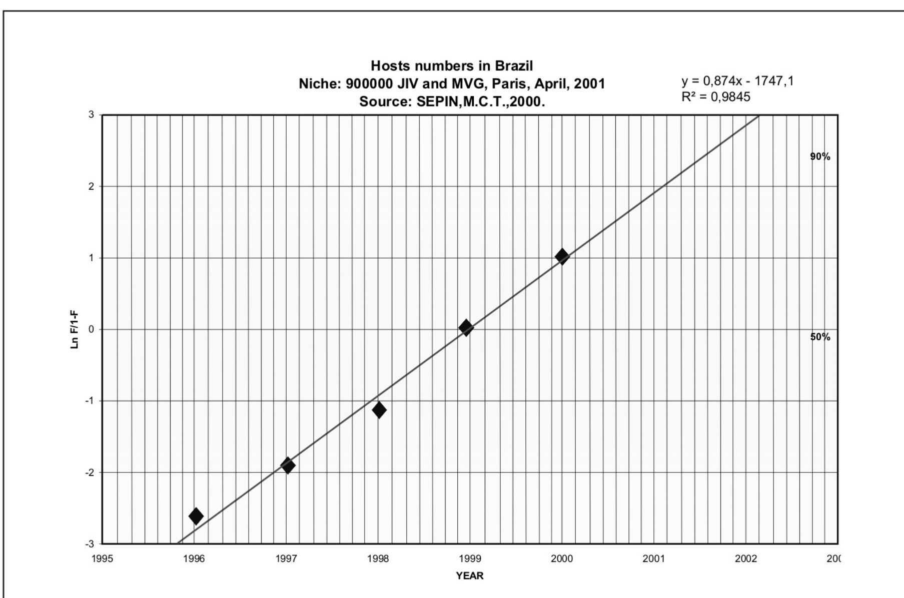
■ FIGURE 20



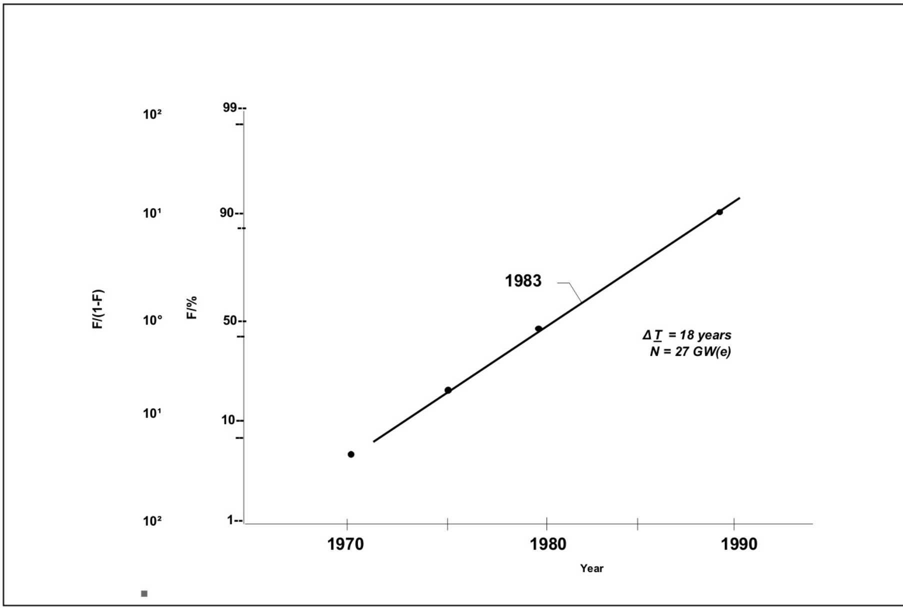
■ FIGURE 21



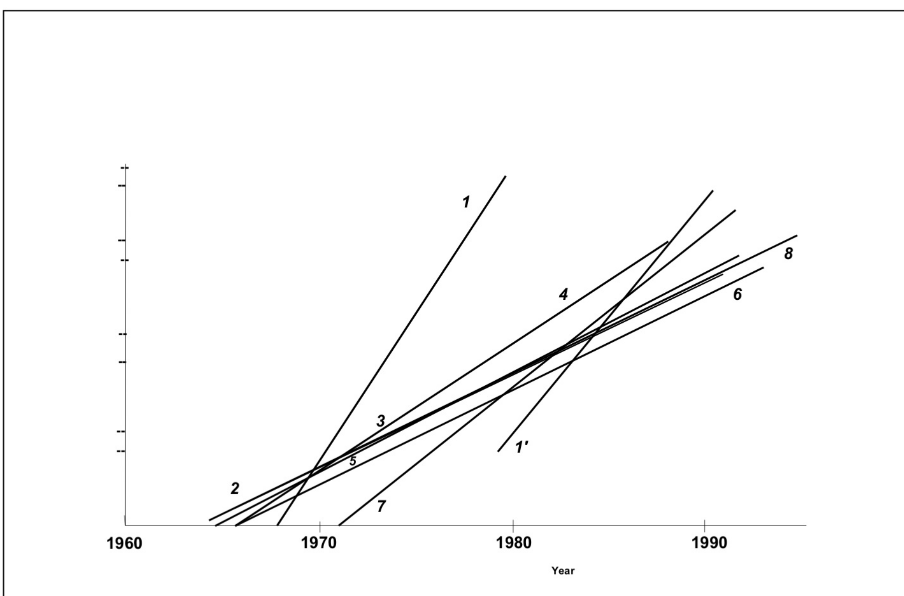
■ FIGURE 22



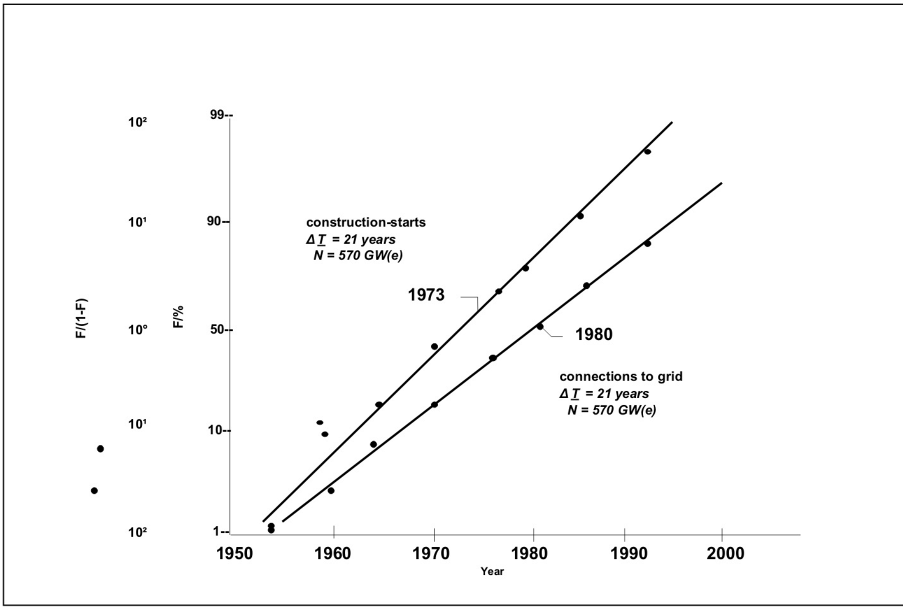
■ **FIGURE 23-1**



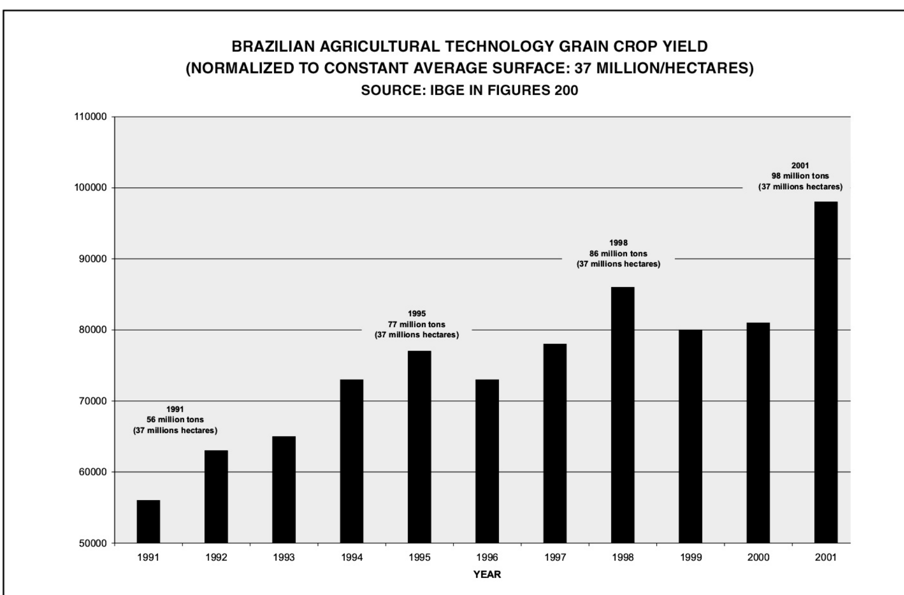
■ **FIGURE 23-2**



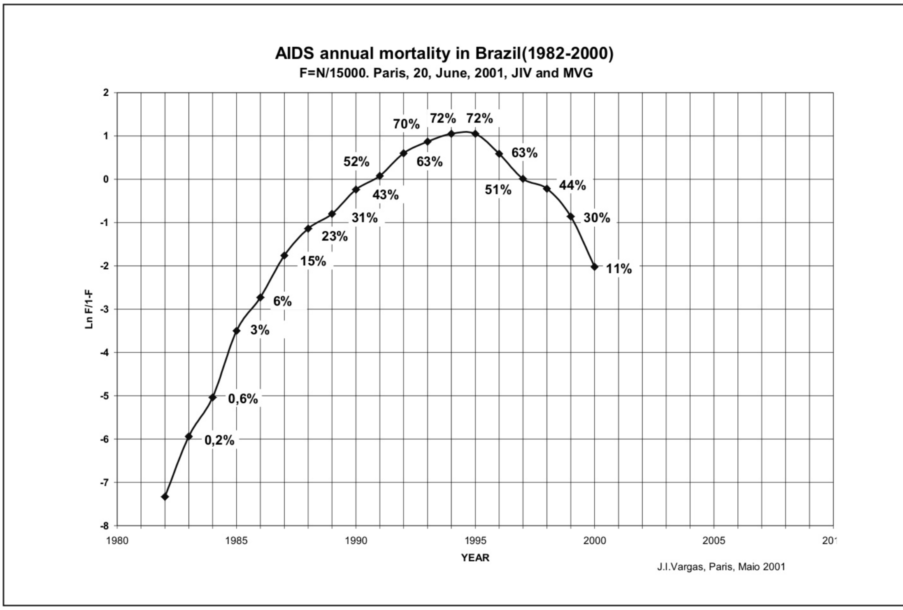
■ FIGURE 23-3



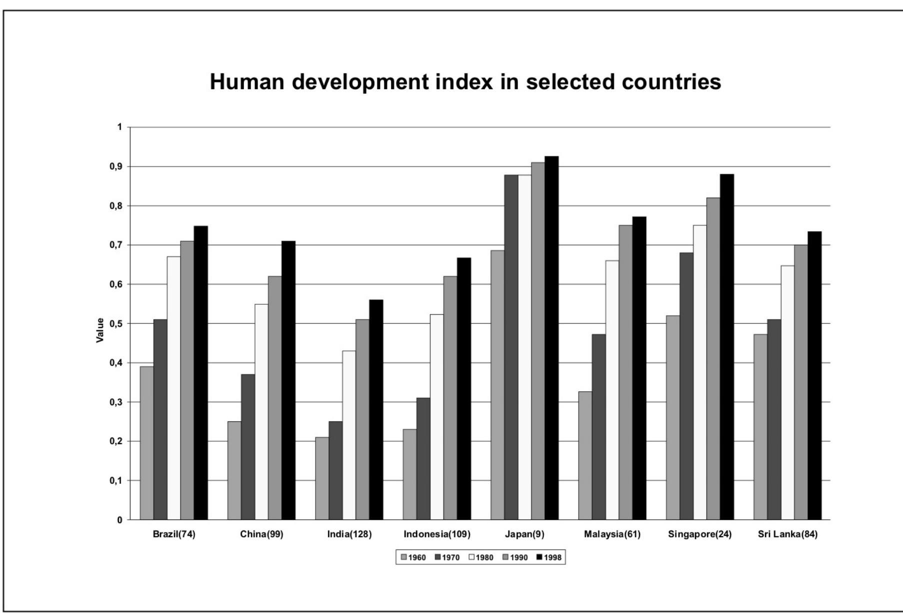
■ FIGURE 24



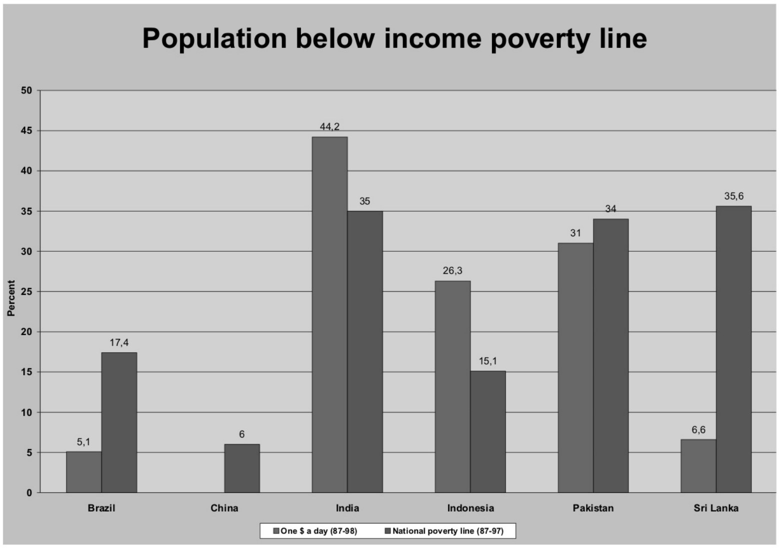
■ FIGURE 25



■ FIGURE 26



■ FIGURE 27


Population below income poverty line
Percent
50
45
40
35
30
25
20
15
10
5
0
5,1
17,4
6
44,2
35
26,3
15,1
31
34
6,6
35,6
Brazil
China
India
Indonesia
Pakistan
Sri Lanka
One $ a day (87-98)
National poverty line (87-97)

■ **Table 1**

World top-10 countries by economic size, 1998

	GDP, PPP (current international $)		GDP at market prices (current US$)		Population, total	
	bn. US$	In % of world	bn. US$	In % of world	Million	In % of world
United States	8002.2	21.3	8230.4	28.6	270.3	4.6
China	3846.2	10.2	959.0	3.3	1238.6	21.3
Japan	2940.0	7.8	3783.0	13.2	126.4	2.2
India	2034.6	5.4	430.0	1.5	979.7	16.8
Germany	1818.9	4.8	2134.2	7.4	82.0	1.4
France	1246.1	3.3	1427.0	5.0	58.8	1.0
United Kingdom	1201.0	3.2	1357.2	4.7	59.1	1.0
Italy	1185.5	3.2	1171.9	4.1	57.6	1.0
Brazil	1097.7	2.9	778.2	2.7	165.9	2.9
Russian Federation	947.7	2.5	276.6	1.0	146.9	2.5

Source: World Bank
"Country Survey: Brazil", OECD 2001

■ Table 2

MAIN INDICATORS ON THE BRAZILIAN HIGHER EDUCATION SYSTEM

	1937	1994	1998	GROWTH
UNIVERSITIES	2	127	973	486
HIGHER EDUCATION PROGRAMMES	200	4.367		218
PROFESSORS	3.300	160.000	174.289	53
UNDERGRADUATE STUDENTS	25.000	1.600.000	2.125.958	85

Source: IBGE Brazil in Figures, 2000

	1994	2000
POST-GRADUATE PROGRAMMES: DOCTORATE	562	837
POST-GRADUATE PROGRAMMES: MASTER	1.074	1.537
MASTER STUDENTS	41.400	63.591
DOCTORATE SUTUDENTS	16.300	33.004
MASTER DIPLOMAS CONFERRED	7.500	18.374
DOCTORATE DIPLOMAS CONFERRED	1.700	5.344

Source: MCT/ABC, LIVRO VERDE 2001

■ TABLE 3

BRAZIL MAIN ENERGY AND CO_2 EMISSION INDICATORS, COMPARISONS WITH SELECTED LARGE COUNTRIES, 1998.

	Brazil	Argentina	Mexico	India	China	South Korea	Japan	OECD Europe	USA
Total TPES(Mtoe)	175	62	148	476	1,031	163	510	1,737	2,182
% annual growth 71-98	3.5%	2.3%	4.5%	3.6%	3.7%	8.9%	2.4%	1.2%	1.2%
TPES per capita (toe)	1.1	1.7	1.5	0.5	0.8	3.5	4.0	3.4	8.1
% annual growth 71-98	1.5%	0.8%	2.0%	1.5%	2.2%	7.5%	1.7%	0.7%	0.2%
Eletricity cons. per capita (kWh)	1,939	2,053	1,906	504	942	5,068	8,192	5,893	14,135
% annual growth 71-98	5.0%	2.8%	4.3%	5.5%	6.7%	10.8%	3.0%	2.4%	2.0%
Energy import dependency (% of TPES)*	28%	-29%	-54%	13%	1%	83%	78%	35%	22%
Energy intensity (TPES/ GDP, toe/'000 US$)	193	209	195	320	248	303	198	223	310
CO_2 per capita (tonnes)	1.8	3.8	3.7	0.9	2.3	8.0	8.9	7.7	20.1
Carbon intensity (CO2/ GDP, tonnes/'000 US$)	326	466	470	611	687	687	437	504	768
Carbon intensity of energy mix (CO2/TPES, tonnes/toe)	1.69	2.23	2.41	1.91	2.77	2.27	2.21	2.26	2.48

* A negative figure indicate an exporting country. Source: IEA.
"Country Survey: Brazil", OECD,2001

■ TABLE 4

ELECTRICITY COSTS

Some comparative electricity generating cost Projections for 2005-2010, in cents per kilowatt-hour.

	Nuclear	Coal	Gas
France	3.22	4.64	4.74
Russia	2.69	4.63	3.54
Japan	5.75	5.58	7.91
South Korea	3.07	3.44	4.25
Spain	4.1	4.22	4.79
United States	3.33	2.48	2.33-2.71
Canada	2.47-2.96	2.92	3.00
China	2.54-3.08	3.18	

Source: OECD/IEA NEA

Bibliographic References

1. AZEVEDO, Fernando, ed., *As ciências no Brasil*. São Paulo: Melhoramentos, 1954. 2 v.

2. SCHWARTZMAN, Simon. *Formação da comunidade científica no Brasil*. Rio de Janeiro: FINEP, 1979.

3. MCT. *Ciência e tecnologia nos anos 90*. Brasília: 1998.

4. VARGAS, J. I. *Political constraints to science led development in the South: the case of Brazil*. Third World Academy of Science, Ministerial Meeting, 5th TWAS General Conference, Rio de Janeiro, 1996.

5. MCT and Academia Brasileira de Ciências. *Ciência, Tecnologia e Inovação*, Brasília (DF), julho 2001.

6. SOUZA SANTOS, M.D. A multivibrator counter circuit. *Ann. Acad. Bras. Sci.*, Rio de Janeiro, 12 (3): 179-189, 1940.

7. WATAGHIN, G., POMPEIA, A. and SOUZA SANTOS, M.D. *Phys. Rev.* 57: 51.

8. WATAGHIN, G. and SOUZA SANTOS, M. D. Cosmic-ray showers at great depths. *Ann. Acad. Bras. Sci.*, Rio de Janeiro, 11: 1-9, 1939.

9. LATTES, C.M.G. and WATAGHIN. *G. Phys. Rev.* 69, 1946.

10. SHOENBERG, M. and GAMOW, G. *Phys. Rev.*, New York, 59 (7): 539-547, 1941.

11. LATTES, C.M.G., OCCHIALINI, G.P.S. and POWELL, C.S. *Nature*, 159: 694-697, and also 453, 1947.

12. LATTES, C.M.G., OCCHIALINI, G.P.S. and POWELL, C.S. *Nature*, 160: 486-492, 1947.

13. BURFERMING, J., GARDNER, E. and LATTES, C.M.G. *Phys. Rev.*, 75: 112-117, 1949.

14. FRANK, C. Nature, 160: 525.

15. ZELDOVICH, Y.B. *Dokl. Akad. Nauk. SSSR*, 95: 493, 1954.

16. ALVAREZ, L.W. et al. *Phys. Rev.*, 105: 11-27, 1957.

17. Calculated from OECD, *Economic Survey – Brazil*, preliminary version, 232, June 2001.

18. MADISON, Angus. *Historia del desarollo capitalista – sus fuerzas dinamicas*, Mexico DF: Ariel, 1990.

19. VARGAS, J. I. and KLINGL, O. Calculated from data contained in a) *Estatísticas históricas do Brasil*, v. 3, Séries Econômicas, Demográficas e Sociais 1550 a 1985. Rio de Janeiro: IBGE, 1987; b) IBGE Brazil in Figures, 8 and from MINISTÉRIO DE MINAS E ENERGIA, *Balanço Energético Nacional, 2000*. Brasília: 2000.

20. VARGAS, J. I. *A prospectiva tecnológica*: modelos matemáticos. Parcerias Estratégicas, Secretaria Especial de Assuntos Estratégicos, 1, 49, Brasília, 1995.

21. MODIS, Theodore. *Predictions*. New York: Simon & Schuster,1992.

22. MARCHETTI, C. Society as a learning system: discovery, invention and innovation cycles revisited. IIASA, Technological Forecasting and Social Change, 18: 267-282, 1980.

23. MARCHETTI, C. Fifty year pulsation in human affairs: analysis of some physical indicators. *Futures*, 17: 376-388, 1986. IIASA, Laxenburg, Austria.

24. VARGAS, J. I. Brazillian energy scenario. Roundtable 8, G.T.N. – UNESCO Science Symposium, CBPF, CS – 003/92 Rio de Janeiro, 1992 and data used from Reference 12.

25. VARGAS, J. I. (apud MARCHETTI). Science and technology development: government action and some human resources issues. Colloquium on Science and Technology for the Future of Latin America, UNESCO, Mexico City, 2-6 Dec. 1990 and IBGE, Brazil in Figures, 8, Brasília, 2000. (Figure 9 – calculated with data from last reference by VARGAS, J. I. and GARZON, M. V., Paris, April 2001.

26. Data from Confederação Nacional da Indústria and Confederação Nacional do Comércio, and personal communication, INEP (National Institute for Educational Research), Brasília(DF), August 2000.

27. INSTITUTE FOR SCIENTIFIC INFORMATION, 1981 – 2000, obtained through the Ministry of Science and Technology of Brazil.

28. MCT, Secretary for Information Technology Policy. *Report*. Brasília: 2000.

29. VARGAS, J. I. and GARZON, M. V. Paris, April 2001, calculated with Data from World Intellectual Property Organization, Geneva, 2000.

30. CASSIOLATO, J. Balanço tecnológico do Brasil 1990-1996. *MCT/FINEP report*. Rio de Janeiro: 1997. Data from the Brazilian Central Bank and the Brazilian Institute for Industrial Property (INPI) up to 1996; for 1995-1999, data from the Brazilian Central Bank /DEPEC/DEPRAP, summed up in Reference 4.

31. MARCHETTI, C. Perspectives in Energy, 2: 19-34, 1992.

32. WEI ZHANG M. and COORAY, N. S. Sustainable industrialization in East and Southeast Asia: Indonesia and China compared in the 1990. Symposium on Sustainable Development in an Era of Rapid Technological Change, Institute of Advanced Studies, United Nations University, Tokyo, June 14th, 2001.

33. Ministry of Health, Secretariat for Health Policies, National Coordination for STD and Aids, The Brazilian Response to HIV/AIDS: Best Practices, Brasília: 2000.

ANNEX 1

BRAZILIAN LEGISLATION ON INCENTIVES TO PROMOTE SCIENCE AND TECHNOLOGY

LAWS

Law no. 10197 of February 14, 2001.

Adds disposals to Decree-Law no. 719 of June 31, 1969, to provide the financing of the implementation and recovery of research infrastructure in higher education and research public institutions, and takes other measures.

Law no. 10168 of December 29, 2000.

Creates a contribution of intervention in the economic field with the goal to finance the Incentive Program of Company-University Integration to the Support of Innovation, and takes other measures.

Law no. 10148 of December 21, 2000.

Gives new wording to article 1 of Law nº 9530 of December 10, 1997 that treats about financial dividends and surplus of indirect Federal Public Administration funds or entities.

Law no. 10052 of December 24, 2000.

Creates the Telecommunications Technological Development Fund – FUNTEL – and takes other measures.

Law no. 9994 of July 24, 2000.

Creates the Technical and Scientific Development Program for the space sector, and takes other measures.

Law no. 9993 of July 24, 2000.

Assigns financial allowance from hydrological resources utilization to generate electric energy and from mineral exploitation to the science and technology sector.

Law no. 9992 of July 24, 2000.

Changes the assignment of proper revenues coming from contracts signed with the National Road Department aiming at financing scientific research programs and projects and at technically developing the productive sector of land transportation, and takes other measures.

Law no. 9991 of July 24, 2000.

Takes provisions about investments in research & development and in energetic efficiency made by enterprises who were given concessions, permissions and authorizations to deal in the energy sector, and takes other measures.

Law no. 9478 of August 6, 1997.

Takes provisions about the national energetic policy, activities related to oil monopoly and creates the Energetic Policy's National Council and the Oil National Agency, and takes other measures.
(regulated by Law no. 9847 of October 26, 1999 and by Decrees nos. 2455 of January 14, 1998 – 2457 of January 14, 1998 – 2705 of August 3, 1998 – 2745 of August 24, 1998 – 2851 of November 30, 1998 – 2926 of January 7, 1999).
(See Decree no. 2851 of November 30, 1998 – Decree no. 3520 of June 21, 2000 – Order MCT no. 552 of December 8, 1999 and Order no. 553 of December 8, 1999).

Law no. 8172 of January 22, 1991

Restores the Scientific and Technological Development Fund – FNDCT.

Law no. 8001 of March 13, 1990.

Defines the distribution percentiles of the financial allowance treated by Law no. 7990 of December 28, 1989, and takes other measures.
* With changes stated by Laws no. 9433 of January 8, 1997 and no. 9993 of July 24, 2000.

Law no. 7990 of December 28, 1989.

Creates for states, federal district and municipal districts a financial allowance for results coming from the exploitation of oil and natural gas, hydrological resources to generate electric energy, and mineral resources, in their respective territories, continental platforms, territorial waters or exclusive economic zones, and takes other measures.
(with changes stated by Laws no. 8001 of March 13, 1990 – no. 9648 of May 27, 1998 and no. 9993 of July 24, 2000).
(regulated by Decree no. 1 of January 11, 1991)

DECREES

Decree no. 3737 of January 30, 2001

Takes provisions about the FUNTEL (Telecommunications Technological Development Fund) regulation, and takes other measures.

Decree of April 3, 2000

Creates the work group responsible for proposing the set up of a Scientific and Technological Development Program to the health sector and its own financing model.

Decree of April 3, 2000

Creates the work group responsible for proposing the set up a Scientific and Technological Development Program to agribusiness and its own financing model.

Decree of April 3, 2000

Creates the work group responsible for proposing the set up a Scientific and Technological Development Program to the aeronautical sector and its own financing model.

Decree no. 2851 of November 30, 1998

Takes provisions about scientific and technological research support programs applied to the oil industry, and takes other measures.
(with changes stated by Decree no. 3318 of December 30, 1999)
(See Law no. 9478 of August 6, 1997 – Order MCT no. 552 of December 8, 1999 and Order MCT no. 553 of December 8, 1999)

Decree no. 2705 of August 3, 1998

Defines standards for the counting and collecting of government shares created by Law no. 9478 of August 6, 1997, applicable to exploitation, development and production activities on oil and natural gas, and takes other measures.

Decree no. 1 of January 11, 1991

Regulates the payment of the financial allowance created by Law no. 7990 of December 28, 1989, and takes other measures.

INTERMINISTERIAL ORDERS

Order MCT/MEC no. 509 of August 24, 2000

Designates delegates to form the interministerial committee as stated by article 2 of Intern Measure no. 2021-4 of July 28, 2000 taking provisions about financing the introduction and the restoring of research infrastructure in research and higher education public institutions.

ORDERS

Order MCT no. 1004 of December 19, 2000

Designates delegates to form the coordination committee that manages the application of resources provided to FNDCT (Scientific and Technological Development Fund) as a substitute of another member designated by Order MCT no. 205 of May 24, 1999.

Order MCT no. 968 of November 30, 2000

Designates delegates to form the coordination committee that manages the application of resources provided to FNDCT (Scientific and Technological Development Fund) as a substitute of another member designated by Order MCT no. 205 of May 24, 1999.

Order MCT no. 795 of September 28, 2000

Designates delegates to form the coordination committee that manages the application of resources provided to FNDCT (Scientific and Technological Development Fund) as a substitute of another member designated by Order MCT no. 205 of May 24, 1999.

Order MCT no. 553 of December 8, 1999

Confirms the Internal Regulation of the Coordination Committee of the National Plan for Science and Technology for the Oil and Natural Gas Sector. CTPETRO.

Order MCT no. 552 of December 8, 1999

Confirms the National Plan for Science and Technology for the Oil and Natural Gas Sector – CTPETRO for the period 1999-2003.

Order MCT no. 205 of May 24, 1999

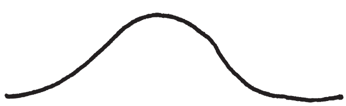
Designates delegates to form the coordination committee that manages the application of resources provided to FNDCT (Scientific and Technological Development Fund)

* with changes stated by Orders MCT no. 795 of September 28, 2000 – no. 968 of November 30, 2000 and no. 1004 of December 12, 2000.

ANNEX 2

THE MATHEMATICAL METHODOLOGY *

The mathematics used in this analysis is extremely simple. Because historians may not be familiar with it, we add this note for illustration. The basic concept that *action paradigms* diffuse epidemically, is condensed in the epidemic equation:



$$dN = aN\,(\bar{N} - N)dt$$

saying that the number of new adopters *(dN)* during time *dt* is proportional (*a*) to the number of actual adopters *(N)* multiplied by the number of potential adopters *(N - N)*, where *N* is the final number of adopters.

The integration of this equation gives

$$N = \bar{N} \,/\, [1 + \exp - (at + b)]$$

* *C. Marchetti, Anthropological Invariants in Travel Behavior. International Institute for Applied Systems Analysis, Laxenburg, Austria. August 1992.*

which is the expression of a logistic S-curve well known to epidemiologists and demographers. *We apply it to ideas*.

In the charts of the present paper the logistic equation is presented in an intuitively more pregnant form. N is measured in relative terms as fraction of $\bar{N}(F=N/\bar{N})$, and the S-curve is "straightened" by plotting log ($F/1$ - F) (Fisher-Pry transform).

$$Log\ (F/1 - F) = at + b$$

The time constant T is the time to go from $F \simeq 0.1$ to $F \simeq 0.9$. It takes the central part of the process (80%) and the relation between T and the a in the equation is

$$\Delta T = 4.39/a.$$

The central date T_0 is defined as b/a.

The final number of adopters $\bar{N}$ is given as a number in parenthesis.

AUTHOR

José Israel Vargas

Member of the Brazilian Academy of Sciences; PhD from Oxford University; and present Permanent Delegate at the United Nations Educational, Scientific and Cultural Organization (UNESCO).

Area of Agrarian Sciences

JOSÉ ROBERTO POSTALI PARRA
ERNESTO PATERNIANI
JULIO MARCOS FILHO
RAUL MACHADO NETO

THE IMPORTANCE OF AGRICULTURE FOR BRAZIL

An adequate analysis of the Agrarian Sciences should, necessarily, consider its interfaces with other areas of knowledge, such as, biological sciences, exact sciences and earth sciences, as well as social and applied sciences, specially economics (Azevedo, 1993). Although research financing organs, like CNPq, include Agrarian Sciences as an isolated activity, it is essential to recognize its complexity within the context of the other areas with which it presents significant interactions.

In a similar way, although it is very common to evaluate Brazil's performance in agriculture, by comparing it with those of countries of temperate climate, especially the USA, such comparison is out of place, due to the fact that the conditions for plant growth, the varieties used and the infrastructure are completely different from those of a tropical region. Thus, the climatic characteristics, the edaphic conditions, the occurrence of pests, diseases and weeds differ completely, as well as the characteristics of the cultivars, the phenology and the development of plants. Such differences become even larger if we consider the distances between the research centers, the transportation and communication characteristics and even the number of existing researchers in the USA and in Brazil (Paterniani, 1990).

Without any doubt, Brazil is the leader in tropical agriculture and, consequently, of Latin America. Brazil has been able to develop, in many areas, production technology appropriate to its conditions, instead of simply transferring technological packages from countries of temperate climate, which were not adequate for our country, for the reasons already cited.

Around 30% of the Brazilian GDP is from agribusiness and of this total, 30% comes from agriculture and animal husbandry. This value could be a lot more significant, taking into consideration the immense territorial extension that is still available for agriculture and animal husbandry. The increase of agricultural production would promote additional benefits to a large part of the population, still in need of food and, above all, it would justify the agrarian vocation of the country, increasing the exports of agriculture and animal husbandry products, bringing substantial funds to our economy.

Such objective will only be reached through research in the area, with a critical mass appropriately trained and able to act in the different regions of Brazil. However, the investment on research has not been proportional to what agriculture represents for the GDP, remaining far behind what is expected, since the Federal Government invested only 18.97%, in 1999, in agriculture (Figure 1A). Besides these problems, it is worth mentioning the great concentration of resources in certain areas of the country (Figure 1B). Even in states where the investments are larger, such as São Paulo, the Foundation for Research Support of the State of São Paulo (FAPESP) invested in 1999, 9.28% in agronomy and veterinary, an inferior value to those invested in human and social sciences, engineering, health and biology (Figure 2).

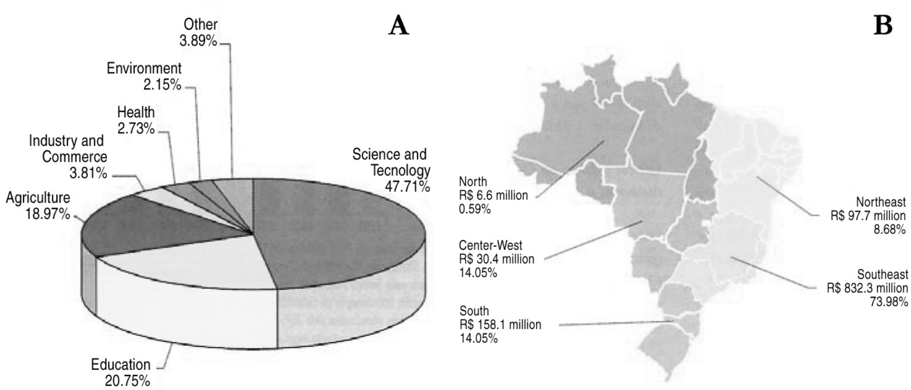


Figure 1A. Federal resources applied in S&T, according to the ministries. Brazil. **Figure 1B.** State resources applied in S&T 1999 (Silva & Melo, 2001).

In relation to Latin America, the Brazilian situation is comfortable, because the Brazilian Company of Agriculture and Animal Husbandry Research (EMBRAPA) alone, invests more than 50% of the total expenditures of the national research institutes in Latin America on Research and Development (R&D), being the expenditures per scientist, on average, three times larger than the remaining institutes

(Table 1). However, these expenditures are small when compared to developed countries, due to the fact that in these places the investments amount to 2 to 4% percent of the GDP, while in Brazil, such investments only amount to about 0.9% (Table 2). An interesting fact shown by Table 3 is that in Argentina, up to the present date, very little research is done at the university, which was a common situation in our country before the beginning of the graduate courses in the 1960's. It could be observed as well that the participation of the private sector is a lot larger in developed countries in comparison to developing countries.

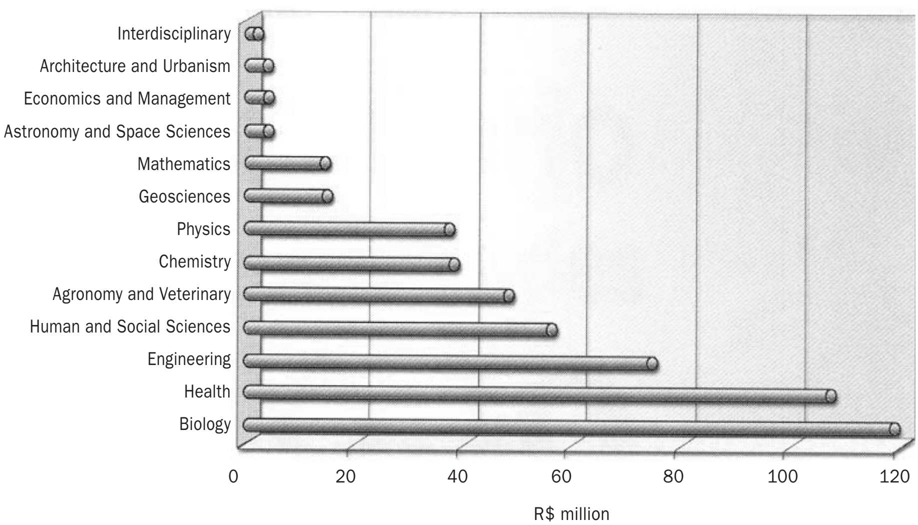


Figure 2. Distribution of total investment per area of knowledge – 1999 (FAPESP, 1999)

There are, however, very successful cases in Brazilian agriculture that will be further detailed under the subtitle "Socioeconomic Impact of the Agrarian Sciences", such as the production of coffee varieties, the rise to leadership in the world's production of *Citrus* and the "soybean case". In these cases, after the adaptation of the American model to temperate climate conditions, cultivars adapted to different photoperiods were developed. Such development allowed an augmentation of the plantation area from the south to the north of the country, with the use of cultivars that yield a productivity comparable to North American standards.

■ **Table 1**

National Investment of the Research Institutions in Agriculture in Latin América, 1981 – 1992 (Lemos & Moro, 2000)

	Total Expenditures (US$ million in 1985)					Cost per Scientist (US$ thousand in 1985)			
Country	1981	1986	1991	1992		1981	1986	1991	1992
Brazil	333	304	437	464		211	177	208	221
Mexico	265	156	118	98		154	72	69	65
Other	267	269	256	270		96	89	87	89
Total	865	729	811	832	Média	142	105	120	126

■ **Table 2**

National Expenditures with R&D as GDP percentages. Brazil: 1999 and selected OCDE countries – 1991/1998 (Silva & Melo, 2001)

Countries	**1998**	**Countries**	**1998**
Sweden	3,7	European Union	1,8
Japan	3,1	Canada	1,6
Finland	2,9	Ireland	1,4
USA	2,7	Italy	1,0
South Korea	2,5	Brazil	0,9*
Germany	2,3	Spain	0,9
France	2,2	Hungary	0,7
UK	1,8	Mexico	0,3

However, the productionist agricultural model that was diffused and became notable after WWII, is under discussions that include additional parameters. "The supply side, contributes with the imbalances between the chronic surpluses of the developed countries and the food scarcity in the peripheral areas of the Third World. The demand side contributes with the new consumption patterns based on the revalorization of food products and on the institutionalization of the environment's defense. Thus, the bases of the productionist model are questioned, because more than producing great quantities to guarantee the supply, this production must be obtained with conservationist care and the agricultural products must have qualitative attributes, aspects that received little attention from the productionist model" (Salles Filho, 1998).

It should be pointed out, however, a growing tendency of questioning the participation of science in the development of an efficient agriculture. Actually, the adequate use of advanced technologies can effectively contribute to a sustainable agriculture, environment preservation, soil conservation and improvement, while at the same time producing healthier crops. Just like chemistry (organic and inorganic) was a key factor of the productionist model, biotechnology will probably be the basis of the technological model.

■ **TABLE 3**

RELATIVE PARTICIPATION IN THE INVESTMENTS IN RESEARCH IN AGRICULTURE IN 1995 (%) (LEMOS E RAMOS, 2000)

Countries	Federal Research Institutions	Universities	Private Sector
USA	15	31	54
UK	37	5	57
Brazil	63	29	6
Mexico	50	17	33
Argentina	89	5	6
Chile	75	20	5
Colombia	61	2	37
Ecuador	52	5	33
India	43	33	24
Philippines	46	18	36

EVOLUTION ON THE TRAINING OF HUMAN RESOURCES

The XXI Century will be the century of science, technology and innovation, propelling cultural, social and economic achievements.

The scientific activity in Brazil, in the last few years, has become more structured and professional, with the training of multi and interdisciplinary groups, capable of developing research in levels comparable to First World standards. The country went through a transitory phase, leaving aside that research (of an excellent level in many cases) done by individuals or even isolated institutions, with little government or private support.

This change started to happen with the beginning of the graduate courses in the 1960s, a fact that generated great modifications in the area of Agrarian Sciences (as well as in other areas), because, until then, the majority of the research was done by isolated institutes (*Instituto Agronômico de Campinas*, IAC; *Instituto Biológico de São Paulo*, IB; *Instituto Butantã*; *Instituto de Botânica*, etc). From then on, a large part of the research started to be done at the universities, by the graduate programs, including joint actions with students of scientific initiation, specialization, masters, doctorate and post-doctorate.

The link of education and research is fundamental for the emergence of continuous and lasting programs and for a significant generation of knowledge, basic as well as technological. Such link is started at the undergraduate courses, which in 1998 offered 13,207 positions in the area of Agrarian Sciences, mostly at the South and Southeast regions of the country (68.54%), including federal, state, municipal, private and regional institutions (Figure 3), with widely varying education levels and quality.

However, the main cause for the growth of the Brazilian research system is undoubtedly graduate education. Graduate education goes beyond training new researchers, which are the basis of any solid research system, but it is also constantly open to renovation, because such a graduate course policy becomes, for recent graduates, an attractive option for the formal and systematic qualification, which continuously augments the critical mass in the area.

The creation of EMBRAPA, in 1973, contributed in a significant way for the increase in the number of post-graduate researchers, and for the increase of research programs, distributed among the “National Research Centers” allocated in different Brazilian states. EMBRAPA can be considered today the largest research company in Agrarian Sciences of the Third World, generating processes and products, creating conditions for productivity increase, and mainly generating its own technology for completely distinct regions of Brazil, with their own characteristics and cultures.

It is fitting to emphasize here the important role played by the federal support agencies, such as CNPq, heavily investing in scholarships, starting with those of Scientific Initiation. This category is traditional and consecrated in the Brazilian education and research institutions, because CNPq awards this kind of scholarship since its foundation in 1951. Currently, CNPq makes 14,500 Scientific Initiation Scholarships available, of which 11,1% are destined to Agrarian

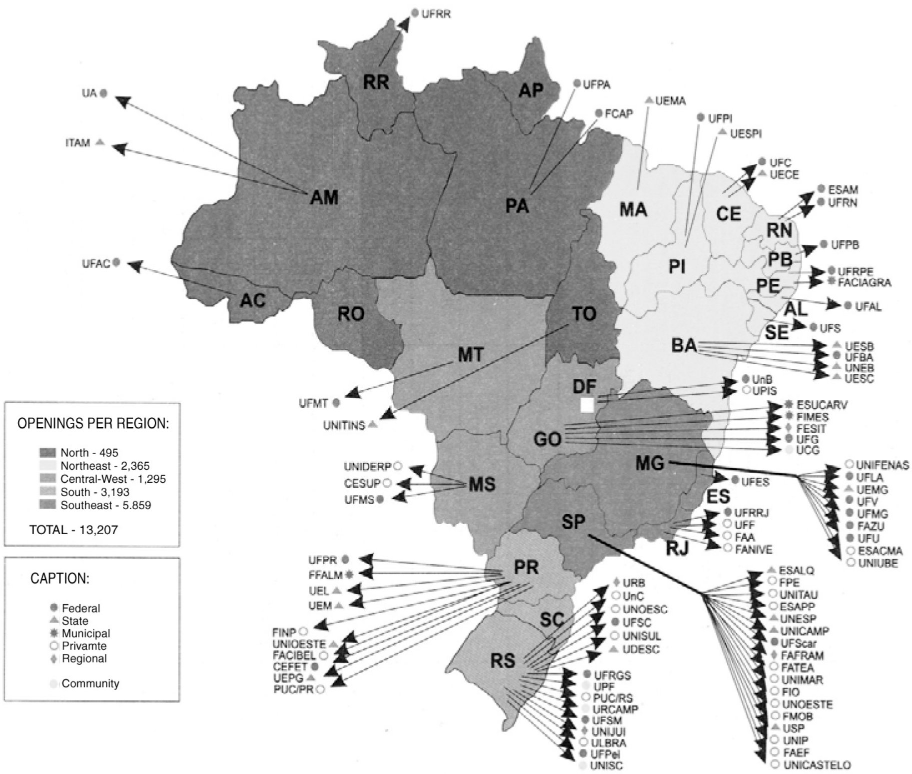


Figure 3. Agrarian Sciences Schools in Brazil (ABEAS, 1998)

Sciences. In 1988, the Institutional program was created – PIBIC, in connection to the different universities of the country, to narrow the relationships between teaching and research institutions. The Scientific Initiation scholarships do not only contribute to the academic and professional training of the student, but also increase the possibility for the identification of talents for research and contribute to a significant reduction of the average time taken for the conclusion of the graduate courses.

CAPES, along with CNPq, has played a relevant role in the area of human resources for graduate education. The training of masters and doctors in the area of Agrarian Sciences has been growing significantly in the last few years. Thus, while in 1996, 1,308 masters and 313 doctors graduated, in 2000, the number of professionals in the area of Agrarian Sciences who received the titles of master and doctor were 1,979 and 550 respectively.

This training and education of critical mass allowed the number of scientific articles in S&T to go from 1,889 in 1981, to 9,511 in 2000, corresponding to a variation of 403.49%, ranking Brazil in 17th place, in worldwide terms. In the Agrarian Sciences, this number also increased considerably. Although it has not reached the desired levels of excellence, it must be taken into consideration that it is an area with its own characteristics, and that, many times, a regional or local publication can be of extreme relevance. After all, the national productive sector needs to have access to the new knowledge for the development of specific technology in order to take care of the country's interests.

Another aspect of great relevance is the existence of a very strong preoccupation with the quality of the educated critical mass, from the undergraduate to the graduate levels. Thus, in the last few years, the "Course Evaluation Exam" (Provão) for the undergraduate level, and the CAPES Evaluation System for the graduate level, have followed this direction. The first is still being implemented; however, the second has already been totally accepted by the scientific community and comes forth as a model for the whole country. As in all areas, there is a high concentration of courses evaluated by CAPES as levels 5, 6 or 7 in the Southeast and South regions, as well as the highest number of CNPq 1A researchers of scientific productivity (Figure 4), fruit of the highest investment in research. In São Paulo, FAPESP, as the main state foundation, inputs a considerable amount of funds (R$ 48,044,369.00 in 1999) in the area of agronomy and veterinary, which corresponds to 9.3% of the total investment in financial aid and 8.52% of the total scholarships invested in graduate education. Other foundations begin to play their role in the states of Rio Grande do Sul, Minas Gerais, Pernambuco, Paraíba, Espirito Santo, Rio de Janeiro, Santa Catarina, and Goiás, although many of them still play it in a very modest way.

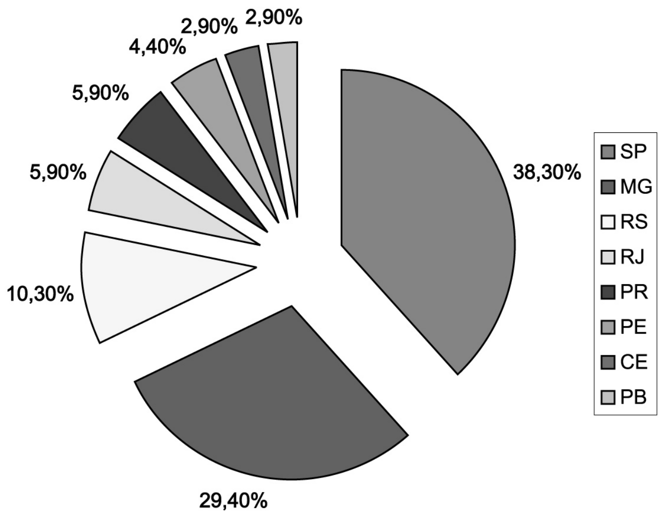


Figure 4. Distribution of felloships among 1A CNPq researchers, by State, in Agrarian Sciences.

EVALUATION OF THE STATE OF THE ART IN BRAZIL AND WORLDWIDE

Brazil has reached good technological development in various areas such as genetic improvement, biotechnology, pest and disease control (especially biological control), seed technology, plant nutrition, agricultural practices, including irrigation, soil conservation and no-tillage planting.

The great challenge of the new technological model is to increase productivity, taking into consideration the quality of the processes and the products, without environmental degradation and, if possible, in a sustainable way.

Although it may increasing, the number of graduate professors is Brazil is still small if compared to the United States for example. Thus, in 1997, 27,180 doctors graduated in the area of sciences and engineering in the United States, and 2,691 in Brazil. This is a reflection of the investment in S&T, because while we invest 0.9% of the GDP in Brazil, such investment corresponds to 3.7; 3.1; 2.9; and 2.7 in Sweden, Japan, Finland and the United States, respectively. Therefore, independent from the individual quality and of excellent research groups created in the last few years in Brazil, we are still lacking researchers to equal the scientific development of the countries of the First World. Some examples could be cited:

while in the United States, 70% of the researchers who work with life sciences use restriction enzymes in their research, this number does not go above 5% among Brazilian researchers; in the area of bioinformatics, which is fundamental for the studies of molecular biology, there are practically no specialized Brazilian researchers developing software for the laboratory routine; groups involved with the management of pests or integrated production are still incipient in our country, being that many times, the same researcher gets involved with different cultivated species due to the lack of critical mass in the area.

Therefore, it is fundamental that there is a continuity for the human resources training programs in the country, especially in strategic areas, including training abroad, especially in programs of training fellowships, which represent a smaller burden to the country, due to shortening of the time taken for the conclusion of the course and the possibility of exchange with centers that are more highly advanced.

The high investment in the training of human resources in the Southeast and the South regions has distanced even further the research centers of less favored areas. It is fundamental that there is a balancing between the investments on the training of human resources and on aid to research, because many times, the trained researcher becomes frustrated as he returns to his place of origin and does not find the appropriate structure for the realization of the research or the inputs to guide it forward.

FAPESP must be taken as an example that, through the Project of Infrastructure contributed for the recovery of the physical structure of research in the State of São Paulo in the 1990s. Therefore, it fostered a considerable technological advancement, and in many cases, originated centers of excellence of international standards.

To keep the lead in research in the tropical and subtropical regions, preserving the environment, maintaining the biodiversity and improving the quality of life of the Brazilian people, it is fundamental to develop mechanisms for hiring this human contingent that has been and continues to be trained, with salaries that are proper and compatible with the market. There should be, above all, a policy of retiree replacement and a system of evaluation and, mainly, of valorization of the "productive ones" who are fully dedicated to teaching and research.

Priorities shall be defined in crops of economic importance to the country, with regional characteristics, that yield to Brazil a leadership in the tropical and subtropical areas of the globe; thus, creating opportunities to transfer the technology generated under these conditions.

Centers of Excellence shall be created, which shall work as diffusion centers for the less favored areas and could, for certain periods, receive researchers from less favored centers, as a preparation period for their return to their original centers. In these places, certain groups could be associated, such as, of traditional and molecular genetics, that many times do not yield the results expected by society when acting in an isolated manner.

SOCIOECONOMIC IMPACT OF THE AGRARIAN SCIENCES

Although there may be isolated success cases, it was since the investment in technology in the 1970s, that Brazil had a great advancement in agriculture. Even in the 1980s, when the country had little growth, the slow down of the growth in the agricultural sector was proportionally small when compared to the economy as a whole (Brandão, 2000).

Since the productive chain is composed of three steps, in a mandatory sequence: research → extension → implementation (Malavolta, 2000), there have been cases in which the extension was not sufficiently strong and active in order to transfer the research results to the productive sector, a common characteristic in less developed countries. Only a few examples will be cited in order to give an idea of the economic impact of the area.

- **Coffee.** The production of coffee grew at an annual average rate of 1.2%. This growth was largely sustained by the growth in productivity. Due to technological innovations, the biennial characteristics of the crop go unnoticed today, with the use of new cultivars and coffe high density plantation in areas that are not traditionally used for coffee growing (e.g. Triângulo Mineiro). This development is due to the research developed since the 1930s at the IAC, which permitted production leaps, especially with new cultivars resistant against diseases (*Hemileia vastatrix*) and nematodes. This genetic improvement resulted in an annual increase estimated in 16,273,712 coffee bags/year in the Brazilian production (Vencovsky & Ramalho, 2000).

- **Soybean.** It is today the most important leguminous cultivated around the world, due to its high protein content (40%) and percentage of edible oil (20%). Up to the beginning of the 1970s, Brazilian soybean was not representative in the international scenario, because it amounted to only 2% of the world's production. Currently, the country produces 20% of the world's production. Thanks to genetic improvement, adapting the cultivars to the regions with different photoperiods of the country, we achieved, mainly due to the effort of the different research areas of the EMBRAPA/soybean, a gain of 1,200 kg/hectare in 38 years of work. It is the crop in which pest management is most used, due to the high level of research in the area of entomology, phytopathology and of weeds. The importance of research for the establishment of the soybean crop in Brazil can be illustrated by the fact that this leguminous is native to latitudes close to the 40°N. Thus, without the efficiency of the results of the genetic improvement works, it would be impossible to cultivate it in many areas of the country, especially in the North and Northeast regions.

- **Maize.** Is the crop that united the largest number of breeders, searching and achieving spectacular results in productivity increase, with increases reaching up to 123 kg/hectare/year, in the period from 1946 to 1995. The incorporation of agronomic characteristics, conferring resistance against diseases, more compact plants, resistance to drought, resistance to the lodging, was done in this crop. The development of varieties used out of the conventional period, with the utilization of irrigation, known as second season (safrinha), has contributed for the augmentation of the Brazilian production. In 2000, 3 million hectares were cultivated, with a production equivalent to 13% of the total produced in Brazil and to 22.8% of the area used for maize production in the country.

- **Beans.** One of the basic components of the Brazilian people's diet, and the main source of protein used by the Brazilian population. A large volume of papers has been produced about genetic improvement, among which 69 new cultivars were recommended from 1982 to 1995 (Vencovsky & Ramalho, 2000). These cultivars associate greater productivity, resistance to diseases and pests, adaptation to different climatic conditions, adaptability to mechanized harvesting and acceptance of the grain by the customer due to the crop's place and market.

- **Rice.** The average Brazilian person consumes 42 kg of rice per year, constituting beyond any doubt, the main source of nourishment of the population. In the last 20 years, there has been a considerable increase in the production/area, in the order of 33 kg/hectare/year for dry rice and of 44 kg/hectare/year for irrigated rice. However, there is a necessity for the intensification of investments for research on this crop, because the levels of national productivity are still distant from the genetic potential that is characteristic of this species.

- **Citrus.** In spite of all the existing phytosanitary problems, the challenges are being overcome by the researchers, with the production reaching a level of 400 million boxes/year and generating an annual income of US$ 1,5 billion from the export of concentrated juice and byproducts only.
  In the 1940s, the tristeza disease of citrus, a virus transmitted by aphids, killed up to ten million plants. The problem was solved with the change of the rootstock, for the sour orange, and the pre-immunization of the plants with the use of weak strains of the virus. Problems like the citrus canker, a bacterium that intensified its occurrence after the rise of the citrus leafminer *Phyllocnistis citrella* in 1966, and the citrus variegated chlorosis (CVC) or *amarelinho*, a bacterium transmitted by sharpshooters, have been studied within the genome project and controlled in a conventional manner by eradication, pruning, pulverization or use of plants exempt from the diseases. Other phytosanitary problems, like the leprosis mite, rust mite, citrus fruit borer, fruit fly, scales, black spot, etc, are being researched, in a joint action of a private company (Fundecitrus) and official research organs, associated to FAPESP, CNPq, and international organisms. In this case the research is justifiable because the problems can affect the 200 million citrus plants and the more than 450 thousand direct and indirect jobs generated by the citriculture.

- **Temperate Climate Fruits.** Among the various fruit trees of importance to Brazil (apple, peach, pear, prune, fig, strawberry, pecan, etc.), the apple is the most important and its cultivation has undergone great advancements in the last 20 years of research in Santa Catarina and Rio Grande do Sul.
  Apple consumption went from 1.5 kg/person/year in 1985 to 5.0 kg/person/year in 1996 [Small if compared to Argentina (15 kg/person/year) or Europe (60 kg/person/year)]. These apples of the *Fuji* (80%) and *Gala* (20%) varieties,

have been adapted to the Brazilian conditions, on what concerns the break of dormancy, the resistance to diseases (scabies, oidium, collar rot) and pests (woolly apple aphid). There were possibilities for a decrease in the importation, due to the fact that the production increased from 16 thousand tons in 1977 to 495 thousand tons in 1995. Such increase demanded the construction of refrigerated chambers in order to store 350 thousand tons. Thus Brazil became, in a short period of time, an exporting country.

- **Eucalyptus.** Imported in the first half of the twentieth century, eucalyptus became the most important type of wood for general use. The research done by the private sector and public institutions resulted in an increase in productivity from 20 m^3/hectare/year in 1960 to 40 m^3/hectare/year in 1998.

- **Plant Nutrition**. The relationships among soil fertility, plant nutrition and agricultural productivity are beyond question, in the same way that the contribution of the Brazilian research for the evolution of knowledge and development of procedures directed to the rational use of the soil/plant relationships. Illustrative examples of these initiatives can be represented by: a) the improvement of the methodology for conducting the physicochemical analysis of the soil and the interpretation its results, with direct reflections in the production of species of economic importance; b) through the efforts developed by various research institutions, among them, the EMBRAPA System, IAC, UFV, ESALQ, directed to making the agricultural use of the cerrado possible. The cerrado occupy an area with agricultural potential of approximately 204 million hectares, which up to the middle of last century, was totally unused. Currently, approximately 47 million hectares are used with perennial crops (4%), annual crops (21%) and cultivated pastures (75%) with evident success and return, both economic and social.

INTEGRATED PEST MANAGEMENT (IPM)

With the abusive use of chemical products in the period from 1940 to 1960, a series of problems arose, which lead the scientific community to introduce a new pest control philosophy, with the integration of various control methods (alternative to chemical, if possible), taking into consideration economic, ecological and social criteria.

Since the 1970s in Brazil, there have been spectacular cases with the introduction of this Pest Management or of alternative control methods in substitution to chemical control.

Thus, in the case of soybean, the use of the virus *Baculovirus anticarsia* to control the velvetbean caterpillar, *Anticarsia gemmatalis*, which was applied in approximately 1 million hectares, starting in 1979 and developed under the coordination of Dr. Flávio Moscardi, of the EMBRAPA/soybean, generated savings of about US$ 100 million in agrochemicals and avoided the application of 11 million liters of insecticide in Brazil. It is the largest program of biological control in the world, being imitated in developed and developing countries.

In the case of sugarcane, the program of biological control of the sugarcane borer, *Diatraea saccharalis*, with the imported parasitoid *Cotesia flavipes*, done by the Federal University of São Carlos (former PLANALSUCAR), COPERSUCAR, and ESALQ, generated savings in the order of US$ 80 million per year to São Paulo. That is because until the massive introduction of this natural enemy, the losses due to the attack of the borer to the sugarcane were in the order of US$ 100 million per year, and today, such losses reach about US$ 20 million per year, due to the introduction of this natural enemy from Trinidad-Tobago (Parra, 2000).

The control of aphids in the crop of wheat with the use imported natural enemies in the 1970s is another example that resulted in savings of US$ 16.2 million per year during the period from 1978 to 1992. Furthermore, the imported natural enemies were of such efficiency in the control of the aphids that of the 99% of the farmers who used agrochemicals against the aphids, only 5% continue to do it today.

Other success cases could be cited for tomato plant, citrus, cotton tree, forests, soybean, etc (Parra, 2000).

PERSPECTIVES

In the present century, science and technology will be increasingly more valued as factors of production. Society is ever more demanding, not acquiring products of unknown origin or that have received certain agrochemicals in their production process. The human contingent educated in graduate school shall be aware of the change from the productionist to the technological conception, aimed at a sustainable agriculture, not allowing large productivity with serious environmental damage.

The current paradigm has as its main components: quality of the products, prices, production stability (genetic materials that are resistant to climatic adversities), market image (high quality products, with high sanitation standards) and long term contracts (stable supply, with product certification) (EMBRAPA, 2000). Within this context, the close association among teaching, research, and the transfer of knowledge and technology is fundamental. Thus, the universities, research institutes, government sector, private sector shall be more integrated in multi and interdisciplinary programs, in national and international levels, in the search of solutions for our problems. More and more incentive should be given to the interaction with the private sector, as occurs in the developed countries, without hindering the freedoms of research. This has already begun to take shape, due to the fact that 50% of the critical mass educated in graduate school has been assimilated by the private sector.

There has been great progress in Brazil in the last few years. Grain production, which remained at the level of 50 million tons per year for a long time, reached 100 million in the last few years. Biotechnology shall take the spotlight in the XXI Century. Up to the middle of the 1990s, Brazil had a underprivileged position in terms of competence in the area of molecular biology. In 1997, FAPESP articulated and financed a program of genome sequencing. A group of researchers organized in a network (Onsa Network) began the study of the *Xylella fastidiosa*, a bacterium responsible for the CVC (citrus variegated chlorosis), commonly named *amarelinho*. This bacterium is responsible for great losses in the citrus production in the State of São Paulo. The success of this program inserted Brazil in the context of developing countries that are creating internationally competitive critical mass, and that are a part of the club with advanced genomics technology. Other research on Functional Genome of *Xilella*, Sugarcane Genome, *Xanthomonas citri* Genome (vector bacterium of the citrus canker) followed. Embrapa's Character Bank shall accelerate the study of biological mechanisms, identification and cloning of regulatory genes and modules that are useful for the expression of molecules of interest to the bioindustry, as well as the development of plants, animals and microorganisms with superior attributes.

In agriculture, the development of biotechnology is slower than in public health. Such molecular techniques shall complement the conventional techniques of genetic improvement. An interdisciplinary integration of genetic engineering, in vitro techniques, conventional crossings and bioinformatics, shall consolidate Brazil's scientific position in the international scenario.

The critical mass increased in the last few years, and the 1,352 CNPq research groups in Agrarian Sciences, represent 12% of the total number of groups in the different areas.

Some research lines shall receive incentive in order for Brazil to be further inserted in the international context:

- **Biotechnology.** The transgenic plans already occupy 52.6 million hectares in the world, with 68% of the total in the United States and 23% in Argentina (James, 2001). Countless other countries count with the cultivation of transgenics, emphasizing the growing cultivation of Bt cotton in China, where small farmers cultivated, in 2000, a total of half million hectares, resulting in a significant reduction on the use of insecticides, an increase in productivity and a reduction of the accidents with farm workers (Pray et al., 2000).

  In Brazil, the transgenic plants are inserted in the Law no. 8,974 of January 5, 1995 and the subsequent regulation by the Decree no. 1,752 of December 20, 1995, that created the National Technical Commission on Bio-security (CTNBio). The country counts with excellent technical qualification on the subject, in the public and private sectors. Thus, more than 900 authorizations in the environment, involving the crops of cotton, rice, potato, sugarcane, eucalyptus, beans, tobacco, papaya, maize and soybean, have been approved by the CTNBio for experimentation.

  It is fitting to highlight EMBRAPA's position, which among other aspects, emphasizes that it has been strategically preparing itself, for more than fifteen years, to generate and adapt cutting edge agriculture and animal husbandry technology and believes that the secure use of genetic engineering will play a highly relevant role in the sustainable development of the national economy, through the possibilities it creates on reducing production costs and environmental impacts in the rural environment.

EMBRAPA classifies the question of transgenic plants in four dimensions. These dimensions are as follows: I – The relevance of recombining DNA technology for the sustainable development of Brazilian Agriculture; II – the guarantee that such technology will be made available in a safe manner to consumers and to the environment, based on the existing scientific knowledge on biosafety; III – The possible commercial advantage to Brazil of the origin certification of some transgenic commodities; and IV – The right the consumers have of choosing non-transgenic crops. Although Brazil is inserted in the closed group of countries that have genomic technology, transgenics plants have their commercial production prohibited by a judicial measure in our country. However, it is fundamental that the research on this subject be continued, so that Brazil doesn't suffer a technological delay that may affect its development.

Brazil really has critical mass available in this area, because the sequencing of the *Xilella fastidiosa* brought together 190 scientists, from 11 universities and research institutes in 30 laboratories, forming the Organization for Nucleotides Sequence and Analysis which resulted on the acronym ONSA for the created network. After a work that lasted less than two years, and for the first time in the world, the team mentioned did the sequencing of the *X. fastidiosa*, whose results were published in Nature Magazine, in July of 2000.

This area, more than the others, shall include the association with the private sector, because in the United States, 60% of the biotechnology companies created between 1980 and 1994 still persist to the present date. The Fundecitrus (The Fund for citriculture of the State of São Paulo) has been developing partnerships with universities, research institutes and research financing organs, for the research on citriculture, alongside other companies in other crops. Among the various peculiar aspects of biotechnology, bioinformatics shall be prioritized.

- **Biodiversity.** The mapping and the analysis of the biodiversity, including fauna, flora, macroscopic and microscopic fungi and microorganisms, in both terrestrial and aquatic environments; maintaining the germ plasms and identifying benefic insects and microorganisms for biological control and symbiotic processes, should be intensely researched.

The Biota Project, of FAPESP, is a beginning of this kind of work, which involves an investment of R$ 8.3 million and that uses a virtual model connecting more than 200 researchers from the State of São Paulo, united in 15 projects, associated to public institutions, through the internet.

The final objective, which shall be imitated, is the formation of a databank with systematized information, allowing the elaboration of public policies of conservation and sustainable use of the State's biodiversity, as well as the training of human resources in basic areas in order to subsidize the study of the biodiversity (FAPESP, 1999).

- **Integrated Production.** Defined as "an agricultural system of production of food and other high quality products, using natural resources and regulatory mechanisms, aiming at avoiding the damaging effects to the environment, assuring a sustainable agriculture in the long term".

  Globalized agriculture demands more and more for products with certified quality. Such production has pest management as a crucial point, due to the fact that the products will not be allowed to have toxic residues above the limits established by law. It is, above all, an integrated action, involving plant material that is adequate to climatic variations, certified plants, windbreakers to avoid the drifting of chemical treatments to rivers and water sources, and that works as a refuge for the benefic fauna; moreover, it includes the fertilization of the soil and the management of the plant covering, management of the crop (planting orientation, succession of species, pollination); irrigation; pest management, with control alternatives (biological control, sexual pheromones) or the use of selective products; adaptation of machinery for phytosanitary treatments, quality and production management (harvest and post-harvest).

  The excellent programs of Pest Management in the country (in sugarcane, soybean, tomato, wheat, etc.) shall receive incentive, forming multidisciplinary teams that tend to the Integrated Production, acting on the search of control alternatives, specially through Biological Control.

- **Precision Agriculture.** It is a system of local management of the agricultural production that involves data collection in the field, the diagnostic, the interpretation of the data and the interference in the process, with the recommendation of the adequate dosage of inputs wherever it is most necessary in that area.

  In developed countries, such technology has been used since the 1980s. In Brazil, it was started in 1995. In precision agriculture, the information obtained is the productivity map, which shows an image that represents the total harvested in each part of the terrain. For such, it uses sensors such as DGPS and GPS.

- **Agribusiness.** Approximately 30% of Brazil's GDP comes from agribusiness, and 30% of agribusiness is agriculture and animal husbandry. Agribusiness is constituted by the articulation of the factors in the productive chain, based on the premise of a recognized interdependence, and having as its objective the maximization of the agricultural product's competitiveness in the market. It is important to note some of the important components of the agribusiness, such as the practice of the futures trading, the agricultural price index and transportation logistics, which shall gain increasingly more space in the Brazilian agriculture. The use of the futures trading assures resources to manage the risk of the agricultural activity, thus making financing viable.

  The generation of price indexes practiced in the agricultural market moderates the differences of market power between the producers and the companies.

  On the other hand, transportation logistics is of fundamental importance in order to minimize losses and optimize efficiency in moving the agricultural production, especially in a country of continental dimensions like Brazil.

- **Irrigation and Climatic Zoning.** Brazil has great potential, especially in tropical fruit growing, due to the climatic possibilities of continuous production, like in the São Francisco Valley, in the country's northeast. 5% of our cultivated area is irrigated (3 million hectares), with a potential to reach 20 million hectares. In the philosophy of Integrated Production and Agribusiness, it may be possible to achieve, with the use of irrigation, the control over the time for production, which is a differentiated commercialization strategy to aggregate value. Studies on environmental contamination (soil, water, lixiviation, water table) should be prioritized.

The definition of areas (agro-climatic zoning), linked to genetic improvement programs for plants, may minimize the risks of the uncertainties in the production.

- **Production Systems.** New production systems adapted to the tropical reality should be stimulated. Second season is already a reality in Brazil, allowing the effective control of erosion and the conservation of the soil's physical and chemical characteristics. There are already approximately 12 million hectares with no-tillage in the country, favoring the increase of organic matter, avoiding the moving and compaction of the soil, yielding a better use of water and increasing the availability of N, P and K. Other examples are represented by the crop rotation system, mixed crop, use of the climatic and edaphic conditions for a more efficient production.

  The production of vegetables has taken a new direction with the growing adoption of the protected cultivation system and the technique of plant transplantation for various species of economic importance. The verified success of these initiatives is directly dependent of the technological development supported by scientific research.

  The impact of these new systems on the characteristics of the soil, fauna and flora are also being investigated. Harvest forecasts, with simulation models involving computer studies of the modeling, shall be prioritized, because they constitute advancements for the improvement of the productive system, with subsidies supplied by the research.

- **Energy.** Besides alcohol as fuel (world leader project and resulting from intense work with sugarcane varieties, for production and resistance against pests and diseases), agricultural activity generates sub-products with potential to produce thermoelectric energy. We could lay emphasis on the bagasse and the green mass of the sugarcane, organic products for biodigestion and residues from wood processing.

FINAL CONSIDERATIONS

Science in Brazil has been recording incontestable advancements in the last decades, in spite of the problems with infra-structure, financing, and research management (organization).

It is necessary that partnerships be established with the various sectors of society for the social, economic and cultural development of the country. The sectorial funds can help these partnerships, but the interaction between the official research and the private sector is imperative to solve the specific problems and for the progress of knowledge.

The human resources training programs shall continue, now in a more selective form. The efforts of the support organs shall continue to increase, following the example of CNPq in the agribusiness programs, with the platform projects (Citrus, No-tillage, Coffee, Pheromone, Biological Control, etc). The incentive programs to post-doctorates also deserve special attention.

It is fundamental that the scientific community develop its own technology, suitable to the tropical conditions, and more independent of imported technology. The direct dependence on the importation of foreign technologies is undesirable, due to the fact that these technologies are usually from regions of temperate climate and are not suitable to our reality. However, above all, it is imperative that there exist mechanisms for the innovations obtained here, to be transferred and used by the customer and that there is a total participation of society in this process.

ACKNOWLEDGEMENTS

To Mrs. Angela Meneses and Rosana Arcoverde, for supplying the statistical data on the CNPq and CAPES scholarship receivers, respectively.

BIBLIOGRAPHIC REFERENCES

ASSOCIAÇÃO BRASILEIRA DE ENSINO AGRÍCOLA SUPERIOR. Guia das instituições de ensino superior: ciências agrárias – graduação e pós-graduação. 8.ed. Brasília, 1998. 167p.

AZEVEDO, J.L. *A pesquisa agropecuária no Brasil*. São Paulo: FGV, 1993. 63p.

BRANDÃO, A.S. Evolução da agricultura brasileira e papel da tecnologia. In: PATERNIANI, E. (Ed.). Agricultura brasileira e pesquisa agropecuária. Brasília: EMBRAPA, Comunicação para Transferência de Tecnologia, 2000. p. 153-168.

CALDAS, R.A. A construção de um modelo de arcabouço legal para ciência, tecnologia e inovação. Parcerias Estratégicas, v.11, p. 5-27, 2001.

CASTRO, C.E.F.; BATAGLIA, O.C. Fatores críticos e cenários para a pesquisa agropecuária de São Paulo. São Paulo: SAA, CPA, 1997. 52p.

CHAMBOULEYRON, I. (Org.). Mais vagas com qualidade: o desafio do ensino superior no Brasil; fórum de reflexão universitária. Campinas: UNICAMP, 2001. 122p.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA. Centro Nacional de Pesquisa de Soja. EMBRAPA soja: 2000-2003: II plano diretor. Londrina, 2000. 42p. (EMBRAPA Soja. Documentos, 141).

FUNDO DE AMPARO À PESQUISA DO ESTADO DE SÃO PAULO. Relatório de atividades. São Paulo, 1999. 96p.

JAMES, C. Global review of commercialized transgenic crops. 2000, ISAAA Briefs, Nº 24, ISAAA, Ithaca, NY, 2001. 20pp.

LANDI, F.R. (Coord.). Indicadores de ciência e tecnologia em São Paulo. São Paulo: FAPESP, 1998. 144p.

LEMOS, M.B.; MORO, S. O contexto macro da dinâmica de inovação do sistema agroalimentar no MERCOSUL ampliado. Montevídeo: PROCISUR; BID, 2000. 37p. (Série Documentos, 1).

MACHADO NETO, R. Livro da pesquisa ESALQ: 1998/1999. Piracicaba: ESALQ, 1999. 85p.

MALAVOLTA, E. Impacto da pesquisa sobre a fertilidade do solo e nutrição de plantas e adubação. In: PATERNIANI, E. (Ed.). Agricultura brasileira e pesquisa agropecuária. Brasília: EMBRAPA, Comunicação para Transferência de Tecnologia, 2000. p. 107-135.

PARRA, J.R.P. Manejo integrado de pragas. In: PATERNIANI, E. (Ed.). Agricultura brasileira e pesquisa agropecuária. Brasília: EMBRAPA, Comunicação para Transferência de Tecnologia, 2000. p. 91-101.

PATERNIANI, E. Maize breeding in the tropics. *Critical Reviews in Plant Sciences*, v.9, p. 125-154, 1990.

PATERNIANI, E. Biology and life sciences. In: BRAZILIAN ACADEMY OF SCIENCES. Science in Brazil. Brasília, 1999. p. 41-46.

PATERNIANI, E. (Ed.). Agricultura brasileira e pesquisa agropecuária. Brasília: EMBRAPA, Comunicação para Transferência de Tecnologia, 2000. 194p.

PRAY, C.E., D. MA, J. HUANG, F. QIAO. Impact of *Bt* cotton in China. 4th International Conference on the International Consortium on Agricultural Biotechnology Research (ICABR). Ravello, Italia, 24-28 Ago. 2000, 2000. 119-143.

SALLES FILHO, S. Política científica e tecnológica para a agricultura. In: WORKSHOP SOBRE CAPACITACIÓN EM ANÁLISIS DE CADENAS AGROALIMENTARIAS MACROECONOMIA, Rio de Janeiro, 1998. Políticas agrícolas en América Latina: trabajos

SILVA, C.G. da; MELO, L.C.P. de (Coord.). Ciência, tecnologia e inovação: desafio para a sociedade brasileira; livro verde. Brasília: Ministério da Ciência e Tecnologia, Academia Brasileira de Ciências, 2001. 278p.

VENCOVSKY, R.; RAMALHO, M.A.P. Contribuição do melhoramento genético de plantas no Brasil. In: PATERNIANI, E. (Ed.). Agricultura brasileira e pesquisa agropecuária. Brasília: EMBRAPA, Comunicação para Transferência de Tecnologia, 2000. p. 57-98.

AUTHORS

José Roberto Postali Parra *(Coordinator)*

Member of the Brazilian Academy of Sciences (ABC); PhD in Entomology from ESALQ/USP and Professor at the Department of Entomology, Plant Pathology and Agricultural Zoology of ESALQ/USP.

Ernesto Paterniani

Member of the Brazilian Academy of Sciences (ABC) and a retired Professor of the Genetics Department of ESALQ/USP.

Julio Marcos Filho

Professor at the Plant Production Department of ESALQ/USP; currently director of ESALQ/USP.

Raul Machado Neto

Member of the Brazilian Academy of Sciences (ABC); Professor at the Animal Science Departament of ESALQ/USP.

Area of Biological Sciences

HENRIQUE KRIEGER
BERNARDO BEIGUELMAN
ERNEY PLESSMANN DE CAMARGO
MILTON KRIEGER
SERGIO ANTONIO VANIN

Currently, to efficiently analyze the science and technology indicators in the biological field is a difficult task, due not only to the development that the biological sciences underwent, but also to the overlapping that they experienced among themselves and with the biomedical, medical and agrarian sciences, as well as with physical anthropology. Actually, the framework that characterized the 1950s changed a lot during the last half of the XX century. On one hand, this was due to the exponential growth of genetics, which began to influence the genetic research of all areas, due to the advances on molecular biology and genetic engineering. On the other hand, many local factors clearly contributed for the formal qualification of researchers in the country. Among these factors, the creation of graduate courses that started in the 1970s, the expansion of scholarship programs, including those of scientific initiation, as well as the investments done by official institutions to fund projects, modernize laboratories and the general infrastructure necessary for research, was of absolute importance.

Beyond the botanical and zoological research that was already traditionally done in Brazil, ecological research about distribution patterns and ecological patterns of different animal classes started to gain emphasis.

Biological research began to intensely interact with other scientific areas, mostly the ones of biomedical, medical and agrarian sciences as well as physical anthropology. This interaction makes it difficult to simply adopt numeric values for the evaluation of the scientific production, since the publication of biology papers in journals that are not formally characterized as biological is frequent. It is important to notice in this particular case that molecular biology, which is of biological ancestry, as its own name indicates, was almost completely absorbed by the biomedical sciences, where its production is registered and where it will be analyzed. In any case, the data supplied by the Brazilian Academy of Sciences with regards to the distribution, during the period from 1981 to 2000, of the number of publications of Brazilian researchers in biological sciences, of the citations that they roused and of the impact of the journals in which these scientific articles were published, allows us to have a clear notion of the tendency of these indicators (Figs.1-3).

In fact, Figure 1 allows us to see that the increase in the number of publications from the second half of the 1980s was staggering; however, it is possible that this tendency may now be towards stabilization, due to the fact that the decrease observed in the year 2000 shall, evidently, be attributed to the incomplete amount of information for this year, due to various factors. The citations roused by these publications (Fig. 2) also had a strong increase starting from the 1990s, and the decrease observed in the last two years can be attributed to the time that is naturally necessary for these citations to occur. In regards to the decline of the average impact of the publications, after a tendency towards growth that started in the 1990s (Fig. 3), it is possible that we are facing a transitory phenomenon or that this decline may result in a greater awareness of the Brazilian researchers with respect to the fallacy of this index's value.

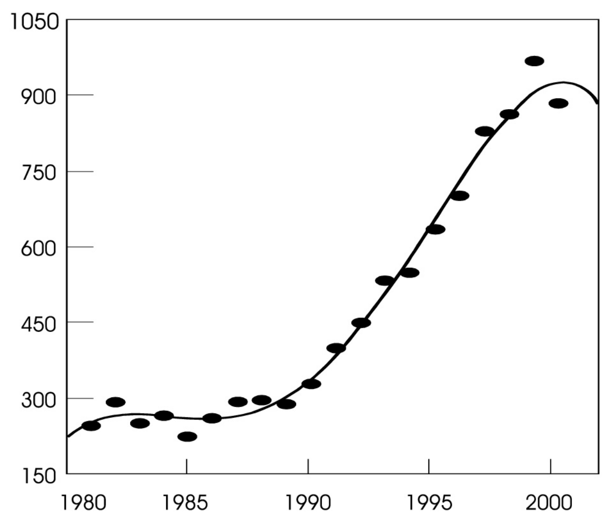


Figure 1 - Distribution of the publications on the area of biological sciences in the period of 1981-2000. The regression that best fit was a 4th degree polynomial (y = a + bx + cx2 + dx3 + ex4 where a = 218.830; b = 43.674; c = 12.578; d = 1.280; e = 0.033) with s = 30.004; r = 0.995.

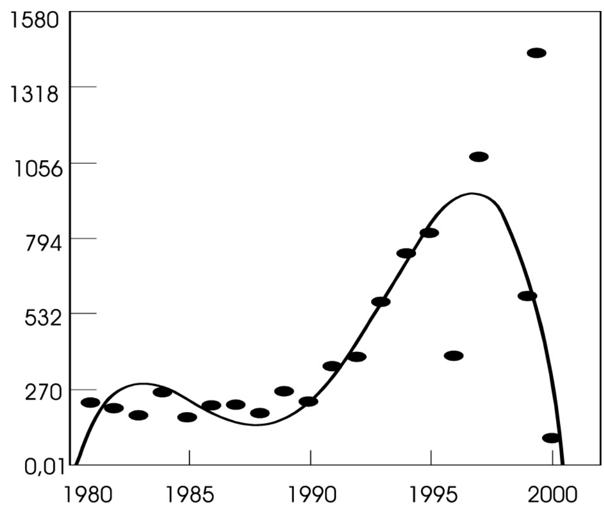


Figure 2 - Distribution of the number of citations generated by publications in the area of biological sciences in the period of 1981-2000. The regression that best fit was the 4th degree polynomial (y = a + bx + cx2 + dx3 + ex4 where a = -98.935; b = 304.291; c = -76.816; d = 6.818; e = -0.185) with s = 216.997; r = 0.834.

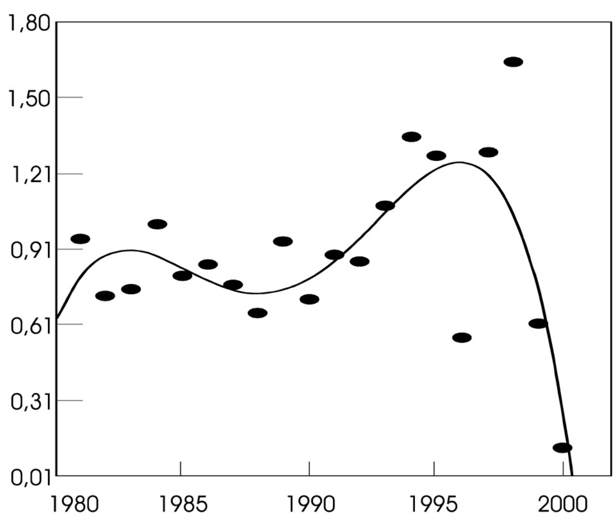


Figure 3 - Distribution of the impact of the publications in the area of biological sciences in the period of 1981-2000. The regression that best fit was the 4th degree polynomial (y = a + bx + cx2 + dx3 + ex4 where a = 0.603; b = 0.248; c = -0.067; d = 0.006; e = -0.00017) with s = 0.269; r = 0.693.

THE IMPORTANCE OF THE SYSTEMATICS (ZOOLOGICAL, BOTANICAL AND OF MICROORGANISMS) FOR THE STUDY OF THE BIODIVERSITY

Human beings share the Earth with approximately one and a half million other species already described and named by the systematists. This number, which may seem very large for the majority of people, accustomed to identify only a few mammals, birds, fish, trees, bushes and fungi, represents only a very small fraction of the total existing number, of five to one hundred million species. What the real number is, we may never know. Until today, evidence indicates that the great majority of the still unknown organisms live in the tropical zones, in particular in the rain forests, such as the Amazon and Atlantic Forests. A single tree of the Amazon Forest can shelter hundreds of insect species, and under it, in the litter and in the soil, hundreds of other species of small acari, collembolans, insects, nematodes and microorganisms. Considering that more than one hundred different tree species can live in one hectare of this forest, it could be inferred that the richness of species is enormous! However, one cannot ignore the many species that are still unknown that live in the varied oceanic ecosystems, from the continental shelf to the abyssal regions, some of which are verifiable richness, such as the coral reefs and the mangroves.

This diversity of forms is the result of more than three billion years of evolution history, of which we know only a few fragments. The complex relationships among the species and the environment are reasonably understood for some organisms of greater interest to man, but unknown for the great majority of species. The life of man depends on the existence of a large number of these species. Though unknown, they are intrinsically tied to the formation and maintenance of the atmosphere, the climate and the Earth's physical characteristics. Since antiquity, man has been using a small fraction of the biodiversity for its nourishment, clothing and shelter, through agricultural and animal husbandry, fishing and forestry activities. These activities are responsible for moving good part of the economy. More recently, other species have been more useful in the biotechnological development, and many more may become of use to man.

Brazil is one of the countries with greatest biological diversity, because 20% of the planet's species occur within the country. The tasks of discovering, describing the morphologic and anatomic characteristics, knowing the natural history, ecology, behavior and geographical distribution of the majority of these species are still to be done. The urgency of this endeavor becomes even more evident if we consider the fact that the planet is suffering a fast decline on its biodiversity. The action of man is causing the disappearance of various habitats in the search of new spaces, especially in the tropical regions. The anthropic activities around the world cause the pollution of the continents and oceans, making the environment unbearable to many species.

However, it is not enough to obtain the data. Once gethered, they should be synthesized and stored through classifications that reflect their evolutionary evolution history, creating the possibility for the recovery of the indexed information and to elaborate forecasts of interest to science and to society. The theory of systematics suffered profound modifications since 1950, when the German entomologist Willi Hennig revolutionized the study of systematics and of biological classifications. For him, systematic problems should be solved through rational analysis, and not through a subjective choice amongst distinct opinions, based on the experience and prestige of the authors. Hennig showed that the classification of the organisms is related to the comprehension of the phylogenetic relationship. The existing diversity is the result of the ramification process of the ancestral species into descendent species. Thus, all the characteristics that can be observed in the species, and used for classification, emerge in the course of the phylogeny. The use of some randomly chosen similarities to elaborate a classification system does not imply that we can understand the patterns of the other existing characteristics. However, the use of phylogeny makes it possible to understand the evolution of all the characters. If the biological classification aims at producing a general reference system, then it shall base itself on phylogeny. Such classification will be useful for the systematist, for the biologist in general, and for researchers of the remaining areas correlated to biology. It will serve as a link to all those interested in some aspect of the biodiversity.

Hennig's initial ideas and his phylogenetic method have been and continue to be improved by subsequent authors, thanks to the advances in the theoretical foundations and the improvements in computing technology. More recently, molecular methods were developed, making the knowledge of phylogeny in the gene level possible, and are being used on an increasing scale. Consequently, the phylogenetic reconstruction became accessible to biologists who are not trained in the field of systematics. Some systematists see the probability of a decrease in the interest and investment on the studies based in morphology, mainly because the procedures with molecular data make it possible to obtain phylogenies a lot faster. This framework would lead to the extinction of the specialists in some specific taxons, and on the study centered on organisms. The study of the evolutionary and gene processes would persist. Since there is evidence that the gene trees and the organism trees can be different, although they express real evolutionary histories that are equally relevant for the understanding of the biodiversity, it would be a shame that that part of the information was not researched and obtained. Another aspect is that, in general, molecular biologists are not focused on obtaining classifications, which as we have seen, are fundamental in order to create a system of recovery of biological information. Strengthening and cooperation among the researchers involved in molecular and organism studies would be highly advantageous for the comprehension of the biodiversity.

The information gathered about the biodiversity may become very useful, under many aspects. The newly found species will represent an increase in the genetic resources that are potentially exploitable by man; some of them may be selected and diversify the agricultural production; others will make possible the discovery of new substances that may be used in medicine. Detailed studies about new species will make possible the use of potentially useful organisms in biological control of pest-species; will expand the available information to the ones responsible for the elaboration of conservation and environment management policies, permitting an estimate of the degradation and of the rate of extinction of species.

A more complete knowledge about the systematics of species, their relationships and ecology, has great economic potential. Two examples, among many available, are given below.

- 1) An expedition of American botanists collected in 1962, in the Andes, more than one thousand plant samples. Among these were collected seeds of a new species of wild tomato, *Lycopersicum parviflorum* Rick. This new species was crossed with the regular tomato. The hybrids obtained presented an increase in the content of soluble solids, mainly fructose, glucose and other sugars, a characteristic of great economic value for the tomato industry. After a careful selection, a tomato variety with 7 to 7.5% more soluble solids was made available to horticulturists. According to specialists, the new genes found in the tomato species were yielding approximately eight million dollars per year. A value a lot higher than the twenty one thousand dollars, which was the cost of the one year expedition to the Andes, subsidized by the National Science Foundation.

- 2) If there is no precise systematic information about the relationships between the parasites and their vectors, the efforts made to control the parasite will result in a loss of time and money. A classic example is the control of the mosquitoes that transmit malaria in Africa (*Anopheles gambiae*), United States (*A. quadrimaculatus*), India (*A. culicifacies*) and Thailand (*A. dirus*). Effective control measures could only be implemented after the conclusion that each "species" represented in reality a complex of species, each one with different ecologies and potentials to transmit malaria.

The understanding of how the ecosystems work implies on the comprehension of how thousands of species interact. However, the difficulty on the identification, even of the most abundant species, causes difficulties to index the information obtained and, mainly, to make comparisons possible. The species presented as the number 1234 in one work can be identical to the one referred as 4321 in another, but this information is not available. Only the precise information and the use of the scientific name allow the indexation and recovery of the biological information. Precise identifications, ecological as well as geographical distribution data are essential for the conservationists to determine which areas must be preserved and which species are in need of particular protection measures. Precise identifications and accurate knowledge about the auto-ecology of the species are fundamental for fishing. The fishing industry acting in the Gulf of Mexico and the east of the United States of America became interested on the exploitation of a certain species of mackerel (a scombrid fish), and based itself on the published data available in Brazil. However, a systematic study showed that the Brazilian fish population (*Scomberomorus brasiliensis*, sororoca) represents a different species from the North-American population (*S. maculatus,* Spanish mackerel). The existing biological differences between the two species are sufficient to make the procedures, based on the existing data for the southern species, inadequate for handling the northern species.

Another example that serves to emphasize the importance of precise identifications. An aquatic fern, native of Brazil, was introduced in Australia around the 1950s. It was being used by aquarists, but it got out of control and became a serious pest, obstructing Australian rivers and lakes, hindering transportation, fishing and recreation. During approximately 20 years all the attempts to control the pest were unsuccessful, even with the use of biological control. It was later verified that the plant had been identified incorrectly. It was not *Salvinia natans*, but *Salvinia molesta*, both with distinct geographical distributions in the South-American Continent. After a study on the natural enemies of the *S. molesta* in the southeast of Brazil, an effective controlling agent was found, a new species of weevil, *Cyrtobagous salvinae*. After laboratory and field studies, this beetle was introduced in 1980, and rapidly controlled the populations of the aquatic fern. The first introduction of the weevil was done in the Moondarra Lake (Queensland). In 14 months, the 19.000 initial tons of *S. molesta* were reduced to less than one ton!

Studies on biodiversity are based on the knowledge of the taxons, of their relationship, classification, past and present geographical distributions, and on the comprehension of how they behave in the ecosystems where they occur. For the great majority of the organisms, this information is only available in the biological collections. These serial collections, together with the libraries and databanks connected to them, represent the only permanent record of our biota. They constitute an investment of society for the comprehension of the natural world. They provide the record of eventual alterations that occurred in communities and ecosystems, because they act as documents, making it possible to read these environmental alterations as time goes on, and can serve as evidence to possible extinctions. The collections shall also store the witness-material related to the acquisition of the biological information for the applied areas, such as epidemiology (vectors and pathogens), parasitology (parasites), agronomy (animal and plant pests, species that work in biological control). In case of doubt or incongruence with respect to a certain biological characteristic, the identification can be verified. Regretfully, this procedure is still not followed by the majority of the Brazilian researchers, who do not have the habit of depositing their witness-material into institutional collections. Another important aspect of the collections of organisms is that they may serve as the basis for environmental education programs, rousing the ecological consciousness of the citizens. This can become even more effective with the use of live specimens from the zoos, botanical gardens and aquariums. Other important collections are the cultures of microorganisms and the storage of frozen tissue.

USE AND CONSERVATION OF THE BIODIVERSITY

Biological diversity is the variety and variability of all life forms on Earth, wild as well those domesticated by man. It includes, therefore, plant, animal and microorganism species, as well as the ecosystems and ecological processes of which they are a part. The relationship that those species maintain amongst themselves and with the environment is of an enormous complexity and just now begins to be understood.

Number of identified species in the world	
microorganism	5,760
invertebrates	1,020,561
plants	322,311
fish	24,618
birds	9,702
reptiles and amphibians	10,484
mammals	4,629

Source: Atlas of the environment

Number of species – million	**million**
estimated	30
catalogued	1.4

Source: Atlas of the environment

The forest fragments are today, practically, the last refuge of terrestrial biodiversity. In the State of São Paulo, only 7 percent of the natural forests still exist and they present every type of fragmentation. The populations contained in those fragments are subject to all sorts of disturbances in their genetic structure.

The great pressure due to human population growth, with consequent loss of habitats caused by all kinds of human activities, puts in risk a large part of the world's diversity. If this process is not reverted, in a period of a few decades, it is expected that a large part of the genetic diversity will disappear. Although the extinction of species may be considered by some as a collateral effect of development, it is already known that the consequences of this process are extremely serious for several types of human activities.

Three aspects of the biological diversity have been compromised by man's direct action: the genetic diversity within each species, the diversity among species and the diversity of ecosystems. The conservation of the germ plasm *in situ* seeks to conserve the genetic diversity in its natural form through the protection of ecosystems. The genetic conservation of a species still implicates in the knowledge of the genetic variation among and within their populations. Thus, it should be known: 1) The number of individuals that form a minimum viable population; 2) How these individuals are distributed in the natural populations; 3) How is the dynamics of the populations in its natural habitat.

Coincidentally with the fact that there is a considerable improvement in the quality and the quantity of the material being stocked in the germ plasm banks of the developed countries, the loss of genetic diversity in the developing countries (where there is greater diversity *in situ*), has been drastically worsened for various reasons. It is known that the access to the genetic material stored by the rich countries may not be very easy in the future. Thus, it is necessary that the developing countries preserve their genetic resources. Considering that great part of the world's biological diversity is found in those countries, and that those countries have few technical and financial resources, the best process is the conservation *in situ*.

CONSERVATION *IN SITU*

The best and cheapest way of conserving the biological diversity in its three levels (ecosystems, communities and species) would be to prevent the destruction of nature. However, due to the false dilemma of environment vs. development, nature always loses.

This process of environmental degradation on behalf of development has been known since the XIX century, when the first national park, the famous National Park of Yellowstone, was created in the United States. In Brazil, the Tijuca National Park was created by Dom Pedro II in the same XIX century. This park is currently the world's largest conservation unit within an urban area.

The conservation of nature in its own environment is known as conservation *in situ*, and it is the most efficient way of protecting the biodiversity, because besides conserving the species, it also protects its natural habitat, as well as the interactions among the species, which in many cases are totally unknown.

Starting from the 1980's, several researchers' studies have been pointing to the importance of the conservation *in situ* of the biodiversity, since then several areas have been indicated as priorities. It was Norman Myers who, in 1988, referred in a systematic way to these areas, which he named "hot spots". Myers indicated 18 of these areas, which although they collectively represent a petty amount of space in the Earth's total area (less then 0.5 percent), they are at the same time the exclusive home of 1/5 of the world's plant species:

1. California's Floristic Province
2. Central Chile
3. Colombian Chocó
4. West Ecuador
5. West Amazon Plateaus
6. Brazilian Atlantic Coast
7. Southeast Ivory Coast
8. East Arch Forests of Tanzania
9. Cape's Floristic Province in South Africa
10. Madagascar
11. Slopes of Himalaya
12. West India
13. Sri Lanka
14. Peninsular Malaysia
15. Northwest of Borneo
16. Philippines
17. New Caledonia
18. Southwest of Australia

Source: Myers 1988

In 1997, Conservation International (CI) introduced the "hot spots" map indicating the updated areas, which add up to less then 2% of the planet's surface, situated in their majority in the tropical region, and containing more than 50% on the terrestrial biological diversity.

The main criteria of the list are the existence of endemic species and the degree of the threat to which these species are subject. The destruction of 75% of the original plant covering of a region with great diversity also puts the area on the list of "hot spots".

1. Meso-American Forest (Mexico and Central America)
2. Polynesia and the islands of Micronesia, including Hawaii and Fiji
3. Chocó (Colombia and Ecuador) and West of Ecuador
4. Tropical Andes (Venezuela, Columbia, Ecuador, Peru and Bolivia)
5. Cerrado (Brazil)
6. Atlantic Forest (Brazil)
7. Guinean Jungle (Africa)
8. Darien (Panama)
9. West Indies
10. South Africa
11. Madagascar (Western region of the Cape)
12. Ghats of India and Island of Sri Lanka
13. Philippines
14. West of the Sunda region (Indonesia, Malaysia, and Brunei)
15. East of the Sunda region (Indonesia)
16. East region of the Mediterranean
17. New Caledonia
18. Southwest of Australia

Source: Conservation International, 1997

Nine points that are different from Myers' list can be verified. Among these differences there are two Brazilian biomes present (Atlantic Forest and Cerrado). The Amazon was left out because it presents more than 75 percent of its original covering.

GERM PLASM BANKS *(EX SITU)*

Usually, they are public and private centers or institutions that conserve genetic material sample of germ plasm representative of an individual or of several individuals of a population. In broad terms, any constant individual record present in a germ plasm collection.

N. I. Vavilov (1887-1943) was a pioneer in the collection and conservation of plant genetic resources. He was a Russian agronomist and geneticist, who collected and studied the origin of cultivated plants. In his trips, Vavilov collected about 70,000 plant samples with some agronomic interest, in other words, not only the cultivated variety, but also the wild forms or species within the same genus, such as *Glycine gracilis, G. soja,* and *G. tomentella*, species of the *Glycine* genus, to which soybean *G. max* belongs. These species are the source of genes of important crossings among them, in spite of the low fertility it always produces viable individuals. Some authors defend the idea *t*hat what we call *G. max* are actually cultivated varieties of *G. gracilis*, in other words, the species *max* does not exist, it is just the domesticated form. The same happens with other crops like banana, were species of the *Musa* genus are collected in several parts of the world, including Brazil, which is not the center of origin of the banana.

After processing and organizing all the material collected in his trips throughout the world, Vavilov identified eight centers of origin of the cultivated plants, which also came to be known as Vavilov Centers. These are regions where the wild ancestral displays the largest genetic diversity for a select number of characteristics, diminishing the variability as it moves to the periphery of the distribution, and they are still the first reference for those who want to collect species of agronomic interest. In the 1970s, Harlan and de Wet, expanded the Vavilov regions to 12, and began to call these regions diversity centers. These authors use as criterion the high number of species of a genus or of genera of a family, contrasting with its smaller occurrence in other regions. One should not confuse diversity center with domestication center. Many crops (such as the rubber-tree) were domesticated independently by several human groups, in different times and areas, as a consequence of the large geographical distribution of the species. This origin is called non-centric. Other crops like the tomato were domesticated outside of the “area of natural occurrence of the wild forms”.

USE OF THE BIODIVERSITY

Man is by far the living being that uses biodiversity the most, whether it is in agriculture, pharmacology, industrial processes, ornamental plants, etc. Man uses around 1,000 species, a small number, even considering the minimum number estimated of 5 million species. Thus, the potential of the biodiversity for humanity's use is enormous; however, greater knowledge of the potential use of the biota is necessary.

The first plant to be domesticated was probably wheat in the Middle East, during the Neolithic 10,000 years ago, and since then it has been the main agricultural crop. It is the most cultivated plant in the world and is the nourishment basis of almost all human regions and cultures. Brazil had been self-sufficient in wheat, but today it has a limited production of this grain. Wheat and chick-pea were domesticated in the Middle East, soybean and rice in Asia and corn and bean in the New World. These three domestication processes happened in a totally independent way. It is interesting to notice that in these three centers of domestication, by coincidence or not, a grain and a pulse that nutritionally complement each other as carbohydrate and protein sources were cultivated.

RECOMMENDATION ON THE CARES WITH THE UNIVERSITY-COMPANY INTERACTION

General rule, the fundamental achievements of the Biological Sciences have taken more time to be applied than those obtained in areas like physics and computing, mainly as a consequence of natural difficulties of a complex nature (environment-living being interactions, generalized multifactoriality of important biological processes), besides ethical and political causes. In this aspect molecular genetics constitutes an exception, because its techniques propitiate the extremely fast transfer of the scientific discovery to the industrial production, which in other areas can take years. Since there is currently a tendency in Brazil to stimulate, among us, a copy of the relationship model between universities and companies created in United States, that is, on one hand the formation of small biotechnology companies in which professors and university students have participation, and on the other hand, the agreements of university departments with large multinationals; it seems important that the scientific community is alert for the ethical dilemmas created by that spurious relationship, which were deeply analyzed by some North American authors, like Kenney (*J. Business Ethics 6*: 12-135, 1987) and Rule (*Dissent*: 430-436, 1988). There is a great difference between the moral standards that bind a university and the ones that bind a company, thus, the social roles played by a businessman and by a professor are judged by very different ethical systems, being numerous the situations in that business ethics goes directly against university ethics. Thus, for instance, the primary duty of a company is to generate profits, but the concern with profits cannot be brought to the University, because it hurts the ethical standards to which the University is subject.

RECOMMENDATIONS REGARDING THE RESTRICTION HINDERING OF SCIENTIFIC CREATIVITY

The demonstration that the Brazilian scientific community can be rapidly recruited, even in times of peace, to reach defined objectives and that there are no insurmountable difficulties for the researchers of our universities to work together in spite of being distributed in different cities, was given by the great success of the genome program of the *Xylella fastidiosa*, supported and motivated by FAPESP. This success, which had a large and fair repercussion, was only partial, due evidently to the fact that it was still unable to prevent that until 2003, 42 million orange trees will be pulled out in the State of São Paulo (24% of the total number of planted trees) due to the "amarelinho", which is the name commonly given to the disease caused by the *Xylella fastidiosa* (citrus variegated chlorosis).

In any case, it seems advisable not to allow that the repercussion from the São Paulo scientific feat in the uncovering of the genome of this bacterium, begins to encourage the laboratories of various Brazilian universities to dedicate themselves, basically, to the job of sequencing new species; since this would contribute for a large number of young people to dedicate great part of their time to a repetitive routine that inhibits creativity.

The recruiting power demonstrated by FAPESP in the Xylella case and that had already been used by CNPq, when unchaining a process of high-level scientific creation centered on the solution of our problems (Integrated Program of Endemic Diseases, PIDE), can evidently be extended to the priority problems raised by interdisciplinary work. Brazilian scientists can give an important contribution to the solution of such problems.

RECOMMENDATION REGARDING INTERDISCIPLINARY PROJECTS

Interdisciplinary projects differ from the multidisciplinary because on the latter, several researchers work independently in the exploration of different aspects of a problem, while the interdisciplinary work demands a higher level of organization and scope, since the different aspects of a problem should be, obligatorily, discussed and criticized by a group of specialists of similar level who will work on the problem towards well specified objectives. An example of an interdisciplinary project is the development of microbiologic processes for the recovery of non-ferrous in ores and of heavy metals in industrial waste, before this waste is introduced into the environment. For such, it is necessary that:

1. Genetic, cytological and biochemical analysis of microbial lineages that interact with heavy metals.
2. Kinetics of microbial growth in contaminated environments.
3. Planning of bio-reactors in industrial scale for the recovery of precious and toxic metals (silver, gold, cadmium, copper, zinc, etc.).
4. Development of metallurgical processes based on biolixiviation for the recovery of metals.

RECOMMENDATIONS TO STUDIES OF SYSTEMATICS AND BIODIVERSITY

The main responsibility for the study of the Brazilian biota falls on the Brazilian scientists. On the basis of the biodiversity studies is systematics. The number of Brazilian systematists is small and are in danger of becoming even smaller due to the limited incentive and power of attraction of the subject which lost part of its prestige due to the monotony of the taxonomic works of the past. Some important measures to stimulate the training of researchers and personnel in this sector are:

To motivate the introduction of disciplines that teach the foundamentals of systematics and biogeography in the Biological Sciences undergraduate programs. This may give rise to the student's interest for an area that is not generally covered in the universities.

The incorporation of molecular biology tools to the teaching and practice of taxonomy. Molecular biology is certainly one of the main attractions for students and young researchers in the biomedical area and general biological areas. Its application possibilities on the solution of problems in those areas exercise great fascination of young researchers. This can be observed by the ease with which FAPESP recruited and set up research groups for the study of the *Xylella* genome, which in their great majority were young groups. On the other hand, the tools of molecular biology have great power of analysis of the genomic organization, and since the genome the melting pot of evolution, techniques of analysis of genomic targets are applied to the study of evolution and of ancestry/offspring among the species, that is, their phylogeny. Regretfully, Brazil has not yet fully incorporated the resources of biology to the study of systematics. There are few groups in the country that are capable of giving a molecular treatment to phylogeny. Molecular taxonomy should not cast aside classic taxonomy, which is centered in morphologic traits, but both should work together in order to make the phylogenetic studies more dynamic and consistent. If the lack of classic taxonomists is added to the absence of molecular taxonomists, any attempt of the country to know its biodiversity will be useless.

Molecular biology may be necessary for the study of systematics but it is not sufficient. The data generated by molecular biology must be processed. Bio-informatics plays that role. This discipline begins to grow among us and equally gives rise to great fascination among students and young biologists, particularly those with mathematical inclinations. It was also considerably impelled in the country by the *Xilella* project of FAPESP and even further now by the Genome-Cancer Program. With the sequencing of genomes, begins the true work of understanding its organization and operation. Due to the task's dimension and complexity, it can only be done with the dissection and analysis instruments of informatics. It was this way that bio-informatics gained space, whose resources are equally applicable to systematics and phylogeny. The statistical programs of phylogenetic analysis are more and more complex and must be constantly improved. Unlike the production of molecular data, the production of programs of phylogenetic analysis is an area in which Brazil still does not compete, using programs generated in the First World. It is absolutely fundamental that this area grows among us if in fact we want to know and to analyze our biodiversity. It is highly advisable that biology courses incluse disciplines of bio-informatics and that special programs from the financing agencies motivate the development of this area in the country.

However, it is not enough to train personnel. It is necessary to assimilate them into the universities and research institutes. Once again, it would be the case of the financing agencies and ministries of the area to promote special programs of priority hirings for the researchers in the area of bio-informatics.

Another problem that conspires against the correct appreciation of our biodiversity is the one of publication and disclosure of researches in the area. The specific job of the systematist is to correctly classify and position new species and, when necessary, to reorganize the distribution of the ones already known. The basic, daily work of describing new species does not find space in international publications of wide circulation, which contributes to the frustration of the systematists. However, without the description and taxonomic positioning of species, it is not possible to evaluate the biodiversity, the ecology and the genetic improvements.

Corollary to the study of biodiversity is its appropriate documentation. That includes, besides publications, the serial collections of organisms, from microorganisms (collections of cultures and fixed and conservative material) to primates, with all the intermediary range of animals and plants (museums, zoos, botanical gardens and biologic reservations). These collections are expensive and the institutions that maintain them have well-known difficulties to maintain and enlarge them within their budgets. On the other hand, it is not very popular among the financing agencies to support collections of organisms. It should be, and programs of this kind should be motivated.

BIBLIOGRAPHIC REFERENCES

KENNEY, M. The ethical dilemmas of university-industry collaborations. *Journal of Business Ethics 6*: 127-135, 1987.

RULE, J.B. Biotechnology: big money comes to the university. *Dissent (Dissent Publ. Corp.):* 430-436, 1988.

HENNIG, W. 1950. Grundzüge einer Theorie der phylogenetischen Systematik. Deutscher Zentralverlag , Berlin.

WORK BANK, 1992. Work development report. *New York. Oxford University press*. 286 p.

CONSERVATION INTERNATIONAL, 1997. Annual report Conservation International, Washington, D.C. 421 p.

WILSON, E.O. A situação atual da diversidade biológica, 3-24 p. *in* Wilson, E.O. (ed) *Biodiversidade.* Editora Nova Fronteira, RJ, 1997. 657 p.

AUTHORS

Henrique Krieger *(Coordinator)*

Member of the Brazilian Academy of Sciences (ABC); PhD from the University of Hawaii (USA); and Professor at the Biomedical Sciences Institute of the University of São Paulo (USP).

Bernardo Beiguelman

Member of the Brazilian Academy of Sciences (ABC); PhD in Medical Sciences from the University of São Paulo (USP); Professor at the State University of Campinas (Unicamp); and visiting Professor at USP.

Erney Plessmann de Camargo

Member of the Brazilian Academy of Sciences (ABC); PhD in Medical Sciences from the University of São Paulo (USP); and Professor at the Biomedical Institute of the University of São Paulo.

Milton Krieger

Agronomic engineer and coordinator of the Support Center for Culture and Extension of the Escola Superior de Agricultura Luiz de Queiroz (ESALQ/USP).

Sergio Antonio Vanin

PhD in Biological Science from the University of São Paulo (USP); and Professor of Biosciences on the same University.

Area of Biomedical Sciences

WALTER ARAÚJO ZIN
DORA FIX VENTURA
HERNAN CHAIMOVICH
JACQUELINE LETA

If you think that basic biomedical research is expensive, try disease.
A. Kornberg

The central focus of basic scientific research is to facilitate the progress of knowledge, and the motivation to research is the scientist's curiosity. New knowledge can contribute with broader goals, generally attainable only through complex chains, demanding the contribution of various activities and institutions to reach practical applications.

The relationship between the progress of knowledge and innovation is complex and will not be analyzed here. However, it is important to notice that the portion of Brazilian exports in the global market has been decreasing regularly, going from 1.7% in 1984, to 1.0% in 1996 (Horta and de Souza, 2000). This decrease happens in spite of the incorporation of technology in some sectors such as the agricultural/animal, mineral and aeronautical. Therefore, to increase technological content by the incorporation of knowledge is a strategic goal for a continental country that faces gigantic internal socioeconomic challenges. Furthermore, it must concomitantly compete in a global market, which is becoming increasingly dominated by the knowledge content.

In this connection, biomedical research has been contributing in a significant way to our understanding of the means and methods that help to decrease morbidity and mortality caused by some diseases, as well as in the increase of life expectancy.

Biomedical research focused on clinical aspects, on its own, is not sufficient to reduce infant mortality, for instance. Many other activities are necessary, among which can be found: the transfer of results from scientific research to the medical practice, the development and diffusion of equipment and/or medical products, and the education of the parents. Other necessary factors include: sustained pregnancy until the physical fetal maturation, a social culture capable of absorbing new medical procedures or health guidelines, and, probably the most important factor, appropriate financial resources to assure that every mother and baby have guaranteed access to medical treatment and nourishment of undisputed quality.

It is a fact that wherever the investment in research in the biomedical area is large, life expectancy has increased, health conditions have improved, and the costs of disease treatment have decreased. The number of concrete opportunities that originate from research in the biomedical area, considered from a broad point of view, is especially important for Brazil. The improvement of the life conditions of the Brazilian population depends partially on how the knowledge produced by the biomedical sciences is used within the country.

The analysis of biomedical research occurs when the Brazilian scientific contribution to universal knowledge is growing, reaching 1.4%, as estimated from the indexed papers on the data bank of the Institute for Scientific Information, ISI (Table 1). Recent analysis shows that this growth has been proportionally distributed among the areas of knowledge, following global tendencies (de Meis and Leta, 1996). As it will be analyzed later on, the equilibrium among the areas of knowledge is important because modern biomedical research is only possible if other areas of the exact sciences reach comparable levels of development, and its applications certainly depend on other areas of knowledge. Table 1 presents the total amount of Brazilian papers in the ISI data bank, and the fraction that they represent in the respective bank. A significant increase should be noticed in the Brazilian scientific production, which certainly expanded the visibility of the science done in the country. It should be pointed out that in the last five years the percentage of indexed Brazilian papers (ISI) containing authors that reside outside Brazil is approximately 30%, a relationship that shows the insertion of Brazilian science in the world as well as its independence (Leta and Chaimovich, 2002). The group of researchers that produced this knowledge is also responsible for the formation of qualified faculty in the graduate programs in the country. Furthermore, those same researchers are the only ones that can translate the remaining 98.5% of the knowledge produced in the world in order to apply it to local problems.

Taking into account that a linear and direct relationship does not exist between the production of knowledge and its application, especially in a country like Brazil, we must also state that without active and crescent basic research activities in the biomedical area, we will not even be able to use conscientiously the knowledge produced elsewhere. The relationship between basic knowledge produced locally and the development of local innovation in all the areas of economic activity was thoroughly demonstrated (Narin et al, 1997).

■ **TABLE 1**

BRAZILIAN PAPERS INDEXED IN ISI#

Year	Total of Indexed Papers	% from Brazil in comparison to the world
1981	1889	0.44
1982	2185	0.50
1983	2207	0.49
1984	2271	0.51
1985	2313	0.48
1986	2480	0.50
1987	2525	0.51
1988	2770	0.54
1989	3074	0.57
1990	3555	0.64
1991	3907	0.69
1992	4636	0.76
1993	4490	0.75
1994	4833	0.76
1995	5508	0.83
1996	6057	0.90
1997	6749	1.00
1998	7915	1.13
1999	8948	1.25
2000	9511	1.33

The total number of Brazilian indexed papers represents the papers in the ISI databank with at least one address in Brazil.

We can anticipate possible important advances in the future if the public financing of basic research is maintained and if, at the same time, the public and private productive sectors assimilate the qualified human resources as well as the knowledge produced locally.

Biomedical research has produced a revolutionary change in our understanding of the life sciences. Many phenomena that until recently were part of life's great mystery are nowadays understandable. When this knowledge is integrated with collective health policies important decreases in infant mortality and significant increases in life expectancy can be observed, as it has been happening in our country. At the same time, it is true that emerging and reemerging diseases generate ever changing challenges requiring a great deal of attention from the biological and sanitary points of view. Biological research produces significant impacts when dealing with phenomena still evading the present knowledge, as well as when leading to lower costs and consequent socialization of health procedures.

The treatment of AIDS illustrates quite clearly the influence of biomedical research on health. New therapies for the treatment of this disease resulted from the understanding of the three-dimensional structure of proteins and from the methods used to calculate the forces linking small molecules to the active sites of enzymes. These fields of knowledge were described until recently as "esoteric", "not applicable", and so forth. Although AIDS continues to be a serious public health problem, the protease-inhibiting molecules that have surfaced from the study of these two fields brought new hope to, and improved the quality of life of people with the HIV virus. It is not a matter of multiplying the examples, but, instead, to stress the dramatic effect on health resulting from the knowledge generated by the biomedical sciences.

The role of public investment in biomedical research is more critical in Brazil than in developed countries. All over the world, whenever public funds are invested in basic science, they are directed predominantly to universities and research institutes. These institutions supply the open, exempt and transparent environment that accelerates the training of qualified human resources. This environment also allows the verification, in an unbiased way, of research results originated from private and public sources, and forms the basis of innovation and invention. In the last 25 years there has been an explosion of biomedical discoveries, most of which have not been transformed in medical therapies or diagnostics. This is a worldwide phenomenon, and does not exclusively apply to Brazil. Recently, in the United States (Pober et al, 2001) the discrepancy between biomedical science and its applicability was attributed to factors such as: the lack of specific financing, the lack of qualified personnel, to an academic culture that hinders the collaboration among the clinical and basic researchers, and the traditional structures in the university centers that favor the departmental structures over the interdisciplinary programs. This collection of obstacles is well-known among us. Actually, this specific transcultural problem presents two aspects. On one hand, the most competitive groups in the biomedical sciences tend to retain the best graduates in the basic area. On the other hand, the majority of the groups in the applied sectors displays an important degree of resistance to incorporate young graduates originated from the basic sciences.

FINANCING RESEARCH AND DEVELOPMENT

The financing of R&D varies vastly from country to country. Comparative analysis of financing are hindered by the lack and by the diversity of information presented. In Brazil it is not easy for the scientists (or any other group) to understand the data regarding the investment in science, technology and innovation. This difficulty has hindered a continuous process that yields precise international comparisons. Thus, the interested communities have limited themselves to the analysis of the investments of some federal agencies, few state research support foundations and some ministries that supply data in a systematic way. However, in other countries, the access and the availability of systematized data are easier. According to the National Science Foundation of the United States (www.nsf.gov), expenditures with R&D in the American universities has increased 40.3% from 1991 to 1998, when the top 10 American institutions are taken into account, and 46.5% when the top 100 are considered. These data are presented in Figure 1.

The systematization of this kind of data in Brazil is scanty but emergent (www.mct.gov.br). Partial data for Latin America can be consulted at the *Red de indicadores de ciencia* y *tecnologia Iberoamericana/Interamericana* (www.ricyt.edu.ar).

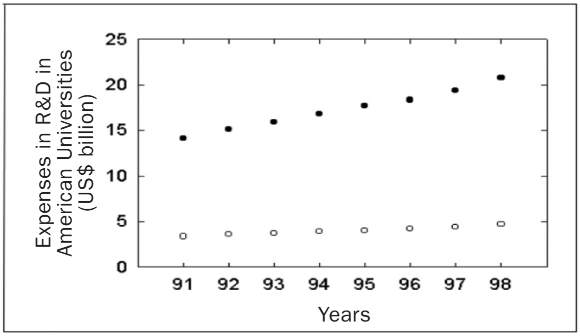


Figure 1. Expenditures in Research and development (R&D) in American Universities. The light and dark dots represent the financing data for the top 10 and top 100 institutions respectively.

Thus, for our analysis information about South Korea, United States and Great Britain (that present similar profiles), Italy (with intermediary characteristics) and Argentina and Brazil (as representatives of a distinct group with regards to R&D investment) was collected. One of the characteristics that justify this grouping is, for instance, the R&D investment originated in the public sector. The relative contributions of the public sector to the total invested in R&D for South Korea, United States and Great Britain are 26.8%, 25.8% and 35.1%, respectively. In Italy this percentage is equivalent to 45.4%, while in Argentina and in Brazil the public sector is the principal investor (70.9% and 54.5%, respectively). These data reinforce the notion that in the developed countries the private sector investments in R&D are mainly directed to the development of products (Brito Cruz 2000). Figure 2 shows the total expenditures in research and development in these six countries in relation to the number of inhabitants and researchers. The investment of US$ 797 per inhabitant in the United States contrasts sharply with the US$ 34 invested per Brazilian. When the investments per researcher are considered, once again the United States leads the statistics, with US$ 174,000 per researcher, against US$ 11,000 in Brazil. As for the total investment on research and development, expressed as a percentage of the gross domestic product, Figure 3 shows that South Korea leads with 2.79%, closely followed by the United States (2.64 %) and farther away by Great Britain (1.94%) and Italy (1.05%). Brazil and Argentina invest 0.76% and 0.42% respectively. The United States have 3.63 researchers per 1000 inhabitants, while Brazil presents a value of 0.30.

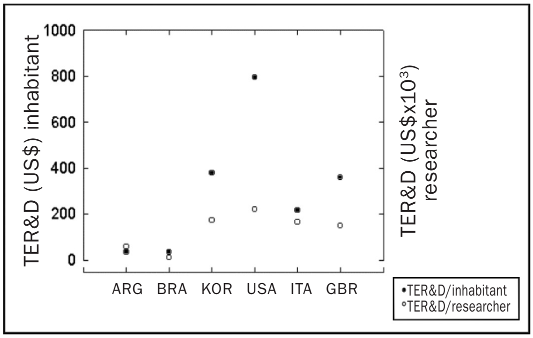


Figure 2. Total expenditures with research and development (TER&D) per inhabitant and per researcher in six countries: Argentina (ARG), Brazil (BRA), South Korea (Kor), United States (USA), Italy (ITA) and Great Britain (GBR). (Source: National Science Foundation, fiscal year of 1998).

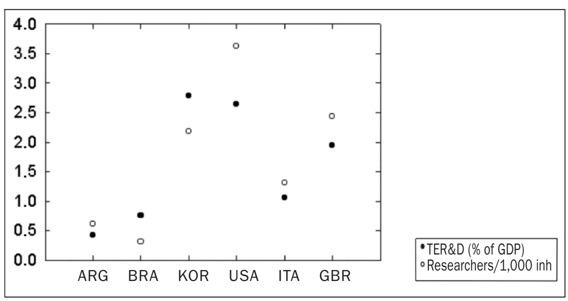


Figure 3. Total expenditures with research and development (TER&D) expressed as percentiles of the gross domestic product (GDP) and number of researchers per 1000 inhabitants in six countries: Argentina (ARG), Brazil (BRA), South Korea (Kor), United States (USA), Italy (ITA) and Great Britain (GBR). (Source: National Science Foundation, fiscal year of 1998).

Some indicators show that in Brazil, like in other countries, the biomedical area occupies a significant percentage of the resources invested in R&D&I. It is necessary to notice, however, that a more precise comparison is difficult to be presented, as it has been previously discussed. An additional difficulty is represented by the decision of selecting only some areas when describing the scientific production of the biomedical area.

The Brazilian scientific production is correlated with the amount of graduate students (see below). Therefore, it is interesting to observe the position of the biomedical area when the investment in graduate scholarships is analyzed. In

2000, for instance, the expenditures of the Ministry of Education in scholarships and financial aid for graduate education were about US$ 200 million. Of this total, 8.5% were directed to the biological sciences, where the vast majority of subjects of the biomedical sciences are found. A thorough analysis of the investments in graduate education, considering all the financing sources (public and private), still needs to be done.

THE NATIONAL SCIENTIFIC PRODUCTION IN THE BIOMEDICAL AREA

The national scientific production has been analyzed using the data from ISI. This data bank, in spite of its quality and operational simplicity, covers only a small part of the Brazilian scientific production in journals of strict editorial policy (Gibs, 1995; Vessuri, 1995). Thus, the analysis represents only a part of the intellectual production of the biomedical area.

Figure 4 shows the evolution of the Brazilian scientific production recorded by the ISI in the last two years. The data refer only to full publications (abstracts, editorials and letters were excluded) with at least one address in Brazil. Another methodological decision was to limit the group of areas of the biomedical sciences to those considered as belonging to the fundamental or basic sciences. This decision, which may seem arbitrary, was due to the necessity of dislodging the health area, which is considered in another chapter. The separation of the papers in areas is a delicate topic, since much of the biomedical research demands intellectual, methodological and disciplinary interactions that cannot be subject to a narrow classification. On the other hand, the simple integrated description of the biomedical sciences hinder more detailed observations, which are sometimes necessary to characterize each area and to plan future actions. Thus, we have opted to present the indexed publication divided in areas. The division itself is controversial. A way to identify the areas is to accept already existing classifications, such as that offered by ISI. ISI's classification is based on journals that, according to ISI, best characterize each area. The list of journals of each area is supplementary material to this chapter. Therefore, in spite of the inconveniences and stimulated by the simplicity that the data bank offers, we have decided to use ISI's areas. The following areas were chosen from the group defined by ISI: biochemistry and biophysics (Bch&Bph); cellular and developmental biology

(Biol Cel); chemical analysis and methodology (Anal Chem); endocrinology, nutrition and metabolism (Metabolis); experimental biology (ExpBiol); immunology (Immunol); microbiology (Microbiol); molecular and genetic biology (MolGenBiol); neurosciences and behavior (Neuro); pharmacology and toxicology (Pharmacol) and physiology (Physiol).

The production of full articles in these areas grew 4.6-fold (from 356 to 1640) in the period 1981 to 2000. On the other hand, the number of citations went from 646 to 5313 (1981-1998), an 8.2-fold gain (Figure 4). The number of citations represents the sum of the citations in the year of publication and of the two subsequent years, routine analysis in scientometric studies. Thus, the citations of the papers published in 1999 and 2000 were not computed. As aforementioned, when developed countries are analyzed, there is a correlation between the number of publications and their impact (Katz, 1999). This correlation is applied to Brazilian scientific literature especially in last few years, when the growth of the Brazilian production impact was significantly superior to the global average (Leta and Chaimovich, 2002). The biomedical sciences production clearly follows the increase in volume and impact of the Brazilian scientific output. The impact of the biomedical sciences, measured by the ratio between citations and publications went from about 1.5 to 3.7 in only 18 years. The increase of the volume and the impact of the biomedical area seems to follow the Brazilian indicators in scientific production.

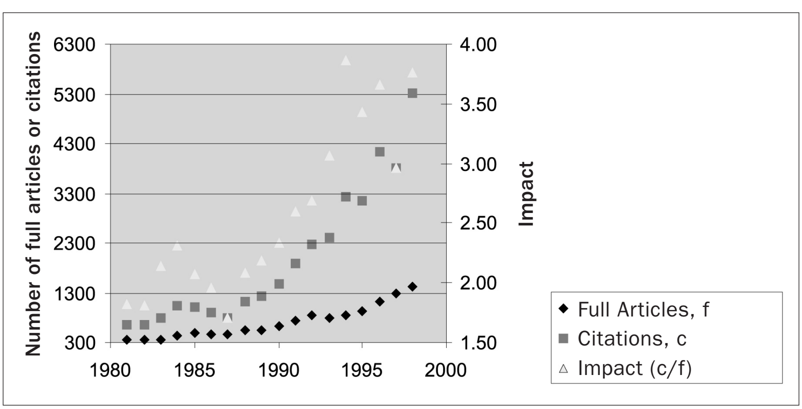


Figura 4. Number of full articles, their citations and average impact index as a function of time. Brazilian publications in the biomedical area.

The growth of the volume and impact of the Brazilian scientific production in all areas, or particularly in the biomedical sciences, is not easily correlated with the individual policy components of science and technology. Among the many variables, the number of graduate students can be best correlated with the growth of science production (Leta and Chaimovich, no prelo).

Table 2 presents the data regarding the total number of publications of the areas considered in this chapter.

■ TABLE 2

FULL PUBLICATIONS INDEXED IN ISI.

	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	2000
Bch & Bph	64	62	59	73	62	73	67	69	81	79	87	123	93	117	130	165	180	191	201	239
Biol Cel	15	12	19	18	18	20	11	18	18	20	15	27	21	23	46	45	52	65	57	54
Anal Chem	16	30	14	18	24	20	21	22	24	25	39	37	57	41	64	84	117	98	154	159
Metabolis	10	13	10	26	19	19	12	22	24	25	37	42	37	40	41	62	57	91	81	74
Exp Biol	45	39	50	80	91	77	75	92	85	94	91	117	23	24	29	28	22	39	38	29
Immunol	14	20	24	21	30	35	23	30	25	29	56	49	75	81	77	100	98	113	138	124
Microbiol	36	36	47	51	50	46	68	69	80	82	102	98	136	131	133	161	206	240	261	268
Mol Gen Biol	78	79	67	81	82	72	73	96	80	114	114	116	134	119	144	177	166	184	193	183
Neuro	26	23	25	23	39	33	33	41	46	69	87	95	76	92	106	135	175	157	206	241
Pharmacol	39	31	36	39	50	53	48	56	66	71	77	103	100	126	128	147	179	198	235	223
Physiol	13	15	16	19	24	19	28	18	30	27	25	43	33	41	19	24	39	37	34	46
Total	356	360	367	449	489	467	459	533	559	635	730	850	785	835	917	1128	1291	1413	1598	1640

With the exception of the area "experimental biology", it can be observed that the others have experienced a significant growth during the period. The case of "experimental biology" can be explained by the fact that a journal, which apparently is largely used in this area, *Revista de Medicina Tropical da USP*, has not been indexed in the ISI since 1993. This isolated fact shows the necessary care in the interpretation of scientometric data.

In all the areas the variation of citations (Table 3) follows the variation of publications, showing once again that the knowledge produced in the country is used by the global biomedical community. These data can be more clearly analyzed when the impact of the area is calculated, estimating the relationship citation/ publication (Table 4).

■ TABLE 3

CITATIONS (IN 3 YEARS) OF THE FULL PUBLICATIONS.

	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98
Bch & Bph	134	184	213	252	176	182	185	211	277	247	234	402	335	577	569	761	704	815
Biol Cel	24	33	25	32	19	38	9	50	27	76	42	102	65	54	197	76	138	228
Anal Chem	30	41	36	38	64	27	36	51	52	84	82	109	193	163	225	262	291	322
Metabolis	19	12	19	70	22	34	35	39	70	54	87	98	73	81	130	196	178	409
Exp Biol	61	63	51	58	59	75	57	49	76	86	73	45	35	61	90	74	41	94
Immunol	42	40	81	138	157	189	44	109	83	89	311	265	429	527	359	596	369	583
Microbiol	88	91	78	215	128	132	109	243	250	239	340	286	473	479	419	637	587	894
Mol Gen Biol	82	71	88	47	76	38	65	74	81	171	166	269	177	491	345	663	396	660
Neuro	78	50	79	58	190	89	107	135	137	223	354	420	348	422	487	436	689	716
Pharmacol	58	38	87	82	75	73	92	115	139	157	178	195	241	238	315	380	369	523
Physiol	30	29	29	48	48	38	43	33	31	54	25	95	40	131	13	41	54	69
Total	646	652	786	1038	1014	915	782	1109	1223	1480	1892	2286	2409	3224	3149	4122	3816	5313

■ TABLE 4

IMPACT OF BRAZILIAN PUBLICATIONS PER BIOMEDICAL SUBAREA.

	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98
Bch & Bph	2.09	2.97	3.61	3.45	2.84	2.49	2.76	3.06	3.42	3.13	2.69	3.27	3.60	4.93	4.38	4.61	3.91	4.27
Biol Cel	1.60	2.75	1.32	1.78	1.06	1.90	0.82	2.78	1.50	3.80	2.80	3.78	3.10	2.35	4.28	1.69	2.65	3.51
Anal Chem	1.88	1.37	2.57	2.11	2.67	1.35	1.71	2.32	2.17	3.36	2.10	2.95	3.39	3.98	3.52	3.12	2.49	3.29
Metabolis	1.90	0.92	1.90	2.69	1.16	1.79	2.92	1.77	2.92	2.16	2.35	2.33	1.97	2.03	3.17	3.16	3.12	4.49
Exp Biol	1.36	1.62	1.02	0.73	0.65	0.97	0.76	0.53	0.89	0.91	0.80	0.38	1.52	2.54	3.10	2.64	1.86	2.41
Immunol	3.00	2.00	3.38	6.57	5.23	5.40	1.91	3.63	3.32	3.07	5.55	5.41	5.72	6.51	4.66	5.96	3.77	5.16
Microbiol	2.44	2.53	1.66	4.22	2.56	2.87	1.60	3.52	3.13	2.91	3.33	2.92	3.48	3.66	3.15	3.96	2.85	3.73
Mol Gen Biol	1.05	0.90	1.31	0.58	0.93	0.53	0.89	0.77	1.01	1.50	1.46	2.32	1.32	4.13	2.40	3.75	2.39	3.59
Neuro	3.00	2.17	3.16	2.52	4.87	2.70	3.24	3.29	2.98	3.23	4.07	4.42	4.58	4.59	4.59	3.23	3.94	4.56
Pharmacol	1.49	1.23	2.42	2.10	1.50	1.38	1.92	2.05	2.11	2.21	2.31	1.89	2.41	1.89	2.46	2.59	2.06	2.64
Physiol	2.31	1.93	1.81	2.53	2.00	2.00	1.54	1.83	1.03	2.00	1.00	2.21	1.21	3.20	0.68	1.71	1.38	1.86
Total	1.74	1.73	1.97	2.10	1.98	1.80	1.54	1.93	1.94	2.12	2.33	2.42	2.82	3.49	3.04	3.28	2.63	3.23

On the average, the impact of the publications doubled in the period. It is clear that some areas had a smaller variation in their relative impact. In this sense, it is important to notice that these indicators are global and should not be analyzed in relation to the production of any researcher individually. Another aspect to be noticed is that this extraordinary growth was spontaneous, the result of a policy that correctly identified the necessity for harmonious growth among the areas of the biomedical sciences. Some areas, however, did not follow the rhythm of change; others may not even have developed to the point of fulfilling the Brazilian necessities. For example, the biomedical research related to malaria, a disease with an increasing incidence, especially in the Amazon Region, was little developed when compared to the efforts related to other infectious diseases (Rodrigues et al, 2002).

THE FUTURE OF BIOMEDICAL RESEARCH

Throughout the years, research in the biomedical area focused on aspects related to biological systems, a fact that is reflected in the departmental structure of the universities and on the initial mission of some research institutes. In the last 15 years, however, it has turned its focus to larger interconnected fields, in an effort to understand complex phenomena at the molecular level. The structure of the great majority of the universities and research institutes did not follow this tendency. The maintenance of rigid departmental structures that do not follow the demands of the scientific knowledge can be an important obstacle to the new ways of intellectual production. Few university departments created in Brazil in the 1970's can accommodate the multidisciplinary approach required by today's biomedical research.

At the same time, part of the holistic formation has been forgotten. An example of the reduction in the holistic approach in the biomedical sciences can be observed in the comparison between the evolution of biochemistry and biophysics, typically reductionists, with the evolution of physiology, which maintains its holistic character. Figure 5 presents the temporal variation of the number of papers and of the impact (citations/number of full papers) in these two areas. The divergence between the two areas is evident. The volume of production in biochemistry/biophysics grows exponentially and its impact follows the growth. In physiology, the volume grows very little in the same period of time and the impact of the production tends to diminish. If this tendency is maintained, it can yield a negative impact in the application of the molecular knowledge to the phenomena that require a vision of organs, systems or organisms. Once the stage of drafting the human genome sequence is over, it will be necessary to finish it and to "write it down", that is, characterize all of its genes and figure out their functions. The first step will be the identification of all the coding regions of proteins, which will give a good indication of the number of functional genes. The complete annotation will be a very complex task: such annotation has not yet been accomplished on the two chromosomes (21 and 22) that are completely sequenced. A network of powerful computers spread throughout the world may be established in order to accomplish such a goal. The task is still unimaginable. As a starting point, let us consider: the 46 human chromosomes present an estimated number of 30,000 genes, which possibly generate 300,000 to a few million proteins. This estimated total of genes will be identified in three years, according to the Human Proteome Project, a sequel of the Genome Project, with the approximate cost of US$ 500 million. On the other hand, the full comprehension of the cellular and molecular mechanisms involved in the human physiology and pathology will require extensive studies in functional and structural biochemistry of proteins and, furthermore, in cellular, tissue and complex organic systems.

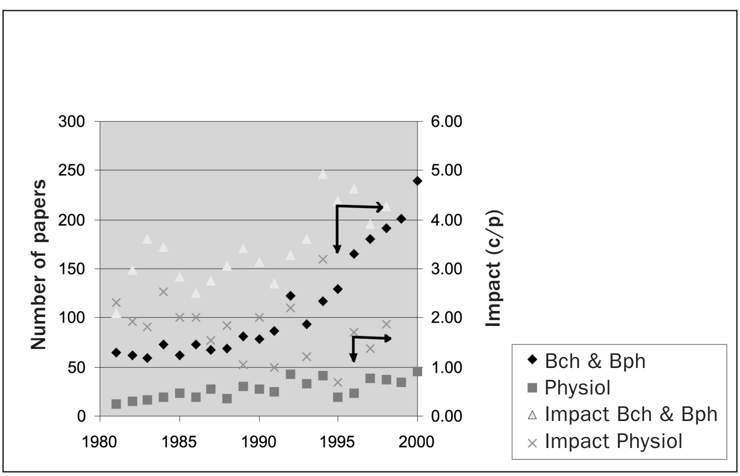


Figura 5. Variation of the number of papers and of the impact in biochemistry & biophysics and in physiology.

Thus, the announcement of a pre-sequence of the human genome in June of 2000 was the reward for 50 years of studies. Considering that the complete sequencing of the genome is not an end, but a beginning, we arrive at the prediction that the biological analysis of the genome will require efforts and work of a much higher magnitude than those employed in the sequencing. However, one cannot diminish the importance of sequencing more and more genomes, whether they are animal or plant bearing in mind the information to be generated by comparative genomics. The analysis and comparison of a range of genomes, from bacteria to primates, will yield powerful analytical tools for the functional understanding of the genetic charge of living beings.

The next important steps in genomics are the determination of the three-dimensional structures and functions of all the proteins, and the complex interactions among systems. We will get into in systematic programs of x-ray crystallography, spectroscopy through nuclear magnetic resonance and other methods. Structural genomics will identify how proteins, of known structure, share forms and gene sequences with proteins of unknown structures. This problem can only be solved with large numbers, after hundreds of thousands of proteins have been observed and compared. In the computational field, structural modeling studies represent a powerful tool of bioinformatics, which yields important mechanistic data to the biomedical area.

In due time, we will be able to learn how proteins, RNA's and other molecules interact in order to create and maintain the vital functions of living beings. The unmasking of the control mechanisms that regulate these processes will be the most difficult stage, due to the amount of information necessary for this task. At this point, the circle will be closed with the integration of all the scientific and methodological approaches of biomedicine.

SOME HINDRANCES OF BIOMEDICAL RESEARCH

The closing of this circle constitutes one of the greatest challenges of science in the present. One of the hindrances of biomedical research was presented in a recent article of *Science*, signed by the president of the Howard Hughes Medical Institute and collaborators of other important medical institutions (Cech et al., 2001): The information originated from molecular biology needs to be translated into treatments. This kind of research, named translational research and carried out by the physician-scientist, needs to be stimulated. Indeed, the huge accumulation of new knowledge is producing a growing hiatus between basic research and application, as a result of the insufficient number of researchers that work in both basic and medical areas and that can carry on translational research. Not only has the number of these researchers been stagnant, but a decrease has been detected, especially in the United States, due to low incentives given for research activities and the competition with other activities in the medical career.

In his recommendation document for the financing of the biomedical and other related areas in the United States, the Federation of American Societies of Experimental Biology (FASEB) highlights the urgent necessity to revert this situation (FASEB, 2001). Added to this global hindrance there is an evident necessity for fomentation, especially in Brazil, of research and training of personnel in the area of integrative physiology that, as aforementioned, has received little attention and will be essential in the short-term. Indeed, physiology studies intact organs and organisms, thus constituting the level where genetic and therapeutic manipulations can be analyzed *in vivo* with new drugs. Therapeutic progress cannot occur without this level of analysis. The appeal of molecular biology has reduced the number of competent physiologists. The remaining scientists that study organic and systemic properties must be encouraged with budgets and special incentives. In this way they will be able to promote the training of the new generation of scientists capable of studying the organism as a whole.

THERAPEUTIC TOOLS ORIGINATED FROM BIOMEDICINE

In an era when biomedical sciences have progressed with incredible speed, it is worth remembering that about 60% of the medicines in use are based in composites obtained directly from nature. This framework, however, may change soon.

The annotation of the genome points to a new process of development of therapeutic agents. Trial and error, which led to the discovery of medicines throughout the millennia that preceded us, gradually gives place to the detailed and specific design of the active composites. Scientists are more and more able to identify the molecules (or group of molecules) that make us susceptible to a certain disease.

With this information they can construct new molecules directed to specific targets, thus reducing the collateral effects of this new generation of drugs.

One of the approaches derives from the public data bank of the genome. Initially a certain target-protein is identified by the experimenter, for instance, the angiotensin converting enzyme (ACE). In the genome database, DNA sequences similar to the ACE are searched through informatics. Then, the clones that are corresponding to the sequences found in the data bank are selected from the genomic and DNA libraries. Each one of them is hybridized to the RNA obtained from different cells of the organism. (In the example under discussion, especially lung, heart and kidney cells, where the ACE acts.) The microarray technique allows the simultaneous identification of a large number of active genes in tissues. These chosen sequences are submitted to tests to verify if the corresponding protein really converts the angiotensin. The positive segments are once again tested against composites obtained in the library of ACE inhibitors. If there is an inhibition of the conversion, the composite is a candidate to animal tests and, subsequently, to clinical tests.

Another approach uses monoclonal antibodies, small proteins that are copies of a single antibody and that link themselves to a specific antigen, for example, a bacterium, a virus or a tumorous cell. Then, a series of events takes place in the immune system, destroying or neutralizing the target. Other antibodies carry radioactive isotopes or toxins that can eliminate the cells to which they are linked. In 1993 monoclonal antibodies began to be generated in the cells of mice, which had their own antibody-producing genes inhibited but had transplanted human antibody-generating genes. Thus, the cells of these mice became able to generate an unlimited supply of highly specific human antibodies with extensive therapeutic application.

Another important therapeutic tool can be genic therapy, which aims to treat or prevent a disease through the introduction of a therapeutic gene in target cells, producing a protein that gives a pharmacologically active response. This transgene is inserted in the target through a range of vectors, such as retrovirus, adenovirus and plasmids. The viral vectors have high transfection efficiency, though they present complex problems of toxicity, pathogenicity and induction of hyperacute immune response. Recent progress in the modification of the properties of plasmids, associating them with ligands that promote their cell internalization mediated by specific receptors or encapsulating them with polymers that prolong their lifetime, are improving the perspectives of using these vectors, and thus, this tool.

Contrasting with the production of therapeutic agents or vaccines, regenerative medicine is individual, directed specifically to each case, in its particular context. Therefore, it concerns an individualized medicine, whose action may have two stages, independent or associated: 1) the manipulation *ex vivo* of the patients own cells, their expansion, differentiation and potential integration into superior ordered structures that will be reintroduced into the harmed regions in the regeneration process (bioengineering or tissue engineering); and 2) the introduction, in the injured regions, of supramolecular structures, similar to the extracellular matrix elements and associated intracellular mediators, easing the mobilization, expansion and integration of regenerative cell populations, and helping the repair of injuries or degenerations (biomimetics).

Algorithms obtained from bioinformatics can also aid in the construction of pharmacologically active molecules. The goal is to predict the function of proteins codified by recently identified genes. These proteins can be compared with others of known structure, in an attempt to suggest their biochemical functions and even to find a way to deactivate them. Considering that an active protein can have its structure modified, the understanding of this phenomenon can be crucial for the design of active molecules. Thus, computer simulation comes into the picture, capable of suggesting how a protein structure is altered when activated, as well as identifying small molecules able to disarm these targets.

BIOINFORMATICS

Part of the biomedical sciences is going through a paradigm change similarly to what happened in physics, when the sharing of large facilities such as particle accelerators were substituted for experiments in small laboratories. Many disciplines, like biomedicine, were characterized in the past by experiments conducted by one researcher of a small team. However, part of the community is becoming more and more digitally interconnected, sharing data and relying on highly comprehensive databases. The manipulation of large data banks becomes gradually an integral part of research and of scientific discovery.

In this context, biomedical sciences are becoming familiar with the impact of cataloging, among other data, the 3 billion pairs of bases that constitute the human genome. These numbers progressively receive additions from the genomes of other organisms. Many future scientific discoveries shall be originated from comparative studies of genomes. One of the revolutions in biomedicine is passing from a science that identified the basic components of cells, organisms and populations to a science that seeks the physiological understanding of these complex systems.

New levels of chromosomal information may be discovered. For example, the types of information contained in DNA and RNA, the signs that regulate the spatial and temporal amplitude of the genic expression, the families of repeated sequences that are believed to aid in the evolutive chromosomal alterations, and the epigenetic chromosomal characteristics that preserve the fidelity of the information regulation.

Another challenge for informatics is the conversion of the linear information of the gene sequence into the three-dimensional structures of the proteins. Other dimensions must still be incorporated, for instance, the kinetics of the behavior of intracellular information paths. Imagine the transformation of the digital codification of the genes in the 10^{12} cells of the central nervous system with its 10^{15} interconnections, all modulated by environmental signs! Naturally, computer modeling will be necessary to describe the structure and the dynamics of proteins in such a system, as well as the mutual interactions among them.

In this new era, scientists really need a rigorous theoretical structure and powerful quantitative tools. The understanding of the non-linear interaction among hundreds of genes to produce a cancerous cell is only an example. Advanced techniques to organize data as well as new theoretical tools of multidimensional data bank analysis will be more and more necessary in order to unravel the complex interactions of biological systems. The organization of terabytes – 10^{12} bytes -- of biological data is a theoretical challenge of great magnitude in computer science and in the mathematics of complex systems.

Biomedicine shall integrate the various levels of biological information and transform the data in models that describe the highly complex properties of these systems. It is possible that the experimental planning of the future may become dependent on the way the existing information is analyzed. In other words, the questions may come to depend on the previous computational tools. All the elements in the system shall be defined and characterized. These shall become the basic steps for the organization of a theoretical structuring in biomedicine.

PERSPECTIVES FOR RESEARCH IN THE BIOMEDICAL AREA IN BRAZIL

When the São Paulo State Research Supporting Foundation (FAPESP) launched the project to establish the sequence of the genome of a bacterium that compromised orange trees, the main objective was the training of the scientists from São Paulo in the techniques of genomics and to install a capacity to manage network programs in the State of São Paulo. Using this model, the DNA sequence of the *Xylella fastidiosa* was published (Simpson et al., 2000). In fact, the sequencing of the *Xilella* was done by a consortium, with an approximate cost of US$ 13 million. The project leaders searched for their niche in genomics, choosing an organism of local economic importance and used a collaborative model, linking various laboratories of various sizes. The idea of a consortium is not new and is becoming more and more used in science.

The concept of a managed network and funding compatible with the problem are being presently applied to programs of research support agencies of the federal government. Some state governments, such as Rio de Janeiro's, have also given the go-ahead to projects of genome sequencing. It is a meritorious initiative, which shall be added up to the federal efforts in the nation's remaining states.

Many scientists, however, call attention to the fact that to carry on this high scientific level, the career plan of university professors, as well as that of researchers from institutions directly linked to the Ministry of Science and Technology (MCT) ought to be reformulated. On top of this, fair salaries and appropriate working conditions are long overdue. Considering the speed of progress in the biomedical sciences, it will be an enormous challenge to maintain the country's current prominent position in this field.

In Brazil, the production of fundamental knowledge in biomedical research occurs, largely, at the academic institutions. The country has centers of excellence in biochemistry, pharmacology, immunology, biophysics, and cellular biology, but they should be in a much larger scale. The scientific competence in these areas is already installed and human resources of the highest level are already available. The analysis of national scientific capacity and productivity points to these as areas of excellence, either in terms of generating new scientific data, or in terms of the training capacity of graduate human resources. The remaining areas of biological research certainly present highly qualified researchers, but their numbers ought to be rapidly multiplied. Some of the latter areas receive special incentives from the National Council for Scientific and Technological Development (CNPq).

Innovation, the products and services developed from the knowledge generated by the biomedical sciences, involves other factors besides academic research. Although there are academic centers of excellence in Brazil, the interaction with the production line is not solidified.

Various kinds of financing are necessary in order to keep pace with the increase of the global knowledge and to contribute to innovation. The size and the quality of the scientific system in the biomedical area in Brazil already allow quality judgments of development and funding policies. The national and international experiences show that balance among programs (with defined priorities) and grants (financing that pays heed to the curiosity of the researcher) is essential in order to maintain the life circle of creation. A lack of equilibrium leads either to the lack of a straightforward policy (when only the grants are preferred), or to the dismantling of the system's structure (when there are programs without the adequate funding).

In conclusion, the lack of continuous and sufficient support of research and development in the country, not to speak of the difficult maintenance of the existing personnel due to the low salaries and of the absence of the required expansion of their numbers by hiring our highly qualified trainees, turned the efforts made by the National Council for Scientific and Technological Development (CNPq), the Coordination for the Improvement of Higher Education Personnel (CAPES), the Ministry of Science and Technology, some state research supporting foundations and a few private foundations into merely satisfactory results. Brazil has an installed research capacity and a considerable collection of human resources, almost entirely placed into public, federal and state institutions. It can be improved in order to continue what has been already attained in the Brazilian biomedical area as long as the public sector:

- continues to coordinate and implement the country's scientific development;

- offers more fixed positions for thoroughly qualified personnel;

- creates new and necessary research and development centers in the country;

- clearly establishes efficient mechanisms for transferring private investments into public institutions with development and human resource capacities already installed;
- clearly establishes efficient mechanisms for the return of benefits divided in a just manner between the productive sector and the public research and development sectors;
- uses its purchasing power to generate companies where the innovation is mandatory, or to allow that the small, medium and large companies, public or private, receive benefits from their own local R&D investment.

We need a new generation of biomedical scientists and a continuous governmental commitment with scientific research so that we can achieve sovereignty. We cannot allow ourselves the luxury of losing the opportunity that is currently offered to us.

BIBLIOGRAPHIC REFERENCES

BRITO CRUZ, CH Revista Humanidades 45, 15-29, 2000

FASEB Office of Public Affairs. The Benefits of Biomedical Research. *Physiologist* (1999) 42: 389-395.

CECH TR., EGAN LW., DOYLE C, GALLIN E, LICHTMAN MA., Queenan III CJ., and Sung N The Biomedical Research Bottleneck. *Science (*2001) July 27; 293: 573 (in Editorial)

COCKBURN I, HENDERSON R, ORSENIGO L, PISANO GP. *Pharmaceuticals and biotechnology*. Pp. 363-398 in MOWERY DC (ed.), US Industry in 2000: Studies in Competitive Performance. Washington, DC: National Academy Press, 1999. http://books.nap.edu/books/0309061792/html/363.html#363

De MEIS, L. and LETA, J. *O perfil da ciência brasileira*. Rio de Janeiro: Editora UFRJ, 1996.

Gibbs W. The lost science in the third world. *Scientific American* (1995) 273: 76 – 83.

HOLMER AF. HOLMER. New Drug Approvals in 1998. Washington, DC: PhRMA. 1999. http://www.phrma.org

HORTA MH e de SOUZA CF, IPEA, *Texto para Discussão No 736, Rio de Janeiro, Junho* 2000

HOYERT DL, KOCHANEK KD, MURPHY SL. DEATHS: Final data for 1997. *National Statistics Reports 47* (June 30). 1999. http://www.cdc.gov/nchswww/releases/99facts/99sheets.htm

J.S. KATZ, Scale-independent indicators and research evaluation. *Science and Public Policy* (2000) 27: 1–23.

LETA J. and CHAIMOVICH H. Produção científica brasileira nas Ciências da Vida: a contribuição relativa da Universidade de São Paulo nos periódicos de maior impacto e de maior número de artigos. (Aceito para publicação na revista Parcerias Estratégicas, MCT.)

LETA J. and CHAIMOVICH H. Recognition and international collaboration: the Brazilian case. *Scientometrics* (2002) 53: 325 – 335.

LICHTENBERG FR. Do (more and better) drugs keep people out of hospitals? *American Economic Review* (1996) 86: 384-388.

NARIN F, HAMILTON KS, OLIVASTRO D. The increasing linkage between US technology and public science. *Research Policy* (1997) 26: 317-330.

National Institutes of Health. Cost Savings Resulting from NIH Research Support, second edition. NIH Publication no. 93-3109. 1993, revised 1996. Bethesda, MD: NIH.

PARDES H, MANTON KG, LANDER ES, TOLLEY HD, ULIAN AD, PALMER H. Effects of medical research on health care and the economy. *Science* (1999) 283: 36-37. http://www.sciencemag.org/cgi/content/full/283/5398/36

Pharmaceutical Research and Manufacturers' Association. Drug companies to invest $20 billion on R&D as they continue to work on 1,000 new medicines. *Facts and Figures*. Washington, DC: PhRMA, March 1998. http://www.phrma.org/facts/phfacts/3_98a.html

POBER JS, NEUHAUSER CS, POBER JM. Obstacles facing translational research in academic medical centers. *FASEB J* (2001) 15:2303-2313.

RODRIGUES, P.S., FONSECA, L. and CHAIMOVICH, H. Mapping cancer, cardiovascular and malaria research in Brazil. *Braz J Med Biol Res* (2000) 33: 853 – 867.

SIMPSON AGJ, REINACH FC, ARRUDA P, et al. The genome sequence of the plant pathogen Xylella fastidiosa. *Nature* (2000) 406: 151-157.

TOOLE AA. The impact of federally funded basic research on industrial innovation: Evidence from the pharmaceutical industry. Madison, WI: Lauritis R. Christensen Associates, 1997.

VESSURI H. Recent strategies for adding value to scientific journals in Latin America. *Scientometrics* (1995) 34: 139 – 161.

Winsconsin Association for Biomedical Research and Education. Bioscience Research, Development & Industry: Impact on Health & Economic Growth in Wisconsin. Milwaukee, WI. 1996. http://www.wabre.org/

AUTHORS

Walter Araújo Zin *(Coordinator)*

Member of the Brazilian Academy of Sciences (ABC); PhD in Sciences (Biophysics) from the Carlos Chagas Filho Biophysical Institute; and Professor of Physiology at the Federal University of Rio De Janeiro (UFRJ).

Dora Fix Ventura

Member of the Brazilian Academy of Sciences (ABC); PhD in Experimental Psychology from the University of Columbia (USA); and Professor of Experimental Psychology at the University of São Paulo (USP).

Hernan Chaimovich

Member of the Brazilian Academy of Sciences (ABC); PhD in Biochemistry from the University of São Paulo (USP); and Professor at the Chemistry Institute of the same University.

Jacqueline Leta

PhD in Biological Chemistry from the Federal University of Rio de Janeiro (UFRJ); and associate researcher at the Advisory Board to the Dean of Research at the University of São Paulo (USP).

Area of Engineering Sciences

JOSÉ AUGUSTO P. ARANHA
HANS INGO WEBER
HÉLIO WALDMAN
LUIZ FERNANDO SOARES

STATE OF THE AREA IN THE WORLD AND IN BRAZIL

The technological area seems to face, in a world context, a paradoxical situation: if on one hand the great economical boom of the 1990s, which was mainly observed in the developed countries, is associated, as the analysts say, to the productivity gains related to technological development; on the other hand, a distancing of the youth from technological activity can be observed in these countries. It is significant, in this context, to observe that in the prestigious American universities the largest contingent of graduate students in the areas of engineering is foreign, mainly from countries with peripheral economies. In the central countries, the largest part of the well-prepared youth prefers the managerial and business areas instead of the technological area. Although this tendency has always been observed, maybe it has been hypertrophied lately due to the following specificities.

On one hand, technological education is of slow maturation. It is a vertical and rooted knowledge, which has more difficulty in adapting itself to the volatility that has been lately observed in market. The horizontality of the managerial area is more favorable to mobility, it conforms better to the unpredictability of the market and due to that fact, it establishes a more attractive pact with the youth, which searches for stability during change. On the other hand, salaries in technological activities are, in their majority, inferior to those in the managerial area: thus, and immediate gain is also added to the stability pact, making the technological option an adventure not only risky but with a low premium according to the values presently accepted by society. These questions are relevant, not only because they are reduplicated in the specific case of Brazil, as we will see later on, but because they also explain a series of measures that have been taken by the main engineering schools in order to make their courses more attractive to youth: the movement proposed today seems to be towards defocusing from the dominant themes of classical engineering in the undergraduate level, providing a more general view, less compromised with specific problems, but not abdicating from a solid basic education.

However, in the graduate level, which is where research occurs, no significant change in direction was observed, in spite of the greater volatility of the market: continues to be important, less for the direct resource[1] contribution, more for the suggestion of problems and mainly for the creation of job opportunities for graduate students. Large part of the research activity in the United States is done within industry, where more than 80% of the country's PhDs are found and the great majority of the patents are generated. The publishing of scientific articles produced by professionals working in industry is significant, reaching in some areas, such as electricity and computer science, the same production level of the universities.

In order to finish this brief introduction about some of the peculiarities of the technological research developed today in the world context, it is important to lay out here some indicators on the scientific production in the area, so that later, they can be compared with the data regarding the Brazilian production. Particularly, an important comparative datum is the one associated to the quality of scientific production, measured in general by the impact index, which relates the number of citations of a certain author (or publication) with the number of papers disclosed by the author (or publication). This factor varies from area to area of knowledge; however, and in order to estimate it in the field of engineering, the following procedure was adopted: since 83% of the scientific production in the area comes from the "central countries" (USA, Europe and industrialized Asia), it is reasonable to suppose that the average impact index of the main engineering journals is an estimate of this indicator for these countries. Table 1 shows the impact index of some important engineering journals, indicating an average value of 1.10, a ratio that, according to the argument above shall be a reference value of the quality of the scientific production in the area of engineering.

1. *Even at the Massachusetts Institute of Technology (MIT), which is leader in the USA in raising funds from industry, less than 20% of its budget is derived from this activity; the majority of the resources for research comes from governmental sources.*

■ **TABLE 1**

IMPACT INDEX OF SOME IMPORTANT ENGINEERING PERIODICALS

Periodicals	Impact
J.Fluid Mech.	1.609
IEEE *	1.350
I.J.Nume.Meth.Eng.	1.114
I.J.Heat and Mass	0.690
J.Sound and Vibration	0.681
J.Structur.Eng.(ASCE)	0.440
J.Hydraul.Eng.(ASCE)	0.319
Average (weighted)	1.11

* Among the 88 IEEE periodicals, were selected the 26 that had an impact index larger than 1. Then, the average of these 26 was taken.

The area of engineering in Brazil shares some characteristics observed in the central countries and it differentiates itself in many others. The complicating factor is that it identifies itself on the problems, and distances itself from the more developed sector as it begins to present its best qualities. Research activity in engineering is concentrated in the Southeast[2] Region of the country, mainly in São Paulo and Rio de Janeiro. Since these are being more and more identified as "business regions", the same phenomenon observed in the central countries can be observed here: there is great difficulty to attract the engineering undergraduate students to graduate school in the São Paulo-Rio de Janeiro axis. In this region, they are attracted by the managerial and business areas, and graduate school, specially the doctorate, is filled in great part by students of other parts of the country and even, in more recent times, of other Latin American countries. This characteristic can be used positively, as discussed in the final section of this document, through a consistent policy of decentralizing technological development, not in an open and unstructured way, but in a focused and concentrated manner.

What differentiates us from the "central countries" has historical reasons that are worth being remembered here. First of all, technological research in the Brazilian universities is recent (about 30 years old) and when it was installed in the country, it found a faculty with a well-defined profile, and for the most part, with

2. *This region is responsible for 83% of the research scholarships from CNPq in the area of engineering.*

a posture that was culturaly antagonistic to the one suitable for research activity. The engineering schools professors were in general successful engineers, who in one way or another projected the infrastructure of this country and gave support to the industries that were here installed, especially since the 1950s. The majority of these professionals was from civil engineering and the most prominent and sophisticated technological activity, was associated to consulting. It just happens that the profile of the consultant is, roughly speaking, opposite from the profile of the researcher, because while one looms over current problems, demanded by the industry, the other projects himself on what is still to come. If we do not understand this cultural dimension, reinforced by the just argument that they were solving the country's most pressing technological problems, maybe we will never understand why the engineering schools resisted for so long incorporate of the new operation mode proposed to the Brazilian university system, specially the more traditional schools, where this culture was certainly more ingrained.

Table 2 exemplifies this point in an exact way. Latin America is responsible for 2.1% of the world's scientific production and its worst performance is exactly in the engineering area, where the scientific production represents only 1.2% of the world's total. The argument above mentioned is reinforced by the observation that the second worst performance of Latin America occurs in another professional activity, medicine. On what engineering is concerned, it must be observed that the scientific production originated from industry in the "central countries" reaches, in some specific areas, production levels similar to those of the universities. On the other hand, Latin America, and particularly Brazil, have a virtually nonexistent scientific production originated from industry.

■ TABLE 2

PERCENTAGE OF SCIENTIFIC PRODUCTION IN DIFFERENT AREAS OF KNOWLEDGE

Areas	Biology	Medicine	Applied Biology	Chemistry	Physics	Mathematics	Earth/Space	Engineering
Developed Countries*	90.6%	90.0%	81.3%	78.9%	76.4%	79.5%	83.7%	82.9%
Latin America	1.7%	1.4%	3.3%	1.8%	2.7%	2.0%	2.4%	1.2%
Other	7.7%	8.6%	15.4%	19.3%	20.9%	18.5%	13.9%	15.9%

Source: “”The state of world science””, R.Barré & P.Papon, Nature Yearbook of Science and Tech.-2000. * USA, Europe and Industrialized Asia.

However, another indicator seems to suggest that the observed distortions on Table 2 may be corrected with time. Table 3 presents the total number of articles published in magazine in the different areas of knowledge in the years of 1981 and 2000. The largest rate of increase was in engineering (8.52) and the second-largest was in medicine (7.60). It can be argued, with some authority, that these high rates are also due to an initial stage where the scientific production was very small. However, a more detailed analysis of the data shows that the number of publications has in fact increased year by year throughout the 1990s, indicating that the growth observed represents a consistent fact.

■ TABLE 3

TOTAL NUMBER OF ARTICLES PUBLISHED IN MAGAZINES (ACADEMIC AREAS)

ABC	Chem	Agr	Biol	Biom	Phys	Hum	Math	Earth	Med	Eng
1981	167	192	281	1115	383	129	53	60	332	140
2000	1090	510	994	4347	1765	348	177	333	2525	1193
Taxa	6.50	2.66	3.54	3.90	4.61	2.70	3.34	5.55	7.60	8.52

Source:ABC.

Considering the impact index as a reliable indicator of the quality of the scientific production, Table 4 shows that the quality of the Brazilian production in the engineering area is good, comparable to that of technologically more advanced countries. However, this statement must be observed with caution, specially because it is based on indirect information about the impact factor of the "central countries".

■ TABLE 4

IMPACT INDEX IN THE AREA OF ENGINEERING

	(FI)-Impact Index	**(FI)-**Developed Countries*
1981	1.14	(-)
1997	1.14	1.10
2000	1.21	(-)

Source: ABC. *USA, Europe and Industrialized Asia. Impact Index of 1.10, estimated as Table (1) indicates.

Much has been said, and much has been done, on the question of the university-industry interaction. But before we linger on the advantages of such interchange, it is important that we make a few points, which although critical, may assist us on orienting a policy that is more appropriate to the country's objectives. First of all, it is relevant to observe that about 75% of the capital invested by the industry in the universities comes from one single source, PETROBRÁS, a federal company. This indicates a fragility in this interchange, not so much due to the universities, that have opened themselves more and more to the productive sector, sometimes even too much, but instead due to the apparent lack of interest from itself industry.

Another point that deserves some reflection is the following: what is observed today, also due to industry's reluctance in facing the question of technological innovation, is that this interchange has been generally characterized by a particular *modus operandi*, where the university is required to act as a service provider, making available to industry a reserve army trained in the problems that affect it. Although this *modus operandi* may be important as an approximation ritual, by itself, it is unable to promote genuine technological innovation. It also not differentiate much from the former consulting based *modus operandi*. A consequence of this mode of operation is that a certain orthogonality between the gathering of resources and scientific production can already be observed within the universities. This perpendicularity has a possible double impact on the question of technological innovation: on one hand, transferring power back to the university activity that is more refractory to innovation, the one that deals only with market problems. On the other hand, detaching scientific production from genuine problems, a movement that may come to circumscribe it into a ghetto, leading it to develop its own dialect, incomprehensible to the living language of society.

Having stated all that, and with latent problems that always surround any interchange put away, the relationship with industry is fundamental for the technological area of the universities, because it is in industry that lays the motivation for their studies, and where their graduates will go. The great bottleneck of the technological question in the country does not reside so much in the training of its university environment, but in the productive sector. It resides in the fact that few of the industries installed here, whether national or foreign, have really active research centers. It is important to understand the objective reasons why industries are reluctant in following this direction, and conditions must be provided in order to overcome this impasse; hence, a certain industrial policy must be sketched. However, this policy will be discussed here in a purposely vague manner, in order to avoid creating an early antagonism on the eventual readers. It is never too much to remind that one of the few Brazilian industrial brands with a certain international visibility, EMBRAER, has a didactically cartesian history: first came ITA, in 1950, right afterwards came the CTA and almost 20 years later EMBRAER emerged. In a way, the genesis of the aerospatial complex centered in São José dos Campos is similar to one in Silicon Valley, California, which appeared in the trace of *Caltech* and *Stanford,* and of *Route 128*, in Massachusetts, which appeared in the trace of MIT. In all these cases all that existed in the beginning was human capital and technical training; the physical capital came afterwards, also in order to create a demand for such a generous offer. To paraphrase Pirandello, we have now, again, not "six characters searching for an author" but all the technological training is in search of an industry, in search of real problems that are worth solving: a more coordinated political initiative is still lacking in order to face this challenge, although it is perceived through the creation of the sectorial funds, the beginning of a movement in this direction.

In the final section of this document we will get back to the questions asked above, and we will finish this section by supplying some relevant data about the technological population of Brazil, including indicators of the relative distribution in the different subareas of engineering.

Table 5, although a little outdated, supplies data on the population involved with technology (engineering) in the country. Note the saturation that is already being delineated in the training of masters, but an always crescent vector in the training of doctors.

■ **TABLE 5**

ENGINEERING POPULATION IN BRAZIL

Category	**1985**	**1990**	**1995**
Researchers	1700	2100	2410
PhD Students	2440	2790	3280
MSc Students	6500	7260	7200
Graduate Courses	121	162	186

Source: L.Bevilacqua, "Science in Brazil", ABC.

About Table 6, which supplies the distribution of CNPq research scholarships in general, and of level I scholarships in particular, it is important to observe that 83% of the research scholarships are allocated to the Southeast Region, a concentration factor that is curiously the same as the one observed worldwide (see the last column of Table 2). However, the division in subareas of knowledge still indicates an excessive weight on civil engineering, certainly due to the historical origins and the fact that the country still demands high investments in infrastructure.

■ TABLE 6

RESEARCH SCHOLARSHIPS FROM CNPq

	Reseach Scholarships	Individual Scholarships
Civil*	33%	31%
Electrical	20%	20%
Metal-Mat	18%	19%
Mechanical	17%	20%
Production	12%	10%
TOTAL	832**	287

Source: CNPq web site. * Civil: sanitary, civil, environmental and transports; Electrical: electrical and biomedical; Mechanical, marine and aerospace mechanical; Metal-Mat: metallurgy, materials, mines and chemistry; Production: production, energy planning. ** CNPq scholarships cover, in general, 20% of the community; the number of researchers in the area of engineering is approximately 4000, a relatively higher number than the one on Table (5). It was not possible to check the consistency of the data.

A hybrid area, which involves aspects related to both technology and the exact sciences, is computer science. It is curious to observe, as Table 7 demonstrates, that in this area, which is more recent and modern, there is a greater tendency to homogenization. Although it is still concentrated in the Southeast Region, which is responsible for about 60% of the academic production, the Northeast and South Regions of the country are responsible for almost 40% of the national production.

■ TABLE 7

COMPUTER SCIENCE INDICATORS

Region	Research	CNPq
Southeast	55%	62%
South	24%	20%
Northeast	14%	17%
Center-West	6%	0.8%
North	1%	0.2%
TOTAL	952	238

Source: Brazilian Society of Computer Sciences

The data from Table 7 strengthen even further the argument that the extreme concentration observed in the traditional areas of engineering is in part due to the historical reasons that have been pointed out. Also, a consistent decentralization policy may produce interesting results for the country as a whole.

SOCIOECONOMIC IMPACT

The socioeconomic impact of engineering unfolds itself in various activities that, for didactic effect, will be concentrated here under three broad titles: infrastructure, import substitution and the country's modernization.

The country's lack of infrastructure is evident and among the various aspects covered by such a broad title, three seemed to deserve special emphasis: Water resources, environment and energy. Although these activities are multidisciplinary in theory, it seems clear that they are very closely related to civil engineering. In the energy issue, in particular, a series of energy alternatives began to the studied in the beginning of the 1970s, among which wind and solar energy; however, these studies were discontinued in the country as the petroleum shock was absorbed. However, in the central countries like the USA and Germany, for instance, research continued and today, products in this area are offered in the market. If Brazil had followed the same policy, maybe today it would be facing a lesser impact from the energy crisis, at least regionally. Even the controversial nuclear energy, which was object, in the middle of the 1970s, of a great technological training effort, was not only stagnated, but also lost part of the training that had been accomplished, since the human resources in the area were dispersed.

The country faces today a disequilibrium in the balance of payments that seems to justify a selective policy of *import substitution*, emphasizing the area of microelectronics. The effort to create national training in this area was also frustrated, since the competence in the country has been stagnant for the last 20 years, which represents in fact, a retrocession in relative terms. In the case of wind and nuclear energy, as well as in the case of microelectronics, the maintenance of basic research activity, even when market conditions are not favorable, is a strategic question that should not be neglected, as it is painfully observed today. Even if there was an abundance of capital, the problems originated from this neglect would not be suddenly solved and the country suffers from this lack of foresight.

Finally, under the title of “modernization of the country” cutting edge activities are included. Such activities are fundamental for the insertion of the country into the most active segment of the economy. Of these activities, the following should be emphasized: information technology, modernization of the industrial area, development of products that aggregate more sophisticated technological content, and an approximation of the biomedical area, which will certainly play a relevant role in the next 10 years.

DEVELOPMENT PERSPECTIVES

The perspectives that are set for the country’s area of engineering have been, up to a certain point, addressed in a general way in the preceding item. However, to explain these measures in detail seems to be a useless exercise, since they are largely dependent on the country’s general setup and not on an act of will or foresight. Thus, we understand that it is more relevant to lay down here some general concepts that may allow a continuous technological development and that may benefit the country as a whole.

First and above all, a complex country, heterogeneous and large such as Brazil shall not belittle itself and be content with a limited and peripheral view of its role, nor launch itself in an irresponsible adventure. It is towards the fine equilibrium between these two conflicting tendencies that we have to move, and in order to attain this equilibrium, it is fundamental to outline an industrial policy for the country. Today we are exposed to a wave of technological penetration without precedent, taking the real risk of becoming simple customers of technology without dominating the knowledge. Such condition would place us forever in the periphery of the world’s economic system. Only with a solid industrial policy we will be able to project a scenario of some stability and hope, and maybe then, attract the enthusiasm of youth, without which we will never overcome the the barriers that have to be faced: the keywords here are “some stability” and a certain optimistic “professional perspective”.

It is evident that an industrial policy involves complex considerations that go much beyond the scope of this document, but the question of technological training is one of the issues of this policy, and it is on this question that we will focus here. Specifically, the fundamental task is to find work opportunities for junior

PhDs, which presently are almost exclusively offered in a saturated university system. Two measures can be suggested in this direction: the first, more focused on the short-term, would be to give incentives to companies that come to install research centers in the country; the second, directed to the medium and long-term, would be to promote an ordered decentralization of the technological apparatus that exists today in the country.

The Rio de Janeiro-São Paulo axis will, from now on, apparently become increasingly specialized in the area of business, and this realization deserves deeper reflection. On one hand, due to the deregulation of broad, technology intensive economic sectors (e.g. telecommunications), there is currently a growing articulation between technological development and the business world. The Rio de Janeiro-São Paulo axis seems to be a privileged location to further this articulation. On the other hand, it is certain that the universities located in these areas will also find themselves challenged to assimilate large contingents of students from the entire social strata, who will demand university education in the next few years. It is possible that this effort may require some of the energy that is dedicated today to research and to graduate education. Thus, it seems correct to geographically expand graduate education and academic research to the country's interior, concentrating them into regional universities, which in turn would induce the rise of technological parks in their surroundings. Thus, it will be possible to preserve, in a relatively protected and stable environment, a necessary distancing from the dynamism of the metropolises, which are forced today to privilege sociopolitical innovation in detriment of intellectual elaboration. Nevertheless, the metropolitan areas will continue to play a fundamental role on conducting the country's technological development efforts, through business and political decisions. The bets will be placed in the big centers, but enlightened by academic and entrepreneurial intelligence centered in the research universities, which will need to distance themselves a little from the noise of the metropolises and megalopolises.

In this sense, it is encouraging, to observe that in the most recent and modern technological activities, such as the computer sciences, there is already a tendency towards a greater decentralization. It is also important to remember that the sectorial funds allocate a significant amount of its resources to be invested in the North and Northeast Regions. However, on behalf of effectiveness, it would be interesting that this decentralization was not unstructured, or in other words, that it was not a "centered decentralization", focused on subjects that would create the possibility of centering thematic[3] training poles. Furthermore, on behalf of common sense, it would be desirable that such decentralization did not constitute another chapter of “creative destruction” and that it would make good use, in a profound and fertile way, of the technological training found today in the country’s economic center.

In spite of the troubled times in which we live, at our current technological stage, we still have objective reasons that indicate that initiative recovery is possible, at least on the academic side. We have a certain technological training that is still lacking in many aspects, but that has been consistently built throughout the last thirty years, and we have today a more stable financing source, based on the sectorial funds. It is only necessary that the government makes the use of these funds less bureaucratic, so that they may truly serve to support research in its most fundamental aspect: the attraction, training and consolidation of human resources. From the academic side, it is important that the use of these funds becomes universalized as fast as possible, so that they do not become restricted to certain sectorial feuds, but in fact aggregate a critical mass originated from all the correlate areas. More than simply being generous with the country, such an attitude will only bring advantages to the sector for which the fund was originally created. Lastly, to reinforce this moderate optimism, there seems to be a more favorable environment in the country today, where a responsible industrial policy is no longer seen, at least by a significant part of the opinion makers, as the quintessence of delay.

We have tried, at least up to this point, to take a panoramic look on some of the conceptual questions that we consider important for technological development, even as we recognize a priori the necessarily restricted character of this exercise. The topics proposed, and many others that are not dealt with here, certainly deserve a much more careful and detailed treatment goes beyond the limitations of this paper. However, we could not end this document without turning our attention to the more mundane aspects of engineering, which could give the eventual reader a more concrete feeling about the area, and that served as stimulation and

3. *The issue of “thematic poles” refers to the idea of “comparative advantages” and, although something in this direction should always be evaluated, we have to observe this idea with some reservation. Just as a provocation, we would like to remind that if the argument of “comparative advantages” was invoked in the mid-1960s, EMBRAER would never have been built.*

orientation in the training of engineers. Once again, the statements that follow are far from exhausting the universe of possibilities; however, we believe that they supply a perception that is now supported by tangible facts and circumstances. Within this context, the following points deserve to be cited.

a) currently, in the central countries the demand for engineers is larger than the supply, which consequently increases the salaries. Countries that used to import an untrained labor force for rudimentary work, are importing today computer technicians (Germany) or engineers. This reversion in relation to the past decade has an impact that is difficult to be evaluated for Brazil; although in theory, it is beneficial for engineering;

b) the complete engineering cycle, with the conception, project and development of a product, will be less and less developed in one single place or country. In spite of that, it is possible, and history confirms, that great engineering products can be developed in the peripheral countries and serve as starting paths towards the center, as long as the absent parts are searched for abroad and that a high level technological transfer is promoted. In the area of civil engineering we have already built Itaipu and the Rio-Niteroi Bridge; EMBRAER itself is an example of this, and the Brazilian space project as well as the nuclear submarine project can also be cited, although the latter had its trajectory interrupted. Of these examples we observe that the final success of the job always depends on a clear vision of the immediate socioeconomic gain of civil society;

c) the immersion into the globalized market will only be possible with cutting edge infrastructure, in order to guarantee the expected production. The sophistication of this equipment demands a contingent of well trained maintenance engineers, originated from all areas of engineering;

d) industrial production demands today, more than ever, adjustments and operations of integrated and automated parts. Besides specific technical training, industrial production demands that the engineer has an integrated vision of the whole, a systemic vision;

e) lately, Engineering has surpassed, in an almost systematic manner, the previously set frontiers of knowledge and defined new menus in this journey. The interdisciplinary areas are more and more important (biomedical, biomechanical, environmental, etc) and ten years from now, we may not be able to recognize some of the areas of engineering in their classic definitions.

BIBLIOGRAPHIC REFERENCES

BARRÉ, R. & Papon, P. (2000), “The state of world science”, Nature Year Book of Science and Tech.

BEVILACQUA, L. (1997), “Science in Brazil”, Brazilian Academy of Sciences.

JOURNAL CITATION REPORTS (1997), Science Edition Social and Science Edition.

Site CNPq: www.cnpq.br

AUTHORS

José Augusto Penteado Aranha *(Coordinator)*

Member of the Brazilian Academy of Sciences (ABC); PhD from the Massachussetts Institute of Technology (MIT) and Professor at the University of São Paulo (USP).

Hans Ingo Weber

PhD in Engineering from Technische Universität München (Germany); and Professor at the Pontifícia Universidade Católica do Rio de Janeiro (PUC-Rio) and at the University of Campinas (UNICAMP).

Hélio Waldman

PhD in Electric Engineering from Stanford University (California, USA); and Professor at the University of Campinas (Unicamp).

Luiz Fernando Soares

PhD in Computer Sciences from the Pontifícia Universidade Católica do Rio de Janeiro (PUC-Rio); and Professor of Computer Sciences at the same University.

Area of Physical Sciences
Physics in Brazil: present and future

CARLOS ALBERTO ARAGÃO DE CARVALHO FILHO
ALAOR SILVÉRIO CHAVES
HUMBERTO SIQUEIRA BRANDI
LUIZ NUNES DE OLIVEIRA
MARCUS VENICIUS COUGO PINTO
PAULO MURILO CASTRO DE OLIVEIRA
SÉRGIO MACHADO REZENDE

In this document, we present the evolution, the research areas and the socioeconomic impact of physics in the world. We also analyze its current stage of development and its future perspectives in Brazil.

THE EVOLUTION OF PHYSICS

Physics is an experimental science, whose language is mathematics.
Galileo Galilei

Physics is the science that investigates the universe through the study of its components and of the natural phenomena that result from the interactions among them. It describes them in mathematical language and tries to infer general laws whose correlation can lead to physical theories. Those theories are translated into mathematical models which, besides describing and explaining nature, allow the prediction of experiment results, of new phenomena, and even of new components of the universe.

Phenomenology, the systematic description of phenomena, makes use of careful measurements, obtained from observations and from performing experiments, whose mathematical modeling aims at the induction of physical laws. As the ultimate objective, the laws should be included in a general theory that, through mathematical calculations, will lead to predictions to be tested by experiments and observations. Experimental proof is the only validity criterion of the physical theories. Therefore, experiment takes part in the construction of physical theories at both ends: as its source of inspiration, and as its final test.

The study of our solar system is a good illustration of the scheme outlined in the previous paragraph, known today as the modern scientific method, whose paternity is attributed to the physicist Galileo. Countless astronomical observations, specially those of Tycho Brahe, allowed scientists to systematize data, to describe them in mathematical language, and to infer phenomenological laws, such as the one of Johann Kepler. These were incorporated in the “Classical Theory of Mechanics and Gravitation” by Isaac Newton, who used integral and differential calculus in order to accurately obtain planetary orbits and to explain Kepler’s phenomenological laws.

Later on, his theory led to the prediction of the existence of Neptune, which was necessary to explain anomalies in the orbit of Uranus, and of Pluto, this time based on anomalies in the orbit of Neptune itself.

In physics, as in the movies, scripts are not always followed as planned. There are historical examples of skipping stages in which a theory emerged from pure physical intuition linked to the right mathematical choices. In some cases, phenomenology was by-passed, fundamental laws were postulated, and the theory that emerged from them was experimentally tested with success. Mathematical generalizations, dictated by intuition or even by an aesthetic sense, generated theories whose laws and phenomenology were obtained and tested *a posteriori*. Whichever the creation process, physical theories are linked to mathematical disciplines, experimental techniques, instrumentation, and in the longer term, which is being shortened every day, to technological advances.

The bases of what we call today classical physics were established between the XVII and XIX centuries. Theories like mechanics, electromagnetism, thermodynamics, dynamics of fluids and statistical mechanics made use of calculus, vector analysis and of differential equations in their mathematical development, while a great variety of instruments and experimental techniques were created to investigate the phenomena, and to identify the agents of classical physics. The industrial revolution of the XIX century, with the spread of the steam engines, emerged from progress in thermodynamics; similarly, the progress in electromagnetism, besides leading to the unification of the electric and magnetic phenomena through Maxwell's equations, revolutionized the areas of energy and communications as it introduced the electric light and, already in the XX century, the wireless telegraph, the radio and the television. At the end of the XIX century, the accomplishments of classical physics in the description of the phenomenology known at that time gave the sensation that we had already attained the essential to describe nature. However, that sensation succumbed before several results that contradicted classical physics, such as the verification that the classical model of the atom predicted its instability.

Right in the beginning of the XX century, two theories emerged that would revolutionize the world: Quantum Mechanics, whose origin was a phenomenological law proposed by Planck, in 1900, to explain the electromagnetic radiation of warm bodies, named blackbody radiation, and whose theoretical formulation was developed throughout the first 30 years of the century, on the basis of a wide range of phenomena precisely investigated by Einstein, Bohr, Schrödinger, Heisenberg, Pauli, and Dirac, among others; and Einstein's theory of relativity, special relativity, in 1905, and general relativity, in 1915. It can be said that the Physics of the XX century was built upon the foundations of these two theories, plus a great number of revolutionary experimental discoveries, such as superconductivity, in 1911, and electronic conductivity in semiconductors, in the 1940's.

Based on those foundations, physics followed two routes that were frequently interlaced: inclusion, which tried to embrace the largest possible number of phenomena; and synthesis, which sought to unify its theories in order to possibly arrive at a unified theory of interactions, a dream that was not accomplished by Einstein. To follow those two paths, it was necessary to sweep through different energy scales, from submultiples of the electron-volt (eV) to Planck's energy, of 10^{19} GeV.

Quantum mechanics was originally used to describe phenomena of atomic physics, and obtained results of great impact such as the calculation of the hydrogen spectrum. Its applications were soon extended to lower energies, including molecular physics, as well as that of groups of atoms and molecules, the solids and fluids, whose study constitutes today the physics of condensed matter. Its extension to submultiples of the electron-volt took it to multidisciplinary regions, arriving at physical chemistry and biological physics, diversifying its methods to deal with complex systems. On the other hand, its extension to higher energies, going from the atomic keV up to the MeV that are characteristic of nuclear physics, demanded a synthesis with special relativity in order to deal with subatomic particles of relativistic energies. That synthesis gave rise to quantum field theory, whose genesis goes back to the pioneering work of Dirac. That theory, after experimental discoveries of impact, such as the existence of the positron, antiparticle of the electron, and of the anomaly in the spectral lines of hydrogen, the Lamb shift, quickly developed to become the basis of the current standard model of elementary particle physics.

General relativity was soon applied to cosmology. The classical description of Einstein's theory led to the study of the evolution of the universe to the point where a new synthesis was made necessary: this time to study the "nucleosynthesis" initiated with the formation of the lightest nuclei, like H^2, He^3, He^4 and Li^7, starting from hydrogen. The further back one moved in cosmological time, the need to include phenomena in increasingly higher energies imposed new syntheses. Almost as by-product of that, there emerged particle astrophysics, incorporating subatomic particles and quantum descriptions to the classical methods of the astrophysics of the preceding centuries.

As for experimental discoveries, many preceded the theory that explained them, while others followed the theory that predicted them. So, superconductivity, superfluidity, the quantum Hall effect, integer and fractional, and many other examples in condensed matter physics appeared before their corresponding theory was known. The same happened with the discovery of the great majority of the subatomic particles, classified today as hadrons and leptons, and to the identification of the quarks as being the building blocks of hadrons. On the other hand, several theoretically predicted particles were detected in experiments involving accelerators, the same happening with the universe's background radiation, with a temperature of 2.73 Kelvin, whose spectrum is described with the precision of the measurements by Planck's law of blackbody radiation, which marked the birth of quantum mechanics.

The evolution of observations, experiments and theories through the paths of inclusion and synthesis during the century led to a description of the physical world that can be subdivided as in the list that appears in the recent publication of the "American Physical Society", commemorative of the physics of the turning of the millennium and of the centennial of that society: physics of particles and fields; astrophysics; nuclear physics; atomic, molecular and optical physics; condensed matter physics, statistical physics; physics of complex systems; plasma physics; physical chemistry and biological physics; computational physics; and applied physics.

THE RESEARCH AREAS

Science is made of facts, as a house is made of stones;
but an accumulation of facts is not a science,
in the same way that a pile of stones is not a house.
Henri Poincaré

The physics of particles and fields is responsible for the current standard model that describes the strong and electroweak interactions, typical of subatomic phenomena. In that model, all the matter already observed is made up of particles denominated quarks and leptons, which interact through gluons, in the strong interactions, or through intermediate bosons and photons, in the electroweak interactions. Quarks and leptons are subject to the "Pauli exclusion principle", which states that two of these identical particles cannot occupy the same quantum state; they are called fermions in order to be distinguished from the bosons that intermediate the interactions, like the gluons, the photons and the intermediate bosons of the weak interactions: W+, W - and Z°. Those bosons evade Pauli's principle, and can be interpreted as radiation "quanta". There is another boson, the Higgs boson, postulated by the model to generate masses, which has not yet been detected, and is the object of intense experimental search. The phenomenology of the standard model is an area of great research activity that aims at calculating the physical processes that are being studied, or that will be studied, in several experiments. The experimental part of the physics of particles and fields is done with the great particle accelerators of laboratories like CERN, in Europe, Fermilab and Brookhaven, in the United States, among others; furthermore, the physics of cosmic rays has been increasingly used in the observational part, allowing access to energies that are unattainable in the laboratories, like the ones involved in the Auger project (10^{20} eV). The theoretical part involves the use of sophisticated mathematics: quantum field theories, which include nonabelian gauge theories and constitute the formal basis of the standard model, which uses results from group theory, differential geometry, topology, and functional analysis. Supersymmetric extensions of the standard model allow the transformation of fermions into bosons, and predict the existence of supersymmetric partners for all of the particles already detected, whose search will be a great experimental challenge in times to come. Finally, superstring theories, which seem to have as their backbone the so called M-theory, try to unify the interactions of the standard model with gravitation, and require mathematics even beyond the frontiers already formalized by the mathematicians.

Astrophysics includes cosmology, the true chronicle of our universe, and astronomy, its phenomenological basis, with its observational data obtained through the use of telescopes, atmospheric balloons, and satellites connected to cutting edge optics and electronics. Here, astronomy and cosmic ray physics bring information on the history of the universe. The initial page of this chronicle tells of Erwin Hubble's experimental discovery in 1929 that the galaxies are distancing themselves from us as if the universe were in an expansion process. Today, there is unquestionable evidence that the universe expands and cools down, apparently starting from a great initial explosion, the "Big Bang", an evolution that cosmology describes in its "standard cosmological model"; exotic objects like black holes are being sought; physicists try to find the dark matter that will account for the mass needed in order to explain the universe in the terms of the standard cosmological model; the subtle gravitational radiation is being investigated; the microwaves of background radiation have been studied in order to extract from them, among other things, information about the formation process of about 50 billion galaxies that populate the firmament. Beyond the standard cosmological model, the so-called inflationary models are the object of much theoretical investigation: they should be refined, and possibly modified, with the emergence of new observational data.

Today's nuclear physics benefits from the existence of a theory of strong interactions, "quantum chromodynamics", as well as from modern cosmology, to investigate possible phase transitions that happened throughout the history of the universe, which resulted in the formation of hadrons, composed of quarks, and later, of light nuclei. There are current experiments, and projects of future experiment, in Brookhaven and at CERN, to try to replicate and understand this "hadronization". Accelerators of various energy ranges continue the study of nuclear phenomena. The data gathered are often treated through phenomenological models, as the hydrodynamic ones, due to the difficulty of relating them directly to the more fundamental underlying theory. These "effective models" and their consequences are studied at length, and they bridge the gap between theory and phenomenology.

Atomic and molecular physics, as well as optics, have gone through a great revolution with the discovery of the laser, intense and monochromatic radiation originated from cooperative effects in atomic transitions. In those areas, predictions of quantum mechanics and, currently, of quantum electrodynamics – the quantum field theory that describes the interaction between electrons and photons – are tested with an accuracy of one part in 10^8 or even in 10^{12}, thanks to the laser, to the production of atomic and molecular beams, and techniques for trapping atoms and molecules in cavities. The study of the interaction between radiation and matter is the emphasis of those areas, where spectroscopy, manipulation of atoms and molecules, photo-interaction, and atomic collisions are commonly used methods. In the cutting edge of the research, there is an attempt to use quantum processes to transmit information, which has already led to the dissemination of the term "quantum information". There is enormous current activity, both theoretical and experimental, in bosonic condensates obtained from quantum phase transitions that occur at low temperatures, the so called "Bose-Einstein condensates".

Condensed matter physics is one example where, traditionally, theory followed experiment. There are countless phenomena discovered and investigated, which involve atomic and molecular clusters, structured in solids and fluids, herein included polymers, glasses, and amorphous alloys. Conformational structure, as well as electrical, magnetic, optical, mechanical, and thermal properties of these clusters have been measured and calculated with increasing accuracy. The experimental techniques include sophisticated electronics, cryogenics and optics. The experimental investigation of the materials according to the principles of quantum mechanics led to the understanding of the physics that governs semiconductors, superconductors, superfluids and, more recently, other quantum fluids, such as the quantum Hall fluid. The study of strongly correlated systems, of superconductivity at high temperatures, of superfluidity, and of quantum liquids occupies great part of the experimental and theoretical work. The experimental techniques for growing heterostructures, developed in the study of semiconductors, allowed the manufacture and study of idealized systems, known today as quantum points, wires and wells. That development gave rise, at the end of the last decade, to an explosive growth of research on nanoscopic semiconductors and magnetic structures aimed at building electronic devices. As we shall see, this is an area of great interface with the industrial sector.

Statistical physics made use of the examples from atomic and molecular physics, from optics, and from condensed matter physics to formulate a general statistical treatment, applicable to systems with a large number of degrees of freedom. This treatment gave rise to the theory of phase transitions, phenomenologically inspired, based on the largely comprehensive “renormalization group”. The development of statistical physics in the last three decades led to the discovery and elucidation of some very interesting and closely related phenomena. The beginning of this process was the recognition that close to a phase transition, systems lose their characteristic reference scales in both time and distance. Therefore, such systems are linked by self-similarity relations, called “scaling laws”, to their own reduced or enlarged replicas. Such self-similarity relations are the basis of the previously mentioned renormalization group theory for phase transitions. A consequence of the loss of characteristic scales is the emergence of the universality phenomenon: the behavior of the system only depends on its symmetries and some qualitative properties, and no longer on its quantitative details.

The physics of complex systems makes use of the already mentioned universality to study similar phenomena, recognized in many systems out of the equilibrium, including the systems denominated as super-cold, those unable to break the energy barriers that separate them from the state of equilibrium. A term was coined to describe systems that are self-similar to their reduced or enlarged replicas: they are denominated “fractal”. Fractal behavior was also recognized in the fluctuations of statistical variables, and in this case, such variables no longer obey the famous statistics of Gauss, but instead, they obey the so called statistics of Lévy. In particular, climatic variations, fluctuations in the stock market, and other economic and social variables exhibit this kind of fractal behavior. All of these discoveries and developments have implications in several areas of physics, from hydrodynamics to cosmology, and also in many other sciences. That is one of the most eloquent examples of recent developments in physics with broad interdisciplinary applications. A fortunate consequence of the universality phenomenon is the possibility to make a computer simulation of a complex system through a simplified model that can unravel the behavior of the complex system if both belong to the same universality class.

The interdisciplinary approach is also the emphasis of physical chemistry and of biological physics, both with great recent progress. The experimental and theoretical techniques of physics have been used in chemistry and in biology with considerable success, stimulating a mutual fertilization with those sciences. Spectroscopy, various scattering techniques, and the handling of microorganisms with lasers are prominent current examples.

Plasma physics is dedicated to the study of fluids made up of charged particles, whether they are electrons or ions. In particular, ions confined by intense magnetic fields, and submitted to high temperatures and pressures are the object of intense investigation, aiming at the understanding of physical processes, as well as at future technological applications such as nuclear fusion. The study of plasmas is also applied to intergalactic space, and to the plasmas that occur in stars.

Finally, computational physics and mathematical physics benefit from progress in each one of the previous areas, systematizing calculational techniques, which are increasingly linked to high performance computing, and formalizing the mathematical techniques that are incorporated into the physics arsenal.

THE SOCIOECONOMIC IMPACT

The peoples without science are nothing more than lumberjacks and carriers of water for the most enlightened peoples.
Sir Ernest Rutherford

Besides generating knowledge and forming highly qualified human resources, all of the areas previously described served to stimulate technological advances of great socioeconomic importance, which contributed to dramatically change the world - not even the most imaginative minds would be capable of predicting the impact of the several areas of physics in the XX century.

We have already mentioned that the energy issue underwent great transformations due to the popularization of electrical power, starting at the end of the XIX century. In the XX century, the nuclear area introduced a new source of energy from the fission of atoms, achieved in a controlled manner in nuclear reactors. Research on solar and fuel cells, which is connected to the study of materials, as well as the quest of plasma physics to achieve controlled nuclear fusion, represent alternative paths of extreme importance in the beginning of the millennium. The current environmental implications of the excessive use of fossil fuels, and the future exhaustion of these sources point to physics as the natural discipline to find alternative solutions to the energy problem, of such great relevance to humanity.

Telecommunications went through a true revolution in the XX century. To the telegraph, the radio, and the television were added: semiconductors, which led to the transistors that replaced valves; integrated circuits and microprocessors, which are responsible for the miniaturization of computers, and several other devices; laser and fiber optics, which enormously increased the fidelity and the speed of information transmission. Thanks to that, communications today use satellites and telephony based on fiber optics for data transmission at speeds and amounts never seen before, causing deep changes in the economic, political and social relationships.

Computing experienced exponential growth with the semiconductors, and all the research in materials. Today, the development of optical computers, with light replacing electrons, is already being discussed, as well as quantum computing. In the latter, quantum mechanics would be the paradigm for the storage and manipulation of information, with the current “bits” giving way to “quantum-bits.”

Microelectronics, optoelectronics and materials science, coupled to the study of magnetism, are responsible for an increasingly large number of devices that are the components of most industrial equipment, as well as of the appliances of every day use in society. A typical home of the new millennium has electrical power, refrigerators, freezers, microwave ovens, photoelectric sensors, CD and DVD players, recorders, and computers – all attesting that the laws of physics supply us with the key to make use of nature as an ally in the improvement of living conditions. This improvement will be even more notable with the advent of nanotechnology, an area of great current activity, where the basic components have the dimensions of the atom.

The impact of physics has also been enormous in medicine. From X-rays, to ultrasound, Doppler echocardiography, tomography through magnetic resonance, and surgical techniques that use lasers, safer means to investigate the human body with much less invasive and more reliable methods are available today. There are also methods developed by physicists in biotechnology, which are relevant, for instance, to genome sequencing. In the several sectors of the civil, naval and aeronautical construction industry, the study of materials acquired crucial importance. Petroleum geophysics, soil geophysics, space geophysics, and climatology are other areas in which physics, and physicists, have had social and economic impact. The introduction of experimental techniques and instruments originated from physics in the industrial sector has become a significant agent of transformation, shortening the distance between basic and applied research, and technological research.

Physics, with its scientific method, became a paradigm for all the natural sciences, and was at the origin of the technological revolution of the end of the XX century. The political and socioeconomic importance of science received universal recognition in the XX century. In the industrialized countries, physicists were called to participate in governmental committees where policies were drawn for the whole of society, due to the impact of their science on the life of the planet. There is no way to deny that nuclear power, electronic war, the hardware of the information society, and other physics related aspects of the world's geopolitics clearly reflect this impact .

Such a rich science, whose mission is so intimately linked to the saga of humanity to learn about its surrounding world, begins the millennium believing to know how to tell the history of the universe from 10^{-43}s to its current age, estimated in 15 x 10^9 years (~10^{17}s), a history that involves at least 50 billion galaxies distributed in gigantic filaments that alternate with immense emptiness. From the megaparsecs of astrophysics, to the 10^{-17}cm investigated by particle accelerators, physics observes, detects, and measures with increasing accuracy, daringly theorizes, to the point of opening up new areas in mathematics, and ventures towards increasingly complex systems, fully adopting the multidisciplinary approach that will probably be the trade mark of the new millennium.

PHYSICS IN BRAZIL

The difficulties were anticipated to him, but he believed in his power to overcome them.
Gilberto Amado

Brazil counts today with more than 6,000 physicists (2,500 PhDs), of which approximately 46% are experimental, and 54% are theoretical, distributed throughout all areas of research, according to the table below:

■ **TABLE 1**

Physicists / Areas	Experimental %	Theoretical %
Particles and fields	2,6	10,4
Astrophysics	4,5	7,7
Nuclear	2,7	3,6
Atomic and molecular	3,4	4,7
Condensed matter and optics	30,0	19,2
Plasma	0,8	1,2
Biophysics	1,0	1,0
Statistical and Computational	-----	7,2

The table reveals distortions: there is a clear unbalance among the areas, and a smaller percentage of experimental physicists from what is observed in industrialized countries (70-75%), especially in the area of particles and fields.

Another aspect to consider is the geographical distribution of Brazilian physicists. There is a strong concentration in the Southeast Region, especially in the State of São Paulo, where 50% of the physicists of the country are to be found. The prominence of physics in the State of São Paulo within the national scenario is attributed to the amount and regularity of the investment in research and in the training of human resources provided by FAPESP.

For the sake of comparison, in the United States there are about 40,000 PhDs in Physics, distributed in significant numbers through all research areas, and 75% of these professionals are experimental. Different from Brazil, where 98% of the physicists worked in universities and research centers in 1993, only 25% of the American physicists work in the academic sector, while the remainder works in the industrial sector, in areas that range from high technology industry to the financial sector. The intense use of physicists in industry in developed countries is intimately associated to the larger proportion of experimental physicists observed there.

The 6,000 Brazilian physicists work as professors and researchers in about 60 education and research institutions, which are mostly federal. Most of them belongs to the Brazilian Physical Society (SBF), which is responsible for the organization of five National Meetings per year, in the following areas: condensed matter physics, nuclear physics; physics of particles and fields, plasma physics, and physics education. The meeting on condensed matter physics includes atomic and molecular physics, optics, and statistical and computational physics. The meeting on particles and fields includes cosmology, gravitation and mathematical physics. The meetings gather researchers and graduate students. The one on physics education also gathers secondary education physics teachers. In the last four years, the numbers of participants have been, on average: one thousand in condensed matter; 200 in nuclear; 300 in particles and fields; 150 in plasma; and one thousand in physics education. The Brazilian physicists also participate in two other national scientific entities: the Brazilian Academy of Sciences (ABC), and the Brazilian Society for the Advacement of Science (SBPC), which are dedicated to all the sciences. There are 4 national periodicals for the publication of research papers in physics: 3 are edited by SBF – Brazilian Journal of Physics, *Revista de Física Aplicada e Instrumentação*, and the *Revista Brasileira de Ensino de Física* - and one edited by the ABC, the Annals of the Brazilian Academy of Sciences, which also include the other sciences.

In the academic sector, the productivity of physicists is evaluated through their performance in research and teaching. Research productivity is measured in publications in periodicals of international circulation. Books and publications in conference proceedings are also used in the evaluations, which are considered reliable when made by peers of recognized competence. In spite of being much more common in the industrial sector, patents are also considered as an indicator of productivity in the academic field. In the case of education, the contribution of physicists includes the training of scientists and engineers of various specialities.

The research productivity of the Brazilian physicists can be appraised in different ways as, for instance, by the number of publications in the "Physical Review" and "Physical Review Letters", which are periodicals of international prestige of the "American Physical Society". In 1995, 1996 and 1997, the number of Brazilian papers published in these periodicals reached 170, 210 and 250, respectively, an increase of 45% within that period; however, while the American production in the same period represented 35% of the total, the Brazilian corresponded to only 1.5%. This percentage could certainly increase with an increase in the number of physicists in Brazil, since the per capita production of 0.1 article of the American physicists in that group of periodicals is equal to the one of their Brazilian colleagues. If we also include the publications of Brazilian physicists in all the periodicals indexed in the "Science Citation Index", we will have in 1995, 1996 and 1997, respectively, 924, 1,163 and 1,298 articles, which represents an increase of 40% within that period. Finally, if we concentrate on the publications in the "Physical Review Letters", a periodical aimed at publishing impact results, worthy of fast dissemination, the Brazilian articles jumped from 2 in 1977, to 43 in 1998, a much larger increase than the 45% experienced in the group of publications of the APS, which seems to favor quality over quantity.

The research performance of Brazilian physics raised it to a level of maturity that places it in the leading position of the national scientific scenario. Next to the biomedical sciences, it shows the largest impact indexes of the country: the number of citations per article in physics has been between 2 and 3, in the last 20 years, a respectable number according to international standards. This maturity can be attested by some data from São Paulo: while the numbers of scientific initiation, masters and doctorate scholarships of FAPESP seem to have reached a stationary point in Physics, post-doctorate scholarships have been increasing, and represent 25% of the total. Also in the "temáticos" (projects focused on specific themes) of FAPESP, projects that require good scientific articulation, physics plays a prominent role: of the 21 "temáticos" of 1994, 4 are from physics (three million reais of the 17 million available), while in 1999, that number went to 10 of the 65 "temáticos" (5.3 million of the 55.7 million available). The same prominence can be verified in the requests for grants in competitive projects, such as the one created to recover research infrastructure. Nationally, the scenario is not different, as the PRONEX (Program of Centers of Excellence) results make evident: of the 55 projects in the area of exact and earth sciences, 2 are in astrophysics, and 29 are in physics; among these, 18 are experimental, and 11 are theoretical, and they are distributed among practically all of the research areas previously listed.

Paradoxically, in spite of physics being responsible for about 30% of all the scientific production in the country, its number of research productivity scholarships from CNPq has been kept below 10% of the total number of scholarships, which makes the areas of physics and astronomy the most competitive and rigorous in their concession criteria: the 637 physicists and astrophysicists with research productivity scholarships have curricula and scientific production of verified international standards, but the same can be said about many who do not hold scholarships, an indication of excessive and inhibiting rigor. This reflects a tendency that must be corrected: the research productivity scholarship program of CNPq, which initially introduced a quality differential in universities and research centers, and served as an incentive to scientific production, is not being capable, due to a lack of expansion, of including competent researchers that would deserve to participate. The lack of investment in the expansion of the program has been inhibiting the creativity of researchers - a great number of them stay away from more involved projects, that could require more time to be published - and creating a negative and unjust stigma for many that were kept out of the scholarship system. It is important to notice that the cost-benefit relationship of this expansion is very good, because nowadays the program requires only about R$ 90 million, and it is one of the main factors responsible for the notable increase in the national scientific production since its creation.

The maturity and the quality of Brazilian physics explain its increasing insertion into large international projects such as Gemini, Soar and ESO, in astrophysics; the Auger project, and the several collaborations with CERN, Fermilab and Brookhaven, in the nuclear area and in the area of particles and fields. Furthermore, it justifies its outgoing attitude in taking part in large experimental projects in the country, such as the one that seeks to detect gravitational waves. Furthermore, physicists have been participating more and more in multidisciplinary projects, many times leading large national collaborations, as in the case of the National Laboratory of Synchrotron Light (LNLS), almost totally built in Brazil, which together with the National Laboratory of Astronomy (LNA) is one of the first examples of laboratories shared by groups from all around the country and Latin America. Other important examples are: the Internet, created by the physicists at CERN, whose implementation in Brazil counted with the decisive participation of the Brazilian physicists, the same being valid for other very useful multidisciplinary instruments, such as the "Web of Science".

It is equally important to evaluate the productivity of the Brazilian physicists in education, in other words, in the training of human resources for science and technology in Brazil. They participate every year, through teaching the so-called service disciplines, in the training of thousands of scientists (mathematicians, chemists, geologists, biologists, etc.) and engineers, besides being responsible for the training of new physicists. In the case of the latter, it is worrisome that, in 1999, 655 students were trained in the discipline, which represents only 5.8% of the 11,184 enrollments in physics courses. This number is yet another example of the "exclusion funnel" of Brazilian education: in 1998, 20% of the students enrolled in elementary education passed to secondary education, of which 30% enrolled in college; among these, 12% concluded their training, while in graduate school only 6% of those enrolled finished the course. In spite of that exclusion, in 1998 there were 1,600 graduate students in physics, which amounts to an increase of almost 100% in the number of graduate students over the ten previous years. In the same period, the number of PhDs in physics in Brazil went from 600 to 2,400; therefore, it quadrupled. Within the period from 1970 to 1998, the number of PhDs in physics in Brazil increased by a factor of 12. This amazing factor confirms the remarkable capacity to respond to investments in physics, in spite of their being irregular and parsimonious as percentages of the GDP. Actually, this capacity to respond exceeds the most optimistic expectations, as the study done in 1992 by physicist Sergio Machado Rezende, of UFPE, demonstrates: in that study, a linear extrapolation of the number of PhDs in physics projected an increase of 100% until 2006; besides that, another estimate, considered optimistic by the author, projected an increase of 160%; the number of PhDs today indicates that even the most optimistic prognostic for 2006 will be surpassed. Initiatives like the one from SBF, which has been organizing physics olympics for secondary education students, will certainly contribute to increase even further our number of PhDs.

In education, as in research, a strong concentration can be noticed in São Paulo. The physics from São Paulo is responsible for 53% of the 436 PhDs trained from 1996 to 1998, while the federal universities contributed with 29%, and the remaining with 18%. As for masters, of the 730 trained in the same period, 42% were trained in universities from São Paulo, 47% in federal universities, and 11% in the remaining institutions. Once again, the productivity follows inexorably the amount and the regularity of the financing in physics in the country. Also, it should not come as a surprise that the ratio between the number of experimental and theoretical physicists in the State of São Paulo is larger than the Brazilian average, and closer to the American.

With regards to the socioeconomic relevance of Brazilian physics, it is important to emphasize its role in the training of scientists and engineers, and its importance to any profession of technological nature. The scientific basis that is taught to physics students becomes more and more necessary in a technological society, and its improvement is now viewed by several professions as imperative. As for the direct impact of Brazilian physics in the generation of technologies, and of new products and services, the situation is very different from what happens in the industrialized countries. Only in a few cases, it is possible to identify examples of physics applications in the industrial sector: in São Carlos and Campinas, the optoelectronic industry established successful companies thanks to groups of physicists from the local universities. There are six companies in optics in São Carlos, with annual revenues of US$ 40 million, which stand out in the international market. In Campinas, the number is even larger; besides, groups from UNICAMP have partnerships with the telecommunications industry in fiber optics, lasers and amplifiers, and the LNLS generated a demand for companies of technological basis, as it happens with large laboratories in the United States, Europe and Japan. The efforts in the area of tomography through magnetic resonance are worthy of note: in São Carlos, the tomograph built at USP already serves the local hospital; in Recife, there is a similar project; with the medical physics courses that are being created, such as the one at UFRJ, such efforts will acquire more visibility, and power of attraction. There are also jobs in physics dedicated to pollution monitoring. In the Directory of the CNPq Research Groups, there are records of physicists active in areas such as: environmental aspects, new materials, computer science, electro-electronic industry, telecommunications, space research, energy, meteorology and climatology, and even in nutrition.

There are efforts from FAPESP to increase the participation of scientists in industry through programs to promote the hiring of PhDs by companies, through special financial credit lines to small and medium companies of technological basis, and through incentives to the creation of incubators of companies, and technological parks. Other state foundations, such as FAPERJ, have been making similar efforts, in smaller scale. As a result, among the 16 patents registered through FAPESP in

2000, three belonged to physicists, and it is estimated that the physicists represent 10% of the participants in their projects for small companies. In spite of that, the number of examples of physics applied to technology is a lot smaller than what the community of physicists could produce, if there were an industrial policy in the country focused on that objective. Along with the success cases mentioned, there were also experiments that did not achieve their potential, such as the one in microelectronics, not due to the lack of scientific and technological competence, but due to the lack of a well articulated policy to face foreign companies interested in eliminating the competition at any cost, a practice that is well illustrated by the Canadian competitor of EMBRAER in a recent incident. In areas like semiconductors, crucial for integrated circuits, there is very little applied physics in the country, in spite of the existence of some sophisticated machines for crystal growth (MBE's); in magnetism the scenario is the same, the sum of these two deficiencies contributing to compromise the Brazilian chances of taking part in the adventure of nanotechnology; in plasmas, we are just crawling. There is a lot of scientific and technological competence installed in the country, and it is necessary to put it to the service of society as soon as possible.

The system where the Brazilian physicists develop their activities is made up mainly of universities and research centers which interact with several other elements. First of all, the several units of physics of the universities are filled by students from the secondary education system. The training of these students, the research, the university administration, and the extension activities are the physicist's tasks in the universities. Research centers out of the universities also accomplish some of these tasks. For all these activities, the system counts with financial endowments originated from several governmental financial organizations: FINEP and CNPq, of MCT; CAPES, of MEC; and several state foundations that support research (FAP's). Private institutions also count with financial resources from their students' monthly fees. The activities of the system also benefit from the support given by several scientific societies: ABC, SBPC, SBF, etc. The system trains new physicists that, in their majority, return to it, hired as professors and researchers. Only about 2% of the physicists go to the country's industrial and service sectors. This small percentage is due to the absence of an industrial policy that aims at conquering market shares that are dominated today by foreign companies, and to the naïve faith that the industrialized countries will export cutting edge technology that will make us competitive. The system has an indirect influence in the market through those in it who have received training in physics in the university system: engineers, chemists, geologists, and other professionals that, in their training, studied physics as a service discipline. Finally, the system of activities in physics interacts with other university and scientific systems in Brazil and worldwide. It is important to notice that the system increases at an annual rate of 7%, while the Brazilian population grows 1.8% a year; and that it is responsible for about 1.5% of the publications in the "Physical Review", while the country's GDP is 1% of the world's total GDP.

PERSPECTIVES FOR BRAZILIAN PHYSICS

... wanting to take advantage in it, everything will spring from it...
Pero Vaz de Caminha

In evaluating the perspectives for development in the next ten years, we will not make forecasts about which of the areas and subareas, among the ones that have been considered, are more or less promising. That is because all of them already went through the evaluation sieves of decades, or even centuries and, mainly, because they form a minimum structure, in which the parts are mutually influenced and favored. Experience shows that the attempt of doing good physics in just one area, in detriment of the others, does not yield success. The eventual emphasis in some area should be examined at each moment on a case by case basis. Experience also shows the failure of trying to develop cutting edge technologies without the parallel development of a scientific basis.

In the last few years, the Brazilian physicists have tried to match their academic activities with the production standards of the best physics in the world. They concentrated on the publication of scientific articles in the best periodicals worldwide, on the training of MScs and PhDs in our country, and on assimilating techniques of experimental and theoretical physics from the most developed countries. This stage was successfully accomplished, after an amazingly fast evolution. It is enough to remember that the extremely modest number of 200 PhDs in physics that we had in 1970 was multiplied by 12 by 1998, or that in a period of three years, from 1995 to 1997, the number of publications in what is considered today the most influential group of periodicals in the world increased by 45%. Now, it is important to ask in what area of physics are we recognized as a world reference, or which one of the Brazilian periodicals in physics is globally known, read, and considered prestigious, or still, which technology sustained by our physics makes us unbeatable in the international market. With those questions in mind, we can outline two perspectives of development for Brazilian physics in the next ten years.

The first perspective would be of a development in the molds of the previous years. If the financing of Brazilian physics returns to the best moments of the last 40 years, we can predict that within this perspective we will be publishing more and better articles in periodicals of international prestige, we will be training PhDs in larger numbers and quality, and our physics will control more techniques that were created some time ago by the most advanced countries. If we base ourselves in examples of other countries, we can foresee that evolution tending to stagnation, maybe not in the next ten years, but not much later than that.

The second perspective would be a consequence of planning a leap of quality for our physics in next decade. We can maintain our academic training in publishing and contributing with competence to the physics generated at the central countries and, at the same time, we can venture into generating a more independent physics, of globally recognized excellence and originality, and of positive socioeconomic impact in our nation. If we take the number and the quality of the production of our experimental and theoretical physics community in, for instance, Condensed matter, we can affirm that we are ready to accomplish a leap of quality in Brazilian physics. In order to accomplish that, there must be an increase and a regularity in the investments in physics, and the planning of our physics for the next ten years should be followed by policies focused on education, technology-industry, and on more aggressive market competition.

On the question of educational policy, first we have the problem of attracting young talents to physics. Up to this moment, our attitude before the great number of youths in Brazil with immense talent for physics, who certainly exist, has generally been one of collecting the survivors from the process of educational exclusion, and not one of cultivating the talents that are still in the seed. If the largest revolution in the history of humanity was the passage from the system of hunting and collecting to the farming system, maybe the largest productivity leap in Brazilian physics will happen when we are able to train young talents for physics while they are still in their secondary education. This new attitude implies stimulating the creation of a physics literature in our language, in the most varied levels of specialization and depth: ranging from books of scientific popularization, to textbooks for secondary and college education. An effort to improve the physicists' wages is imperative, because, as experience shows, we know that many young talents that could become good Brazilian physicists seek other professions, since there is a real perspective that the long and arduous training demanded by physics will end up leading to a profession with insufficient pay for its full time practice. The perspective that a good number of young talents will sacrifice the possibility to constitute a family, and to lead a reasonably safe and comfortable life to dedicate themselves to physics is too romantic, to say least.

The educational question is closely related to the technological and industrial questions. Brazilian physics trained, between 1996 and 1998, an average of 140 to 150 PhDs per year. The academic sector, made up of universities and research centers, has about 3,000 placements for physicists; that means that in order to replace the retirees, we would have to introduce something of the order of one hundred physicists per year into the academic sector. However, for some time there have not been any openings in the federal universities, which are responsible for the majority of the placements. Even if this happened, we would have a surplus of at least 50 physicists per year to be assimilated by the industrial sector, whether as physicists or working in related activities. Given the lack of supply in the academic sector, the number to be assimilated is much larger.

What we described above could be interpreted as a problem for the physicists alone. Actually, it is a problem for the country and for the entire community of scientists and engineers. The incapacity to incorporate research and development (R&D) to the Brazilian industrial sector was explained, until the 1970s, by the lack of qualified scientists and engineers in the country. Our universities came into existence in the 1930's. Only at the end of the 1960's, and during the 1970's, cutting edge research groups were established in the most technological areas (COPPE, from UFRJ, and CTC from PUC of Rio de Janeiro are notable examples), as well as strong experimental groups in physics and chemistry. Unfortunately, in spite of the enormous academic progress of these groups, the necessary number of qualified scientists and engineers never arrived at the industrial sector in order to revert the situation. Only the adoption of an industrial policy that stimulates the local production of technology and replaces imports will be able to alter this scenario. Due to the policy adopted in the country throughout its history, our industry has dismissed scientists and research engineers. The policy of creating academic centers of excellence in order to train scientists and engineers was not followed by an industrial policy that favored their assimilation by companies of the industrial sector. Today, we have a competent scientific-technological community recognized by international standards, which is anxious to collaborate in the development effort, but without the means to do it. The formula to connect R&D, and its advantages, with our companies still has not been found.

Even more dramatic is the fact that the stagnation of the eighties, and the difficulties of the current times have jeopardized the academic community, due to the lack of investment, and the consequent obsolescence of its infrastructure. A sophisticated academic complex has been created to contribute to fill the gap between the academic and industrial sectors; since the work was left incomplete, the (academic) part that is finished (and working well) has been left to chance, and is blamed for not bridging the gap, something it cannot accomplish alone. However, in the few cases where the introduction of R&D in the industrial sector was well articulated (oil prospection in deep waters of CENPES, PETROBRÁS, nitrogenated grains of EMBRAPA, the alcohol program, airplanes of EMBRAER, and the already mentioned examples of applied physics), it was fully successful.

To give an idea of the numbers involved, according to IBGE, the country had 156 million inhabitants in 1995, of which 74 million constituted the workforce. Among these, according to the data collected by Carlos Henrique de Brito Cruz, a physicist from UNICAMP, 83 thousand were scientists and engineers working with R&D. About 57 thousand of these professionals were in universities, 12 thousand in research institutes, and only 13 thousand in companies. Meanwhile, in the United States, with about 250 million inhabitants, there are almost one million scientists and engineers, of which approximately 80% work in companies (in South Korea, about 60 thousand of these professionals work in companies, 29 thousand in universities, and 16 thousand in institutes).

There is no doubt that in the present-day technological society the participation of the physicists in the industrial sector has been growing enormously. Among the factors that contribute to that growth are: i) the evolution of computational capacity, with wide use of high performance computers; ii) the evolution of experimental techniques that today incorporate lasers, fiber optics and semiconductors, which are responsible for the revolution of opto- and microelectronics; iii) the decrease in the time between a scientific discovery and its technological application; iv) the globalization of the economy, which has altered the means of production by incorporating technology in order to increase competitiveness, and due to that fact, currently demands better scientists and engineers, with the physicists playing a prominent role.

More specifically, theoretical physicists have a strong grasp of modeling techniques, numerical simulation and resolution of differential equations (including non linear equations), which are increasingly required by the industry. Petroleum, energy, climatology, optimization and control are areas in which such knowledge is translated into enormous savings. Experimental physicists work with opto- and microelectronics, as well as with magnetism. They have a grasp on techniques of radiation-matter interaction (X-rays, lasers, magnetic resonance) that have an influence in areas that range from medicine, to food conservation, to the analysis of structures and materials. They also take the first steps in nanoengineering, besides working with new materials, with metrology, and with the monitoring of environmental and ecological conditions. In cases like the one of nuclear energy, it is certain that physicists will play an important role in the solution of the problems involving the recycling and reutilization of nuclear waste.

Therefore, it is important to promote a dramatic change in the way the country has been dealing with science and technology. It is necessary to introduce the habit of technological innovation in the Brazilian industrial sector, in order to be prepared for the new millennium, where S&T will have a dominant role. The task of incorporating S&T into production, using R&D, is carried out by companies in all industrialized countries. The American government, for instance, subsidizes technological development through contracts with companies which aim at technological advances (the aerospace industry is a good example).

In Brazil, there are approximately 70 thousand scientists and engineers in the universities and institutes. In the United States there are about 200 thousand, which is reasonable, given the population difference. However, while our companies hire 13 thousand scientists and engineers, the American companies hire more than 800 thousand. To face this situation, the country urgently needs to reformulate its industrial policy, after a discussion involving scientists, engineers, entrepreneurs and government, in order to define strategic areas, bottlenecks and technological niches, in order to obtain comparative advantages in the international scenario. That should be followed by a professional qualification effort in industry, so as to absorb the PhDs who will eventually change it. They will be responsible for maintaining a dialogue with the universities, without interfering with their mission of training human resources and generating knowledge. If that happens, maybe our exports will increase once again, since the low aggregate value of our current products hinders us from the benefits of the traditional incentive mechanisms, in a global market where technological goods have primacy.

By creating conditions to settle dedicated R&D scientists and engineers in companies, giving them the means to be in permanent contact with the universities and research centers, adding technological goods and services to the qualified national industrial park, the government will be taking important steps to modernize our industry, and to make it more competitive. In this process, Brazilian physics has ensured its contribution to national development as the trainer of highly qualified human resources and generator of scientific and technological knowledge.

AUTHORS

Carlos Alberto Aragão de Carvalho Filho *(Coordinator)*

Member of the Brazilian Academy of Sciences (ABC); PhD from Princeton University (USA); and Professor at the Federal University of Rio de Janeiro (UFRJ).

Alaor Silvério Chaves

Member of the Brazilian Academy of Sciences (ABC); PhD in physics from the University of Southern California (USA); and Professor at the Federal University of Minas Gerais (UFMG).

Humberto Siqueira Brandi

Member of the Brazilian Academy of Sciences (ABC); PhD in physics from the Massachusetts Institute of Technology (MIT); and Professor at the Federal University of Rio de Janeiro (UFRJ).

Luiz Nunes de Oliveira

Member of the Brazilian Academy of Sciences; PhD from the University of Cornell (USA); and Professor at the Physics and Chemistry Institute of São Carlos (USP).

Marcus Venicius Cougo Pinto

PhD from the University of Rochester; and Associate Professor at the Federal University of Rio de Janeiro (UFRJ).

Paulo Murilo Castro de Oliveira

Member of the Brazilian Academy of Sciences (ABC); PhD in physics from the Pontifícia Universidade Católica do Rio de Janeiro (PUC-Rio); and Professor at the Federal Fluminensis University (UFF).

Sérgio Machado Rezende

Member of the Brazilian Academy of Sciences (ABC); PhD in physics from the Massachusetts Institute of Technology (MIT); and Professor at the Federal University of Pernambuco (UFPE).

Area of Human Sciences
The Social Sciences in Brazil[1]

ELISA PEREIRA REIS
PAULO DE GÓES FILHO

INTRODUCTION

Several characteristics differentiate the human sciences from the other major areas of knowledge. The most important difference is that both the subject and the object of the knowledge in question are the same, which raises epistemological problems that don't exist in the other sciences, consequently making both objectivity difficult and impartiality problematic. These are complex, albeit not insoluble questions: the solution being to diminish or administer partiality by defining it in a clear and precise way. The axis of production of the human sciences revolves to a great extent around the exploitation of the ways in which this overlap affects knowledge generation (Janine Ribeiro, 2000).

Due to this trait, progress in the human sciences does not evolve in the same manner as in the remaining areas. It is less linear and even the great paradigm transformations evolve in a different way. *"It is therefore fundamental to acknowledge that: 1) in the human sciences the subject and the object overlap to such an extent that they influence the knowledge produced; 2) however, the link which makes such knowledge problematic is precisely the main source of knowledge in human sciences; 3) the link is essentially that of knowledge and action, namely the ability of the individual as agent to synthesize it as a thinking being" (Janine Ribeiro, 2000, p. 2).*

Another characteristic of the human sciences is the fact that it traditionally uses natural language. While other fields of scientific knowledge gradually evolved by formalizing their linguistic jargon and traditionally resorting to mathematical

1. *This article is an updated version of* Social Sciences in Brazil, *which was published by the Brazilian Academy of Sciences (ABC) in* Science in Brazil: an Overview, *in 1999, and written by Elisa Pereira Reis e Paulo de Góes Filho. The introduction incorporates the contributions of Simon Schwartzman and Renato Janine Ribeiro to the workshop* No Caminho do Futuro, *held in Brasília in February of 2001.*

terms, in the human sciences the use of natural language prevails, albeit strictly and precisely employed in each of the individual disciplines.

Besides the “classic” social sciences – sociology, anthropology and political science – this field includes other subjects that nowadays encompass the largest number of higher education students in Brazil (about 16%) in administration, law, pedagogy, education, demography, communication and social service. This number increases if we include the humanities: history, geography, literature, languages and philosophy. These schools of learning comprise the largest contingent of Brazilian higher education students (65%), oriented towards general education, despite not being recognized as such, concealed as they are behind the formal appearance of specialized courses. Any coherent long-term educational policy must, by definition, consider the necessity of providing general education, with the appropriate content and form, to this large body of students on applied social science courses, as they represent the overriding majority of higher education students.

Nowadays, the great frontiers of interdisciplinary work in the social sciences are at the intersection between economics and social sciences, on the one hand and on the side of law, with administration and the humanities on the other hand. Economists and jurists are increasingly in need of solid knowledge on social institutions, cultures and networks; administration has gradually become more and more “human”, thanks to the development of new management and information technologies. For their part, social scientists seek the more precise and practical instruments of the economists and administrators as well as the contributions of the humanistic and literary traditions (Schwartzman, 2000).

Among these subjects, economics boasts the highest degree of autonomy, especially in terms of research, and today the range it covers is no longer limited to the traditional lines of economic production and markets, as it includes ever deeper incursions into themes such as education, poverty, social inequality, justice, urban planning, to name but a few. In the case of law, a subject that preceded the classic social sciences, Brazil conducts little research in its universities, which preserve an academic, speculative and “jurisprudential” tradition having little contact with empirical analyses, comparative studies and more systematic knowledge about different cultures, practices and forms of organization of the legal system and their implications.

For Schwartzman, most of the applied social sciences lack the same work tradition and internal consistency that is inherent to economics and the classic social sciences; therefore, they depend largely on researchers educated in the aforementioned subjects for their development. A good part of the theoretical contributions and the most important research in such areas as education, organizational theory, administration and communication have been conducted here by political scientists, anthropologists and sociologists and, increasingly, by economists.

For Janine Ribeiro, there is still some resistance to applied research in the human and social sciences, as well as in other areas. A considerable part of the community rejects this option, as it perceives it as a threat to the freedom of the researcher and to pure research. Despite this, many social scientists are increasingly working in the applied areas, as it is primarily in these areas that the strongest relationship between knowledge and the central themes of Brazilian reality occur. The area of education is an example, where little is yet known about the breakdown of the academic system, functional illiteracy, and curricular obsolescence, among other themes. Social scientists have only recently started to deal systematically with the theme which has been foisted upon educators whose training in research and social theory frequently yields less than might be hoped for; or upon economists, who analyze the issues using powerful statistical and quantitative instruments, which are generally limited to few variables[2].

Administration is the area that boasts the largest number of students at higher education level in Brazil (12% of total enrollment). The demand for courses is mainly for night courses in private schools. Since the academic level is usually low, these courses don't require much prior education, they are relatively straightforward and the market covets them. However, adequate teaching of administration is highly specialized, requiring research and a profound knowledge of organizational theory, group psychology, complex systems of planning and management, microeconomics, among others. These are areas where little research is conducted in Brazil. In respected foreign schools, research work is carried out by the economists and social scientists, while the administration specialists devote their attention to consulting and more applied works.

2. *To understand how and why children learn or not; the different characteristics of the educational systems; the alternatives and dilemmas of decentralization; the role of the public and private sectors; the importance of culture in the acquisition of basic knowledge; alphabetization techniques and their limits; the potential and the problems of the new educational technologies; the alternatives, scope and limitations of the performance evaluation processes; the relationship between knowledge, competence and job market; the problems and alternatives to the training of school teachers; all these represent topics of great importance to the country.*

In the human sciences, the bulk of investigation, even that which is not mainly of an applied nature, may result in a new social, political and human conscience, which depends directly on the manner of disclosure. The dissemination of knowledge generated to the society as a whole deserves some reflection. The fact that it addresses the public does not necessarily signify that it should have a direct relationship with it. On the contrary, this relationship has a series of intermediaries, notably the media. Considered from the standpoint of common sense, political science is seen primarily as the science that facilitates an understanding of the functioning of the state and, especially, the options of the electorate. Sociology should contribute to the formation of a "good society", albeit from a perspective in which the social aspect is perceived either as the goal of public policies or as the scope of action of well-intentioned NGOs. Lastly, anthropology should deal with subjects related to minority groups or to cultures other than the dominant culture. Taken from these perceptions based on common sense, the practical application of the human sciences becomes fragmented and is not understood in its broader political dimension. Instead, it merely becomes limited to generating a critical conscience on subjects that affect us all, thus ignoring that their contributions may not only provide input for the formulation of public policy, but also contribute to the understanding of social processes susceptible to transformation.

Consequently, the framework of applications for the social sciences is far broader and more complex. Besides education, law and administration, it includes the whole area of public health, urban infrastructure, social mobility, poverty, social delinquency, demography, employment, transformations of the value systems, senior citizens, social welfare, and violence, among others. Among the largest social research centers in Brazil today are the *Instituto de Pesquisa Econômica Aplicada* (IPEA) and the *Instituto Brasileiro de Geografia e Estatística* (IBGE), not only in terms of the work that they accomplish in the area of economics and of demography, but also, increasingly, in the area of education, employment, social welfare, informal work, poverty and social justice.

One of the basic issues for the social sciences is that of international cooperation. The international and cosmopolitan dimension of the social sciences does not arise as directly and as automatically as in the natural sciences, but it is no less important and should be encouraged. For Janine Ribeiro, although we are not necessarily inferior in relation to the research that is developed abroad, it is essential to increase the dialogue among Brazilian researchers of proven excellence, in addition to fostering international cooperation.

As far as the author is concerned, another relevant point concerns the use of the Portuguese language, which is little known abroad, and the insistent recommendation to publish in English. It is necessary to qualify this suggestion, since a good many of our articles abroad end up in reviews restricted to publications concentrating on Brazil. Strategies need to be devised to overcome this limitation.

The question of the relationship between the social sciences and the natural sciences also deserves attention. In the past, scientists tended to espouse and believe naively in the innate virtue of science and of rational knowledge, believing that the essence of any scientific policy should consist, simply, in giving more resources to those who could further their ideas and projects. Today we live in a paradoxical world; on the one hand the power and the importance of scientific and technological knowledge are increasing, while on the other hand there is a growing concern at the possible negative effects of this science that grows by leaps and bounds, with the alternative forms of organization of scientific work, and with the frontiers between the "rational" and the "social." Societies no longer grant scientists the autonomy that they always counted on in the name of reason. The broad consensus about the reach, the limitations and the responsibilities of scientific work is still tenuous in our area. The area of the social study of science is interdisciplinary par excellence, a convergence point for natural scientists, epistemologists, philosophers, sociologists and anthropologists, and it deserves an important place in the elaboration of a long term project for Brazilian science and technology.

INSTITUTIONALIZATION

The institutionalization of the social sciences in Brazil can be traced back to the third and fourth decades of the XX century as part of the effort to build a modern nation-state (Miceli, 1995; Peirano, 1995). At around this time, the first undergraduate courses in social sciences were established. This process meant that some remarkable works on Brazilian society available since the first decades of the century, such as those of Gilberto Freyre and Oliveira Vianna among others, gained a wider forum of debate.

Either as critical reflections about the country's historical processes or as attempts to identify development alternatives, differing social disciplines made important academic contributions and prepared the ground for future systematic research. However, it was only in the last three decades that the dissemination and consolidation of graduate programs in social science disciplines across the country opened the way for the appearance of a significant research community in this area.

Due to time constraints on gathering information related to other fields of social science and humanities such as history, geography and psychology, this paper is restricted to the areas of sociology, anthropology and political science[3].

HISTORICAL BACKGROUND

Prior to the 1930s, social sciences did not represent an area of academic specialization or professional training for educators in the country. Some subjects such as sociology were taught at Law Schools, while others like anthropology were part of the curriculum of Medical Schools. However, independent intellectuals who were concerned with the Brazilian social reality produced several studies, which have become landmarks in Brazilian social sciences.

In 1933, the Escola Livre de Sociologia e Política, founded in São Paulo, became the first institution to offer a Bachelor's degree in Sociology and Politics. The faculty included Brazilians and some foreign visitors, such as the American professors Donald Pierson and H. Lowrie, who introduced the use of quantitative methods in social surveys in Brazil.

The second institution to offer a BS degree in Social Sciences was the Escola de Filosofia, Ciências e Letras of the University of São Paulo (1934). Several foreign lecturers, such as Roger Bastide and Lévi-Strauss, were invited to be part of the faculty of this School and soon a new generation of researchers was formed.

At the same time, the University of the Federal District (1935) was founded in Rio de Janeiro. Subsequently, the Faculdade Nacional de Filosofia, Ciências e Letras of the University of Brazil was established, further contributing to the diffusion of social sciences in the country (Nogueira, 1977; Schwartzman et al, 2000).

3. *In the case of economics, the importance of this discipline within the ambit of Brazilian social sciences requires a separate treatment, which will only be possible on another opportunity.*

The next two decades witnessed the establishment of several other Schools of Philosophy, Sciences and Arts all over the country, which conferred the Teacher's Certificate in Social Sciences with the purpose of training school teachers. The period from 1940 to 1960 saw a marked expansion in higher education, particularly in the social sciences. In 1940, there were 62 courses in Schools of Philosophy, Sciences and Arts in which 1,703 students were enrolled. By 1959, the number of courses had already increased almost tenfold (590), while the number of enrolled students grew even more (18,712).

Although the majority of these Schools were not originally set up as research centers, in some of them a new generation of social scientists began to elaborate a series of studies that would significantly change the characteristics of intellectual production in the Brazilian social sciences. Instead of papers covering generic aspects of Brazilian society and culture, these social scientists conducted in-depth analysis based upon rigorous scientific methodology and exhaustive data collection focusing on specific aspects of society. These studies, compiled as pre-requisites to obtain graduate degrees, established a new model for social research in Brazil.

Besides these researchers, trained mainly in São Paulo in the forties and fifties, many social scientists went abroad to study sociology, anthropology and political sciences. This number rose significantly during the sixties and the early seventies, when such exchange programs intensified. Soon the nucleus of an incipient scientific community developed in the field, comprising individuals with different backgrounds, specialties and fields of interest.

During this same period a series of research centers was established in the area of social sciences, such as the Centro Brasileiro de Pesquisas Educacionais (CBPE), the Instituto Superior de Estudos Brasileiros (ISEB) the Centro Latino Americano de Pesquisas em Ciências Sociais (CLACSO) the Instituto de Ciências Sociais of the University of Brazil in Rio de Janeiro and the Instituto Joaquim Nabuco in Pernambuco.

The demand for a qualified workforce, linked to the prestige attributed to the diploma, contributed to the expansion of higher education in the country. By 1970, there were 961 courses in Schools of Philosophy, Sciences and Arts with 128,402 enrolled students.

The greatest change, however, occurred in the seventies, when the national system of graduate courses (MS and PhD) was established on the same lines as the American model. This system made possible graduate training within Brazil of social scientists who gave continuity to the work initiated by the pioneering intellectual elites responsible for the establishment of Brazilian social science research. Furthermore, increasing support was provided by the National Science and Technology System, through agencies such as the National Research Council (CNPq), the Financing Agency for Studies and Projects (FINEP), as well as the Ministry of Education through the Commission for the Further Training of Higher Education Personnel (CAPES). International foundations also played an important role in contributing to the consolidation of social sciences in Brazil. It is also important to mention the role of the Research Support Foundation of the State of São Paulo (FAPESP), which was established in 1960 and effectively began operations in 1962, and was followed by other state foundations granting research support, chief among which were: the Research Support Foundation of the State of Rio Grande do Sul (FAPERGS – 1964), Carlos Chagas Filho Foundation of Research Support of the State of Rio de Janeiro (FAPERJ – 1980), Research Support Foundation of the State of Minas Gerais (FAPEMIG – 1985), and the Foundation of Science and Technology Support of the State of Pernambuco (FACEPE – 1989).

By 1985 there were 36,614 professionals qualified in social sciences if we restrict our scope to graduates in archeology, anthropology, sociology and political sciences. This figure represents 1.17% of the total of Brazilian professionals.

During the past 15 years, social research in Brazil has been conducted mainly in the graduate programs of public universities and at some independent research centers. The leading centers are CEBRAP (*Centro Brasileiro de Análise e Pesquisas*); IDESP (*Instituto de Estudos Econômicos, Sociais e Politicos de São Paulo*); IUPERJ (*Instituto Universitário de Pesquisas do Rio de Janeiro*), CEDEC (*Centro de Estudos de Cultura Contemporânea*) and the João Pinheiro and Joaquim Nabuco Foundations. Some of the more traditional private universities also participate in this effort.

It is also important to mention that a large part of the human resources formed in the graduate programs has been absorbed not only by the universities, but also by public sector agencies, consulting firms, and more recently by NGOs.

PROFILE OF THE SOCIAL SCIENCES IN BRAZIL

Research and publications in Brazilian social science are invariably the output of research institutes and graduate programs in sociology, social anthropology and political science. Brazilian scientific production in these areas has increased steadily, particularly over the past two decades. Two major aspects characterize this process: on the one hand there has been a significant diversification and specialization in the field, while on the other hand there has been a continuous process of integration of specialties across several interdisciplinary networks. This process has benefited greatly by the existence of scientific associations. The performance of the National Association of Graduate and Research Programs in the Social Sciences (ANPOCS), has been particularly important in this sense, but it is also important to stress the importance of the work of other scientific associations organized around specific themes, such as the *Associação Brasileira de Estudos do Trabalho* (ABET), the *Sociedade Brasileira de Economia e Sociologia Rural* (SOBER), the *Associação de Estudos Populacionais* (ABEP), the *Associação Brasileira de Pós-Graduação em Saúde Coletiva* (ABRASCO) and the *Associação Nacional de Pós-Graduação e Pesquisa em Planejamento Urbano e Regional* (ANPUR).

Apart from contributing to the enhancement of scientific knowledge in the areas of sociology, anthropology and political science, the work produced by social scientists had significant impact on the emergence of other disciplines such as collective health and social medicine, education and urban and regional planning.

Subjects studied in social science also bear a close relationship to neighboring areas such as history, geography, linguistics and demography that are not considered in this paper.

According to data to be found in CNPq's Research Directory, sociological research in Brazil is conducted by 187 research groups and involves 1,002 researchers and 946 students and trainees. The Southeast Region concentrates 37.5% of these groups, the Northeast 26.2%, the South 25.1%, the Center-West 7.5%, and the Northern Region 3.7%. The regional distribution of researchers shows a larger concentration of these in the Southeast/South axis and in the Federal District, where 68% of the total are located. The national average of the number of researchers per group is five, except in the North Region where the average number of researchers per group is four.

Although some of these groups work in centers dedicated exclusively to research activities, the majority of them is found in the university system, developing teaching and research activities simultaneously. 51.3% of the total number of research groups are located in federal universities, 14.4% in state universities and the remaining 34.3%, in private universities or in institutions dedicated exclusively to research.

Graduate courses, rated by CAPES in the area of sociology, are offered in 30 academic centers, both public and private. Of these, 15 are in the Southeast, 6 in the Northeast, 5 in the South, 3 in the Center-West and 1 in the North. 20 of these centers offer PhD courses.

With regards to financing, taking the year of 1999 as a yardstick, the area of sociology received 1.58% of the resources destined by CNPq for support. There were 743 scholarships in the country (1.73% of the total), 2 scholarships abroad (0.37% of the scholarships abroad) and 62 research grants (1.27% of the total of grants). Overall, the area received US$ 3,346,043.10.

Anthropological research is conducted by 113 groups, involving 703 researchers and 609 students and trainees. The Southeast Region has 39% of these groups, the South Region 16%, the Northeast Region 17.7%, the Northern region 14.1% and the Center-West Region 13.2%. The concentration of researchers in the Southeast and South Regions as well as in the Federal District amounts to 68%. Anthropological research has been developed in very diversified areas and on various themes. Therefore, besides continuing the time-honored tradition of ethnological studies of tribal societies, Brazilian anthropologists have been working, for instance, with peasant societies and urban anthropology, opening up innovative lines of research, with repercussions in international anthropology.

12 programs in universities located in 7 Brazilian states and the Federal District offer graduate courses in anthropology. Among those programs, seven offer PhD courses.

As regards financing, in 1999 the area of anthropology received 0.93% of the resources destined by CNPq for support. There were 382 scholarships in the Country (0.97% of the total), 4 scholarships abroad (0.49% of the scholarships abroad) and 46 research grants (0.89% of the grants). Overall, the area received a total of US$ 1,964,411.80.

Political science, the youngest of the three disciplines in Brazil, is developed by 72 groups, involving 406 researchers and 252 students and trainees. The Southeast Region concentrates 52.7% of these groups, the South Region 26.4%, the

Center-West Region 8.3%, the Northeast Region 7.0% and the Northern Region 5.6%. The distribution of researchers is similarly unequal. The administrative distribution of these groups is as follows: 41.7% are located in federal universities, 30.5% in state universities and 12.5% in private universities, particularly catholic universities. The remaining groups are in institutions essentially dedicated to research. Graduate courses in political science are offered by ten programs, of which two are in international relations, distributed among five states and the Federal District. Four of these confer PhD degrees.

With regard to financing, in 1999 the area of political science received 0.67% of the total destined by CNPq for support. There were 288 scholarships in the country (0.72% of the total), 5 scholarships abroad (0.86% of the scholarships abroad) and 17 research grants (0.24% of the total of grants). The total amount destined to the area by CNPq was US$ 1,426,073.00.

The topics of investigation in the area of social sciences are multiple, but it is possible to single out the main areas of academic production based on the activities carried out at the Annual Meetings of the National Association of Graduate and Research Programs in the Social Sciences (ANPOCS). In line with a decision of the ANPOCS General Assembly, starting in 2002 the Annual Meetings will have work groups as their basic organizational format. The new work groups will last for two years and, after this period, the thematic seminar format will be reinstated. Besides work groups, the following activities may be included in the programming of the Annual Meeting: conferences, forums, round table discussions, video sessions, exhibitions and, where necessary, other pertinent activities. Activities that tackle emerging issues, linked to the changes experienced by contemporary society, as well as those resulting from the theoretical-methodological challenges which social scientists currently face, shall be given priority. The organization of the activities of Anpocs gives a clear picture of the main research themes in the Brazilian social sciences.

The XXV Annual Meeting staged in 2001, was attended by approximately 900 participants with a total of 774 enrolled. Four conferences and a course on social theory were given, in addition to lectures on *Anthropological theory, political theory and sociological theory*.

The round table discussions dealt with the following themes: social policy, inequality and difference: theoretical and practical dimensions; mimesis: an idea for the social sciences; new perspectives in the social analysis of the environment;

research traditions; labor, trade unions and the new social question: an international perspective; challenges of peripheral citizenship: how to articulate inequality, diversity and recognition; the Brazilian republic: the state of the art; the information society; sociology of fine arts in Brazil; violence and public safety.

In 2001, 24 thematic seminars were also staged, covering the following themes among others: social sciences and communication; the contribution of the quantitative method for the analysis of the processes of stratification and social mobility; migratory movements; democratic controls and public responsibility; federalism, institutions and public policy in Brazil; transformations of the state, public expenditures and fiscal behavior; parties, elections and political representation; memory and identity; sexuality, reproduction, kinship; nature and culture; capitalism in Brazil; disciplinary perspectives about the themes of difference and of inequality; the metropolitan question in Brazil; social theory and post-national societies; workers, unions and the new social question; and Brazil's standing on the international stage.

With regards to scientific production, the area of social sciences presents specific aspects in relation to other areas. Taking into consideration the total number of articles published in journals registered with the ISI, in the last few years, the participation of articles in the area of social sciences worldwide is in the order of 10%, while in the case of Brazil it amounts to only 3%.

	Country	Abroad	Total
Brazil	4,601	659	5,260
Southeast	2,965	443	3,408
Southeast/Brazil	64.44%	67.22%	

Source: CAPES, 1995

The latest available data on the area of social sciences refer to the year of 1995 and reveal that in that year 5,260 publications were recorded, including articles and chapters of books, of which 659 were published abroad. The participation of the Southeast in this distribution is significant.

Despite this, it is worthy of note that in the three so-called "classic" areas there was a reduction, in absolute terms, in the number of articles published in foreign journals.

SOME IMPORTANT ASSOCIATIONS

- **National Association of Graduate and Research Programs in the Social Sciences (ANPOCS)**: The Association was established in 1977 as the Brazilian forum for research centers and graduate programs in the social sciences. Originally representing 14 such centers, it now brings together 61 institutions in the fields of anthropology, political science and sociology throughout the country.
  In order to respond to the multiplicity of demands of the academic community, ANPOCS has several advisory committees and task groups with specific agendas. The society's homepage is http://www.anpocs.org.br/

- **The Brazilian Association of Anthropology (ABA):** Its first meeting was held in 1953 at the *Museu Nacional*; however, the Association was formally created two years later in Salvador. Today it congregates around 800 individual anthropologists. The society's homepage is http://www.unicamp.br/aba/

- **The Brazilian Sociology Society (SBS):** It was founded in the fifties as a result of the transformation of the Sociological Society of São Paulo, founded in 1935. After the military coup in 1964 its existence became problematic and it was successively replaced by several Associations of Sociologists of a more professional than scientific character. It was reestablished in the eighties as a scientific society aimed at the enhancement of Brazilian sociology. Currently, the association has some 400 members. The society's home page is: http://www.sbsociologia.com.br.

- **The Brazilian Association of Political Science (ABCP):** After a period of inaction the Association was reorganized in December 1996 and has since staged several academic activities. Its membership comprises 200 associates including researchers and graduate students. The society's homepage is http://www. http://www.iuperj.br
  All these professional associations play an active role in the Brazilian Association for the Advancement of Science - **SBPC.**

SOME IMPORTANT JOURNALS

Taking articles, monographs and books together, the volume of publications in the domain of social sciences in Brazil is considerable.
Among the vast array of periodicals, some of the most prestigious are:

- **Revista Brasileira de Ciências Sociais (RBCS):** published three times a year since June 1986 by ANPOCS, it has the widest circulation among Brazilian social sciences periodicals.

- **Dados - Revista de Ciências Sociais:** a quarterly publication of the Instituto Universitário de Pesquisas do Rio de Janeiro (IUPERJ) publishing original articles in the area of social sciences since 1966.

- **MANA – Estudos de Antropologia Social:** published twice a year by the Graduate Program in Social Anthropology of the Museu Nacional (PPGA/MN). The journal publishes research and theory related to social anthropology in its broader sense.

- **Novos Estudos:** published by CEBRAP since 1972 covers all the areas of social sciences and the humanities.

- **Horizontes Antropológicos:** from the Federal University of Rio Grande do Sul. This journal is published every six months, with fourteen published editions since 1995.

- **Lua Nova:** published by CEDEC (Centro de Estudos de Cultura Contemporânea), São Paulo, three times a year, since 1984.

- **Tempo Social:** publishes articles in the area of social sciences, primarily oriented to the discussion of contemporary themes. It is published twice a year by the Institute of Human and Social Sciences of USP.

- **Anuário Antropológico:** published annually by the Anthropology Department of the University of Brasilia under the auspices of the ABA.

- **Revista de Antropologia:** launched in 1953 as the official journal of the ABA, it is now under the responsibility of the Department of Anthropology of USP. Restructured in 1991, *Revista de Antropologia*, includes national and foreign contributions of anthropologists. It is published twice a year.

- **Revista Brasileira de Ciência Política:** published by the Federal University of Minas Gerais, it is the oldest social science periodical in the country. It is basically oriented to political science and legal studies.

- **BIB:** is the ANPOCS periodical dedicated to reviewing articles on specific themes, as well as ongoing research and graduate dissertations in sociology, anthropology and political science.

- **Sociedade e Estado:** mainly covers the area of sociology. It is published twice yearly by the Department of Sociology of the University of Brasilia.

- **Teoria e Sociedade:** the biennial publication of the Departments of Political Science, Sociology and Anthropology of UFMG.

SOME IMPORTANT EVENTS

- The ANPOCS Annual Congress brings together social scientists from around Brazil, in addition to featuring several foreign guests. On average, 350 papers are selected for presentation. The number of participants has increased exponentially. Thus, while the first meeting in 1977 reunited 57 social scientists, nowadays the Annual Congress attracts around 1,000 professors, researchers and students.

- The ABA Biennial Meeting is a focal point for anthropologists, graduate and undergraduate students organized into 31 work groups. During the XXII Session, in 2000, more then 400 papers were presented.

- The SBS Biennial Congress attracts a large community of sociologists in a lively academic debate. More than 700 papers were selected for discussion at the Congress staged in September 2001.

- The ABCP Biennial meeting is the forum for discussion by political science scholars. The last one took place in November 2000 and was attended by more than 300 participants.

BIBLIOGRAPHIC REFERENCES

JANINE RIBEIRO, Renato “Ciências Humanas” Work elaborated for the Workshop entitled “No Caminho do Futuro”, MCT, Brasília, 2000.

MICELE, Sergio. História das Ciências Sociais no Brasil / São Paulo: Sumaré, 1995.

NOGUEIRA, Oracy. - Pesquisa Social: São Paulo: ed Nacional, 1977.

PEIRANO, Mariza. A Favor da Etnografia / Rio de Janeiro: Relume - Dumara, 1995.

SCHWARTZMAN, Simon “No Caminho do Futuro”: commentary on Human Sciences: commentary on the text on “Ciências Humanas”, by Renato Janine Ribeiro, MCT, Brasília, 2000 (mimeo)

SCHWARTZMAN, Simon . Nos Tempos de Capanema / Rio de Janeiro: Paz e Terra; São Paulo: ed. da Universidade de São Paulo, 1984.

AUTHORS

Elisa Pereira Reis *(Coordinator)*

Member of the Brazilian Academy of Sciences (ABC); PhD in Political Sciences from the Massachusetts Institute of Technology (MIT); and Professor of Sociology at the Federal University of Rio de Janeiro (UFRJ).

Paulo de Goés Filho

Anthropologist; consultant for international affairs and program & project coordinator of the Brazilian Academy of Sciences (ABC).

Area of Mathematical Sciences

Mathematics: a testimony of its insertion in science, technology and innovation

ARON SIMIS
CARLOS TOMEI
NELSON MACULAN FILHO
SUELY DRUCK

PROLOGUE: SCIENTIFIC AND CULTURAL BASES OF MATHEMATICS

Origins and Historical Perspective

The present account is largely based on the principle that mathematics is a scientific activity with social-historical roots, in opposition to a static view that takes it as existent *per se*, quite independent from human culture. The first stand, on whose side one counts famous forerunners, sees mathematics in a position similar to that of other sciences, namely, both as function and agent of society and of the scientifically explainable universe.

The precise language of mathematics and the beauty of its universal formulas are apparently conceived to perfection. This would seemingly justify the platonic-like vision of the discipline as a pure manifestation of the human or divine spirit, which exists independently of a given cultural state of mankind or of its social development.

The nature of the present document moves away from the above vision and tries to convey the idea that the mathematician is as creative and socially productive as his or her equivalent in other scientific areas. By the same token, mathematicians act by collecting experiments and identifying mistakes in order to approach the scientific truth.

In every science the strength of a general theory lies on its prediction power. This simple but effective idea is a remarkable characteristic of science *vis-à-vis* other human activities (such as religion or politics). This is not to mean determinism in science, an idea presently insufficient to explain quantum or chaotic phenomena in nature. Prediction in science does not read absolute certainty; the power to predict is essential despite uncertainty (as for instance in Heisenberg uncertainty principle and, more recently, in chaotic phenomena).

A distinction between mathematics and other experimental areas often translates into the way a theory is scientifically validated. While in most natural sciences validation relies on laboratory confirmation or experimental observation, in mathematics the procedure is by and large internal, based on confronting pre-existing solid theories and fitting the degree of rigor attained at a certain period. As an example, Newton's theory of *fluxions*, if judged in terms of nineteenth century mathematical rigor would hardly make its way through any average mathematical journal.

Cosmology, a science previously based on physical observation, presently derives its most important principles from sophisticated mathematical equations and from bold cosmological models supported on virtual geometric spaces only imaginable by mathematical abstraction. Cosmology is the "experimental" science closest to the mathematical *modus operandi*, even though experimental or indirect observation (as the universe "background noise", which granted a Nobel Prize) is not unavoidable. Some of the features of Hawking or Penrose's cosmological theories are intrinsically unobservable within our universe. If that is so then the only way of probing such theories is by means of confrontation with actual long accepted theories and by the rigor in deriving the mathematical equations that give support to the them.

Very little is known about the nature of the philosophical thought of ancient post-Hellenistic mathematicians. With the possible exception of Francis Bacon, Western World offered practically nil in this direction until nearly the seventeenth century. The inception of a scientifically based astronomy only then began to happen, in spite of the resistance offered by the Church acting as official referee for the acceptable epistemological doctrines. Mathematics was considered to be a mere computational tool whose epistemological meaning few cared about debating. The scene would only substantially change with Descartes' *Discours sur la méthode* and a little after, in the second half of the seventeenth century, thanks to Leibniz (*On ars combinatorica, new essays on the human understanding*) and Spinoza's mathematical incursions. In England the distinguished trio Berkeley-Hume-Locke rose above all and Paris knew, under the encyclopedist Diderot, the power of d'Alembert, Condillac and Rousseau.

Hume wrote (free quotation from a recent book by R. Hersch *What is Mathematics, really*?): "…all (scientific) knowledge degenerates into probability…There is no algebraist or mathematician (sic) so expert on his own science to a point of relying completely on a truth he just discovered, without considering it as a mere probability. More he (the mathematician) reviews his arguing in a mathematical proof more grows his confidence (on the validity of the result), more so when approved by his peers; and he is led to perfection by the consent and general applause of the well educated world." This thought is a clear eighteenth century glimpse of the mathematics as a social-cultural science subject to gradual progress and the acquisition of results of an increasing probabilistic precision.

Jean-le Rond d'Alembert was an autodidactic in both mathematics and physics, having published a *Treaty on dynamics* when he was 26 years old, entered the French Academy when he was 37, later become its perpetual secretary due to his prestige and general admiration. Here are some excerpts from the introduction of Diderot's *Encyclopedia* by him (loc. cit.): "…since not all parts of mathematics possess the same simple goal, the (idea of) certainty...is not equally shared by or distributed among these parts... The more general, encompassing and abstract (the area of mathematics), less obscure will be its principles. It is for this reason that geometry is simpler than mechanics, both being less simple than algebra…"

Transition from the nineteenth to the twentieth century witnessed the rise of two highly qualified mathematicians that deeply influenced the discipline by establishing a course of high effectiveness in mathematics: David Hilbert and Henri Poincaré. Without them it might be otherwise difficult to imagine what would the present face of mathematics look like. Being first rate problem solvers, they often gave the definitive look to a certain theme, thus leaving a deep legacy to the future of mathematics. Roughly, Hilbert's work played a major role in the first half of the twentieth century, while Poincaré's ideas prevailed in the second half of the century. No matter how hard a classification for the philosophical vision of these two mathematicians is pursued, no one can really say that one was a formalist and the other a humanist. Their mathematical lives are indirect proof that both were at least in their professional routine supporters of the humanistic (i.e., social-historical) vision of mathematics.

Mathematics and Society

The interaction between science and human society is extremely complex. Discussion on this theme would demand a special joint symposium of scientists and social leaders. The interaction between mathematics and human society is simpler, less politically minded and less traumatic, although not totally deprived of political and complexity aspects.

We will briefly emphasize some of these aspects. Further details will be indicated along the text.

The most obvious clause of the self-understood pact between mathematics and the social tissue is the teaching in both elementary and high schools. The need of basic education in mathematics is rarely an object of dispute even among activists of a free curricular choice with emphasis on child's humanist education. As far as social trauma is concerned, mathematical ignorance only finds rivalry in full illiteracy. The goal of a minimum mathematical training is deeply rooted in all cultures and societies, a did almost as old as civilization itself. One cannot precisely pinpoint its origin. It probably made its way, simultaneously, in most civilized agglomerates as a response to the intrinsic need of competitiveness and social task.

At any rate, planting basic mathematical literacy is a natural function of modern states. Beyond this basic premise mathematical education competes as equal with other governmental heeds, thereby experimenting the consequences of government's priorities. Besides, it must accomplish goals, respond to the inefficiency of the teaching system and to school repetition statistics and nominate endless committees to discuss and rule the system. As a "bonus" there is the need of permanent syllabus revision in order to keep it competitive and fit a world in which technology develops in an amazing speed independently, so it seems, from the educational system.

Clearly, there is no dissociation between mathematical and science education and society technological progress – at least not in an asymptotic way. However obvious, even amidst societies better structured than our own, this issue is not a result of the pressure of educators or society itself. By and large, the alarm sounds when governments realize that the political-economic strength of a country is dependable on technological development. In turn, the latter is strongly linked to scientific progress, which itself largely depends on permanently renewed professional leaders for generations to come.

In Brazil, eradicating general illiteracy is still a most immediate concern. The Ministry of Education by means of its several past and present policies, many of which without any long-term planning, is far from envisaging reasonably effective policies towards mathematics and science education so as to create a scientific-technological capacity. An exception is the current initiative of the Ministry of Science and Technology in clearly outlining the present picture and planning for the next decade.

While basic mathematical education is a concern of society as a whole, the idea of maintaining a horizontal scientific elite to generate technology and social well being is not very well understood. In this respect, our situation is not much worse than that of most countries, with the exception of those of the so-called First World. Science is viewed as something superior and strange, scaring even the political leadership of the country. On this stand mathematics is even more singular. For many it is not even a science. Others view it as a dead discipline whose results have all been long established. How many citizens have any idea of the relationship between mathematics and applied mathematics? Or between these and technology? Or between these three and the make of the final manufactured product?

This document also concerns the problem of knowledge transition in the above three steps, from the theoretical raw material to the final product accessible to society as a whole. Society is clearly only interested on the final product (and of good quality, please!). The State and the scientific community share the responsibility of explaining to society it will have to pay a price to obtain this product (and it won’t be cheap!). It will have to bear the costs of keeping universities, laboratories, congresses, publications and many other things. This sets up an essential clause in the pact between the aforementioned segments (theoretical and applied scientists, technologists and manufacturers) and society. If this clause is under threat, the whole construct and all the previous investments will irreversibly collapse.

The applicability of mathematics is not a myth: society and government do not have to worry about this. On the other hand, it is not a service or product one pays for and expects next day delivery. The scientific process (i.e., basic science) is by nature slow and largely unpredictable; the transfer to the applied base (generic technology or modeling) is complex and very often ineffective for computational purposes; finally, the portability of technology (manufacture of the industrial product) may prove to be impracticable or anti-economical. It is part of the scientific education of society to understand these processes and the distinction between applicability and industrial product. Society ought to be willing to honor the pact by bearing the costs of science and technology, for only this way it will be building a favorable bio-diverse environment and improving quality of life in the planet.

Mathematics and the Natural Sciences

A few words are in order about the nature of the relationship mathematics and other basic or applied disciplines, however smaller its impact on society. The larger the state of scientific advancement in a given society, the more natural will be this relationship. As an example, countries with a strong tradition in theoretical physics have their scientists routinely refer to phenomena in their areas as a mathematical depiction, without disguising their simple nature. Thus, Hawking says: “the theory of quantum mechanics is based on an entirely new kind of mathematics, which does not describe the real world in terms of particles and waves anymore…” (In *A brief history of time*, Bantam, 1988). The feasibility of particle emission from a black hole (Hawking radiation) sprang out of mathematical verification and not of experimental observation. Until a few years ago, its confirmation was purely mathematical and it strongly pointed to an interaction between general relativity (gravitation) and quantum mechanics, one of the postulates of the as yet unavailable Great Unification Theory (GUT).

Einstein used the jargon of Riemannian geometry to describe the nature of space and time and its curvature – mathematics of the most pure stock! Minkowski was the mathematician who, in fact, best described Einstein’s ideas, introducing a notion of space and time that was based on Lorentz’s transformations - the four-dimensional transformations keeping invariant Maxwell’s equations of electromagnetism. Maxwell’s equations themselves were derived in a purely mathematical way – it is worth recalling that the confirmation of electromagnetic perturbation propagating through waves was only later realized thanks to the experiments of Hertz (1886). A more recent example is the work of Gell-Mann and, independently, Ne’eman, establishing that SU(3), one of the simple groups in Lie theory, is the right mathematical concept to explain an internal symmetry in particle theory. In the words of Nobel Prize winner Weinberg: “It is very strange that mathematicians, guided by their sense of mathematical beauty, developed formal structures that only later physicists would consider useful, even when mathematicians themselves did not have any such goal in mind." (In *Dreams of a final theory*, Random House, New York, 1992, p. 157).

Perhaps was Wigner the physicist who best expressed the philosophical perplexity on the relationship between mathematics and other sciences: "The miracle of the appropriation of the language of mathematics for the formulation of the laws of physics is a marvelous present that we neither understand nor deserve. We should be grateful (to the miracle) and hope that it will hold in future research and extend to…wider branches of knowledge" (In his famous essay *The unreasonable effectiveness of mathematics*). No matter what one's epistemological preferences are, one cannot refrain oneself from guessing that there is, indeed, an extremely deep and complex nature in the above intertwining. There is no shred of evidence that this mutual interaction will cease in the near future, though it may become more consciously interdisciplinary.

The direct interface of mathematics with less orthodox disciplines, such as information theory, game theory (invented by von Neumann), queue theory, control theory, financial mathematics, code theory and cryptography, to mention a few examples, is so obviously applicable to problems of public infrastructure that it would look silly trying to use them as propaganda for the applicability of mathematics. Besides, society may feel relieved in this matter since public investment in mathematics is much smaller, for instance, than that in space technology, whereas the return is a lot more immediate.

MATHEMATICS IN BRAZIL: THE STATE OF THE ART

A general view of the area

This paper reflects the spirit of the *Green book* of the Brazilian Ministry of Science and Technology (MCT), which states "the need of wider investments in science, technology and innovation (ST&I) as a necessary condition to economic development, social justice and well-being and to the full exercise of sovereignty." To this one may add that performance of a competitive economy integrated to the international scenario depends on its power to use scientific-technological resources, while the latter depends largely on fundamental and computational mathematics. In fact, scientific-technological progress was only possible in the last decades due to the advancement of these disciplines. Presently, the enormous progress of natural and social sciences requires the increasing use of mathematics. Interdisciplinary research will surely be the most important characteristic of the model of scientific-technological development in the present century.

According to Rita Colwell, president of the National Science Foundation (NSF) for the period 2001-2004 (we quote) “needless to emphasize how vital mathematics is to keeping our research and development system. Nurturing mathematics is the basis of our large task. We consider mathematics essential to the progress of science and engineering (technology)... As our world and the economy change in a rhythm never seen before, continuous education becomes training necessary for survival. Mathematical literacy will be an even more vital ingredient in this scenario.”

Recognizing the growing importance of the discipline, UNESCO declared 2000 as the World Mathematical Year.

Origins

The history of mathematics in Brazil is quite recent. A few significant isolated cases were not enough to push development across until the first decades of the twentieth century. The University of Brazil, in Rio de Janeiro, and the University of São Paulo had just been established (1920 and 1934, respectively), hence mathematical activity in research was essentially restricted to the presence of foreign visitors (such as Jean Dieudonné, Alexander Grothendieck, Gustav Reeb, Laurent Schwartz, André Weil and Oscar Zariski). The next decade witnessed the increasing presence of Brazilian authors in international journals though most of the research was being developed abroad. Research made its way through the founding of the Brazilian Research Council (CNPq) in 1951 and, subsequently, of the Institute of Pure and Applied Mathematics (IMPA) and the systematic establishment of the first graduate programs.

In the last 40 years, mathematics in this country gradually scaled to a leading position in Latin America and acquired international recognition. Presently, Brazil holds 24 graduate programs in mathematics, of which 15 are currently evaluated as satisfactory to excellent in national scale. The research groups working in these centers publish regularly in excellent journals, enjoying international prestige. As a rule, both undergraduate and graduate programs in these institutions are pretty stable, offering a wide range of courses at a good teaching level.

According to *MathSciNet* (electronically accessed database of mathematical publication organized by the American Mathematical), the number of papers by Brazilian mathematicians in journals of regular international circulation grew by a factor of six within the last 15 years. This shows the success of the area in implementing policies aiming at the consolidation of the graduate programs and national research groups.

An increasing number of MSc and PhD degrees originated in these programs in the last three decades. Presently, the totality of MSc and the majority of PhD graduates come from Brazilian institutions. The figures however fall short of being ideal, lagging behind academic and education demands, more so in the face of the previously mentioned optimism.

Present State

Basic research in mathematics experienced notable advance in the country in the last three decades, presently counting internationally renowned professionals. Systematic action assessed the consolidation of high-level scientific environment along with international meetings and congresses. The country's leadership in the Latin America realm is presently unquestionable. Our graduate programs constitute an effective outlet for innumerous mathematicians from other countries of the continent, part of which go back to their homes to render services to their communities.

Besides the non-trivial cooperation abroad with outstanding centers and specialists, Brazil fits in Group III of the International Mathematical Union, together with Holland, Spain, Belgium, Hungary and Poland, only to mention a few European countries with a large mathematical tradition. The following table, based on data from *Science Watch*, appears in a paper by the biochemist Glacy Zancan in the Brazilian journal *Jornal Ciência Hoje* published by the Brazilian Society for the Advancement of Science (SBPC). It shows the publication impact index in the major areas of exact and natural sciences, in Brazil and in the world.

Area of knowledge	World	Brazil	% Brazil/World
Agronomy	3.38	0.32	9
Molecular biology and genetics	14.44	2.25	15
Biochemistry	11.00	5.50	50
Computer Sciences	3.65	1.96	53
Medical practice	7.19	2.97	41
Engineering	2.88	1.95	67
Pharmacology	8.16	3.70	45
Physics	6.75	3.48	51
Geosciences	6.51	4.60	70
Immunology	13.96	8.00	57
Mathematics	3.16	2.48	78
Neurosciences	12.56	5.84	46
Chemistry	6.47	3.79	58

The table shows that mathematics achieves the highest relative percentage of impact (the right most column). It also conveys that, in spite of the small impact of mathematics globally, – one conjectures this is due to the meaningful presence of populated countries that have not yet accomplished sophistication in the field – this impact is much larger inside Brazil.

As to applied mathematics, a substantial part of its activities are developed outside the mathematics departments. There are groups in sophisticated modeling (meteorology, image rastering, environmental engineering), in advanced technology projects (aeronautics, large integrated systems, oil extraction), and in work related to planning and simulation. There are also theory-based groups in control, optimization, numeric analysis, high performance scientific programming and computer graphics.

In developed countries the use of mathematics in industry generated its own labor task among companies that recruit mathematicians on a wide range of activities. In this country the situation is quite different, with most private corporations severely lacking the proper incentive for production and technological innovation. These corporations by and large are completely unaware of the potential available in the mathematical community. Even amidst state corporations with some tradition in research and development one seldom finds mathematicians in cooperation with other specialists in governmental projects.

Without any direct incentives there is no reason to expect a substantial change in the present state. Graduate students in applied areas have better job opportunities if they are enrolled in engineering programs. These programs themselves make unabashed appropriation of expensive packages generated in developed countries, adapting these to the country's industrial demands, rather than taking the seemingly longer route to the native mathematical resources. Strategic planning of the area expansion could stimulate more effective interaction between applied mathematicians and other specialists in order to get sufficient interest from the corporations.

The interaction between mathematics and computer sciences is one of the modern facets of the area. This interaction grows and diversifies in an astonishing speed. In Brazil one witnesses the following branches of this intertwining: discrete optimization, mathematical programming, operations research, numeric methods in differential and integral equations, parallel algorithms, numerical analysis, statistical methods, cryptography, computational biology, graph theory, computational geometry, formal languages, automata theory, automation and robotics, computer graphics (including image processing, virtual reality, CAD) and computer algebra.

This interaction is developed in several centers for pure and applied mathematics, for computer science and engineering, and centers related to physics, biology and other natural sciences. Substantial part of this interaction output takes place in computer science graduate programs. At present there are 30 of these programs many of which are directly inspired in mathematics or with some mathematical component (e.g., logic and artificial intelligence, including automatic proof of theorems). Quantum computation with a strong physical-mathematical background has not yet been fully undertaken by research groups, but this is a matter of time in the next decade.

The relative success of research in Brazil has regrettably not being replicated in basic education, whose present state is nearly catastrophic. This is especially true in regard to mathematical training, the only piece of science all (!) humans learn since early childhood. There is currently a massive quantity of citizens unable to manipulate simple information such as graphs, scales and interest rates. At the same time, students enroll in undergraduate programs virtually ignorant of those most basic concepts of mathematics they ought to have consolidated during the school years. Shortcoming of mathematics teachers plus their virtual incompetence are among the major causes for this dramatic reality.

Human resources capacity in mathematics at its several levels was subject of a recent document, *Perspective of the human resources in mathematics in Brazil: a growing imperative*, which points to the lack of effective governmental policies in the area of education. Personnel hiring policies in developing countries are as a rule concocted in the short-term perspective. These policies are not speedy enough to trigger results similar to those obtained in developed countries. In the face of the challenge to become internationally competitive in the various segments, the country has to immediately deal with the educational problem lest we be definitely pushed to a position of increasing cultural and technological dependence.

Groups and Research Themes

Presently, research is reasonably consolidated in the following fields:

- 1) Dynamical Systems

  Roughly, this field studies systems that evolve in time, such as those found in physics, ecology, meteorology, biology and economy. In its modern form, dynamical systems have a strong multidisciplinary background. The underlying mathematical theory does not overlook interaction with other parts of fundamental mathematics such as algebra, analysis, geometry/topology and probability. Presently there is an intense activity in this area, both in Brazil and the rest of Latin America. Major themes in this country are:
  - Real dynamics and ergodic theory;
  - Complex dynamics;
  - Bifurcation and stability of sector fields.

- 2) Partial Differential Equations

  Few areas of mathematics, and for that matter, of basic and applied science rival this for its wide range of applications and its power of encoding the local nature of natural phenomena. In Brazil, groups are engaged in large encompassing themes, from equations of fluid dynamics to meteorological phenomena to non-linear elasticity and kinetic theory of gases; from the famous Korteveg-De Vries (KdV), Benjamin-Ono, Schrödinger equations used as mod-

els for atomic physics and quantum to equations of relativity and relativistic quantum mechanics to the algebraic treatment using the formalism of sheaves and complexes of modules. Some central themes are:
- Elliptic and hyperbolic equations;
- Pseudo-differential operators;
- Scattering and inverse problems;
- Fluid dynamics and continuous mechanics.

▪ 3) Algebra

Besides being the oldest of the mathematical disciplines only rivaled by ancient intuitive geometry, algebra is the oasis of mathematical sweat where a theory achieves its definite form. Unlike theories in other areas of human knowledge replaceable by more plausible ones, a correct mathematical theory will be continuously polished till it achieves a stable form. This stable form gets its ultimate simpler form when stated in precise algebraic terms. In recent times, algebra has proved to be extremely effective in dealing with problems of modern world, from communications and cryptography to typical problems of discrete optimization and robotics (via implementation of Gröbner bases algorithms). In Brazil, research in algebra has evolved in the following direction:
- Algebraic geometry;
- Commutative and computational algebra;
- Non-commutative algebra (including group theory).

▪ 4) Geometry and Topology

The amalgam of these two fields has historical roots in Riemann's work of the nineteenth century. Modern geometry and topology cover an extensive range of themes and topics, thus rendering it a monumental effort to establish a clear separation between them. Roughly speaking, there are the differential methods, so peculiar as to allow a distinction between two main disciplines: differential topology and differential geometry. The latter has an early history in IMPA, keeping to this date its tradition of classifying immersions of geometric objects (differentiable manifolds) through the intervention of appropriate differential equations. An important branch of differential topology deals with singularities of geometric objects (local problem), while a more modern branch analyzes the global behavior of an analytic foliation in geometric spaces. The main themes discussed in Brazil are:

- Differential geometry;
- Topology of singularities;
- Topology of a foliation.

▪ 5) Probability and Stochastic Processes

This area derived from classic probability having attained much sophistication and applicability, being related to dynamical systems, ergodic theory and scale theory. A modern trend of the area is the study of critical phenomena in random processes, with application in the treatment of images, linguistic modeling and pattern recognition in stochastic processes. Major themes are:

- Random processes;
- Markov systems of particles;
- Percolation and dynamic phase transition.

▪ 6) Discrete Mathematics

Old elementary combinatorics and the classic finite element method generated a spectacular mathematical field. Generally called perhaps inappropriately combinatorics, the field has a unique charm in its capability to formulate complex problems using discrete models. These models cover an extensive range of objects, such as simplicial and polyhedral complexes, graph and matroids, and toric varieties. Applications vary from chemistry of polymers and crystals to molecular biology, from complex nets to game theory (decision process). The main themes are:

- Graph and matroid theory;
- Probabilistic methods in combinatorics;
- Discrete optimization.

▪ 7) Optimization and Operations Research

These are wide fields directly used in engineering and with a strong relation to and dependence on the computational tool, but also relying on solid mathematical theories such as convex analysis. A tall order in the field is algorithm development, along with the study of its complexity, stability and convergence. Since it is one of the most popular fields of mathematics within the engineering world, it dispenses further introduction. In Brazil, it studies:

- Structural analysis of problems;
- Algorithm development.

■ 8) Mathematical Modeling

This is not exactly a field of mathematics, but one related to the formulation of plausible mathematical models in science and technology. Due to its nature, it does not distinguish between methods or theoretical sources in that it involves a wide range of processes and information coming from several parts of mathematics. Meaningful modeling demands huge mathematical sophistication, going from non-linear dynamics, harmonic analysis, stochastic differential equations, computational mathematics and inverse problems in scattering theory. It is hard to state all the themes related to mathematical modeling in the country. Here are a few major themes:

- Bio-mathematical models;
- Population dynamics;
- Financial models.

■ 9) Computational Mathematics

This field deals with the theory underlying the implementation of computational models. Although the net goal is developing computer algorithms, the preliminary work is eminently mathematical. A modern example is the model of the so-called scale spaces, which is on the base of partial differential equations applied to image processing, including tall order topics such as wavelets, snakes and level set methods. The major themes in Brazil are:

- Vision;
- Image processing;
- Computer graphics;
- Methods of computational linear algebra;
- Numerical analysis.

PERSPECTIVES FOR THE NEXT DECADE

Of the Area Itself

The prospects for the area in the next decade are largely optimistic, especially if seen from a global or international perspective. For a more precise view of the difficult problems the area will have to deal with during the next decades, refer to the appendix below (Gromov's considerations).

The interaction between excellence centers in mathematics and related sciences is becoming more and more intensified. In Brazil, the area has benefited from bilateral cooperation acts with developed countries, particularly with NSF (USA), GMD (Germany) and, more recently, with the *Ministère des Affaires Etrangers* of France. Other than these, direct cooperation has been regularly maintained with several prestigious institutions, which include laboratory research and computational simulation in strategic areas such as oil and climate.

In the theoretical aspect, great progress is coming from direct interchange between dynamical systems and natural sciences. The country already has some fine research groups that, with appropriate governmental incentive through strategic policies in S&T, will be able to develop a more intensive action in the technological and production chain. Another spectacular progress might occur in areas related to inverse scattering, in its most diverse forms. Totally feasible right now (and we mean as this is being typed!) is the analytic-geometric modeling in medical problems, from sophisticated methods of scan to exact geometrization of the arterial and lung systems. Given the progress of medical research in the country, this is a field of boundless horizon. Another field with solid groups is algebraic geometry and its co-disciplines (such as commutative algebra, algebraic combinatorics and computer algebra), its potential applications being not only in theoretical physics and cosmology (mirror symmetry, string theory, membrane theory) but in countless routines along the productive chain (such as cryptography, telecommunications, robotics and car industry modeling).

Theory is never to be underestimated. In mathematics, it is its very *raison d'être*. A solid mathematical theory is the only way to meaningful applied mathematics. As theory evolves, application will naturally follow suit. The extent to which and how this is accomplished is unmistakably complex, but on the long run one will fatally influence the other.

The Interface with Computer Sciences

The prospective research in those themes of computer science directly inspired in mathematics is to receive incentives as well. In Brazil there is nearly a thousand software companies linked to *SOFTEX*, a national system for the make of computer programs. These companies certainly need highly qualified computer scientists, with a solid theoretical base in mathematics and related areas. Only then can one expect some of these corporations to be capable of responding to challenges in technology and business.

Sadly enough, “academic” segments in computer science would rather offer “objective” and “applied” programs in detriment of an adequate training in mathematics, physics and other exact sciences. It is quite common for a student majoring in computer science not having had one single credit in physics and lacking basic notions of mathematics such as those taught on a calculus or linear algebra course. We think this a mistaken and mystified course that jeopardizes the national potential in the field. In order that the latter become more competitive in the international picture it has to keep strong interactions with mathematics, physics, chemistry and biology. Instead of pretending to be overwhelmingly practical – as if in science one could ever have this choice – the programs ought to push the publication in indexed journals of international prestige to stay more competitive since, in any case, at the moment, the whole area can only count very few patents and prototypes

That is not say one should altogether forget about simple national strategies for developing prototypes or new findings. A clear example is hospital technology. Practically deprived of mathematics and computer sciences expertise, the whole sector has seldom generated opportunities to both undergraduate and graduate students in fields such as image processing, computer nets, operational research, database and so forth. University hospitals could nurture a huge laboratory to develop high technology to compete abroad.

In the next country’s decade computer scientists will by and large still concentrate on more theoretical questions and deal with more specific problems such as e-commerce, quantum computation, high-speed nets, high performance computation, numerical methods for large-size problems, and information automatic treatment of large databases.

Major Applied Themes in the area

Fast developing technology can only be faced in the country through clear and stable strategic governmental policies. As reported above, there is a solid, sophisticated research potential in mathematics as well in other basic sciences. Keeping the right proportion, the present national picture is somewhat similar to the situation in the United States and European during the Second World War: with a clear-cut policy and given the opportunity, even the more theoretical (abstract) groups of mathematicians were efficiently mobilized to strategic weapon production. Our purpose is slightly different in that it stresses the urge of sustainable development and technological competitiveness, but similar impact policies may be implemented by the government, perhaps under the coordination of the Ministry of Science and Technology (MCT) – a suggestive choice in peace times.

In general, one can predict intense activity directed to the following relevant themes on which mathematics will be playing an increasing role. Some are already subject of research by some national groups.

- Biological and biomedical modeling:
  - Medical imaging and inverse problems;
  - Hemodynamics of the cardiovascular system;
  - Immunology (especially viral dynamics);
  - Physiology and fractality of the breathing system;
  - Microorganism movement.

- Image Processing and Data Digitalization:
  - Computer graphics: three-dimensional rendering and algorithms based on wavelets, finite elements and algebraic geometry;
  - Application of mathematical fractals to video algorithms, compression without loss, resolution refinement, image compression and recognition;
  - Digital libraries (models and storage algorithms, multimedia recovering, transmission and reproduction);
  - Digital management of assets including digital watermark, cryptography, compression, authentication and distribution.

- Fluid Dynamics:
  - Petroleum (detection and efficient extraction);
  - Meteorology (numeric-computational forecast models).

- Geometric Design:
  - Capture of moving images;
  - Applications to science of materials.

Mathematical Education

A crucial aspect for the next decade is science education, more particularly, mathematical education. As stressed in several parts of this document, in the case of mathematics this is a strategic sector of interface with society. In a strict sense there are two distinct nevertheless intertwining components of science education. One is related to the quality and diffusion of teaching properly, especially throughout college years. The other component aims at the awakening of society to scientific conscience in its large segments. The latter component has a more complex nature, as it pursues the planting of a minimal science literacy in unorthodox sections of the social tissue, from the common citizen to his or her congressman or employer, through the various intermediate layers of administration and bureaucracy. This means a wider project that depends on a joint effort involving all areas of science and its preceptors in private and governmental agencies.

The first component has a simpler and more direct structure to its methods and objectives, but nowhere it complies with naive and immediate solutions to its problems. A lot has been done in the attempt to improving the teaching of mathematics both in elementary and high schools. As previously shown, the teaching of mathematics in public schools is by no means in better shape than general education as a whole. Minimal training in elementary mathematics is essential to any person, lest he or she turns into a second-class citizen, deprived of any access to decent jobs and quality of life. The average person may have a deficient education in certain disciplines or subjects of modern life, but nothing will be as grave a handicap as a poor mathematical training, for it will drive him or her to a progressive and complete alienation from civilized environment.

The National Program Exam (ENC-2000) and the System of Course Evaluation (SAEB) revealed a critical situation among mathematics undergraduates and high school students, respectively. The first disclosed an alarming situation where

88.2% of the participants were given grades inferior to 2.24 in a 0-10 scale. SAEB in turn exposed a serious deficiency among high school third grade students – a poor 50% average - thus pointing to the inadequacy of the present teaching of mathematics.

The mathematical community through its main segments shows concern in face of this situation and is presently looking for the means to entice an outspoken discussion with both public and private sectors, involving the various segments of society. In order for the discussion to entail a few realistic mid-term goals, all parties must rid of formed prejudice. Mathematical education on one hand is an inalienable vocation of mathematicians; its practical enforcement on the other hand is a challenge for an army of people with adequate training. This preliminary point may help to establish a minimal common denominator for this dialogue.

In other segments the situation of educational policies is not disastrous, but requires permanent care by the country's scientific leadership and effective action by government agencies. Attracting young mathematical talent is a long tradition in the field of mathematics, both in the country and abroad. Besides efficiently dealing with a nationwide program of scientific training for incoming undergraduates (PIBIC as it is known) the community has a vast experience in mathematical olympiads. First and unrivaled in the country, now followed by the physics community, this program is a definite success in seizing talents from the high-school bench, eventually leading to a university degree. Whereas PIBIC has developed thanks to a solid policy by CNPq throughout the years, the mathematical olympiad has survived as an autonomous activity in the hands of dedicated members of the community with the help of a few high-school mathematics. It has being gradually institutionalized, presently having its own independent structure (OBM-Brazilian Mathematical Olympiad). Its overall presence is still small, but where it acts it has stimulated young students otherwise mathematically astray. Some of these students have performed remarkably in international Olympiads. Helping finance the mathematical Olympiad is a sure investment that ought to be taken over by the State and private corporations.

APPENDIX: MONITORING SCIENCE AND TECHNOLOGY

In the years of 1945 through 1998 US institutions issued around 11 reports on the situation of scientific education in the country, especially in regard to mathematics. Of these many were ordered by the NSF (National Science Foundation), three of them in 1998: the Boyer Report, the Senior Assessment Panel Report and the Ehlers Report.

These reports analyze in detail the structure of the current mathematical and scientific education in the country, proposing general mid and long-term guidelines. Some of these guidelines were implanted with varying results along the stages. The concern of American institutions with the visible deterioration of the educational model is admirably described in the Report *Moving beyond myths* (1991), ordered by the NRC (National Research Council) to the *Committee on the Mathematical Sciences in the Year 2000*. The Report criticizes the undergraduate courses in mathematics in the country, enumerating a list of common myths in the public conception of mathematics: 1) Any use of mathematics has long been discovered; 2) The whole of mathematics sole purpose is calculating answers; 3) Success in mathematics depends solely on ability, not on continued work; 4) Most jobs require very little mathematical expertise.

The Douglas Report (1992) in turn analyzed general problems in PhD and post-doc programs in the United States (pioneering country in this academic initiative).

To understand the dimension and importance of these reports, it suffices to recall that of these, the famous Vannevar Bush Report (1945) was the germ of NSF founding in 1950, after a preliminary veto by President Truman.

The Senior Assessment Panel Report included several scientists from outside the US, on the purpose of giving an appropriate answer to the “Government Measure of Performance and Results”, whose aim is to have fostering agencies to establish strategic goals and to evaluate progress achieved thereon. One the panelists, mathematician Mikhael Gromov, from the University of Maryland (USA) and the Institut de Hautes Études Scientifiques (IHES, France), summed on the possible tendencies of Mathematics in future decades:

“First, classical mathematics is the pursue of structural harmony. It began with the realization by Greek geometers that our three-dimensional continuum possessed a notable rotational and translational symmetry that pervades the essential properties of the physical world… Deeper non-commutative symmetries (besides those of the rotational O(3) group) were subsequently disclosed: Lorentz and Poincaré in relativity, gauge groups in elementary particles, Galois symmetry in algebraic geometry and theory of numbers, etc. A similar mathematics reappears in a less fundamental level, for instance, in crystals and almost-crystals, in self-similarity of fractals, dynamical systems, statistical mechanics, monodromy of differential equations, etc. The search for symmetries and regularities in the structure of the world will be central in pure mathematics (and physics). Occasionally (and frequently, in an unexpected way), certain patterns of symmetry discovered by mathematicians will have practical and theoretical applications – cf., for instance, integral geometry in the base of X-ray tomography (CAT scan), prime number arithmetic allowing for the generation of perfect codes and infinite dimension group representation, yielding economically efficient high connectivity net design."

"Second, as it grew the body of mathematics itself became a subject of logical and mathematical considerations, thus bearing mathematical logic as a discipline, and later, theoretical computer science. The latter is now in what we could call its aging period, in that it absorbs ideas from classical mathematics and benefits from technological progress in hardware making it possible to implement theoretical algorithms (Fourier's fast transform and fast multiple algorithms are examples of the impact of pure mathematics on numeric methods used daily by engineers). Pressing is the urge for interaction of the mathematical-logic theory with other fields of knowledge is a pressing demand, such as the quantum computation project, molecular design based on DNA, pattern building in biology, brain dynamics. It is expected that, in the next decades, computer science will develop ideas in a deeper mathematical level, followed by a radical progress in industrial application of computers, for instance, a new benchmark in artificial intelligence and robotics."

"Third, there is a wide range of problems, typically originated in experimental sciences, where it is necessary to work with large amounts of loosely structured data. Traditional mathematics, probability and mathematical statistics work quite well when this structure can be practically overlooked. (Paradoxically, the absence of structural organization and of local level correlation yields a high level of global symmetry; thus, Gauss' law emerges from the sum of random variables). However, often we find structured data to which classic probability cannot be applied. For example, the mineralogical building of microscopic images of living tissue hides an unknown correlation to be taken in account. (What we usually "see" is not the "real image" but the result of some wave scattering: light, X-ray, ultrasound, seismic wave, etc). Other theoretical examples appear in percolation theory, in self-evasive random paths (modeling long molecular chains in solvents). Such problems, halfway between pure symmetry and chaos, await a new branch of mathematics. Advance will require looking for new mathematical theories to deal with computers and strict collaboration with experimental scientists (some concrete possibilities are wavelet sign and image analysis, sophisticated techniques of inverse scattering, geometric scale analysis and X-ray analysis of large molecule diffraction in crystallized form). For instance, an efficient inverse scattering algorithm would revolutionize medical diagnosis, making ultrasound equipment at least as efficient as X- ray analysis."

Of great interest to science in general, and to mathematics in particular is the Ehlers Report (Vern Ehlers is a North American Congressman with PhD in physics!). This Report focused on three main aspects: government's role in supporting research; private sector's role in supporting research; and the common responsibility of government, industry and the educational community in the strengthening of mathematical and scientific education. Some specific recommendations made by the panelists in this report are:

- The importance of basic (fundamental) research;
- Basic research is federal priority;
- Large federal support to basic research;
- Critical importance of an outstanding mathematical and scientific education;
- Opportunity creation for technology in education;
- The importance of post-doctoral programs;
- Scientific information in society.

Another important report was prepared by the Society for Industrial and Applied Mathematics, analyzing the role of mathematics and mathematicians in industry and presenting several specific recommendations.

The totality of these reports proved to be important in the elaboration of systematic policies in S&T, especially in that concerning the role of fundamental science in catalyzing society progress. Monitoring of S&T as a request by institutions and enforced by the scientific community may be of great importance to progress as a whole on the face of its feasible recommendations. Except for some isolated frustrated attempts in the past, the present initiative of MCT points to the possibility of serious self-monitoring by the scientific community itself.

Added in time: The first version of this document was written in the Portuguese language in 2001. Since the contents were meant to be read by a larger public than the national scientific communities, it then seemed appropriate to digress a little more on the meaning of mathematics, to tell bits of its history and to mention a few important people in it. It is clear that much of what has been written is known and appears in so many sources in different times. Since this is not a research paper, we saw no need to quote precise references or sources. Thus, there is no claim whatsoever to the originality of the exposed material. However, once in a while, it may be curious to point an inadvertent coincidence of ideas or exposition. Namely, at the beginning of the document we expanded on the origins of the area and saw fit to mention a slight dichotomy in the thoughts of Hilbert and Poincaré. We then suggested what sort of impact the two may have caused on twentieth century mathematics. To our pleasant surprise, this year June/July issue of the Notices of the American Mathematical Society published a version of the Retiring Presidential Address of outgoing President Felix Browder. Besides an intriguing similarity between this article and our document in those parts related to the perspectives of the field, the author quotes the physicist Elliott Montroll as having said some years ago (we quote): “The first half of the twentieth century in physics was era of Hilbert, and the second half was the era of Poincaré”. We thought we ought to bring this small point to the reader’s attention so he can judge by himself the often-coincident view of mathematicians and physicists about the history of science. Another topic of similarity is the words of M. Gromov about the perspectives of mathematics. In this case, our source and F. Browder’s are naturally one and the same.

AUTHORS

Aron Simis *(Coordinator)*

Member of the Brazilian Academy of Sciences (ABC) and of The Third World Academy of Sciences (TWAS); PhD in Mathematics from Queen's University at Kingston (Ontario, Canada); and professor at the Federal University of Pernambuco (UFPE).

Carlos Tomei

Member of the Brazilian Academy of Sciences (ABC); PhD in Mathematics from the University of New York (New York, USA); and professor at the Pontifical University of Rio de Janeiro (PUC-RJ).

Nelson Maculan Filho

Member of the Brazilian Academy of Sciences (ABC); PhD in Production Engineering from the Federal University of Rio de Janeiro (UFRJ); and professor at the same university.

Suely Druck

PhD from the Pontifical University of Rio de Janeiro (PUC-RJ); and professor at the Fluminensis Federal University (UFF).

Area of Chemical Sciences

ANGELO DA CUNHA PINTO
ALFREDO ARNÓBIO S. DA GAMA
ELIAS AYRES GUIDETTI ZAGATTO
MASSUO J. KATO

INTRODUCTION

The appraisal of the areas of knowledge has been continuously developed in the last 20 years, thus representing a recurrent discussion in Brazilian science.

Producing diagnoses, identifying objectives and proposing developmental strategies from these can many times be an individual activity based on qualitative and quantitative data, and also on opinions. This process may also be a collective exercise, in which more representative positions can be obtained, but in this case, a loss of precision in the diagnosis occurs, due to the need of conciliating opinions. Whether these opinions are individual or collective, this is a necessary exercise for the strengthening of the nation and for Brazilian science, aiming at overcoming the inequalities which today separate Brazil from the industrialized countries.

This chapter is based on recent articles published by Riveros[1] and by Galembeck[2] evaluating the Chemical area, and on summary books of the annual meetings of the Brazilian and of the American chemical societies. Prominent members of the chemical community were also consulted, especially young promising researchers that live the day-to-day reality of the laboratories, defining today the horizons of Brazilian chemistry in the years to come.

Considering the complexity of the chemical area, whose frontiers are hard to define due to the close boundaries with other areas of knowledge, we have here adopted the division used by Galembeck in his article published in *Science in Brazil*[2], instead of using the traditional division usually adopted by most chemical institutes in Brazilian universities.

There are two other characteristics of Brazilian science that are very present in the chemical area and that are considered in the present analysis. First, that scientific activities in Brazil are carried our mostly in public institutions, especially universities. Second, that the most important locus for research in the universities is in the graduate schools, in spite of the relevance of scientific initiation programs and of the incipient practice of post-doctoral activities.

Therefore, the identification of the trends of the indicators on chemical research may be obtained in a convenient manner, based on rigorous data, using the information available on the successive appraisals accomplished by the Coordination for the Improvement of Higher Education Personnel (CAPES).

GRADUATE EDUCATION IN CHEMISTRY

The two most important events for the development of graduate education in Brazil occurred at the beginning of the 1960's and 1980's. The first one was the establishment of FUNTEC, in the Brazilian Bank of Economic Development (today BNDES), which endowed subventions to graduate programs and basic research activities. The second, in 1984, was the creation of the Program of Support to Scientific and Technological Development (PADCT), which defined chemistry and chemical engineering as priority areas for financing. The great impact of the PADCT on these areas was demonstrated by Castro and Prescott[3].

Among some recent appraisals of the chemistry graduate education in Brazil, we here consider those developed by Brocksom and Andrade[4] and by Gama et al[5]. These authors describe in their articles the methodology applied by the CAPES committee, and the important modifications introduced in the latest appraisals.

In the latest appraisal by CAPES, 1998/2000 biennium, it can be observed that the chemical area continues to develop rapidly, with a significant increase in the number of PhD and articles published in scientific periodicals with international circulation.

The following charts and tables present a general view of graduate education in chemistry in Brazil.

Publications / Year

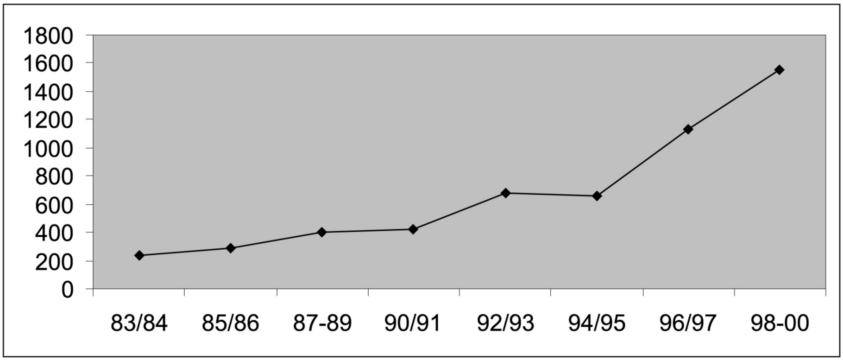


Figure 1. Annual number of publications from the graduate courses in chemistry, in the successive evaluation periods of CAPES

Figure 1 demonstrates that the number of publications produced annually by the graduate programs increased more than sixfolded, in the period between 1983 and 2000.

This increase is mainly due to the increased in per capita productivity of the researchers, that is shown in Figure 2. The productivity tripled, possibly being explained by the maturing of the researchers, as well as by the increase in the number and quality of the graduate students attending the courses.

Publications / Researcher / Year

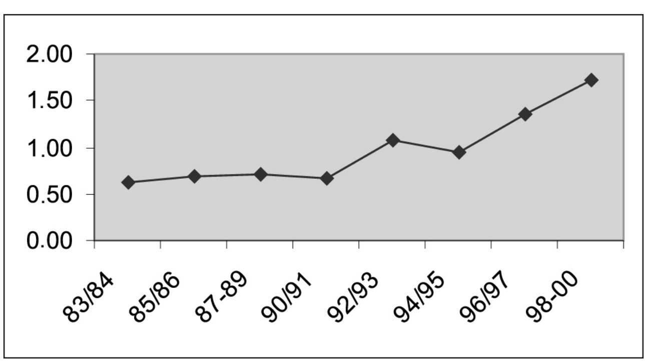


Figure 2. Productivity of the faculty of the graduate courses in chemistry, in the successive evaluation periods of CAPES

Average Graduation Periods (in months)

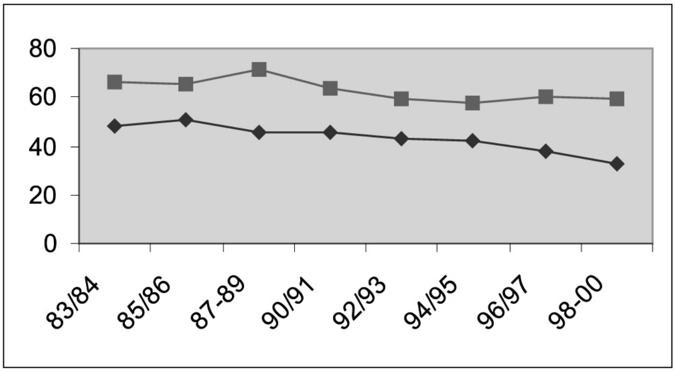


Figure 3. Average time in the PhD and MSc programs (◇)

The average time in the PhD programs is still high, but a decreasing trend is already perceivable. In any case, this indicator must be analyzed with care since successful experiences may be erroneously taken as failures. An example is the case of PhD students invited for jobs by universities or private companies before concluding their studies. These students are benefited by their qualifications, but delay the conclusion of their programs due to new professional obligations. In the statistics, these students will appear negatively when in fact, they might represent positive results. As a matter of fact, as the companies increase their importance as employers, in comparison with universities, more PhD students will be experiencing this situation and, rather than a negative point, this will be extremely positive.

Evolution of the number of postgraduates

The number of PhDs and MScs increases rapidly each year, as shown in Figure 4. This is evidence of the vitality of the system and demonstrates the increasing potential of chemical research. On the other hand, an increase in the offer of qualified professionals without a corresponding increase in the demand may create a very negative situation. At the present moment, there are many demands to be satisfied, either in the higher education system, or in official research institutes. In addition, limited R&D in private companies does not allow these to become important employers. But this situation can be reversed with the use of adequate instruments such as sectorial funds, which may allow universities, research institutes and private sectors to incorporate young PhD.

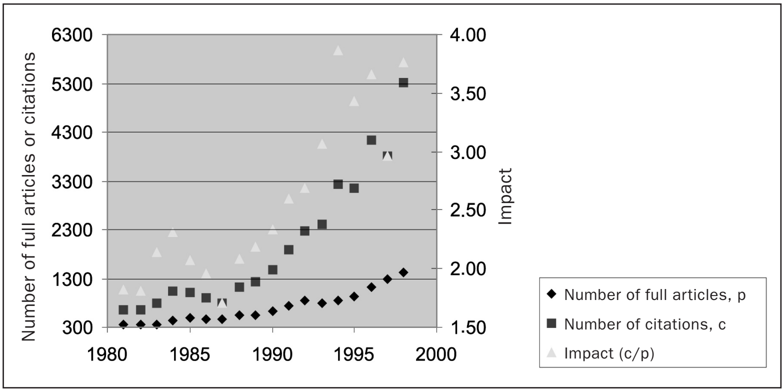


Figure 4. Annual number of last year students in graduate courses in chemistry, in the successive evaluation periods of CAPES. PhDs and MScs (◇)

International Publications / National Publications

The relation between the number of publications in international and national periodicals is illustrated in Figure 5, which shows important growth. This means that the Brazilian scientific production in chemistry has a growing international insertion, increasingly satisfying the standards of international quality.

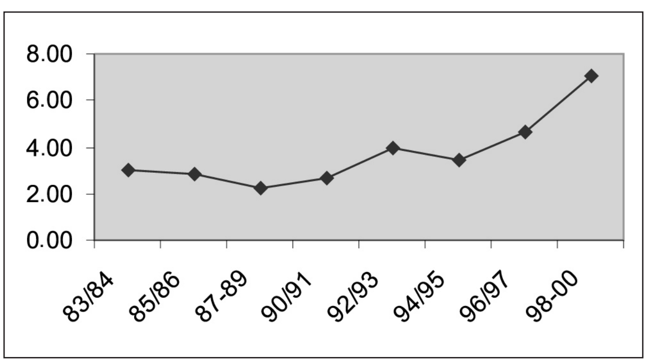


Figure 5. Relationship between the number of publications in national and international periodicals

Distribution of the Publications According to the Classification of the Periodicals (Qualis-Chemistry)

More than 40% of the articles are published in magazines that are classified as the best by the Qualis System, as shown in Figure 6. Almost 90% of the publications are in magazines that are recognized by the system. This demonstrates that most of the scientific production in the area achieves standards that are internationally recognized.

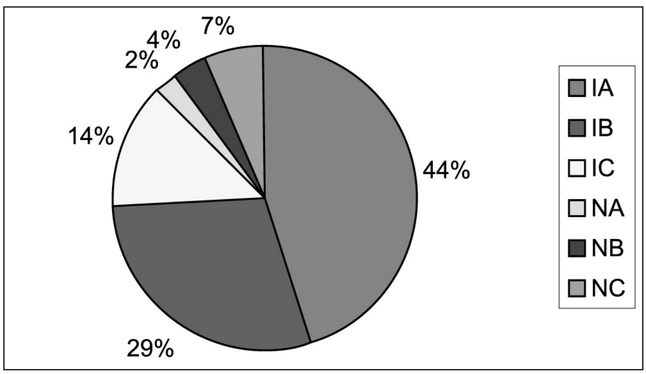


Figure 6. Distribution of the publications in periodicals among the journal categories, according to the Qualis system.

The graphs shown in Figures 1 through 6 were built using the data in Table 1, which presents relevant indicators for an analysis of graduate education in Brazil. The time series represented in Table 1 leads to two assertions: first, all the indicators of the system are growing; second, the per capita indicators are responsible for a significant portion of the growth, or in other words, more than mere physical expansion of the system, this growth is related to productivity gains. Finally, it is very important to observe that the absolute and per capita growth of Brazilian graduate education maintained an accelerated pace throughout the 1990’s, which was a period in which the public universities that represent almost the totality of the graduate courses in chemistry, hired few new members to their staff. Therefore, Table 1 demonstrates the qualification process of the public universities, not only through the expansion of the graduate courses, but also through the increase of its scientific production and international insertion.

EVOLUTION OF THE GENERAL INDICATORS OF GRADUATE EDUCATION IN CHEMISTRY

Periods	83/84	85/86	87/89	90/91	92/93	94/95	96/97	98/00
Number of faculty	376	422	565	624	637	704	842	906
Number of students	875	1149	1660	2018	2347	2059	2981	3208
Graduated MSCs	226	212	411	476	457	446	664	1124
Graduated MSCs/Year	113	106	137	238	229	223	332	374.7
Graduated PhDs	75	81	109	157	178	279	380	631
Graduated PhDs/Year	37.5	40.5	36.3	78.5	89	140	190	210.3
Time for MSC degree	48	51	46	46	43	42	38	33
Time for PhD degree	66	65	71	64	59	58	60	59
National Publications	119	152	368	226	276	299	399	580
National Publications/Year	59.5	76	123	113	138	150	200	193.3
International Publications	358	427	830	610	1090	1024	1870	4078
International Publications/Year	179	214	277	305	545	512	935	1359
Total of Publications	477	579	1198	836	1366	1323	2269	4658
Total of Publications/Year	238.5	290	399	418	683	662	1135	1553
Publications Faculty/Year	0.63	0.69	0.71	0.67	1.07	0.94	1.35	1.71
Publications intern/national	3.01	2.81	2.26	2.70	3.95	3.42	4.69	7.03
Students/ Faculty	1.7	2.04	2.35	2.24	2.58	2.2	3.54	3.2

PRESENT PANORAMA OF THE MAJOR SECTORS OF BRAZILIAN CHEMICAL RESEARCH

Analytical Chemistry

Nobrega et al[6] present a view of analytical chemistry in the period between 1974 and 1994, based on papers presented since 1977 in the annual meetings of the Brazilian Chemical Society, and on the National Meetings of Analytical Chemistry, which have occured biannually since 1982.

Analytical chemistry may be considered common to all the subareas of chemistry and of great importance to the natural sciences as a whole, especially to environmental and materials sciences. Nature is made up of molecules and to understand it one must understand it, at the molecular level. Several disciplines are connected to analytical chemistry: physical chemistry, biochemistry, kinetics, spectroscopic optics, separation methods, toxicology, geochemistry, forensic sciences, etc.

Among the themes discussed at the "EUROANALYSIS XI", realized in September 2002, one the most important meetings on analytical chemistry, the following topics were dominant:

- Bioanalytical chemistry, genetic techniques;
- Complex systems, environmental chemistry, medical diagnosis;
- Genomics, proteomic
- High-throughput screening analysis
- Chemometrics (emphasis on chemical imaging)
- Instrumentation aspects: nano-analytic, "lab-on-the-chip"
- Process analysis (industrial): "on-line, in-line, at-line"
- New fields of analytical chemistry
- Analytical chemistry and administration
- Quality, metrology
- Art, history
- Educational aspects, terminology

Considering that these are significant aspects for the development of analytical chemistry in the years to come, and accentuating the international trend towards clean chemistry ("green chemistry" – less toxic reagents and smaller residue generation), these topics were grouped into three blocks:

- **Theoretical/Conceptual aspects:** Brazil has played an important role on research related to this item, especially regarding new developments in chemometrics (including modeling) and instrumental proposals that are conceptually innovative. Here, special emphasis must be given to the development of sensors and biosensors.

- **Methodological aspects:** New methods have been exhaustively developed on analytical chemistry, most presenting clear advantages in comparison to the previously existent. Nevertheless, few of these have been recognized to the point of constituting new analytical standards. Analogously, new instruments with characteristics superior to those commercially available have been projected, presented and valued by the international community. However, only a few of these have been adopted by industry, even at the national level.

- **Applicative aspects:** The applications of analytical chemistry are verified on several levels, frequently interacting with other areas in chemistry or related fields. The use of analytical chemistry is of special importance in research related to environmental studies, materials sciences, clinical diagnoses, sensorial analyses, metrology, applied isotopy, etc.

Brazil has research groups with high academic competence and international prestige in areas such as gaseous chromatography, high performance liquid chromatography and mass spectrometry, diffused through several universities, some of these out of the Rio-São Paulo area. It should also be emphasized that qualified researchers and modern analytical instruments are also available in R&D centers located in private enterprises. The PETROBRAS research center (CENPES) is considered a center of excellence in organic geochemistry, representing a reference for Latin America as a whole. Researchers from CENPES have frequently assisted international oil companies operating on the continent.

On the other hand, there is no clear evidence that Brazilian analytical chemistry has significantly benefited from the new opportunities generated by the many and rapid advances in genomics, proteomics and correlate activities.

Electrochemistry

Electrochemistry is one of the best consolidated areas of Brazilian chemistry and one of the closest to the international state of the art. The number of electrochemists with international projection is high, regarding those dedicated to theoretical aspects as well as those dedicated to practical aspects of the discipline. The most important research areas are: corrosion; electrodeposition and surface treatment; development and performance of new electrodes; and fundamental aspects of electrochemistry[7].

The electrochemical community has regularly organized the Brazilian Symposium of Electrochemistry and Electroanalysis. This last one was held in Porto Alegre, Rio Grande do Sul, in 2001. In this community, there is a strong commitment to topics that today mobilize researchers worldwide: fuel cells, new “green” batteries and solid electrolytes.

Materials chemistry

Materials chemistry has presented a notable development in the last 15 years. One of the factors that contributed to this growth was the establishment of the Brazilian Synchrotron Light Laboratory, which has made working conditions not found in any other Latin American laboratory available to national and international research groups.

This area contains groups with high levels of excellence developing activities and original themes in several regions of the country, in a fashion comparable to that developed by researchers working in the best laboratories in the United States and Europe[8]. A significant interchange involving researchers in universities and private enterprises also occurs. As a result, high technology products have already been developed and placed on the national and international markets.

The progress and perspectives of new materials, focusing the chemical area, can be seen in an excellent article by Galembeck[9].

Chemistry of natural products

Chemistry of natural products is the subarea that has the largest number of researchers in Brazilian chemistry as a whole.

The major activities in Brazilian chemistry of natural products are currently guided to the description of new products from the country's rich plant biodiversity. This basic research activity is responsible for professional capacity building and for the maintenance of this most traditional school. With the modern techniques of structural determination (NMR and MS) that also make possible the analysis of complex mixtures, access to structural diversity has been increasing rapidly. In addition, studies related to the biological activity of extracts obtained from plants, medicinal or not, have also been increasing. Therefore, Brazil's competitive advantage due to its huge biodiversity, which can facilitate access to a larger slice of the pharmaceutical and neutrocytic markets, today is one of its major challenges.

On the other hand, the major phytochemistry periodicals have been changing their editorial policies, privileging articles involving biosynthesis, regulation, molecular biology, biologic activity and correlated subjects, and considering articles dedicated to structural description commonplace. Consequently, articles on classic phytochemistry have played a minor role in raising citation indexes. As a result, most publications in the area of chemistry of natural products, both national and international, have become of secondary importance.

A sharp diagnosis, that may well indicate the trends of research related to chemistry of natural products in Brazil, may be obtained by comparing papers presented at the Annual Meetings of the Brazilian Chemical Society, Division of Chemistry of Natural Products, and those presented at the Annual Meetings of the Phytochemical Society of North America (PSNA). The theme of the last reunion was *Phytochemistry in the genomics and post-genomics era*, and the great majority of the papers presented reflected the great advances in the techniques and how this dominion is being used in the study of secondary metabolism. In a general view, the papers were dedicated to the comprehension of a complete biological system through the dominion of simultaneous expression techniques of the set of genes (DNA microarrays) (transcriptome), through the analysis of codified proteins (2-DEPAGE and MALDI-TOF/MS)(proteome), and through the obtainment of the profiles of the secondary metabolites (metabolome). Nothing could be more presumable, considering that the biosynthesis of the secondary metabolites is regulated by the genic expression. These profiles have been obtained by means of high efficiency multidimensional techniques, such as GC/MS and CLAE/MS; techniques that are available at many Brazilian laboratories. In this manner, certain genes and enzymes have been associated in the composition of specific secondary metabolites, in a determined biosynthetic path. It is expected that such results might be applied to agriculture, to the study of plant physiology, to ecology, and to the study of transgenic plants. In this manner, a surprising perspective is observed, contrary to the expected polarization between the genomic era and the classic phytochemical activity.

Another important observation is that, in the United States, financial resources for research in the area of natural products does not cover exclusive phytochemical studies, obviously because the continent's biodiversity would not justify such investments. However, due to the explosion in the use of phytotherapics, considered nutritional complements that are increasingly gaining space both in economy and health, huge investments are now being made to appraise the efficiency of such products through the development of methodologies that guarantee consumption security.

In Brazil, the advances in the field of genomics have been expressive, since the complete sequencing of the *Xylella fastidiosa* (bacterium responsible for the citrus variegated chlorosis) and the *Xanthomonas citri* (responsible for the citric canker genomes), which were the first to be described. The political decision to finance the dominion of modern biotechnological techniques generated an extremely positive global impact. Today, the beginning of programs related to the proteome is largely expected. Considering the world trends, we shall certainly complement this cycle of studies through investments in the metabolome phase. The question is when will this be initiated and what the demands on human and financial resources will be. How will teams of specialists be grouped on a central research theme and what are the problems to be faced?

The great expectation in the research of chemistry of natural products is the establishment of multidisciplinary programs that, based on the use of the installed capacity, work towards the solution of national problems. The focus should cover the study of aspects of biodiversity associated to the search for solutions to problems such as tropical diseases, agricultural pests, and other global evils such as cancer, AIDS, etc. This objective cannot be achieved without the efficient study of the action mechanisms of products with biological activity. Thus, the country also relies on specialists in crystallography and molecular modeling that are involved in the study of active enzyme sites and in rational planning of pharmaceuticals. The redirectioning of research activities in correlate areas may be obtained through political decisions, planning and medium and long term investments. Interchanges with other labs both national and foreign is of extreme importance, to build centers dedicated to carry out specific tasks. The country and its scientific community today have the necessary qualifications for this new stage. The challenge is to seek, in the genome-proteome-metabolome perspective, a research model that generates results in favor of society's needs.

The chemistry of natural products community and the Nuclear Magnetic Resonance Users' Association (AUREMN) are greatly responsible for the explosion of the NMR technique in Brazil. Thanks mostly to AUREMN, which has brought to the country the world's most outstanding NMR specialists, Brazil today has research groups covering almost all of the major subareas using NMR: physics, biochemistry, images and *in vivo.* Brazil incontestably holds the leading position in NMR research in Latin America[10].

In the field of chemistry of natural products of marine organisms, there is a consolidation of groups coordinated by young promising researchers. The research lines developed by these groups aim at the discovery of active biological substances, in different bioassays (anti-carcinogen, bacteria against microorganisms resistant to antibiotics, anti-inflammatories) and of substances with environmental implications, such as anti-foulings.

Thanks to the talent and remarkable contributions of Professor Otto Gottlieb in eco-geography and evolution and taxonomy of secondary metabolites from plants, Brazil finds itself on the cutting edge of knowledge in the development of original methods of phytochemistry and quantitative biodiversity, fields of enormous importance to the understanding of nature's patterns and functioning mechanisms.

Organic Synthesis

Organic synthesis first appeared very modestly in Brazil in the 1950's, at the University of Sâo Paulo (USP). The first pioneer studies in the area of organic chemistry of selenium and tellurium compounds were, on the occasion, considered mere curiosities, since nothing was known about them.

Several of the reactions discovered by the Chemical Institute of USP may be today found in any synthetic organic chemistry compendium. An example is the selenium cycling of unsaturated substrates[11].

Brazil presently has an active and internationally competitive community of synthetic organic chemists, which is still small considering the country's demands.

Although there are only a few consolidated groups, these publish their papers in the most important periodicals in the area and are recognized by their fellows abroad[12].

Photochemistry

Among the new research lines in photochemistry, we here emphasize the studies on kinetic processes with electronic situations stimulated by high temporal resolution, allied with a spatial resolution. In this research line are included studies on natural and artificial nanoscopic systems, such as polymer particles, metals, oxides, supramolecular systems, colloids, proteins, photosynthesis reaction centers, and biological photoreceptors. Of strategic interest in this line is the research on photo inducted processes with energy and charge transfer (electron or proton), isomerization, and generation and reaction of chemical radicals. Thus, the photochemistry area has become a part of the broad research theme of nanotechnology, and the photobiology area becomes important for future advances in biotechnology.

An important aspect for the development of these new areas is the use of refined experimental techniques, such as confocal microscopy and near-field optic microscopy, usually connected to temporal methods such as fluorescence by ultrafast laser pulses. Transient measurements by absorption or interference, and the fluorescence over-conversion technique make possible the study of molecular processes with picseconds resolution.

Currently, there are several research groups on photochemistry and photobiology in Brazil (approximately 12 groups). Research on photophysics and photochemistry cover topics related to organic and inorganic chemistry, biochemistry, polymers and colloids. Applied studies include research on solar energy conversion cells, photopolymerization, photodynamic therapy, etc.

In spite of the range of themes and of the qualification obtained in several of the mentioned areas, Brazil is still behind in research in the areas of photochemistry and photobiology, particularly in what is related to the new techniques and methodologies formerly mentioned. It would be very positive to develop research on solid photochemistry and asymmetrical photoreactions, on photochemical reactions on ordered surfaces, on spectroscopy and monomolecular photochemistry, and on non-linear molecular stimulation methods (absorption of two photons and dynamics of superior stimulated phases).

CONCLUSIONS

Chemistry is the field of knowledge has developed the most in Brazil during the last decade, both in quantity and quality. The evolution of the area can be measured by all the available indicators: number of research directories of CNPq; number of qualified graduate courses; number of PhD students; number of PhDs; quality of the scientific production; and, most important, quality and acceptance of the publications published in the country with international circulation. In any case, there is still a critical aspect that must be pointed out: the little support given by the industry to science and technology. Brazil, a country so prodigious in copying and importing models, lack men like John D. Rockefeller, George Eastman, Pierre du Pont and others, who greatly contributed to the development of basic education, universities, science and arts in the United States, leading the nation to assume the leadership position it holds today.

The leap to the future depends on more investments in S&T, in quantities much superior to the current level.

If Brazilian PhDs currently received the same level of endowments that they received during the 70's, the country would presently find itself among the ten nations with the highest scientific production. Nevertheless, if this is not accompanied by social policies, Brazil will not overcome its underdevelopment problem. FAPESP has shown the way, leading the State of São Paulo to the summit of Brazil's science. The distance separating São Paulo from other states is equal or superior to that separating Brazil from the industrialized countries.

RECCOMENDATIONS

1. Stimulate full graduate studies abroad, in English speaking countries, in the best universities. In the United Kingdom: Cambridge, Oxford, and Imperial College; in the United States: these include Harvard, MIT, Stanford, Berkeley and Caltech;

2. Amplification of programs supporting young PhDs, such as the one recently launched by the CNPq (Profix);

3. Development of a federal program supporting partnerships between the private and public sectors (as the Partnership for Technological Development Program established by the government of the State of São Paulo – FAPESP, in state research institutes);

4. Interrupt the historical series model, adopted by CNPq, that does not allow the increase in research productivity scholarships for fields with a performance much superior to other traditional areas that have dominated dominate the system since its implementation;

5. Increase the number of research productivity scholarships, granted by CNPq. These make up one of the most important instruments that greatly stimulate Brazilian science. Due to the poor wages paid today to university professors, many rely on these to complement their income. To keep scholarships, research have been transformed into routine activities in order to maintain high publication index. Chemistry was one of the most penalized areas in the last 10 years. Although it greatly increased in size, it still has the same number of scholarships that it had a decade ago.

6. Instigate the association of chemistry with the biological and health sciences, for at the solution of the great enigmas of science. This is an international trend.

7. Reward patent registering, both national and foreign. This is not done currently in Brazil.

8. Guarantee funding to the scientific periodicals in the chemistry area, especially those indexed to the Institute.

BIBLIOGRAPHIC REFERENCES

1. J. M. Riveros “Química”, em A Capacitação Brasileira para a Pesquisa Científica e Tecnológica, S. Schwartzman (org.), FGV (1996).

2. F. Galembeck “Chemical Sciences” em Science in Brazil an Overview, Academia Brasileira de Ciências (1999).

3. L. A. Barreto e E. Prescott “O Impacto do PADCT na Química e Engenharia Química”, Quim. Nova 20, 15 (1997).

4. T. J. Brocksom e J. B. de Andrade “A Evolução da Pós-Graduação em Química no Brasil”, Quim. Nova 20, 29 (1997).

5. A. A. S. da Gama, F. J. Nome and J. C. Machado “Avaliação dos Programas de Pós-Graduação em Química no Brasil”, Quim. Nova 22, 443 (1999).

6. J. A. Nóbrega, E. A. Neves, F. R. P. Rocha, P. O. Luccas, P. V. Oliveira e S. T. Gouveia “Panorama da Química Analítica Brasileira: 1974 -1994”, Quim. Nova 19, 684 (1996).

7. L. A. Avaca, O. P. Márquez e B. R. Scharifker “Editorial”, J. Braz. Chem. Soc. 8 (1997).

8. I. S. Moreira, personal communication.

9. O. L. Alves “Química de Materiais no Brasil: Um Olhar Através das Reuniões Anuais da Sociedade Brasileira de Química”, Quim. Nova 21, 807 (1998).

10. F. Galembeck “Materiais: Progressos e Perspectivas” em A Importância da Ciência Para o Desenvolvimento Nacional, Academia Brasileira de Ciências (1997).

11. S. M. C. de Menezes “editorial”, J. Braz. Chem. Soc. 10, (1999).

12. M. M. Campos and N. Petragnani “Selenocyclization of Unsaturated Substrates”, Chem. Ber. 93, 317 (1960).

13. J. V. Comasseto, R. A. Pilli and F. Simonelli “Editorial”, J. Braz. Chem. Soc. 12 (2001).

14. M.H. Gehlen, personal communication.

Note: The Brazilian chemical society publish in its 25th (July 2002) year commemorative edition of *Química Nova*, articles about the different areas of chemistry specialization throughout Brazil.

AUTHORS

Angelo da Cunha Pinto *(coordinator)*

Member of the Brazilian Academy of Sciences; PhD in Chemistry from the Federal University of Rio de Janeiro (UFRJ); and professor at the Chemical Institute of the same university.

Alfredo Arnóbio S. da Gama

Coordinator of the Chemistry area of CAPES and professor at the Fundamental Chemistry Department of the Federal University of Pernambuco (UFPE).

Elias Ayres Guidetti Zagatto

Member of the Brazilian Academy of Sciences; PhD in Analytical Chemistry from the University of Campinas (UNICAMP); and professor at the Center for Nuclear Energy in Agriculture of the University of São Paulo (USP).

Massuo J. Kato

Professor at the University of São Paulo (USP).

Area of Health Sciences

MARCO ANTONIO ZAGO
JAIR J. MARI
JOSÉ DA ROCHA CARVALHEIRO
LUIS JACINTHO DA SILVA
PROTÁSIO LEMOS DA LUZ

INTRODUCTION

The evaluation of the state of medical research in the country and the identification of priorities shall take into consideration the special situation of the medical research system. First of all, there is an overlapping or a lack of clear limits regarding the disciplines that constitute the knowledge nucleus of medicine. Diverging from other sciences, which have their own disciplinary domain, medicine is a learned profession supported by sciences (morphology, biochemistry, genetics, immunology, physiology, pharmacology, among others). We will try to focus our attention mainly at the medical research related to applied medicine (clinical, surgical and collective health), but the overlapping with other areas, especially biomedicine, is inevitable and necessary. On the other hand, from the practical point of view, medical research is developed in close association with education (undergraduate and graduate) and with medical practice in large institutions, along with a few biomedical research institutes.

Thus, it is difficult to make an appraisal of the knowledge production system in medicine in the country, so we will limit ourselves to some of the most relevant topics, such as the interaction with the undergraduate and graduate education, and with the planning and management of public health, seeking the identification of the main centers of medical research, of the situation of medical research in the country and of the priority points for intervention.

Interaction with Undergraduate Education

The country counts with 95 medical schools, which train about 9,300 doctors annually and are strongly concentrated in the South and Southeast Regions (Table 1). Only a small number of these schools constitute consolidated medical research centers, identified by the existence of a group of researchers with a PhD title, who publish regularly in well-recognized peer-reviewed scientific journals and who train other researchers. Only eight of the medical schools, which can be identified as large centers of scientific research generation in the medical area, concentrate 115 of the 128 level I researchers of CNPq* in the area of medicine, (90%) or 133 of the 175 researchers in the areas of medicine, collective health and nutrition (76%). The remaining 42 researchers are in nine other medical schools and two health institutions (Oswaldo Cruz Foundation and the School of Public Health of USP*) (Table 2). Thus, only 16 out of the country's 95 medical schools, have evidence of consolidated scientific research activity.

Considering the training role that research and the scientific method play on the education of a doctor, we concluded that a large part of the Brazilian doctors is educated at the periphery of this system, not being prepared to lead or at least to follow and assimilate the innovations in the health sector, which are associated to scientific development. In this aspect, innovation and scientific and technological progress are extremely dependent of a qualitative improvement of medical education, which cannot be dissociated from scientific training and knowledge generation.

■ **TABLE 1**

DISTRIBUTION OF THE MEDICAL SCHOOLS AND OF ANNUALLY GRADUATED MDS IN THE DIFFERENT REGIONS OF THE COUNTRY.

Region	Medical Schools	MDs per year	Population	Inhabitants per graduated MD
South	21	1.619	25.089.783	15.497
Southeast	50	5.463	72.297.351	13.234
Center-West	5	382	12.772.658	33.436
Northeast	15	1.532	47.693.253	31.131
North	4	353	11.737.648	33.325
Total	**95**	**9.349**	**169.590.693**	**18.140**

** CNPq: National Research Council*
** USP: University of S. Paulo*

■ TABLE 2

DISTRIBUTION OF LEVEL I RESEARCHERS FROM CNPQ IN THE AREAS OF MEDICINE, COLLECTIVE HEALTH AND NUTRITION IN MEDICAL SCHOOLS OR MEDICAL RESEARCH INSTITUTES.

More than 10 level I scholarship receivers from CNPq
Escola Paulista de Medicina (Unifesp), FM da USP (S. Paulo), FM de Ribeirão Preto da USP, FM da UFMG, Fundação Oswaldo Cruz, FM da UFRJ
Between 5 and 10 level I scholarship receivers from CNPq
FCM da Unicamp (Campinas), Faculdade de Saúde Pública da USP, FM da UFRGS, FM da UFBA, FM de Botucatu (Unesp), Universidade de Brasília
Between 1 and 5 level I scholarship receivers from CNPq
FM da FFFCMPA/RS, FM de SJ Rio Preto, FMTM (Uberaba), FM da UFBA, UFPE, UFRN, UF Fluminense, UF Pelotas

Interaction with Graduate Education

Graduate education, even more than undergraduate, is solidly associated to research, since the implementation and the maintenance of a graduate program demand a group of advisers with a PhD title, and the diploma of each graduate can only be earned through the accomplishment of research work. Even though, in many programs there is a strong influence of professional education and medical specialization, contributing to stray them from their basic focus: the production of research and the qualification of researchers. Of the 178 graduate programs that earned grades of 4-7 in the last national evaluation done by CAPES*, 154 (87%) are in the same 12 institutions that have more than five level I researchers of CNPq in the areas of medicine, collective health or nutrition.

The scenario in this case is also mixed: it shows a group of institutions that are implementing a policy of research incentive associated with the training of researchers, while more than half of the graduate courses in the medical area are far from fulfilling their central function, focusing in many cases on professional training. The correction of this deviation by combining a restriction policy to those programs that do not satisfy the minimum requirements, with an incentive to those that seek to fulfill the goals of intensifying research, could have great impact on the increase of scientific efficiency in the medical area.

* *CAPES: Office of the Ministry of Education responsible for authorization and evaluation of graduate programs.*

Scientific Production in the Medical Area

The scientific production in the medical area grew proportionally more than Brazilian science as a whole in the last 20 years: the total of publications of the medical area, which amounted 10-11% of the 2,930 annual Brazilian publications in the biennium of 1981-82, grew to 19% of the 13,232 publications on the year 2000; in other words, a growth by a factor of 7.6, well above the growth of scientific production as a whole in the country, which was of 4.5. This number was surpassed only by engineering, which grew by a factor of 8.5. The quality evaluation indexes also show an increase, however less prominent: in the biennium of 1981-1982 the medical publications were responsible for 11% of the 3,087 to 3,540 annual citations on Brazilian articles, while in 1998 this value rose to 14.3% of the 25,301 citations. The growth in the production of scientific articles in all areas of Brazilian science was followed by variable increases of their net impact, which ranged from 1.05-1.21 citations/article in the biennium of 1981-82 to 2.16 citations/article in 1998. In this period, the impact of the publications in the medical area had an intermediary evolution when compared to the other areas of science, rising from 1.16-1.22 citations/article to 1.87 citations/article, an inferior performance to those of chemistry and biomedicine, but superior to engineering and human sciences.

■ **TABLE 3**

PROPORTIONAL GROWTH OF THE NUMBER OF FULL ARTICLES IN THE YEARS OF 1999-00 (899 ARTICLES/YEAR) IN COMPARISON TO THE QUINQUENNIUM OF 1981-85 (222 FULL ARTICLES/YEAR), CLASSIFIED BY AREA OF KNOWLEDGE WITHIN MEDICINE.

Hematology	**16,4**	**Cardiovascular e Respiratory**	**7,0**
Dental Medicine	13,8	Endocrinology and Metabolism	5,1
Rheumatology	13,5	Dermatology	5,0
Oncology	11,7	Reproductive Medicine	4,5
Clinical and Infectious Immunology	9,3	*Global Average*	*4,0*
Neurology	9,2	Surgery	3,2
Clinical Psychology and Psychiatry	8,8	Psychiatry	3,2
Ophthalmology	8,7	Orthopedics and Rehabilitation	2,2
Gastroenterology and Hepatology	7,6	Environmental Medicine and Public Health	2,0
Pediatrics	7,2	General and Intern Medicine	0,4
		Health Services	-

An analysis of the average production by area of knowledge, taking into consideration only full articles, shows a proportional growth of fourfold in the number of yearly published articles, when we compare the years of 1999-00 with the 1981-85 period (Table 3). The largest increases in the number of articles occurred in the areas of hematology, dental medicine, rheumatology and oncology. Smaller growth occurred in the areas of surgery, psychiatry, orthopedics and rehabilitation, environmental medicine and public health, and general and internal medicine, indicating a reduction of the expression of these areas within the medical group, but only the latter presented a reduction in the number of articles, which dropped in average from 64 to 38 articles per year.

Interaction with the Planning and Management of Public Health

- Planning and Management

  Medical research cannot be dissociated from its practical consequence, the transfer of knowledge to the well-being of the population. To approach the issue of well-being (physical, mental and social) and of the problems (individual and collective) is equivalent to enter the discussion on the concepts of health and illness, which nowadays do not have an absolute meaning, being substituted by a concept of health/illness process (H/I). Furthermore, it is considered that this complex relationship between health and illness is strongly influenced by the nature of the "cares" given (to the ill and the healthy!), which leads to the current idea of health/illness/care (H/I/C)[1]. The proposals for individual and collective intervention (the "cares") should be analyzed from a cost/benefit point of view, individual and social. We are not referring only to the economic and financial costs directly associated to the actions, even though this has been a strong tendency from at least the beginning of the 1990s.

  These ideas are not recent. From the middle of the XX century, authors with high international prestige have paved the way to identify the progress in three interconnected fields of the efforts of science in the health area: identify in an increasingly precise manner the individual and collective "problems"; search intensely for the possible "answers", also individual and collective; and the "social organization" of these answers. The latter is necessarily collective: even to organize individual attention in order to solve problems of single individuals is a collective endeavor[2,3].

The organization and operation of the services demand the ability to deal with administrative processes. Although this is essential, it cannot lack the crucial complement of the political meaning of the process. This issue is on the agenda at every moment, as when, for instance, the government is held responsible for the difficulties in the management of the health system. The attempts of public administration of escaping this charge have caused one of the main clashes in the area, materialized on the perennial criticism to the creation of alternatives: direct management by the government, autarchies, public and private foundations, mixed companies, social organizations.

Whatever may be the administrative model, the current complexity demands for an effort on action planning. According to various authors, an authoritarian and centralized logic consists in planning in a normative way at the central level of the health system, leaving the execution to the services network (central normativeness and decentralized execution). A more participatory proposal is the one of strategic planning (situational) which occurs in all levels of the system, in a strong interaction between the technical and administrative powers. The political power is another element of the tripod. Generally, the decision making is based on contributions from the administrative and technical spheres; however, the final decisions are eminently political. This is a research area that has advanced intensely in the last few years, specially in the production presented in scientific congresses of the area of collective health. There are international research networks entirely dedicated to the issue of formulating health policies and to the research models in health services and systems[4].

■ Recent movements: the Global Forum and the "gap" 10/90

From at least the mid 1990's there has been an incessant international effort to discuss the issue of organizing a "necessary agenda" of research to be offered to a Third World that is eager to develop itself. In the ambit of the nations, the efforts should take into account the necessities related to health, hindered from the point of view of economic development in its intimate relations with the well-being of the peoples.

With regards to health, there is an international movement that seeks to redeem the debt with the Third World through R&D, starting from the idea that more than US$ 60 billion are annually employed by the public and private sectors worldwide on health research. Of these vast financial resources, only

10% are destined to research on diseases that affect 90% of humanity. This gap on health research is abbreviated as “gap 10/90”. To defeat this gap is a task that the Global Forum for Health Research, headquartered in Geneva[5] and important motivator of the debate in this controversial area, intends to do. The situation is not so simple, in view of what is identified as the “uncompleted agenda” and as the “double burden” of the developing countries, which still have not solved the traditional health problems tied to transmittable diseases and have already began to see themselves affected by the “modern” problems of chronic degenerative diseases and external causes, specially the ones due to urban violence. The motto of the Global Forum gives a clear idea of its objectives: “To Promote Research in order to Improve the Health of the Poor”. One of its efforts is focused on the discussion about the advantages of the various methodologies proposed in order to identify the research priorities in a given context (regarding the case in question, adequate to the Third World). Recognizing that various approaches are not contradictory, but complementary, it presents an “eclectic model” that takes advantage of the best of each approach. Whatever may be the recommended method to identify the research priorities, it will be inevitably associated to some procedure that establishes the list of the main health problems. Predictably, the various methods identify very similar priority lists, which end up considered (as a whole) as “the list” suitable to stimulate research that serves to “improve the health of the poor”.

■ “Burden of Disease”, a proposal that is gaining strength: the necessity hierarchy.

It the middle of the XX Century, the “Health Indicators” constituted a special chapter in all the didactic texts on epidemiology, life statistics and public health. On recurring logical contradiction, death is the event that is mostly used as a way to measure the state of health. If death is a singular and individual event, its collective equivalent, mortality, refers to the population group in focus. This dialectic character of the averages (in this case, a coefficient) was well explored by the philosopher Álvaro Vieira Pinto in his classic work *Ciência e existência* (*Science and existence*), of 1969. General mortality, child mortality, maternal mortality, life expectancy, the proportional mortality index of Swaroop & Uemura, the mortality curve of Nelson Moraes and its qualification of Guedes & Guedes are all measures of the collective situation of a population group, associated to the death of those who compose that group. Synthetic indexes have an important place in health sciences, and their identification has been a permanent aspiration of the professionals of the area. "Life expectancy at birth" has already been announced as such, having been supplanted by more current proposals such as "the days of active life lost due to disease and to incapacitations in general".

One of the ways to present the more relevant necessities consists on identifying the main health problems through a system of indicators. The principles that fundament the election process of research priorities and of health actions are not unanimous. Besides the incidence of diseases, it should also be taken into consideration its "vulnerability", or the intervention capacity of the health system "which would allow *a priori* a greater prevention of deaths at a lower cost"[6]. There is a recent proposal of employing a special methodology, capable of determining the "burden of disease", which emerged in the current health scenario through the influence of the economist segment and in virtue of the preoccupation of the health sector with costs and effectiveness. The World Bank, in its 1993 Annual Report *Investing in Health* notably influenced the introduction of this detailed methodology[7]. On the development of these ideas, it is considered that countries like Brazil have an uncompleted agenda (lack of control of transmittable diseases) and deal with a "double burden" because the chronic degenerative diseases already reach them with an even higher incidence than most of the infectious diseases.

■ The health agendas

The most important current example that can be understood as a process of formulation of the main topics for the health debate is given by the United States with their program Healthy People 2010 (Healthy People 2010)[8], explicitly considered as an "agenda for prevention": "Healthy People 2010 is the prevention agenda for the Nation. It is a statement of national health objectives designed to identify the most significant preventable threats to health and to establish national goals and reduce these threats".

It constituted a group of objectives to be reached by the United States in the first decade of this century, based on two previous publications, edited with a twenty year interval that served as a reference for the development of state and local plans. The agenda was built through a wide consultation process and founded on the most solid scientific knowledge. The agenda Healthy People 2010 has only two dominant goals: 1st to increase the duration of healthy life; 2nd to eliminate the disparities in health. It concentrates the proposals in 28 focal areas, listed on Table 4.

Complementarily, to follow the Nation's "State of Health", only 10 indicators were chosen: 1. Physical Activity, 2. Overweight and Obesity, 3. Tobacco Use, 4. Substance Abuse, 5. Responsible Sexual Behavior, 6. Mental Health, 7. Injury and Violence, 8. Environmental Quality, 9. Immunization, 10. Access to Health Care.

Its major use resides on the multiplicity of groups that make of this agenda an instrument for health improvement; for instance, the National Institutes of Health and other research support agencies started to require that those submitting a grant request explicitly indicate in which item the request fit within the goals of this agenda. The history and the development process of this agenda were remarkable for the wide participation: hundreds of institutions and thousands of people contributed to the process.

This agenda from the United States serves as an example of how a collaborative process for the elaboration of goals that has progressively improved can be conducted seriously. In an inquiry done in 1993, it was observed that 70% of the local health departments had employed "at least some" of the objectives of the Healthy People 2000. Since the announcement of Healthy People 2010, many North American states began to develop their own versions of the agenda.

■ **TABLE 4**

FOCAL AREAS OF HEALTHY PEOPLE 2010

Access to quality health services	Injury and violence prevention
Arthritis, osteoporosis, and chronic back conditions	Maternal, infant, and child health
Cancer	Medical product safety
Chronic kidney disease	Mental health and mental illness
Diabetes	Nutrition and overweight
Disability and secondary conditions	Occupational safety and health
Educational and community-based programs	Oral health
Environmental health	Physical fitness and activity
Family planning	Public health infrastructure
Food safety	Respiratory diseases
Health communication	Sexually transmitted diseases
Heart disease and stroke	Substance abuse
HIV	Tobacco use
Immunization and infectious diseases	Vision and hearing

Medical Research Centers

Table 5 lists the main medical research centers in the country. They are responsible for more than 80% of the publications in the medical area (and a large part of what qualifies as Biomedical), house more than 80% of the level I CNPq scholarship receivers in medicine and collective health, and concentrate more than 80% of the medical graduate courses with a grade from CAPES equal or higher than 5. Many are complex institutions that associate university education, laboratories and research centers as well as highly differentiated hospital groups, comparable to the best medical research centers in the world. This evaluation only considered the centers dedicated to applied research (medical or public health) or that have a mixed character, but the centers or institutes that are predominantly dedicated to basic research were excluded.

A common characteristic to them is that they are all public institutions (directly managed by the government, autarchies or foundations that are essentially maintained with public funds); there is only one case of a private institution with significant scientific production. However, it must be recognized that there exists a number private institutions that concentrate large numbers of highly qualified medical and support professionals, that have high quality infrastructure and equipment and that could increase their participation in medical research if they received incentives on that direction and were willing to change their way of working.

Furthermore, it is possible to identify numerous institutions that are going through the organization stage of their process of productive research. A challenge of joint planning among interested institutions and government organs (CNPq, MCT, CAPES), regional and state support foundations is the establishment of mechanisms that allow for the incorporation of these institutions into the permanent scientific and technological productive process in the health area.

In general, when the large network of university hospitals in the country is considered, the number of medical research centers that are recognizable for their significant quantitative and qualitative scientific production is still small. The physical and infrastructural restoration of these hospitals, if accompanied by the remodeling of the research groups associated to them, can serve as the basis for the expansion on the number of medical research centers in the country.

■ TABLE 5

MAIN MEDICAL RESEARCH CENTERS IN THE COUNTRY

Escola Paulista de Medicina da Universidade Federal de São Paulo
Faculdade de Medicina da Universidade de São Paulo (including the Instituto do Coração)
Faculdade de Medicina de Ribeirão Preto da Universidade de São Paulo
Fundação Oswaldo Cruz
Faculdade de Medicina da Universidade Federal de Minas Gerais
Faculdade de Medicina da Universidade Federal do Rio de Janeiro
Faculdade de Medicina da Universidade Federal do Rio Grande do Sul
Faculdade de Ciências Médicas da Universidade Estadual de Campinas
Faculdade de Saúde Pública da Universidade de São Paulo
Faculdade de Medicina de Botucatu da Universidade Estadual Paulista
Faculdade de Medicina da Universidade Federal da Bahia
Instituto Ludwig de Pesquisas sobre o Câncer e Fundação Antonio Prudente

Broad Thematic Areas: Current State and Perspectives

The epidemiological profile of the country clearly places it within the category that the Global Forum for Health Research[9] classifies as double burden. The epidemiological profile that is characteristic of richer countries (prevalence of non transmittable diseases) is predominant in large regions of the country, which include the majority of the large urban centers and a large part of the South and Southeast Regions; however, in other regions, but also living in the large urban centers, are large populations with an epidemiological profile that is characteristic of poor countries, where infectious diseases, perinatal, birth and maternal conditions and those derived from malnutrition preponderate. This scenario is even more complex because there is not an exclusively geographic separation of the two epidemiological profiles, but the populations affected by both patterns have a complex distribution that is geographic and tied to the socioeconomic profile at the same time. Finally, the health grievances derived from the “third” epidemiological profile affect indifferently the two previous groups: alcoholism, drug addiction, urban and rural violence, accidents and pollution. In general, the evaluation through mortality causes shows a profile where the chronic degenerative and non-transmittable diseases are predominant.

■ **TABLE 6**

MAIN CAUSES OF DEATH IN BRAZIL, IN 1998 (SOURCE: MINISTRY OF HEALTH)

Disease Group	Percentage
Cardiocirculatory	27.6 %
External Causes	12.7 %
Neoplasias	11.9 %
Respiratory Diseases	9.9 %
Infectious Parasitic Diseases	5.2 %
Other causes	32.7 %

The evaluation of the medical research conditions and a projection of priorities demand a clear distinction between the health system and the social welfare system. In spite of the interactions between them, major health problems resulting from the lack of sanitation, of education or resulting from misery and unemployment, cannot be solved by medical or social research. Instead, they need to be solved by government actions oriented by long-term policies, or institutional actions, predominantly (but not exclusively) public.

Probably the key element in the planning of our scientific development in the medical area shall be to reinforce the necessity of acquiring our own experience: Brazil needs to obtain its own data, formulate its own policies and solve the country's specific problems. We should follow this principle in whatever field of action.

Geriatrics and Gerontology

Social and economic development, improvement of basic sanitation, of nourishment and of education, associated with the evolution in medicine have significantly raised the average life expectancy. In Brazil, life expectancy at birth has undergone a significant increase, going from 33.7 years in 1900 to 63.5 years in 1980[10]. Mortality reduction, especially in the higher age groups (above 60 years old) and the decrease of fecundity resulted in a relative and absolute increase in the elder population, which started to become more apparent in 1960. As a consequence, the number of people with more than 80 years of age is growing within the general population, constituting the so called "fourth age". From 1900 to 2025 the Brazilian population will have been multiplied by five and the segment of people with more than 60 years of age will have their number multiplied by 15, making Brazil go from 16th (in 1950) to the 6th place in the world (in 2025) in the absolute number of people with more than 60 years of age or more, when one in every seven Brazilians will be a part of the elder contingent of the population and we will have a life expectancy at birth of approximately 73 years of age (Table 7).

■ **TABLE 7**

EVOLUTION OF LIFE EXPECTANCY AT BIRTH AND OF THE PROPORTION OF PEOPLE WITH 60 OR MORE YEARS OF AGE WITHIN THE BRAZILIAN POPULATION, FROM 1900 TO 2025

Year	Population with more than 60 years of age		Life expectancy at birth (in years)
	Number (x 1,000)	%	
1900	558.4	3.21	33.7
1920	1,234.2	4.03	34.5
1940	1,675.5	4.07	38.5
1960	3,313.6	4.73	55.9
1980	7,216.0	6.47	63.5
2000	14,352.0	8.00	68.6
2025	33,882.0	13.80	72.9

Source: IBGE 1986 and 1987

Another parameter that gives a dimension to population aging is the so called demographic transition, which is defined as the passage from a situation of high fecundity and mortality, in which there is a low proportion of elderly people, to a situation of low fecundity and mortality, with a high proportion of elderly people[11]. An important aspect that has been following population aging is the rapid growth of the group of the "very old"[12]. In Brazil, in the period from 1985 to 2000, it is expected a growth of 50% for the segment of 60 to 64 years old and of 80% for the segment of 75 to 79 years old. The estimated annual growth rate for the population over 75 years of age of some countries, including Brazil, in the period from 1985 to 2025 is 16 times larger than the estimate for the United Kingdom[13] (Table 8).

■ **TABLE 8**

ANNUAL GROWTH RATE (%) OF THE POPULATION WITH 75 YEARS OF AGE OR OLDER, FROM 1985 TO 2025

Countries	Annual Growth (%)
United Kingdom	0,25
Italy	1,56
Japan	3,36
Brazil	3,97

An epidemiological indicator of the socioeconomic consequences of population aging is morbidity. Some measurements of morbidity can be obtained through a consultation of the health services record, such as the coefficient of hospital releases and the average duration of hospitalizations, whose values increase significantly with the progress of age, reflecting an addition to the costs of health care associated to the population aging.

The high occurrence of chronic degenerative diseases in elderly people increases the use of hospital resources. For instance, from 1980 to 1995, in a large university hospital, there has been a decrease of 20% to 50% in the number of hospitalizations of patients within the age group of 0-30 years old and a concomitant increase of 140% to 205% in the number of hospitalizations of patients with more than 60 years of age[14]. The increasing use of hospital and outpatient health resources, which has serious and evident economic implications (already demonstrated in other countries), raises population aging to the condition of a serious public health problem. The correct way to approach these patients can only be achieved through the adequate training of professionals in the health area, and by giving incentive to research in themes related to aging, from the comprehension of its biological and molecular basis (such as dementias, alterations of the energy, protein and bone metabolism in the elderly, and cancer), to themes directly related with health care, the maintenance of the quality of life, of the autonomy and of the functions of everyday life.

Scientific development is more dependant of the progress in education and in functional qualification than in other areas of medicine. Practically unknown as an area of professional education until recently, the introduction of undergraduate and graduate courses in geriatrics and gerontology as part of medical education, and its inclusion in the medical residency programs, constitute important elements for the formation of a critical mass of professionals and researchers interested in the scientific development of the area.

The identification of priorities must take into consideration the weight of the different health problems among the elderly and the current research situation in geriatrics in the country. The epidemiological reports from the SUS* (2000) pointed to the diseases of the circulatory system, neoplasias and diseases of the respiratory system as the main causes of death and hospitalization after 60 years of age, between 1980 and 1996 (Table 9).

■ **TABLE 9**

HOSPITAL MORBIDITY (% OF THE TOTAL OF HOSPITALIZATIONS) AND PROPORTIONAL MORTALITY (% OF DEATHS DUE TO THAT CAUSE) BY DISEASE GROUPS, IN THE AGE GROUP ABOVE 60 YEARS OLD, IN THE YEAR OF 1999 (SOURCE DATASUS)

Disease group	Hospitalizations	Mortality
Respiratory system diseases	21.42%	15.45%
Circulatory system diseases	28.76%	45.51%
Digestive system diseases	9.95%	
Genital-Urinary system diseases	6.05%	
Infectious-parasitic diseases	5.80%	3.54%
Neoplasias	4.43%	16.57%
Lesions and poisoning	4.16%	3.20%
Mental disorders	2.05%	
Other causes	17.34%	15.73%

**SUS Sistema Único de Saúde: Brazilian Health Administration System*

The neurodegenerative diseases, including Alzheimer's disease and other dementias, in spite of not standing out in the statistics of hospitalizations, have an important prevalence in this age group, estimated in 5% at 65 years of age and doubling every five years thereafter. Medical education and health research still need to focus on the great geriatric syndromes like: urinary incontinence, falls, iatrogeny, homeostatic instability, acute confusional state, and metabolic alterations such as diabetes mellitus, malnutrition and osteoporosis.

In contraposition to its increasing importance as a public health problem, medical research in geriatrics is still incipient in Brazil. In general, epidemiological surveys and cohort studies are still predominant. The two extremes, represented by the basic research of aging mechanisms and their consequences from the cellular and molecular point of view on one hand, and the research about the organization of health assistance and services to improve the quality of life of the elder on the other, are still almost nonexistent. An indication of the immaturity of this sector is the existence of only two scholarship recipients whose research projects focus on the topics of geriatrics or gerontology among the 188 researchers in medicine of level I of CNPq in the areas of medicine, collective health and nutrition. However, there are research groups in various organization stages, but the total production is still qualitatively and quantitatively of little expression when compared to other countries, such as the United States, Japan and those of Europe.

From the previous analysis, we conclude that the expansion and the consolidation of geriatrics research in the country will depend on two approaches: a) education and training in all levels, such as the inclusion of geriatrics in the curriculum of medicine, expansion of the medical residency and of the graduate programs; b) positive action of the financing organs aiming at stimulating research in geriatrics and gerontology, particularly basic research and the kind of applied research that can yield practical results for the attention to the health of the elderly.

Within this perspective, some special research topics are stressed for the development of gerontology in the country:

- Biomolecular aging mechanisms, especially its the understanding of the process from the point of view of cellular and molecular biology and biochemistry;
- Energy, protein and bone metabolism in the elderly;
- Molecular biology, biochemistry and physiology of dementias;
- Studies on cardiovascular diseases, especially those related to arteriosclerosis, myocardial insufficiency and hypertension;

- Molecular bases and treatment of cancer;
- Indexes for measurement and factors that determine the quality of life;
- Autonomy and functional capacity maintenance;
- Instruments and scales for evaluations of the cognitive, functional, humor and other capabilities.

Mental Health

The epidemiological surveys carried out in the community in Brazil[15,16] point to an approximate prevalence of mental disorders of 30% of the adult population, in the period of one year (Table 10), while about 20%, or 1/5 of the adult population demands some kind of mental health attention in a 12 month period. Among women, the most common disorders are anxiety disorders (9.0%), somatophorme disorders (3.0%) and depressive disorders (2.6%). Among the male population, alcohol abuse shows up as the most important problem (8.0%), followed by anxiety disorders (4.3%). Thus, there is in the community a concentration of anxiety and depression in women and of alcohol abuse among men. The psychiatric disorders in the community are more common in the female population, increase with age and point to an excess in the low income stratum. The majority of the epidemiological surveys carried out in different countries to evaluate the magnitude and the nature of mental disorders in general practice[17] rate the prevalence of mental disorders between 27% and 48%. The median of the prevalence is about 25%, cases that have similar gravity to those of patients treated in specialized psychiatric outpatient clinics. The most frequent psychiatric disorders in general practice are minor psychiatric disorders: anxiety, depression and sematophorme disorders[18].

■ **TABLE 10**

PREVALENCE OF LIFE ADJUSTED BY AGE (LOP) AND ESTIMATE OF 1 YEAR PREVALENCE WITH POTENTIAL FOR TREATMENT (PNT), BASED ON DSMIII DIAGNOSES IN THREE METROPOLITAN AREAS OF BRAZIL (1990-1991).

Metropolitan Area	Brasília		São Paulo		Porto Alegre	
	LOP	PNT	LOP	PNT	LOP	PNT
Anxiety Disorders	17.6	12.1	10.6	6.9	9.6	5.40
Phobias	16.7	11.6	7.6	5.0	14.1	7.1
Somatophorme Diseases	8.1	5.8	2.8	1.9	4.8	2.8
Obsessive-Compulsive Disorders	0.7	0.5	-	-	2.1	1.2
Adaptation Disorders	2.0	1.3	0.6	0.4	1.6	1.0
Depressive states	2.8	1.5	1.9	1.3	10.2	6.7
Mania and cyclothymias	0.4	0.3	0.3	0.2	1.1	1.0
Psicoses	0.3	0.2	0.9	0.6	2.4	2.0
Alcohol abuse-dependency	8.0	4.7	7.6	4.3	9.2	8.7
Mental retardation	3.0	1.9	2.6	1.6	3.4	1.8
Total*	50.5	34.1	31.0	19.0	42.5	33.7

*The total of estimated cases does not correspond to the sum of prevalences per diagnostic due to the occurrence of co-morbidity (Table extracted form Almeida-Filho et al8).

■ **TABLE 11**

PREVALENCE OF THE CONSUMPTION OF PSYCHOTROPIC DRUGS PER ONE THOUSAND INHABITANTS, DURING A ONE YEAR PERIOD IN THE CITY OF SÃO PAULO IN 1990.

	Men		Women		Total	
	n	Index	n	Index	n	Index
Tranquilizers	39	46.2	101	112.6	140	80.4
Hypnotics	5	5.9	16	17.8	21	12.1
Antidepressant	1	1.9	4	4.5	5	2.9
Neuroleptics	2	2.7	3	3.3	5	2.9
Other	3	3.6	12	13.8	15	8.6
Total	49	58.0	128	142.3	177	101.6

The majority of these disorders is under the responsibility of the general practitioner, since only one in 20 psychiatric cases detected on primary care is referred to a specialist. This data is corroborated by the intake of psychotropic drugs by the population, which shows that more than 10% of the adult population uses some kind of psychotropic medication in the period of one year, being the prevalence larger in women than in men (14% vs. 5%) (Table 11). Other studies done in the community show the necessity for the physicians to develop better ability in identifying psychiatric cases, and that only 1/5 of the depression cases treated in the community received adequate care. Another study carried out in three primary care centers in the city of São Paulo comparing the level of real morbidity and the prevalence identified by the generalists, verified a loss between 22% and 79% of undiagnosed cases. This finding demonstrates the necessity for the physicians to undergo a better training to improve the ability of identifying psychiatric cases[20].

■ Economic and social costs of mental disorders

Taking the YLD (Years Lost for Disabilities) calculation as a basis, which estimates the period that a specific individual lives with a specific disability, we reach the diagnosis of the magnitude of the effect that mental disorders have on the general health of the population. Among the ten conditions that cause the greatest disability in the world (estimated by the YLDs), five are due to mental disorders: depression, alcohol abuse, schizophrenia, bipolar disorder and obsessive compulsive disorder[21] (Table 12). The increase in longevity and the improvement of the health indicators in the last few decades, have placed mental disorders among the five most important conditions of public health in Brazil (taking into account the direct costs and retirements due to disability), getting closer to cancer, cardiovascular diseases and infectious diseases.

■ **TABLE 12**

THE 10 CONDITIONS THAT CAUSE THE GREATEST DISABILITY IN THE WORLD, AS EVALUATED BY THE YLDS.

Cause	Total in US$ millions	%
Depression	50.8	10.7
Hypochromic Anemia	22.0	4.7
Falls	22.0	4.6
Alcohol	15.8	3.3
Chronic Obstructive Pulmonary Disease	14.7	3.1
Bipolar Disorder	14.1	3.0
Congenital Anomalies	13.5	2.9
Bone Arthritis	13.3	2.8
Schizophrenia	12.1	2.6
Obsessive Compulsive Disorder	10.2	2.2

A case that illustrates well the economic impact of mental disorders is schizophrenia, a serious psychotic disorder that affects about 1% of the adult population, having a prolonged course in 60% of the cases. In spite of its importance, there was no estimate of the cost of this disorder in Brazil. The study done by Leitão[22], that aimed at estimating the direct physician-hospital cost of schizophrenia to the public sector of the State of São Paulo, in 1998, concluded that there are 177 thousand patients with schizophrenia in the State*, of which approximately 81.5% are covered by SUS, distributed as follows: 3.7% are in temporary hospitalizations, 2.3% are in permanent hospitalizations, 23% are receiving ambulatory treatment and 71% are without regular treatment. The total direct cost of schizophrenia to the public sector, in the State, for the year of 1998, was of R$222 million†, of which 30.5% correspond to permanent hospitalizations (dwellers), 48.7% to other hospitalizations, 11% to ambulatory treatment and 9.8% to patients without regular treatment. Ambulatory treatment, which has been associated to a better quality of life for a lower-cost, received only approximately 11% of the resources allocated for the treatment of this disorder. Most of the direct costs of schizophrenia treatment fall upon municipal and state governments, since the federal subsidies do not reach 40% of the total spent. These costs are equivalent to 2.2% of the total resources spent in the health sector in the state of São Paulo in 1998. This study showed that although the treatment of schizophrenia consumes an important part of the health budget, it is predominantly hospital-based and do not take care of a large contingent of patients who demand specialized assistance.

■ Mental health and social class

Population surveys on mental health in Brazil were started with Coutinho[23], at the historical center of Salvador, Bahia. Two other important epidemiological studies were done in Salvador[24,25], at the "Bairro do Ó", a poor area of the seashore, and in an industrial area of the metropolitan region. All found an inverse relationship between economic condition and mental disorders and, generally, an excess of morbidity in the female population[26]. These results have been confirmed in population studies with the elderly[27], occupational studies[28] and studies with the clientele of basic health services[29].

** For a total population of the state in the order of 30 million inhabitants.*
† Roughly equivalent, at the time, to US $ 200 million.

A study of transversal cut of population basis conducted in Pelotas, a large town in the State of Rio Grande do Sul, with the objective of studying the associations among the use of benzodiazepines, minor psychiatric disorders and socioeconomic factors[30], in a representative sample of the city's urban zone, demonstrated that 12% of the population had taken some type of psychotropic drug (predominating the benzodiazepines). An inverse association among the income and education levels and the prevalence of minor psychiatric disorders was observed, as well as a positive association between income and the intake of benzodiazepines, showing the presence of the "inverse care law" in Brazil[31].

▪ Distribution of equipment and human resources

An estimate of the coefficient of psychiatrists in Brazil points to a sufficient number of specialists (5.75 per 100,000 inhabitants, close to the OMS recommendation of 5 per 100,000); however, these professionals are concentrated in the South (6.3/100,000) and Southeast Region (8.65/100,000) (Mari 1992). The number of psychologists is high in all the geographical regions of the country, also with the largest surplus in the South and Southeast Regions (41/100,000).

▪ TABLE 13

COST OF HOSPITALIZATIONS IN THE BRAZILIAN PUBLIC HEALTH CARE SYSTEM (SUS) BY THE TYPE OF MEDICAL SPECIALTY, 1997 (SOURCE: DATASUS, 1997)

Specialty	Value (R$)	(%)
Surgery	1,087,167,574.00	33.9
Medical Practice	861,626,571.00	26.8
Obstetrics	443,357,736.00	13.8
Psychiatry	371,054,789.00	11.5
Pediatrics	347,235,006.00	10.8
Other	95,410,347.00	2.9
Total	3,205,852,023.00	100.0

The number of hospital beds was 76,343 in 1996, originating a coefficient of 0.49 beds/1000 inhabitants, heterogeneously distributed among the different geographical regions of the country, from 0.07 in the North to 0.70 in the South east. Still in 1996, the estimated number of hospital beds/day was 1,290 (0.82 beds per 100,000 inhabitants). There were 212 psychosocial care centers in 1998, corresponding to little more than one psychosocial center for every one million inhabitants, and only 15 psychiatric emergency services, the majority of which are concentrated in the Southeast Region, with the coefficient estimated in one consultation for every 10 million inhabitants. It can be observed on Table 13, which has the distribution of the resources spent in 1997, that the psychiatric hospitalizations correspond to 11% of the total hospital costs of the country, reaching a value of R$ 371 million, and about 85% of this amount is passed on to the system of private hospitals that have contracts with the SUS.

The analysis of the hospitalizations in psychiatry and the country shows that 236 hospitalizations per 100,000 inhabitants occur annually, revealing a still significant heterogeneity of coverage and access in the different regions of the country, pointing to the necessity of investments on research projects focused on public policy and management in this area.

▪ Research capacity

There has been an important increase in the production of scientific articles when comparing the two five-year periods (1996-00/1981-85, with the ratio of 3.2), even though it did not reach the values of other areas of health, indicating that investments in mental health may not have been turned into high-level scientific production. The improvement of the evaluation of graduate programs done by CAPES had a great influence in the restructuring of the sector, and will certainly reflect on the scientific production capacity. The key issue for this improvement of the evaluation of graduate programs was the general acceptance of the relevance of intellectual production of each program, and that this production should be verified by the number and the quality of the scientific publications. This approach discouraged thesis supervisors who did not demonstrate familiarity with the scientific method and produced predominantly books and articles in low-impact local journals, not refereed by external specialists. Two centers in São Paulo (USP and UNIFESP), present good graduate education level (level five), with emerging centers at the Federal University of Rio Grande do Sul, at the Federal University of Rio de Janeiro and at USP at Ribeirão Preto. Good quality production can also be found at UNICAMP, UFBA, UFMG, UFPEL and UCPEL, among others.

Conclusions and recommendations

The social and economic burden of mental disorders has been clearly underestimated in our country. The impact of psychiatric morbidity on the general health of the population is substantial and demands an increase of investments for the development and consolidation of the area as a whole (education, research and assistance).

Alcohol abuse emerges as the most important mental health condition in Brazil. About 8% of the male adult population needs some type of medical care regarding the harmful use of alcohol, in a period of one year, being alcohol the cause of approximately 40% to 50% of the new hospitalizations in psychiatric hospitals, which may not be the best place to treat these patients. There is a lack of cost/effectiveness studies to compare the traditional hospital treatment with the cost of brief detoxication treatment general hospitals. In the last few years there has been an increase in the number of specialized professionals in the treatment of alcohol and drug abuse, but this number is still insufficient. Another conclusion is that there is a lenient attitude in relation to the risks of precocious exposure to alcohol. The programs aimed at preventing consumption are precarious, recommending the implementation of antialcoholism public policy and legislation, such as advertising prohibition and intensifying surveillance. As a result, the research of the biological bases as well as the research related with the care of dependent people should be stimulated.

The results of the epidemiologic studies lead to the conclusion that the general physician (or the non specialized doctor) is the most active professional in mental health. This phenomenon can also be observed in developed countries such as England, the United States and Canada, as well as in other Latin American countries[32]. Therefore, it is fundamental that the medical curriculum includes an adequate training for the professional to identify and deal with the mental disorders that occur most frequently in general practice and primary care units. This epidemiologic evidence has not yet been translated into substantial curricular change for undergraduate education.

The change of demographic profile, caused by the move of the rural population to cities with more than half million inhabitants, may be associated with the excess of minor psychiatric disorders (mainly anxiety states). This migratory change resulted in the degradation of living conditions, difficulty with job placing, lack of leisure, and the violence originated from social inequality, and recommends the development or intensification of research related to mental health in disadvantaged urban areas.

The increase of longevity and reduction of the fertility rates derived from the epidemiologic transition resulted on the increase of elderly mental disorders (depression and dementia, among others).

There is a sufficient number of professional doctors working in psychiatry, but their activities are concentrated in private offices at the country's large urban centers. The effect of the "inverse care law" can be observed in this specialty, where the low income population with morbidity excess does not receive minimal mental health care, while a privileged part of the population may be receiving excessive care[33]. Therefore, there is a necessity to establish care priorities, and scientific information and method should fundament this essentially political activity. Short term objectives include providing adequate care for the most serious psychiatric cases such as schizophrenia and bipolar disorder, and the promotion of universal access to mental health through the expansion of the number of outpatient clinics located outside the hospitals.

Trained professionals to organize and plan the mental health services are scarce in the country. There is a strong ideological component in the area, which has allowed professionals with little training from the technical and administrative point of view to occupy these functions. In Brazil, there are no health managers in the area of mental health, which interfaces with epidemiology, anthropology, health policy and health economics. The education of professionals with this profile should be a priority, as research in this sector should be stimulated by support organs. Investments should also be directed to the development of areas such as child psychiatry, forensic psychiatry and eating disorders.

Mental health equipment is relatively scarce and poorly distributed among the different regions of the country (psychiatric posts in hospitals, psychiatric emergency units, psychosocial care centers). Furthermore, there is not an evaluation culture, with cost benefit studies to compare different care alternatives aiming at an improvement of the system's coverage.

The consolidation of the existing research groups strongly depends on investments on the training of human resources. These investments should privilege epidemiologic and anthropological research, focused on the resolution of local problems, like the ones that allowed the consolidation of the national scientific basis in the area (with expansion and modernization of the laboratories).

CANCER

Cancer constitutes the third cause of death in the country, and the tendency is for its relevance to increase as the population's life expectancy increases and there is a reduction on the mortality caused by transmittable diseases. In the year of 2001, it is expected that 305,330 new cases of cancer will occur in the country and that approximately 117,500 people will die from different forms of the disease. The predominant forms are respiratory system, stomach, breast, prostate and colo-rectal cancer (table 14)[34].

The growing importance of this group of diseases has not been followed by a proportional increase of the research efforts and research investments, in spite of the significant progress that occurred in the last few years, which was revealed by:

- an increase of the medical professional expertise for diagnosing and treating cancer, which is still concentrated in a few hospitals and university centers, although there is a tendency towards diffusion. This proficiency involves mainly the surgical area, the use of chemotherapeutic drugs and support to the patient with cancer and immunodeficiency. The more precise and invasive diagnostic methods are still of restricted use, due to the lack of qualified personnel and the high costs involved, as are special approach for treatments. For instance, there is a still restricted number of centers in the country that perform routinely the allogeneic bone marrow transplantation, a well-established form of treatment for hematological neoplasias;
- an increase of the research articles and projects in the area of oncology, including numerous projects that deal with basic, molecular or application aspects of basic knowledge to the clinical area, and not only drug trials. However, among the 188 category I researchers of CNPq in the areas of medicine, collective health and nutrition, there are only seven projects that focus on the theme of oncology;
- the establishment and modernization of hospitals and institutes dedicated to the treatment and study of cancer.

■ TABLE 14

ESTIMATES OF NEW CASES AND DEATHS CAUSED BY CANCER IN BRAZIL IN 2001

Location	New Cases	Deaths
Trachea, bronchio and lung	20,830	15,145
Stomach	22,330	10,765
Breast	31,590	8,670
Prostate	20,820	7,320
Colon and rectum	16,165	7,230
Non-melanoma skin	54,460	830
Other locations	139,135	67,590
Total	305,330	117,550

* In spite of the large number of cases, the disease is easy to diagnose and treat, and is associated to low mortality.

A recent, expressive research effort on cancer done in the country involved a joint initiative of FAPESP* and of the Ludwig Institute for Cancer Research, and represents an excellent example of the association of medical and basic research for the generation of genuinely national knowledge on specific questions. Employing an original method, this laboratory consortium concluded the sequencing of about 1.2 million ESTs (expressed sequence tags), the second most important contribution in the world in this area. From this approach, essentially of basic science, was derived new technical-scientific competence in the country, articles in journals with high scientific impact36,37 and possibilities of other applications through the transfer of results and reagents to clinical tests.

A partial agenda of topics that shall have the attention of cancer research activity in the country in the next few years includes:

- variations of the gene expression in tumors, relation of specific gene alterations with susceptibility to disease, its genesis, evolution and therapeutic response;
- association of cellular mechanisms and histopathological variations with the evolution and response to the treatment;
- development of new therapeutic approaches based on the knowledge of cellular and molecular biology;
- identification of risk factors and environmental factors associated to the various cancers and proposals for prevention strategies;

* *FAPESP Foundation for support of scientific research of the State of S. Paulo.*

- establishment and maintenance of records of population basis;
- development and enhancement of treatment strategies with chemotherapy, radiotherapy, biological agents or transplants, especially through clinical trials in collaboration groups;
- development of treatment strategies to reduce mutilations, and of educational and supportive approaches for the recovery of patients;
- identification of factors that determine the quality of life, as well as autonomy maintenance and functional capability.

Cardiovascular Diseases

This document aims at suggesting a model that allows the establishment of policies that promote the development research in cardiology in the country. Thus, it requires: a) analysis of the current conditions, b) proposal for future actions, c) definition of the areas of scientific interest.

■ Current Conditions

In Brazil there are more than 150 medical centers that perform cardiac surgery, where 44,006 cardiac operations were performed in the year of 1999. Considering the data form the public funded health system (SUS), in 1999 there were 1,013,414 hospitalizations due to circulatory diseases, 54,125 coronary cineangiographies, 11,284 pace-makers were implanted, and 16,186 angioplasties were performed. The country has many well-equipped laboratories of subspecialties such as electrophysiology and images including radioisotopes, echocardiography and magnetic resonance. Furthermore, there are 95 medical schools and approximately 156 university hospitals. In other words, the volume of patients and the variety of services rendered are among the largest in the world. In many centers there are well-trained researchers, many of which have been trained abroad and maintain active research programs.

In spite of this, there is no adequate national data about the coronary risk factors, about morbidity and mortality of many of the most common cardiac diseases such as heart failure or congenital cardiopathies. We do not have concrete data about the resources and costs of our medical activities. Neither have we adequate records that allow the follow up of patients submitted to research and treatment while hospitalized. Thus, we are lacking data on the evolution of children operated from congenial cardiopathy, of myocardial infarction, of heart failure patients, of cardiac surgery on adults (revascularizations, valvular surgeries, vascular surgeries) or post-angioplasties. Due to this lack of data, there is no national experiences that are truly comprehensive and trustworthy in essentially any area of cardiology. Whenever we need to discuss practically any theme with regards to prevalence, incidence or costs, we must rely on foreign data.

Table 15 shows the data from CENIC (National Center for Cardiac Interventions) related to the coronary interventions performed between 1997-2000 in Brazil, including angioplasties with and without stents, aterectomies and laser interventions. A great disparity among regions can be observed with regards to these procedures that are considered complex. The same disparity can be observed when comparing sicentific production in a national event that attracts most of the specialists in the country. Table 16 shows a quantification of the participation of the states with regards to the origin of the free communications to be presented in the Brazilian Congress on Cardiology, 2001, in Goiânia.

■ **TABLE 15**

REGIONAL REPRESENTATION OF CORONARY INTERVENTIONS BETWEEN 1997-2000. TOTAL: 68,236

Region	**Contribution**
Southeast	57.6
South	18.4
Northeast	17.0
Center-West	4.2
North	2.8

■ **TABLE 16**

FREE COMMUNICATIONS IN THE BRAZILIAN SOCIETY OF CARDIOLOGY CONGRESS 2001 CLASSIFIED ACCORDING TO THE GEOGRAPHIC REGION OF THE AUTHORS

State	Number of papers	%
São Paulo	192	50.8
Rio de Janeiro	60	15.9
Rio Grande do Sul	40	10.6
Bahia	21	5.6
Paraná	20	5.3
Minas Gerais	14	3.7
*Other	31	8.2
Total	378	100.0

The data demonstrate a significant regional heterogeneity with regards to the medical services rendered, to education and to research. Thus, we cannot aim at having a single proposal that is applicable to the whole country. We need different proposals for distinct situations, in regions, universities, institutes and medical schools. The only thing in common is that research should be an activity exercised in all education institutions, whether they are universities, university hospitals or institutes. Why in all of them? Because research is the training tool of an intellectual elite that will create the conditions for the country's technological development, culminating in the material and human progress that will diminish the enormous social differences and injustices of our country. Thus research emerges as an instrument of social development, and it should be practiced in all education environments, independent from its level of scientific and technological development.

■ Future actions

It is necessary to distinguish here some situations related to the stage of development of our education institutions. Without this understanding we would be taking the risk of proposing uniform actions, identical for factors that are so distinct that it would be impossible to carry them out. It would be demanding too much from some, and too little from others. The proposals shall make the actions appropriate to the established capabilities, in order for the tasks to be carried out adequately:

1) Centers of excellence -- are institutions already well established, which have

well-trained personnel, equipment, physical facilities, tradition and good medical, education and research practices; these institutions have already been contributing for the development of science and education; some examples of such centers are, the InCor (Heart Institute, University Hospital of USP, São Paulo), the Federal University of Rio Grande do Sul, and the Medical School of Ribeirão Preto, USP. These institutions can work with any level of research complexity, and for this reason should give priority to cutting-edge research; they must be at the frontier of knowledge, focusing on topics such as: new diagnostic approaches using magnetic resonance, radioisotopes or echocargiography. modern treatments (robotics, stem cell transplantation), molecular biology with all its possible applications, nanotechnology, etc.

2) Centers with potential/real development -- are represented by traditional schools, with well-established undergraduate programs, which have associated university hospitals, and broad experience in medical service; however, they do not have research tradition. These institutions should invest on clinical research, development of basic laboratories and training of clinical researchers. Well formulated graduate programs are essential. An effort for improvement in scientific competence should be one of its basic purposes.

3) Emerging centers -- are represented by schools more recently implemented, with a small number of graduated staff, restrict budgets, frequently dissociated from its own university hospital, without academic tradition and even without great quality in medical service (more complex procedures, which may be a part of the medical routine in the country, are not practiced there). Even with these restrictions, such institutions could dedicate themselves to clinical or epidemiological research, thus allowing the students to be in contact with the scientific method and contributing for the knowledge of the Brazilian reality with regards to local diseases and peculiarities.

■ Scientific areas of interest

Some areas, are of special interest to cardiology in Brazil, due to the high incidence of cases, their seriousness regarding morbidity and mortality and the incurred costs. These areas are indicated below.

1) Atherosclerosis: including coronary, cerebral and peripheral vascular diseases. Cardiovascular diseases are the main cause of death in the country, contributing to about 35% of its total. Some topics can be specifically cited:

- new and traditional risk factors (homocysteine, low HDL, plurimetabolic syndrome);
- atherosclerotic plaque instability
- noninvasive detection of the disease;
- myocardial viability;
- genetic markers of atherosclerosis;
- evolution predictors regarding the various disease manifestations;
- influence of diets, action of tropical plants (e. g. flavonoids);
- endothelial dysfunction.

2) Arterial hypertension: multifactorial disease, which results from the disequilibrium of multiple systems, each one of them with a complex regulation, resulting from the interaction of genes and environmental factors. Relevant questions are to identify each component of each system and the related genes, to clarify their regulation, to establish a correlation between the genetic and functional markers, to study the relative importance of each system and to know how they work together. Some topics could be cited:

- mapping of the hypertension genes (including genes related to arterial pressure regulation such as ACE and angiotensinogen, polymorphisms) and improvement of statistical methods to identify genotype-phenotype relationship;
- molecular aspects of the renin-angiotensin system regulation;
- analysis of the neurogenic component;
- analysis of the nitric oxide (NO)/endothelium system;
- the role of physical training.

3) Heart failure: a syndrome that is associated with great mortality, higher than the majority of cancers. At the end of five years of evolution, more than 50 percent of the affected patients will have died. It is also one of the few cardiac illnesses whose incidence is increasing. Therefore, the search for prognostic indexes is an area of immediate interest. General themes include: a) mechanisms, b) the role of inflammation, c) therapeutical approaches, and d) evolutive markers.

The study of inflammatory prognostic markers, such as cytokines (interleukins, TNF) have a particular interest, as has the determination of the value of the anti-inflammatory treatment, based on the concept that inflammation is a part of the most advanced stages of the disease. The study of the molecular bases of the dilated cardiomyopathy and of the heart failure syndrome can allow the identification of new and more efficient approaches to treatment. It has been known for more than a decade that proinflammatory mediators as TNF-alpha modulate the progression of heart failure. What role does inflammation play on the well-known heterogeneity of the evolution of heart failure after its initial presentation? In the cardiac form of chronic Chagas' disease there are growing indications of the involvement of genetic polymorphisms of such mediators in the progression and mortality of heart failure.

4) Arrhythmias: common final pathways that lead to death in many clinical situations, such as coronary insufficiency and heart failures. In heart failure, sudden death due to arrhythmias, represent approximately 35% of the mortality. Supraventricular and ventricular arrhythmias represent a large number of cases and incur enormous costs for diagnostics and treatments, that need an analysis regarding their cost efficiency. General topics of interest include: a) physiopathologic mechanisms; b) drugs; c) defibrillators; d) pacers; and e) ablation. Some topics are of special interest include:

- study of the physiopathology of arrhythmias in Chagas' disease, in other cardiomyopathies, and in coronary insufficiency;
- new techniques for the treatment of high risk arrhythmias: comparison among drugs, ablation and defibrillators.

5) Molecular biology and its diverse forms of application, for instance, disease markers, prognostics, gene or pharmacogenetic manipulation, shall be an area of intense interest for the centers of excellence. It requires laboratories and technical personnel specialized in various levels. The importance of molecular biology is such that it is significantly influencing education, research and medical practice. Thus, it shall represent an essential component of scientific development plans.

6) Nanotechnology: a new science that needs to be initiated in Brazil in centers of excellence. It deals with the studies and applications of the "infinitely small". Not only concepts, but practical applications as well are being foreseen, but its development needs specific investments. In the United States there are approximately 30 centers dedicated to nanotechnology[38].

Public Health and Collective Health

The dialectic character of epidemiology as a scientific discipline and as technology has been extensively explored. However, it was Mendes Gonçalves[39] who established the conceptual bases demonstrating how medical practice is subordinated to epidemiology on the question of organizing the medical care, but that its inverse is not true.

Evidence Based Medicine

A relatively recent development is represented by the so-called clinical epidemiology, with a discourse based on the primacy of medical practice in the health area, in the whole world. The recognition that the mission of directing health ministries is generally attributed to physicians without sufficient epidemiologic knowledge was probably the leading cause to introduce the teaching of epidemiology in the education curriculum of medical practice. This idea was disseminate by physicians of great international prestige who had received, for decades, interns from around the world in their clinical services in the developed countries, creating an International Network of Clinical Epidemiology (INCLEN)[40] in order to consolidate this movement, specially in developing countries. The epidemiologic methodology was used to introduce procedures supposedly "more scientific" into medical practice, originating the denomination "evidence based medicine". However, the limitations of this proposal did not take long to be denounced. On one hand, some professionals of the health area interpreted the movement as a response from the "conservatives" towards the progress and accomplishments of social epidemiology, especially in Latin America. Neither were these accomplishments so great, nor was clinical epidemiology able to surpass in a competent way the limits that were imposed to it by the nature of its object. Without denying the value of the results in the strict ambit in which they were obtained, the impossibility of its generation for the entire health field in the whole world is unanimously accepted. One of the most recent and strong critiques appeared in the traditional British Medical Journal, which carried out an election among its readers of which would be the "sacred cows" to be slain in its Christmas edition of 1998. An almost unanimous first-place was "evidence based medicine". This almost anecdotic fact gives a good measure of the reactions, even in the First World, to the rising tide of the clinical epidemiology movement. On the BMJ debate, irony prevailed, as in the seven alternatives identified by an Australian group: eminence, or vehemence, eloquence, providence, diffidence, nervousness, confidence based medicine[41]. But also, more serious discussions like the "paradigm crises and postmodern science" that generated suspicion and protest regarding the nature of other "knowledges" and the reiterated conviction that scientific knowledge is sovereign. This illustrative and intense debate led to an important contribution on the defense of "narrative based medicine".

- Research and health systems and services

  The international interest for the theme of care organization is old and complex. To mention for instance, the efforts of minister Marc Lalonde, of Canada, who introduced the concept of "health field" with which he intended to equate the new health perspectives of the Canadian people[42]. Maybe it was this first formal incursion through a terrain that was little explored until then: to include lifestyle in the analysis model, besides elements already consecrated as the environment, human biology and the factors of the health system. Regretfully, this new concept was later distorted, not becoming, as it was originally intended, a collective expression of society's life conditions, and started to be trivialized as the sum of habits and practices of singular individuals[43], which led to the definition of "risk groups", for instance, at the beginning of the AIDS epidemics.

  The proposals from the World Bank, enunciated in the Report of 1993[6], *Investing in health*, reactivated the importance of this research field, largely due to the controversy established as the actions were qualified according to the social group to whom they are destined. A group of actions that constitute a "basic framework" was defined, in order to be offered to all by the public sector. The actions that can only be individually used should be privatized, or transferred to the market. Recognizing that its proposal cannot benefit the poorest amongst the poor, the World Bank suggested the focus on more sensible themes, such as maternal mortality, or in more vulnerable social groups, such as catastrophe victims. Certainly, the authors of this proposal were not able to completely appease the protests of their consciences. The issue of the costs of the actions becomes central in this discussion of how to formulate policies and to establish programs and projects involving health systems and services; and consequently, on the selection of priorities for health research.

  The research in health services (and systems) in their version associated to the already mentioned INCLEN Network trivializes the complexity of the theme, reducing it to a kind of application of the clinical epidemiology method, capable of leading to a kind of evidence based public health. It does more, it attributes the realization of research to the health services personnel, after a brief training. It is not able to hide the presumption of the proposal by calling them "investigators" in order to avoid confusion with the professional researchers.

■ Delimitation and importance of the collective health field

The health field shall be seen from a sectorial perspective since various disciplines contribute to its thematic composition. A wide range of subjects are concerned in this field, which goes from eminently theoretical preoccupations with regards to the relationship between health conditions and quality of life, to operational questionings that are as objective as the best way of organizing a line of people in a massive vaccination campaign. As a consequence, the transdisciplinary nature of this field is not a mere figure of epistemological debate.

The great area of health, on the Directory of Research Groups of CNPq[44], can give an approximate idea of the group of activities linked to scientific research that belongs to the health field. It is not simply a matter of scientific disciplines, but of a complex group of human activities socially determined that extract their conceptual bases in order to exercise the actions for which they are responsible in a complex collection of scientific disciplines and other knowledges. The relevance of the area can be sensed by the 3,500 research groups and by the 15,000 researchers that constitute the area. Collective health is one of the areas listed, with three subareas: epidemiology, preventive medicine and public health. Subject to innumerable criticisms, this classification simplifies the field in a certain way. However, if we look at the recent development of research in epidemiology (social, molecular, clinical, etc.), and even in the other two, we verify that the essence of the area is found there.

Currently, health has acquired an expressive international economic relevance as a result of an unhindered and ever increasing technological incorporation of products and processes. Health is considered not only an activity of the social sphere, but it also participates with heavy importance in the process of economic accumulation. Consequently, the participation of health in the mass of international scientific production is impressive. In any of the developed economies, research related to the health field always represents the largest part. Indicators show the relevance of health also among us, specially in the field of scientific research and less on technological development.

A formulation model of priorities in collective health research does not eliminate, but contextualizes, the great compartment of the biomedical research actions ("basic") and of clinical research. It is relevant to notice that the designation of associated basic research, in the field of medicine and of health actions, to the segment of the biomedical disciplines (biochemistry, physiology, pharmacology, anatomy, pathological anatomy, parasitology, microbiology, immunology, genetics) is a reason for criticism from some of those who consider the "flexneran model" outdated, hegemonic since the beginning of the XX century. It is considered for instance that the basic discipline of health actions in the collective ambit is epidemiology.

■ The axes of "collective" research: a possible typology for the thematic field

In 1998, as João Yunes assumed the Health Policy Secretariat of the Ministry of Health, he designated a workgroup in charge of proposing alternatives for the implementation of the National S&T Policy in Health. As a participant of this workgroup, Reinaldo Guimarães, from UERJ, presented a typology draft that was welcomed by the other members. We transcribed the final report of the workgroup (Ministry of Health, 1999):

Role of the Ministry of Health (MH) in S&T

The workgroup reflected about what could be considered the fundamental question of the MH and what would be the response. The MH wants to know what has been done and what is still to be done. As an answer we should say that there is a preceding history and that the expectations (since 1994) coincide in at least six essential points:

1. The sphere of S&T policy in health is sectorial and not exclusive to the MH, although it must be associated to the SUS and be strongly inductive

2. S&T policy in health is essentially an articulator, formulating actions in areas that are recognized as strategic

3. The articulation demands the creation of a *modus faciendi* between the innovator (e.g. NIH) and the conservator (agencies, as for instance, CNPq and others)

4. The extent of the policy comprehends five great fields of S&T in health applied to the following objectives:
   - economic;
   - strategic;
   - of planning and organization;
   - of S&T infrastructure;
   - of the basic research actions.

5. The financing of S&T in health is essentially federal. The question reserving a percentage of the budget of the large projects of the MH for financing S&T should be evaluated.

6. Regarding the institutional structure, it is difficult to go on defending the proposal of a new National Secretariat for S&T in Health.

■ A Brazilian proposal for an agenda and the health research

The formulation of an “SUS Agenda” in Brazil, in 2001, opens new perspectives for the debate about science, technology and innovation (ST&I) in health. This agenda has already been nationally approved by the National Health Council and adapted by the states according to their own realities. At the moment, this agenda is under discussion in the almost 6,000 municipal districts of the country. It is a very dynamic process that must be carefully monitored by the area of ST&I, because it may contain an essential ingredient for the definition of the research priorities. We present on Table 17, an excerpt from the Health Agenda of the State of São Paulo, approved by the State’s Health Council in May of 2001[45].

■ The sectorial funds of research financing, the agencies and the peculiarities of health

In Brazil, the health area has 50 years of experience on national conferences, having carried out the eleventh in December of 2000. Since its eighth version, in 1986, the conferences stopped being mere technical-scientific and administrative meetings, and started to count with expressive representation from broad sectors of society. They were also preceded by state and municipal conferences, which were important stages in the process, amounting to almost 6,000 municipal conferences and 27 state conferences. All indicated their delegates, and the "customers" of the *Sistema Único de Saúde* (SUS) constitute 50%.

Besides these national conferences, which draw the great policy outline, specific thematic conferences also take place, such as the conferences on Sanitary Vigilance and Mental Health. In 1994, the 1st National Conference on S&T in Health took place, the most recent collective manifestation of the community interested in health research. Among the other measures, the creation of the National Secretariat of S&T in Health within the Ministry of Health was extolled; however, it did not become a reality. The contributions from the State of São Paulo incorporated as the conclusions from this conference were: the policy of S&T in health must be considered an integral part of the National Health Policy, as indicated in the Federal Constitution and on the law 8080/90 that defined the *Sistema Único de Saúde* (SUS); in the health area, it is considered that the services network is not a mere S&T consumer, but also, a producer. As a recommendation from the Conference, proposed by São Paulo, was included the creation of state coordinations of S&T in health, similar to what already occurs with the Health Secretariat of this State.

■ **TABLE 17**

AXES AND OBJECTIVES OF THE HEALTH AGENDA FOR THE STATE OF SÃO PAULO

I- Reduction of infant and maternal mortality

1. To reduce the infant mortality rate
2. To reduce the maternal mortality rate
3. To reduce the cesarean rate
4. To raise to 6 or more the number of prenatal consultations of the pregnants
5. To reduce childhood nutritional disorders
6. To monitor the quality of treated water

II - Priority for control of selected diseases and disorders

1. Improve the coverage by vaccination
2. To reduce the incidence of dengue fever cases
3. To reduce the number of municipal districts infested by *Aedes aegypti*
4. To maintain urban yellow fever eradicated
5. To maintain the state without any case of autochthonic measles
6. To increase the detection of cases of lung tuberculosis

7. To reduce the prevalence coefficient of hanseniasis
8. To reduce the rate of incidence of AIDS
9. To increase the coverage of Papanicolaou examinations on women in the risk age for cervix and uterus cancer.
10. To increase the detection and the treatment of breast cancer
11. To reduce the morbidity and mortality caused by circulatory system diseases
12. To reduce the morbidity and mortality caused by diabetes
13. To implement a monitoring system for severe and persistent mental disorders.
14. To improve the coverage of the collective procedures in oral health.
15. To reduce the morbidity and mortality due to external causes.
16. To reduce the number of cases of occupational accidents and diseases.

III - Improvement of the management, access and quality of health actions and services

1. To enlarge and improve the quality of the State Program of Basic Pharmaceutical Assistance
2. Implementation of the State Program of Pharmaceutical Assistance in the Area of Mental Health
3. Maintenance and improvement of the pharmaceutical assistance of the Health Programs of the MH (STD/AIDS, diabetes, tuberculosis, hanseniasis, trachoma, meningitis and others)
4. Maintenance and improvement of the Program for Supplying High-cost Drugs
5. To register the SUS customers for the insurance of the National Health Card
6. To reregister the health establishments
7. To press for the distribution of resources in health actions and services according to the recent Constitutional revision article 29/2000
8. To increase transplant supply
9. To audit the pharmaceutical industry
10. To audit Units of Blood Transfusion
11. To audit Units of Dialysis
12. To supervise the services of sanitary vigilance
13. To implement the State Regulation System
14. To implement the State Component of the National Auditing System
15. To enlarge population access to oral health services
16. To improve the process of supplying prostheses, ortheses, auxiliary support materials and ostomy bags.

17. To implement the creation of rehabilitation centers to give full-time assistance to handicapped people

IV - Reorientation of the model of assistance and decentralization

1. To develop the Process of Regional Management in São Paulo
2. To expand the Family Health Program
3. To expand the oral health teams in the Family Health Program
4. To implement attention for handicapped people in the FHP
5. To implement attention to mental health in the FHP
6. To expand the out-of-hospital equipment network for mental health
7. To reduce the rate of expenditures with hospitalizations within the total expenditures with mental health by the SUS

V - Development of human resources in the health sector

1. Training of professionals to improve service quality
2. Training of municipal managers
3. Training and qualification of professionals

VI - Qualification of social control

1. To train the health counselors

Within this context, the initiative from FAPESP of creating the Research Program of Public Policies has great impact potential on collective health and may influence the new ways of research in this area; however, it continues to be restricted to the State of São Paulo and still has not found a parallel in other states. Finally, in the same state, the Research Institutes of the State Government Administration, linked to the State Secretariats of Agriculture, Environment, Planning and Health, should be examined as a model. It is a way of organizing scientific research that comes from the end of the XIX century, helped in the solution of many specific problems, and urgently needs to be deeply analyzed due to the recurring affirmations that it is a worn out model. Anyhow, the State of São Paulo is the only state in the country to maintain such a large number of Institutes of this nature within the state's administration. In the remaining states, the existing institutions are generally federal, like the Oswaldo Cruz Foundation in the area of health. The research institutes of the Health Secretariat of the State of São Paulo, as a whole, reproduce a structure that is practically equal to FIOCRUZ, enlarged by epidemiological and sanitary vigilance.

The peculiar experience of constructing the SUS in Brazil shall be mentioned as a model for participating organization that should be explored in other ambits. The national health conferences are examples of how to organize social participation in the debate, accompanied by the creation of numerous deliberative instances in the national, state and regional ambits to distribute resources. It is a model for the administration of current or potential conflicts with almost ten years of experience, which can be taken as an example. Although it cannot be mechanically transposed in order to modulate the organization of science, technology and innovation in the health area, it must not be ignored either, because as it was previously mentioned, the idea that the development of ST&I in health shall be an integral part of SUS is a part of Brazilian legislation. This is a theme for discussion that may lead to true integration, but it risks freezing the conflicts within health research area if it is conducted by fundamentalist radicalisms that deny cooperation, and see every scientist who has other disciplinary or thematic tendency as an enemy.

Another peculiar characteristic to health is represented by the effort to formulate a "global determination" model that associates health research to *tout court* development. Our insertion in this project, conducted by the Global Forum for Health Research, demands an analysis of the true situation of Brazil in the world (we are a part of the middle income countries, or emerging economies, in the World Bank's classification). We are not at the extreme poverty pole, but neither in the selective G-8, in the OECD group, which congregate the countries of consolidated market economies. Therefore, we need also contemplate the issues related to the "incompleted agenda" and the "double burden" in health research. We should prepare ourselves to deal, at the same time, with the proposal to overcome the "gap 10/90" and with the new idea of innovation, which was recently introduced into the Brazilian scientific scenario, and that has a lot more to do with the incorporation of advanced technologies than with overcoming the gaps that have led us to the current nosologic situation. In this sense, the project from Ministry of Sciences and Technology (Projeto Prospectar) must be mentioned as a valid effort in the axis of the innovation that needs urgent contextualization, since an omission was attributed to it with regards to the relevant issues on the axis of overcoming the "gap 10/90".

Promoted by the Brazilian Association of Graduate Education in Collective Health (ABRASCO) and the Brazilian Society for the Advancement of Science (SBPC), with the support of the Health Policy Secretariat of the Ministry of Health and of the Pan American Health Organization (OPAS), took place in Brasília, in December of 2000, a workshop aimed at discussing the current state of affairs and the perspectives for the development of health research in Brazil. It included researchers from the various segments of the area to reflect about the proposals related to the new sources of support (sectorial funds*) and the new forms of organization (agencies) that are being contemplated or in the process of organization. The bases of a possible consensus among researchers, managers and policy makers in the areas of health as well as S&T were trying to be established.

The main points of the workshop's report were forwarded by ABRASCO to the Ministry of Health [46]. These points make evident that there was no consensus with regards to the creation of a Specialized Agency on Health Research Support, associated to the Ministry of Health. There was almost a unanimous agreement on supporting the creation of a Sectorial Fund for Health, under the coordination of the MCT, in support of the proposal forwarded to the National Congress. Furthermore, the resources of this fund would not only come from the production and commercialization of alcoholic beverages and tobacco products, but they would also include a contribution from all the sectors of the economy that are recognized as responsible for the "sanitary debt", the generic name for the social result of the circulation of products and activities that are responsible to health damage, like the ones that pollute the environment in a way that is notoriously harmful to people's health. The simple fact that this Workshop took place represented great progress. However, the obvious conflict of interests between the expositions of the two ministries involved and, especially, the way in which no conclusions were reached, but only the main points in the document forwarded by ABRASCO to the Ministry of Health, point to the necessity of a dialogue presided by cordiality and not by mistrust. Particularly, the debate about the Sectorial Fund, its management and the proposal for a various new agencies for the area that involves the main questions about science, technology and innovation in health, including environmental, ethical and regulatory issues, shall be more open and democratic.

* *Sectorial funds: a new form of financing research ant technology with money obtained form specific taxations.*

Infectious Diseases

The research on infectious diseases in Brazil has a long history, is well-established and counts with a long tradition. Well consolidated and internationally recognized groups, constant production and the formation of schools date from the second half of the XIX century, with the so-called *Escola Tropicalista Bahiana*. At the end of the XIX century and the beginning of the XX century, coinciding with the scientific growth in Europe and North America, were founded important research centers, such as the current Oswaldo Cruz Foundation, in Rio de Janeiro and the Butantan Institute, in São Paulo.

- Field Delimitation

  Although well-established, or maybe because of that, the delimitation of the field of work that we denominate in a broad manner as infectious diseases is very vague, without clear limits, forming a continuum that has interface with other research fields, such as microbiology, genetics, agrarian sciences, public health, ecology, to mention only a few. Nowadays, when a large part of research is done in molecular biology, the limits become even less precise. Any attempt to create a more rigorous delimitation will only make sense if it refers to some specific applied area. This difficulty to delimit creates problems in the search for indicators, using the different available databanks, as for instance, the Lattes Databank from CNPq[47] or some existing publications, such as *Research in Brazil* (*A pesquisa no Brasil*), from CNPq [48].

- Traditional research centers

  Some traditional institutions concentrate the majority of the research activity, almost always associated or applied to public health. These institutions played a very important role on the development and consolidation of the medical biological research in the country in general, and particularly on infectious diseases. We can cite some of the traditional research centers, which are still leaders in scientific production and in the training of human resources and researchers: Oswaldo Cruz Foundation and its regional institutions, René Rachou (MG), Gonçalo Muniz (BA) and Aggeu Magalhães (PE); Evandro Chagas Institute; Butantan Institute; and Adolfo Lutz Institute.

- Graduate education

  Among the 156 graduate medical programs recognized by CAPES in 1996, 12 (7.69%) present specific denominations – tropical diseases, infectious diseases, parasitic and infectious diseases, tropical medicine, tropical medicine – showing a considerable number of training programs, considering itself a subarea, as well as a denomination difficulty of the area of work by its own researchers (Table 18). Although the existence of graduate courses does not specifically mean research activity, it is an indirect indicator. Among these 12 courses, only 5 are outside of the Southeast Region – one in the North Region, three in the Center-West Region and one in the Northeast Region.

- Scientific associations

  There are at least two scientific associations whose action is clearly limited to infectious diseases – the Brazilian Society of Tropical Medicine and the Brazilian Society of Infectious Diseases. The first, older, is not characterized as a professional association, which is opposite from the second one, that delimits its field to specialist doctors; therefore, constituting a professional association. Other scientific associations are active in the field of infectious diseases, but transcend this field by much, such as the microbiology, parasitology and immunology societies.

■ **TABLE 18**

GRADUATE COURSES ON INFECTIOUS DISEASES. CAPES, 1996

Denomination	Institution	State	Type
Infectious diseases	UFES	ES	MSc
Infectious and parasitic diseases	USP	SP	MSc /PhD
Infectious and parasitic diseases	UNIFESP	SP	MSc /PhD
Tropical diseases	UFPA	PA	MSc
Tropical diseases	UNESP/Botucatu	SP	MSc /PhD
Medicine (Infectious and parasitic diseases)	UFRJ	RJ	MSc /PhD
Medicine (Tropical Medicine)	UFMG	MG	MSc /PhD
Tropical medicine	UNB	DF	MSc /PhD
Tropical medicine	UFG	GO	MSc
Tropical medicine	UFPE	PE	M/D
Tropical medicine	FIOCRUZ	RJ	M/D
Tropical medicine and infectious diseases	FMTM	MG	M

■ Table 19

Title of the Publication
Acta Cirurgica Brasileira
Anais da Academia Brasileira de Ciências
Arquivos Brasileiros de Cardiologia
Arquivos Brasileiros de Endocrinologia & Metabologia
Arquivos de Neuro-Psiquiatria
Brazilian Journal of Infectious Diseases
Brazilian Journal of Medical and Biological Research
Cadernos de Saúde Pública
História, Ciências, Saúde - Manguinhos
Memórias do Instituto Oswaldo Cruz
Pesquisa Odontológica Brasileira
Psicologia: Reflexão e Crítica
Psicologia: Teoria e Pesquisa
Revista Brasileira de Cirurgia Cardiovascular
Revista Brasileira de Psiquiatria
Revista da Associação Médica Brasileira
Revista da Sociedade Brasileira de Medicina Tropical
Revista de Odontologia da Universidade de São Paulo
Revista de Saúde Pública
Revista do Hospital das Clínicas
Revista do Instituto de Medicina Tropical de São Paulo
Sao Paulo Medical Journal

■ Publications

Among the 22 Brazilian publications in the area of health made available by Scielo [49], four are dedicated to infectious diseases, although the oldest one of them, *Memórias do Instituto Oswaldo Cruz*, is more inclusive, its articles are mainly in the area (Table 19).

■ Financing sources

Besides the traditional research support agencies in Brazil, such as CNPq, FAPESP, FAPERJ and FAPEMIG*, the Ministry of Health supports research in the area of infectious diseases, generally applied to public health. There are also multinationals

* *As mentioned, CNPq is a federal research support agency, whereas FAPESP, FAPERGS, FAPERJ, FAPEMIG are regional agencies that limit their action to one particular state.*

in the area of medicines and vaccines, which support the realization of clinical assays; however, the great majority is tied to themes of their specific interest.

- Available indicators

The delimitation difficulty of the area makes an analysis of the data and indicators difficult. The majority of the databanks from the research support institutions does not delimit the field, thus, research on infectious diseases is distributed among the areas of collective health, medicine, microbiology and immunology. An indirect indicator is the Lattes Databank from CNPq: although it does not present a division that allows a direct evaluation of the research groups on infectious diseases and their research lines, some searches give a general idea of the activity in the area.

Lattes Databank. A keyword search of research lines, where the keyword is "infection", will indicate the existence of 116 research lines (impossible to separate the research lines in veterinary or oral medicine). If the term "infection" is entered as the name of the research line, we will have 105 lines; comparatively, the term "kidney" will result in only 16 lines, or "heart" will select 39 lines. When we use the term "infection" as a keyword for production will have 1.797 publications of the most varied kinds, while for "kidney" we will have 273 publications and for "heart", 460.

- Special programs: emerging and reemerging diseases as an example of research induction

Although the Pluriannual Plan of Science and Technology from the Federal Government 1996/1999 (Ministry of Science and Technology) [50] does not specifically contemplate infectious diseases, the Minister of Science and Technology himself, in a speech given in September 2000[51], was more specific with regards to the research necessities on infectious diseases, already reflecting the Pluriannual Plan of the second mandate of the current government, the *Avança Brasil* Plan:

"With continental territorial dimensions and strong income inequality, Brazil combines, simultaneously, necessities in the health area that are characteristic of developed economies - with various types of cancer and coronary diseases - as well as those characteristic of economies with a lesser degree of development - such as tropical infectious diseases, like cholera, dengue fever, yellow fever, besides emerging diseases...

... finally, the policy to fight against the infectious and parasitic diseases, emerging or reemerging, demands capacity building for the production of vaccines, as a way to expand the local production".

Emerging and reemerging diseases constitute the only specific program of research induction in the area of infectious diseases in Brazil. Once again we have here of a definition, which includes practically the entire area, once infectious diseases, almost without exception, go through transformations.

Emerging diseases are the object of the Program of Strategic Induction of Health Research, from CNPq [52]. "The first among these thematic areas to be elected for support was the one of New, Emerging and Reemerging Infectious and Parasitic Diseases. The priority to this subject was granted due to its strategic importance, since diseases of this category have, in the last few decades, become once again a matter of preoccupation for government organs and the scientific community. In developing countries like Brazil, social and environmental problems create favorable environments for the proliferation of diseases of this kind".

Actually, this line of support concentrates financing only in areas of greater public health interest, leading us back to the scenario that was present in the beginning of the XX century, when an examination of the Brazilian infectious nosology was undertaken, starting from the official research institutes of São Paulo and Rio de Janeiro. Other special programs of research induction, like the Genome Project from FAPESP, are reflected on the quality of research on infectious diseases, although they may not be specific.

FINAL CONSIDERATIONS

Research on infectious diseases in Brazil, besides its long history, presents some evidence of being the most important subarea with regards to the number of researchers, the number of research centers and groups as well as of production, in spite of the difficulty of delimiting it in a precise manner.

Various special programs support the research in the area, explicitly or implicitly, resulting on a larger basis of support than for the other areas of medicine, since the area of infectious diseases, *sensu lato*, includes collective health and some basic areas.

However, it would be useful to analyze more carefully the true proportions of the critical mass of researchers, centers and their production, in order to carry on evaluations with a clear field delimitation.

Despite the difficulty evaluating the current extension of research on infectious diseases in Brazil, there are indications that qualitative and quantitative increases occurred in the area, such the recuperation and maintenance of traditional research centers, as exemplified by the Oswaldo Cruz Foundation. On the other hand, the growth in the number of researchers is indicated by the number of graduate courses, although there are no available data in order to evaluate the total number of scholarship receivers in the country and abroad.

MEDICINE AND THE NEW BIOLOGY

We are living through an extraordinary period of development in the biological sciences. As the techniques of cell and molecular biology are applied to medical research over the next years, we shall undoubtedly solve many of the remaining mysteries of human pathology. Indeed I suspect that the medical sciences are about to move into the most exciting and productive phase of their evolution.[53]

The predictions by Sir David Weatherall were fully confirmed, as the revolution caused by the new genetics was transferred from the basic research benches to clinical applications, initially on diagnostics and prevention of monogenic diseases, and later to complex diseases. From relatively simple methods of detecting DNA mutations, we evolved to approaches that allow the identification of various patterns of gene expression, with applications on diagnostics, prevention and therapeutic interventions. The manipulation, separation and extension approaches *ex vivo* of different progenitor cells obtained from embryos, from umbilical cord blood and from adults have become a reality that promises to modify many of the medical practices in the short term.

What is our position within this panorama? Initiatives from FAPESP[54], MCT and CNPq articulated in a short time a large group of researchers and the infrastructure expansion of more than 100 laboratories in the country qualified for genomics and cellular biology research. The success reached by these programs in the basic area [55] is being transferred to clinical applications: the use of molecular biology methods for the diagnostic and prevention of diseases has already become a part of the routine in many centers. Initiatives under way involve the use of numerous molecular markers as risk or prognostic factors, the evaluation of gene expressions in specific diseases and their diagnostic and prognostic value, the manipulation of cells for cancer treatment and transplants for the regeneration of damaged or constitutively abnormal tissue, the organization of umbilical cord blood banks, among others.

The consolidation of this area, transferring the applications of molecular and cellular biology to medical practice, is not only crucial in order to keep the country's medical practice updated and competitive, but also to allow interactions with the productive sector in order to implement a national biotechnological park.

SUMMARY AND GENERAL RECOMMENDATIONS

1. To revert the notion that professional education in medicine can be dissociated from the generation of knowledge in the medical area, thus strengthening the connection between education and medical research.
2. To support the creation, expansion or consolidation of new centers that may serve for the integrated development of research and education in the health area according to the model of the country's successful institutions.
3. To correct the deviations of graduate education in the medical area, in order to make it fulfill its central function of training researchers.
4. To recuperate the university hospitals as medical research centers.
5. To promote collaborative research as a way to join efforts and resources in order to quickly respond to relevant issues. Besides its efficiency in responding to medical issues, this model facilitates collaboration among more traditional research centers and emerging centers, thus facilitating the expansion of the research centers that generate research in the country, in agreement with objective 2.
6. To promote medical research in association with basic research in order to generate knowledge that is genuinely national on specific issues, also as a way of structuring a productive sector in the area of technology linked to health. This model goes against the current tendency of using the country's professional and university medical resources to serve the international pharmaceutical industry, limiting their work to testing medicines and diagnostic reagents that are planned and developed abroad.
7. To support basic and applied research on infectious diseases, maternal and birth conditions and malnutrition, on what concerns the development of new knowledge that may contribute in the solution of the country's specific problems.
8. Support the basic and applied research on non-infectious diseases, especially cardiovascular diseases, cancer, hypertension, diabetes and conditions associated to aging, seeking, particularly, solutions for the country's specific demands, and solutions for issues that may allow the country to increase its competitiveness in the area of health technology.
9. To stimulate the research in epidemiology, health administration and health policy, particularly seeking to distinguish the situations that demand new

knowledge or new technology that can be promoted through research, from the solutions that depend on the implementation of planning actions or the implementation of public or social development policies.

10. To support all the aspects of mental health research, including the training of human resources and of qualified researchers, with regards to its biological bases as well as to patient assistance, social determinants and service organization, with special attention to alcohol abuse, which is quantitatively the most important condition in mental health.

11. To stimulate medical education, training of specialized personnel and research in all the aspects related to aging and geriatrics, from the basic knowledge of biochemistry, cytology and molecular biology, to the applications to individual and collective cares, determinants of the quality of life, autonomy maintenance, organization and management of health services.

12. To consolidate the research on cellular and molecular biology applied to medicine is not only crucial in order to maintain the medical practice in the country updated and competitive, but also to allow interactions with the productive sector in order to implement a national biotechnological park.

13. To select restricted groups of objectives that must have priority as aims to promote the technological development, according to the country's economic interests and its importance as a health problem. To articulate public and private investments, promoting the integration of scientific groups trained to solve scientific or technological issues related with the industrial or service sector interested in developing or implementing technological innovation.

BIBLIOGRAPHIC REFERENCES

1 Samaja J. *A Reprodução Social e a Saúde - elementos teóricos e metodológicos sobre a questão das relações entre a saúde e condição de vida.* Coleção Saúde coletiva, ISC/UFBA. Salvador: Casa da Qualidade Editora, 2000.

2 McKeown T, Lowe CR. *An Introduction to Social Medicine*. Oxford and Edinburgh: Blackwell Scientific Publications, Second Printing, 1968.

3 Carvalheiro JR. Os desafios para a saúde, *in* Dossiê Saúde Pública. *Estudos Avançados,* IEA/USP, São Paulo volume 13, número 35: 7-20, 1999.

4 Red de Investigación en Sistemas y Servicios de Salud, 2001. http://www.ensp.fiocruz.br/parcerias/redsalud

5 Global Forum for Health Research. *The 10/90 Report on Health Research 2000*. Geneva: ed. Global Forum for Health Research; 155 + xix p., 2000. http://www.globalforumhealth.org

6 Rivera FJU. *Agir comunicativo e planejamento social: uma crítica ao enfoque estratégico*. Rio de Janeiro: Editora FIOCRUZ, 253 p., 1995.

7 World Bank. *World Development Report 1993: Investing in Health*. Washington D.C.: World Bank, 1993.

8 U.S.A. U.S. Department of Health and Human Services. *Healthy People 2010*. 2nd ed. With Understanding and Improving Health and Objectives for Improving Health. 2 vols. Washington, DC: U.S. Government Printing Office, November 2000. http://www.health.gov/healthypeople/Document

9 http://www.globalforumhealth.org/

10 Ramos LR *et al*. Envelhecimento populacional: uma realidade brasileira. *Revista de Saúde Publica*, 21: 211-224, 1987.

11 Siegel JS, Hoover SL. Demographic aspects of the health of the elderly to the year 2000 and beyond. *World Health Statistics Quarterly,* 35: 132-202, 1982.

12 Davies AM. Epidemiology and the challenge of aging. *Epidemiology,* 14:9-19, 1985.

13 MacFadyen DM. International demographic trends. In Kane RL et al. *Improving the health of older people.* New York: Oxford University Press, 1990. p. 19-29.

14 Ferriolli E, Iucif Jr N, Moriguti JC. Reflexos do envelhecimento populacional nas internações de um hospital terciário de referência. *Gerontologia,* 4: 31, 1996.

15 Almeida-Filho N, Mari JJ, Coutinho E, Franca JF, Fernandes JG, Andreoli SB, Busnello EA. Estudo multicêntrico de morbidade psiquiátrica em áreas urbanas brasileiras (Brasilia, Sao Paulo, Porto Alegre). *Revista ABP-APAL*, 14 (3): 93-104, 1992.

16 Almeida-Filho N, Mari JJ, Coutinho E, França J, Fernandes J, Andreoli SB, Busnello ED. Brazilian multicentric study of psychiatric morbidity. *British Journal of Psychiatry*, 171: 524-529, 1997.

17 Mari JJ. Morbilidad psiquiatrica en centros de atencion primaria. *Boletin de la Oficina Sanitaria Panamericana*, 104 (2): 171-181, 1987.

18 Mari JJ, Streiner DL. The management of minor affective disorders in the general practice setting: A critical review of therapeutic interventions. *Malaysian Journal of Psychiatry*, 2 (1): 18-37, 1994.

19 Mari JJ, Almeida N, Coutinho E, Andreoli SB, Miranda CT, Streiner DL. The epidemiology of psychotropic use in the city of Sao Paulo. *Psychological Medicine*, 23, 467-474, 1993.

20 Mari JJ. Psychiatric morbidity in three primary medical care clinics in the city of São Paulo. Issues on the mental health of the urban poor. *Social Psychiatry*, 22, 129-138, 1987.

21 Murray CJL, Lopez AD. *The Global Burden of Disease. A comprehensive assessment of mortality and disability from diseases, injuries, and risk factors in 1990 and projected to 2020*. The Harvard School of Public Health, World Health Organization and The World Bank, Harvard University Press, Boston, 1996.

22 Leitão RJC. *Utilização de recursos e custos diretos da esquizofrenia para o setor público do estado de São Paulo.* Tese de Mestrado em Epidemiologia, Universidade Federal de São Paulo, São Paulo, 2001.

23 Coutinho DM. *Prevalência de doenças mentais em uma comunidade marginal. Um estudo do Maciel.* Tese de Mestrado no Departamento de Medicina Preventiva da Universidade Federal da Bahia, 1976.

24 Santana VS. *Estudo epidemiológico das doenças mentais em um bairro de Salvador.* Instituto de Saúde do Estado da Bahia, Série de Estudos em Saúde 3, Salvador, 1982.

25 Almeida-Filho N, Santana VS, Coutinho DM, Aguiar W, Antonissen D. Prevalência de desordens mentais em uma área industrial metropolitana de Salvador. *Universitas,* 32: 59-72, 1983.

26 Mari JJ. Desigualdade social e saúde mental no Brasil. *Boletim de Psiquiatria*, 25: 5-10, 1992.

27 Blay SL, Mari JJ, Ramos LR, Ferraz M PT. The use of the Clinical Interview Schedule for the evaluation of mental health in the aged community. *Psychological Medicine*, 21: 525-530, 1991.

28 Borges LH. *Transtornos mentais entre trabalhadores de uma usina siderúrgica*. Tese de Mestrado no Departamento de Medicina Preventiva da Universidade de São Paulo, São Paulo, 1990.

29 Mari JJ, Iacoponi E, Williams P, Simões O, Silva JBT. Detection pf psychiatric morbidity in the primary medical care setting in Brazil. *Revista de Saúde Pública*, 21 (6): 501-507, 1987.

30 Lima MS, Hotopf M, Mari JJ, Béria JU, Bastos ABD, Mann A. Psychiatric disorder and the use of benzodiazepines: an example of the inverse care law from Brazil. *Social Psychiatry and Psychiatric Epidemiology,* 34: 316-322, 1999.

31 http://www.datasus.gov.br

32 Bustelo P, Mari JJ, Fernandez C, Andreoli SB, Levav I. A tranquil city with a high tranquilizer intake*. Lancet*, 347: 1264-1265, 1996.

33 Lima MS, Béria JU, Tomasi E, Mari JJ. Use of amphetamine-like appetite suppressants: a cross-sectional survey in Southern Brazil. *Substance Use & Misuse*, 33 (8): 1711-1719, 1998.

34 Instituto Nacional do Câncer. Estimativas de Incidência e Mortalidade por Câncer no Brasil. Ministério da Saúde, Brasil, 2001.

35 Bonalume Neto R. Brazilian scientists team up for cancer genome project. *Nature* 398:450, 1999.

36 de Souza SJ, *et al.* Identification of human chromosome 22 transcribed sequences with ORF expressed sequence tags. *Proceedings of the National Academy of Sciences of U S A,* 97: 12690-12693, 2000.

37 Dias Neto E, *et al.* Shotgun sequencing of the human transcriptome with

ORF expressed sequence tags. *Proceedings of the National Academy of Sciences of USA,* 97: 3491-3496, 2000.

38 *Scientific American,* September 2001.

39 Mendes Gonçalves. *Tecnologia e Organização Social das Práticas de Saúde: características tecnológicas do processo de trabalho na rede estadual de Centros de Saúde de São Paulo*. Tese de Doutoramento, FMSUP, São Paulo, 1986.

40 INCLEN (2001) International Clinical Epidemiology Network. http://www.inclen.org

41 Isaacs D, Fitzgerald D – Seven alternatives to evidence based medicine. *British Medical Journal* 319: 1618-1618, 1999.

42 Lalonde M. (1974) *A New Perspective on the Health of Canadians*. Minister of Supply and Services Canada, 1981. Cat. No. H31-1373. ISBN 0-662-50019-9, 1974. http://www.hc-sc.gc.ca/hppb/healthpromotiondevelopment

43 Center for Disease Control (CDC). Prevalence of Healthy Lifestyle Characteristics - Michigan, 1998 and 2000. *MMWR weekly* 50 (35): 758-761, 2001.

44 CNPq (2001) Diretório dos Grupos de Pesquisa – 5.0. http://www.cnpq.br

45 http://www.saude.sp.gov.br

46 ABRASCO. A reforma do fomento e do financiamento à pesquisa em saúde no Brasil. *Boletim da Abrasco*, ano XVIII, número 80, 2001.

47 http://www.cnpq.br/plataformalattes

48 http://www.mct.gov.br/publi/pesquisa-no-brasil.pdf

49 http://www.scielo.br

50 http://www.mct.gov.br/publi/ppa_1996-99.pdf

51 http://www.mct.gov.br/ministro/conferencias/lesocerebrais.htm

52 http://www.cnpq.br/areas/saude/inducaoestrategica.htm

53 Weatheral DJ. *The New Genetics and Clinical Practice*. Oxford University Press, Oxford, 2nd ed., 1985.

54 http://www.fapesp.br

55 Collins P. Fruits of cooperation. *The Economist*, ed. 8180, July 22-29, 2000.

AUTHORS

Marco Antonio Zago *(Coordinator)*

Member of the Brazilian Academy of Sciences (ABC); Medical Doctor and Professor of Medicine at the Medical School of Ribeirão Preto, University of S. Paulo (USP).

Jair J. Mari

PhD in Psychiatry from the Univesity of London (UK) and Professor at the Psychiatry Department of the *Escola Paulista de Medicina de São Paulo* (UNIFESP).

José da Rocha Carvalheiro

Coordinator at the *Coordenação dos Institutos de Pesquisa* of the State Secretariat of Health of the State of São Paulo.

Luis Jacintho da Silva

Professor of Transmittable Diseases at the *Faculdade de Ciências Médicas* of the University of Campinas (UNICAMP).

Protásio Lemos da Luz

Member of the Brazilian Academy of Sciences (ABC) and Professor at the University of São Paulo (USP).

Area of Earth Sciences

Earth Sciences in Brazil: the state of the art

ROBERTO DALL´AGNOL
ARI ROISENBERG
JOÃO BATISTA CORRÊA DA SILVA
PEDRO LEITE DA SILVA DIAS
REINHARDT ADOLFO FUCK

INTRODUCTION

Earth Sciences have as a primordial goal the characterization of the planet's physical environment and the comprehension of present and past natural processes, as well as the interactions involved among these. It includes studies on the solid earth, hydrosphere and atmosphere, usually concentrating in processes that occur in the lithosphere and in the terrestrial surface. It also tries to contribute to knowledge and rational use of natural resources, especially mineral and hydrological. It supplies basic information for planning the use and occupation of the physical space, permeating our daily life, as well exemplified by the growing importance attributed to meteorological information. Still, it plays an important role in subjects related to environment and its preservation.

Since it studies not only the present, but also the rebuilding of the past of our planet, geosciences are particularized from the other exact and earth sciences for its historical connotation. In a certain manner, this approximates it methodologically to social sciences. Geological time, measured in thousands, or more commonly, millions of years, represents a variable that may not be reproduced in a laboratory.

Earth sciences are constituted by several subareas, whose definition presents a certain degree of subjectivity, which is reflected in the small variations in the way that they are classified in the scientific ambience. For the present paper, we adopted, with a slight adaptation, the classification proposed by Cordani (1996) and Campos et al. (1999), which distinguishes the following subareas: geological sciences, atmospheric sciences, geophysical sciences, physical geography and oceanography (geologic and physical). Particularities present in each of these sub-areas are presented in the mentioned papers.

In this article, our intention is to discuss the state of the art of earth sciences in Brazil, comparing it with the international scenario; to appraise the area's socioeconomic importance; and to present a prospective view to the next decade. Articles with similar objectives have been published throughout the last decade, serving as reference to the current appraisal of the area (Suslick, 1992; Cordani, 1996; SBG, 1996; Fontes, 1996; Fernandes, 1998; Campos et al., 1999).

HISTORICAL RESUME

Only aspects considered determinant to the evolution of earth sciences in Brazil will be here emphasized. More detailed information may be found in the previously mentioned articles.

In spite of the economic importance of the gold cycle to the country, in the colonial period, and of the existence, since the empire, of prominent researchers in the area of earth sciences, these always played a secondary role in the different levels of education and research. After the foundation of the School of Mines of Ouro Preto and the constitution of the Geological Survey (today corresponding to the National Department of Mineral Production) in the last decades of the Second Empire, the first big impact happening in the area was the foundation of PETROBRÁS, in 1953. This generated an important demand for professionals in geology, stimulating, in 1957, the establishment of the National Campaign for the Training of geologists (Cage) and the institution of several schools of geology in the main capitals of the country. The first geologists graduated from these schools entered the job market about 40 years ago and, only in the 1960's, geology courses were offered in all of the regions of the country. Physical geography has always been linked to the departments of geography in the major universities, especially in the Southeast Region of Brazil where, in spite of its relevance, it has played a subordinate role. The first undergraduate and graduate courses in meteorology appeared at the end of the 1960's and 1970's, respectively. The expressive training of specialized professionals in geophysics and oceanography is even more recent. The restricted number of specialized professionals, the fragility of the graduate programs and limitations to the development of research were determinant to retard until the 1980's the scientific development of the area.

In the beginning of the 1970's, aiming the strengthening of the mineral sector, the military government created the Mineral Resources Research Company (CPRM), recently transformed into the Geological Survey of Brazil, and the Rio Doce Geology and Mining (DOCEGEO), which is a subsidiary of the Vale do Rio Doce Company (CVRD). These companies, together with PETROBRÁS, regional mining companies of several states of Brazil, and federal higher education institutions, then became the most important employers of professionals in geology and geophysics. The strong dependency to the governmental sector, on what is related to jobs, education and S&T, becomes a marking characteristic of the area. This represents an important aspect in the current moment, when the state strongly reduces its participation in economy and tries to stimulate a wider participation of the private sector (Green Book; Suslick, 2001).

The 1970's witnessed the expressive expansion of geological mapping surveys in Brazil, through CPRM and the Radambrasil project. This last one was responsible for pioneer studies on the Amazon, integrating geology, geomorphology, vegetation, soils and potential land use, via systematic surveys of the area, using radar images. The initiatives of state and private mineral companies are multiplied and important discoveries were accomplished. Simultaneously, CNPq and CAPES stimulated graduate studies abroad, aiming the amplification of national critical mass and the consequent strengthening of the graduate courses in Brazil.

In the 1980's, the increase in the number of PhDs in the area led to a gradual expansion of research, making possible the dissemination of graduate courses in the country and radically modifying the previous scenery. Financial resources supplied by PADCT I made possible, in the second half of the decade, the purchasing of equipment, installation of new laboratories and development of more substantial projects. For the first time in the history of earth sciences in Brazil, significant critical mass of researchers and modern equipment for research development were available (the same equally happened in other areas of knowledge; Krieger & Galembeck, 1996). During this period, the government drastically reduced the rhythm of basic surveying and the mineral sector found itself in a difficult moment, that was substantially worsened by the end of the decade, when the Federal Constitution of 1988 restricted the presence of foreign companies in mineral exploitation. In spite of this negative aspect, the consolidation of the area was initiated on this decade. Expansion was more expressive in the geology subarea. The other subareas also grew significantly, however, for their peculiarities or larger fragility, these did not expand throughout the country, keeping themselves restricted to a smaller number of universities or research centers.

This scenario evolved significantly in the 1990's, when already at the beginning of the decade an expressive qualitative leap occurred. This decade testified the gradual expansion and consolidation of the graduate courses. PADCT II continued in the line adopted by PADCT I and, despite serious instabilities that affected the S&T sector in different moments of the decade, the area kept growing. With the amplification of the number of graduate programs in the country, particularly in the geology subarea, gradually more and more PhDs obtained their degrees at national institutions, thus reducing the importance of studies abroad. However, in specific subareas or specialties still no entirely covered by the Brazilian system, graduate studies in foreign institutions maintained their importance. Such is the case of oceanography. In the atmospheric sciences subarea, in spite of the existence of an operational service for data collecting since the beginning of the century, an outstanding quality leap occurred only in 1994, with the establishment of the National Institute for Space Research (INPE) and the Climatic Studies and Weather Forecasting Center (CPTEC). This made possible national development of climate and weather numeric forecasts, creating the conditions for the development of new research lines in INPE and in universities.

Eco-92 placed environment in the center of debate. The expression "sustainable development", that marked the decade, became a commonplace, being sometimes used very properly (Clüsener-Godt & Sachs, 1995) and many others in a not so appropriate manner. In the beginning of the new millennium, due to the growing importance of problems related to environment and also to the current trends of research, earth sciences start to face the challenge of a larger integration of its several subareas and, of these, with other areas of knowledge. It is also affected, although indirectly, by the privatization processes and new regulation functions attributed to the state in Brazil.

EVALUATION OF THE AREA

Presentation of data on the development of the area

Undergraduate courses in earth sciences, in general, have expanded very timidly in Brazil. Presently there are 19 courses in geology, 2 in geophysics (with a third being created), 6 in meteorology and 8 in oceanography. Geography courses are the most numerous, however few among these emphasize the physical geography subarea. The expansion of geology and geophysics was essentially contained by the limitations imposed by the market. This generated strong resistance from class associations and scientific societies, which reacted to the disordered growth of new courses in these subareas. Oceanography has expanded recently, what denotes the recognition of its importance in the national scenario. During the 80 and 90's, many courses in the area of earth sciences suffered high indexes of evasion and low demand. The most critical situation is that of geophysics. This situation has apparently reversed in the last years, but attention must be paid to this problem.

Graduate courses in earth sciences, unlike the undergraduate, have presented a gradual and relatively fast growth. In the last 15 years, there was an expansion of 62% in MSc programs and of 100% in doctorates (Table 1; Figure 1). In the case of the geology subarea, the expansion can be verified not only in the South and Southeast Regions, but also in the others, providing a net of graduate programs covering the whole country. The total number of students enrolled in MSc programs grew very little, clearly stabilizing in the last years. On the same period, enrollments in doctorates increased geometrically (Table 1; Figure 1). This growth is largely influenced by the predominance of the doctorates over MSc degrees in the more consolidated programs. In 1987, the relation between students enrolled in MSc programs and doctorates was of 3,76 while in 2000 this ratio was of 1,21. Confronting the data of 1987 and 2000, it is observed that the number of MSc and PhDs increased 127% and 505%, respectively (Table 1; Figure 1). In the same period, the amount of permanent professors in the different courses increased only 30% (Table 1; Figure 1). In the mid 80's, many permanent professors in graduate courses still did not have their PhDs. This scenario is totally different from the current one, revealing that, on these 15 years, there was an accentuated improvement in the qualification of the permanent professors (Table 1). The exponential growth of PhDs is a highly relevant aspect, propitiating new researchers for the renewal and expansion of the area and demonstrating its maturity. In the recent evaluation accomplished by CAPES, which classifies the programs considering their performances in the period contemplating 1998-2000, four courses received the highest possible grade. These four, considering their present situation, are comparable to similar prestigious international programs. Seven other received grade 5, which places them among the courses with level A, as established by CAPES. Meanwhile, other 23 courses received grade 4, and only nine, grade 3. Among these, several are recent programs that still did not have time to mature and consolidate.

The data demonstrate, therefore, that there was a very accentuated quantitative and qualitative growth of the graduate courses in the area (Figure 1). The teachers improved their qualification and the system consolidated, now working with greater efficiency. This makes possible the training of a larger number of researchers in a shorter period of time, result that is obtained without quality loss, as seen in the indicators, which are coherent with what is revealed by the analysis of the scientific production, discussed ahead.

■ **TABLE 1**

DATA ON GRADUATE EDUCATION IN EARTH SCIENCES

Year	Courses		Students Enrolled		Graduates		Permanent Professors	
	MSc	PhD	MSc	PhD	MSc	PhD	Total	PhD
1987	26	15	725	193	135	22	467	345
1988	26	15	849	195	111	17	477	364
1989	26	16	858	247	137	26	538	399
1990	27	16	836	244	170	20	561	423
1991	28	17	783	297	179	65	529	420
1992	31	20	858	341	184	30	563	478
1993	31	20	953	427	179	38	546	475
1994	31	22	862	457	176	46	539	486
1995	32	23	890	513	224	69	552	514
1996	34	23	912	621	236	60	588	547
1997	37	24	970	630	254	85	5,361	5,251
1998	36	25	929	673	283	90	543	530
1999	39	27	900	717	328	107	577	569
2000	43	31	931	768	312	133	618	610

Source: CAPES; 1 Estimated data

Due to the historical conditioners of the area, the geology subarea was the one with the greatest expansion. Geophysics and atmospheric sciences had a moderate expansion and physical geography, seemingly, did not grow in the period. Oceanography, for being very recent in the country, faced difficulties to expand. However, it had its relevance recognized and was chosen as one of the priority areas for sending professionals abroad to obtain their PhDs. The return of these to Brazil will make possible the expansion and growth of the subarea in the next decade.

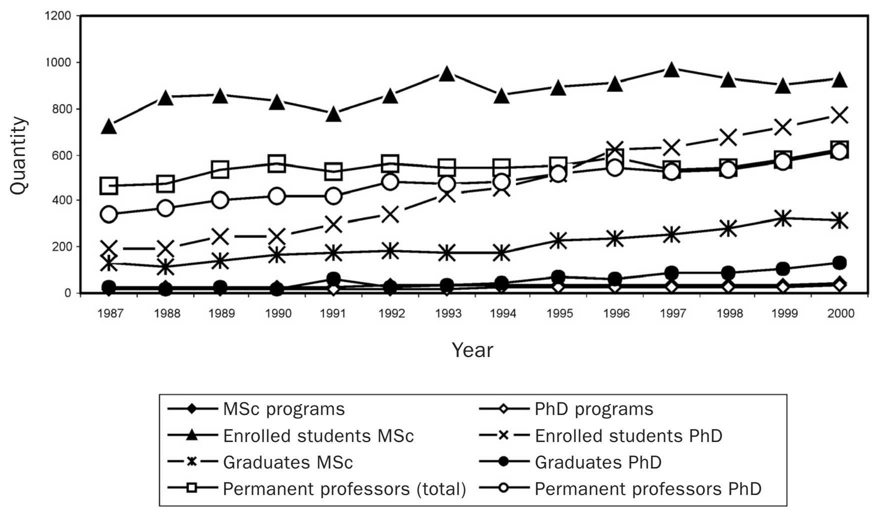


Figure 1. Data on graduate education in earth sciences

An evaluation of the dynamics of the area in Brazil can also be made through the analysis of the indicators supplied by CNPq, particularly those in the Directory 4.0 of the Research Groups. Comparative data between the areas of mathematics, physics, chemistry, geosciences (including geology, physical geography, geophysics, meteorology and geodesy) and oceanography (Table 2) reveal that geosciences involve around 20% of the research groups, research lines and PhDs in the large area of exact and earth sciences. Considering only CNPq's database, there are at least 750 PhDs working with earth sciences in the country (714 in geosciences, plus those working with geologic and physical oceanography, estimated in at least 25% of the total of the subarea). This number is a little higher than that of professors working in graduate courses in the area (about 600; Table 1). In quantitative terms, the participation of geosciences is a little smaller than that of the areas of physics and chemistry, and larger than that of mathematics. As for the researchers with productivity scholarships, the participation decreases to about 17% of the total of the large area, corresponding to a universe of 250 grant holders. Here the relations are similar to those previously discussed in the comparison with chemistry and mathematics, however the relation is much inferior when compared to the physics area (Table 2). Geosciences, as well as mathematics and chemistry, present ratios of productivity grant holders/PhDs a little inferior to the average of the large area, while in physics and oceanography the inverse is observed (Table 2). A preoccupying aspect of the area of earth sciences is the extreme concentration of critical mass in the geophysics, meteorology and geodesy subareas. Only two institutions, INPE and USP, concentrate around 60% of the productivity grant holders.

▪ TABLE 2

STATISTIC DATA GATHERED FROM THE DIRECTORY OF RESEARCH GROUPS (VERSION 4.0) AND SCHOLARSHIPS GRANTED BY CNPQ IN THE LARGE AREA OF EXACT AND EARTH SCIENCES

	Research groups	Research lines	Number of PhDs (ND)	Product. Scholarships (NB)	100x NB/ ND	Regional development scholarships (Brazil) 1999	PhD scholarships (Brazil) 1999	MSc scholarships (Brazil) 1999	Recent PhD scholarships (Brazil) 1999	PhD scholarships (abroad) 1999	Trainning scholarships (abroad) 1999	Post-Doc scholarships (abroad) 1999
Physics[1]	486 (27,5%)	2009 (28,9%)	1377 (36,3%)	622 (41,8%)	45,2	8,4 (23,6%)	345,1 (31,9%)	190,1 (23,7%)	10,1 (29,1%)	18,0 (11,0%)	12,0 (43,2%)	34,4 (43,3%)
Chemistry	598 (33,7%)	2183 (31,4%)	964 (25,4%)	326 (22,0%)	33,8	8,8 (24,7%)	423,7 (39,2%)	239,0 (29,8%)	9,9 (28,5%)	8,8 (5,4%)	2,4 (8,6%)	17,2 (21,7%)
Geosciences[2]	369 (20,8%)	1422 (20,5%)	714 (18,8%)	2514 (16,9%)	35,2	9,0 (25,4%)	171,4 (15,9%)	201,0 (25,1%)	4,1 (11,8%)	23,6 (14,5%)	5,4 (19,4%)	12,0 (15,1%)
Oceanography	92 (5,2%)	370 (5,4%)	165 (4,4%)	83 (5,6%)	50,3	7,7 (21,6%)	26,8 (2,5%)	34,9 (4,4%)	6,4 (18,4%)	85,2 (52.2%)	5,6 (20,1%)	1,6 (2,0%)
Mathematics[3]	227 (12,8%)	960 (13,8%)	571 (15,1%)	203 (13,7%)	35,6	1,7 (4,7%)	113,9 (10,5%)	135,9 (17,0%)	4,2 (12,2%)	27,6 (16,9%)	2,4 (8,6%)	14,2 (17,9%)
Exact and Earth Sciences	1772 (100%)	6944 (100%)	3791 (100%)	1485 (100%)	39,2	35,6 (100%)	1080,9 (100%)	800,9 (100%)	34,7 (100%)	163,2 (100%)	27,8 (100%)	79,4 (100%)

[1] Includes Astronomy.
[2] Includes Geology, Physical Geography, Geophysics, Meteorology and Geodesy.
[3] Includes Probability and Statistics.
[4] Geology and Physical Geography = 157
Geophysics, Meteorology and Geodesy = 94

According to CNPq data from 1999, scholarships for regional scientific development are equally distributed between the several areas, while recent PhD scholarships appear in a smaller proportion in the area of geosciences (Table 2). Geosciences received 16% of the PhD scholarships and 25% of the scholarships dedicated to MSc programs. Scholarships granted to the areas of physics and chemistry reach higher percentages in the doctorate than in the MSc programs, occurring the opposite in geosciences, oceanography and mathematics. This demonstrates that these three areas still dedicate more effort to train MSc than doctorate students. Geosciences absorb 15% of the PhD scholarships abroad and 19% of the training fellowships. The commitment to professional capacity building in oceanography is clearly identified, since the subarea receives respectively 52% and 20% of these scholarships.

In summary, it can be estimated that the area of earth sciences develops around 20% of the capacity building effort, capturing a similar proportion of the available financial resources granted by CNPq to the large area of exact and earth sciences.

The appraisal of the scientific production of the area was developed considering the data supplied by the Institute for Scientific Information (ISI), being based exclusively on the indexed full articles, covering the period from 1981 to 2000. This means that scientific articles that were published only on periodicals with national circulation were not considered, since most of these, with rare exceptions, are not indexed by ISI. In the same manner, the expressive and dense scientific production of PETROBRÁS, disclosed in publications of the own company, also were not included.

The scientific production of the area shows continuous growth in the last 20 years, alternating expressive leaps with periods (81-82, 83-89, 90-94, 95-97 and 98-00) of stable development (Table 3; Figure 2). From a period to another, there is an increase in at least 40% of the scientific production, what is slightly superior to the average growth of Brazilian scientific production as a whole in the same period of time. Compared to the physics and chemistry area, earth sciences and mathematics (Table 3; Figure 2) present a very contrasting scenario. The last two enter the 80's with a scientific production much inferior to that of the mentioned areas, being very similar among them. On the other side, scientific production of earth sciences grew until 2000 in annual taxes inferior to the national average and those presented by the physics and chemistry areas, and superior to that presented by mathematics. As a consequence, currently the scientific production of the area of earth sciences is quantitatively inferior to that of physics and chemistry and superior to that of mathematics (Table 3; Figure 2). The specific contribution of the subareas of geosciences and oceanography (equivalent to earth sciences and aquatic sciences according to the nomenclature adopted by ISI for the subdivisions of the area of Earth Sciences) reveals that quantitatively the first one is more important, however oceanography also presents an expressive production (Table 3; Figure 3).

■ Table 3

Full articles Published

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Chemistry	131	119	126	117	138	156	160	169	193	207	271	339	430	413	469	589	727	729	872	906
Physics	291	276	292	318	350	351	352	380	486	505	612	729	722	771	924	1163	1298	1510	1469	1423
Mathematics	50	55	49	55	61	78	71	77	83	83	97	98	108	109	126	127	146	165	164	172
Earth Sciences	46	43	57	60	63	74	43	82	63	119	102	132	100	112	195	180	209	263	276	273
Oceanography	11	8	17	33	22	30	17	30	18	33	42	40	35	42	57	70	83	90	121	100
Geosciences	35	35	40	27	41	44	26	52	45	86	60	92	65	70	138	110	126	173	155	173

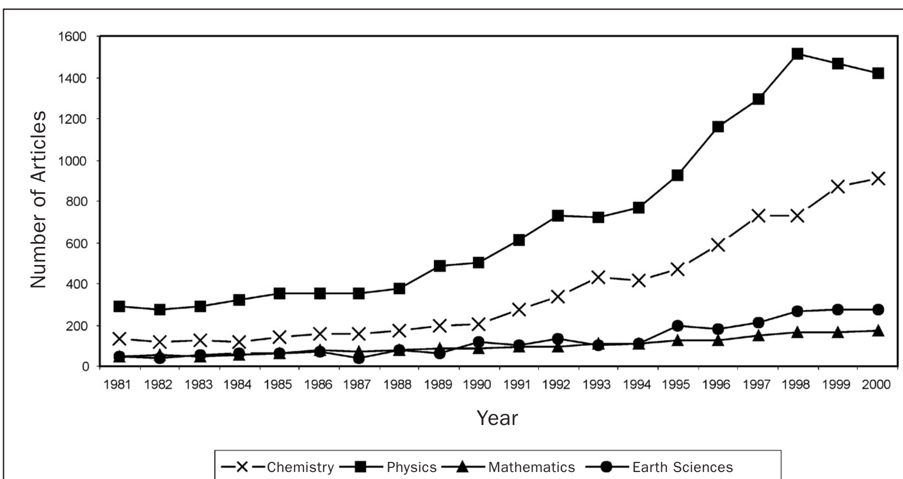


Figure 2. Full articles published. Comparison between Earth Sciences and Physics, Chemistry and Mathematics.

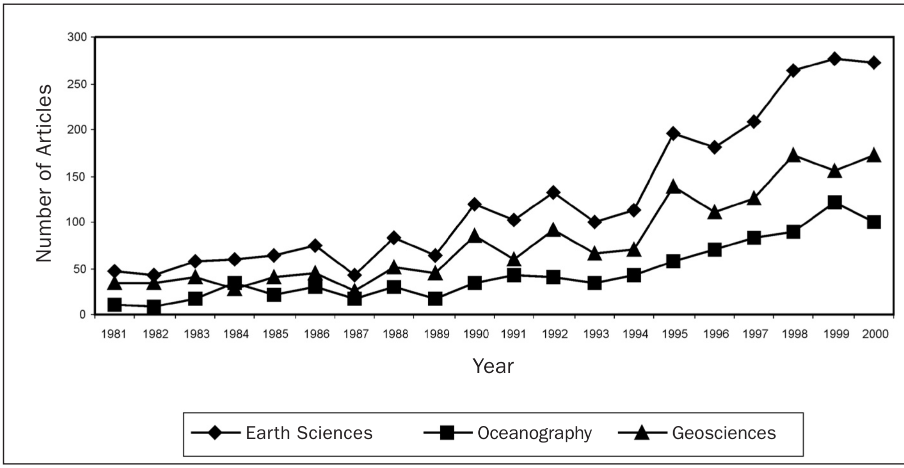


Figure 3. Full articles published. Earth Sciences, Oceanography and Geosciences

Citation of full articles evolved analogously in the same period (Table 4; Figure 4). On what is related to the impact index of the full articles, measured by the relation between citations during a period of three years and the number of cited articles, the evolution is quite different (Table 5; Figure 5). The impact index of the area is above or very close to the national average throughout the period, what is extremely positive. Regarding the subareas, the impact of the publications in geosciences is similar to that of the areas of physics and chemistry and much larger than that of oceanography (Figure 5). The impact indicators demonstrate that the articles published by the area of earth sciences achieve a good repercussion in the scientific community, what reveals the maturity and the international prestige of the most active segment in the area.

■ Table 4

Citations of Full Articles

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Chemistry	291	257	282	261	357	290	251	359	338	546	666	777	1028	1135	1295	745	1813	2226
Physics	794	592	843	641	748	799	753	928	1107	1304	1618	2026	2109	2336	3490	1617	4203	4976
Mathematics	34	50	32	60	74	68	64	74	68	65	106	78	75	106	127	53	121	165
Earth Sciences	82	72	111	116	117	128	57	326	107	264	153	219	244	227	466	469	404	541
Oceanography	18	6	19	25	37	35	27	30	23	28	36	52	35	46	73	62	102	116
Geosciences	64	66	92	91	80	93	30	296	84	236	117	167	209	181	393	128	302	425

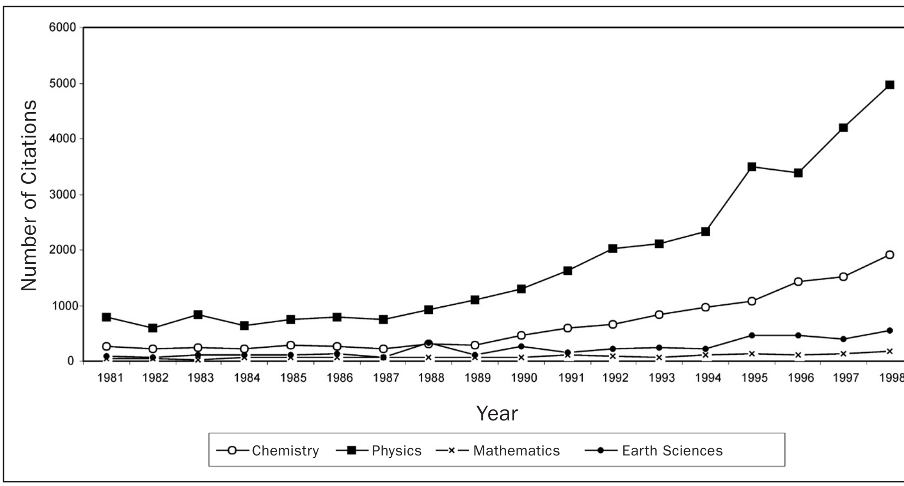


Figure 4. Citations of Full Articles. Comparison between Earth Sciences and Physics, Chemistry and Mathematics.

■ Table 5

Impact Index of Full Articles

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Chemistry	2,22	2,16	2,24	2,23	2,59	1,86	1,57	2,12	1,75	2,64	2,46	2,29	2,39	2,75	2,76	1,26	2,49	3,05
Physics	2,73	2,14	2,89	2,02	2,14	2,28	2,14	2,44	2,28	2,58	2,64	2,78	2,92	3,03	3,78	1,39	3,24	3,30
Mathematics	0,68	0,91	0,65	1,09	1,21	0,87	0,90	0,96	0,82	0,78	1,09	0,80	0,69	0,97	1,01	0,42	0,83	1,00
Earth Sciences	1,78	1,67	1,95	1,93	1,86	1,73	1,33	3,98	1,70	2,22	1,50	1,66	2,44	2,03	2,39	2,61	1,93	2,06
Oceanography	1,64	0,75	1,12	0,76	1,68	1,17	1,59	1,00	1,28	0,85	0,86	1,30	1,00	1,10	1,28	0,89	1,23	1,29
Geosciences	1,83	1,89	2,30	3,37	1,95	2,11	1,15	5,69	1,87	2,74	1,95	1,82	3,22	2,59	2,85	1,16	2,40	2,46

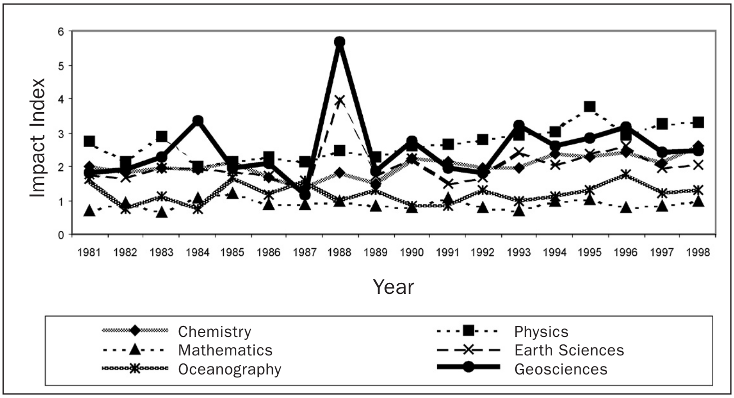


Figure 5. Impact index of fill articles. Comparison between Earth Sciences and Physics, Chemistry and Mathematics.

One can speculate on the reasons why earth sciences have been growing in a less accentuated rhythm than that of the areas of physics and chemistry. The fundamental reason seems to be the comparatively late consolidation of the area, what is revealed by the indicators on scientific production and graduate courses in the beginning of the 80's, also being justified by the history and peculiarities of the area. However, there are no reasons to underestimate the potential of the area, which seems to find itself in a phase of extreme fertility and frank growing perspectives. For this, the current levels of financing must be expanded and effective job opportunities must be offered to young researchers. This optimistic vision is corroborated by the index of specialization of earth and space sciences in South America. Such index is of 1.33 (calculated from data made available by Barré & Papon, 2000), indicating the strength of the area in the continent. As Brazil occupies a prominent position in Latin American's scientific production and research on space sciences is of little expressivity in the continent, this index may also be used as an indicator for Brazilian earth sciences.

The growth levels suggested by several indicators of the area could tentatively be related to specific outstanding facts: 1) 1983-89: beginning of the scientific production of an expressive number of PhDs that return from foreign countries and are settled in graduate programs; 2) 1990-94: laboratories installed with resources from PADCT I begin their routine activities and propagation of the results of their projects; 3) 1995-97: new laboratories financed by PADCT II initiate their activities and publication of the results of the projects associated to these; and 4) 1998-2000: maturation of the area and growth without significant external conditioners. To the mentioned facts are added continuous and decisive investments to develop professional capacity building through extension of graduate courses and efforts for fixing of PhDs by means of alternative measures (scholarships for young PhDs, visiting professors etc).

Analysis of the current situation of the area

Besides the role classically reserved to researchers, professionals in earth sciences have a crucial additional task that consumes much of their energy: the characterizing and monitoring of the country's physical environment. Contrarily to European and other several large countries, such as Canada, United States, Australia and South Africa, Brazil still lacks basic surveys on its landscape. The available geological maps, particularly those on the Amazon Region (ADIMB, 2000), usually do not present scales compatible with the necessary level of information needed by several economic activities, among which are mineral exploitation and planning of land use. Aerogeophysical surveys, fundamental in the support to geological mapping, for the knowledge on lithospheric structure and as guides for mineral prospection, are, excepting the sedimentary basins studied by PETROBRÁS, still incomplete and many times inadequate. To stimulate mineral exploitation, presently the Geological Survey of Brazil (CPRM) is developing a concentrated effort to obtain aerogeophysical data on large areas of the Amazon. Such investments, indispensable to widen knowledge on the country's Geology and Guarantee the growth of the mineral sector, will involve an expressive number of professionals in geology and geophysics. Remote sensing techniques, disseminated in the country by INPE, have been of great utility in different areas of knowledge. They need, however, constant updating both in levels of data collecting and dissemination of images, as well as techniques used in data processing and interpreting. On what is related to this aspect, in spite of the country's effort to launch, in collaboration with China, an environmental monitoring satellite, presently most of the geoprocessing applications are based on satellites belonging to other countries. In certain domains of knowledge, this imposes limitations to research developed in the Southern Hemisphere. There is an expressive net of laboratories on remote sensing in the country and many graduate programs have been established on this subarea. Anyhow, it is necessary that working conditions and incorporation of technical innovations are guaranteed.

Another important aspect is that the subareas of meteorology, geophysics and oceanography need to constantly monitor a series of physical variables, whose control is indispensable for the monitoring of the evolution of the physical environment. Such activities, that usually do not yield publications with high impact, are fundamental as reference for a series of activities in the country, such as meteorological forecasts, and serve as basis for the development of several researches. For this reason, is important to support them and to assure their continuity along time, guaranteeing their permanent technological updating. The distance between operational areas and research in meteorology in the country has been provoking unnecessary effort duplication and waste of financial resources, what must be avoided. The country also lacks systematic studies on physical properties of rocks, which could serve as reference to the interpretation of data obtained in aerogeophysical surveys. The elaboration of multiuser databases, already developed in the case of oceanography (Fernandes, 1998), is equally necessary for geophysics (ADIMB, 2000).

The recent laboratorial growth observed in the area resulted in a clear qualitative leap that is evidenced in the scientific production indicators previously discussed. As an illustrative example, we can mention the amplification or installation of laboratories on geochronology and isotopic geology, whose dissemination in the country made possible an exceptional growth not only in these specialties, but also in Precambrian stratigraphy, petrology and metallogenesis. This allowed notable progress in models of crustal evolution, that is of crucial importance to the comprehension of geological control of mineral deposits. The installation of several electronic microprobes and scanning electronic microscopes stimulated the resurgence of mineralogy in the country. In the same manner, the petrology, paleontology, metallogenesis and geochronology specialties were equally benefited. Laboratories on chemical analysis also grew significantly, however, the area still depends on private laboratories that render their services.

When evaluating the scientific production of the area, some inherent characteristics must be emphasized. Earth sciences, particularly the geology and physical geography subareas, initiated their recent history in the country with the fundamental responsibility of characterizing Brazilian geology and geomorphology. This still represents a challenge to these subareas. Both played an important regional role, due to the continental extension of the country. But restricted interchange with national and international researchers led, during a long period, to the privileging of articles on regional themes. These were published during scientific events sponsored by companies or state institutions, in periodicals of little interest to the international public. An exception to this was the petroleum sector. With the return to the country of PhDs graduated abroad, in a slow and gradual rhythm a new perspective was introduced, allowing the maturation of the area. Publications in national scientific periodicals with peer review increased in number and several regional publications, with a higher scientific level, were created. Gradually these occupied the place formerly occupied by congress annals. However, international projection of the area was only achieved in the beginning of the 90's, when the new laboratories started to generate more quantitative and qualitative data, compatible to the standards demanded by international periodicals. Until then, Brazilian researchers depended on laboratories abroad to generate their data and this limited significantly their opportunities. Since then, the scientific production of the area clearly expanded both in quality and quantity. More recently, with the consolidation of the graduate programs, PhD students started including articles submitted to international periodicals in their thesis, thus assuring the divulging of results obtained in their research and acquiring the necessary training for the elaboration of new articles. The geophysics subarea, although not presenting a very high number of publications, differs from the others since it started earlier the divulging of research result in high impact international periodicals. The geology of petroleum subarea, due to state monopoly, generated specific publications inside PETROBRÁS. These, in spite of their recognized quality and international prestige, do not influence the area indicator since they are not indexed.

Obviously, there is still an enormous space for growth in the area's scientific production and the obtained indexes still are not the desired. However, the results obtained in a period of only 20 years shall not be minimized, especially if considering the discontinuities in research financing, the low wages paid and the severe restrictions to the hiring of new researchers. If working opportunities for young PhDs and adequate and stable financing are guaranteed, a more accelerated growth can be expected in the coming years. Stimulus to researchers in the area, through the amplification of the number of research productivity scholarships, is also determinant. Despite the area's growth, these scholarships remain at the same level since 1988. At the same time, better salaries and new remuneration mechanisms, differentiating according to personal performances, is also a fundamental condition.

Knowledge generated by earth sciences should expressively contribute, through its dissemination in the different school levels, to the improvement of scientific knowledge and general education in the quest for Knowledge Society (Green Book). The almost complete absence of incentives in this direction has been entirely dissociating school education from researchers in the area (Campos, 1997). The absence a licentiateship course in earth sciences – training professionals devoted to education –, which could make possible the dissemination of knowledge in an effective, gradual and consistent manner, since lower to high school, constitutes one of the largest problems of the area. Earth sciences are excluded from common people's perceptions, except in the case of natural disasters, such as earthquakes and volcanic eruptions, fortunately rare or inexistent in our country. A rare example of familiarity to the subject is meteorological forecasting. The lack of historical records in the sector, added to poorly curated paleontological, petrographic and mineralogical collections, as well as its weak disclosure through modern media, represent another enormous deficiency. Thousands of meters of drilling core on areas explored by mining companies are lost, due to the inexistence of an appropriate storing structure. CPRM gave course to a very fruitful initiative on the dissemination of technical information among the municipal governments through the Primaz Program, obtaining great acceptance in countryside communities. Unfortunately, it was interrupted or lost its rhythm. Such experience must be reconsidered. Summarizing, there is a huge space to be occupied on what is related to education in earth sciences. This must constitute one of the priorities of the area.

Similarly to other areas of knowledge, earth sciences face the challenge of a growing demand for articulated work, privileging inter-institutional cooperation and interdisciplinarity. The area timidly moves in this direction. A positive example is given by the oceanography subarea, where promising mechanisms of interaction, at various levels, have already been developed by CIRM (Interministerial Commission for Ocean Resources). Environment certainly represents one of the clearest examples where interdisciplinarity is imposed as an indispensable requirement for scientific progress. The relevance of the area's contribution on this domain will depend, largely, on its capacity to interact with other areas, as well as adapt to a new working and knowledge generation dynamics. Presently, the first steps are being given on this direction. Another example is the need of the basic areas of geology to develop projects that are integrated with the mining, technology, metallurgy and mineral economy sectors. This is necessary to make possible the valorization of the country's mineral resources, through technological investments and optimizing of the sector (Marini, 2001). There is a very big dissociation between basic research in geology and people responsible for the technological use of the mineral resources, what must urgently be surmounted. The applied mineralogy and petrology subareas much have to contribute on this domain.

Comparison with the international situation of the area

Comparing to Western Europe, North America and Oceania, where earth sciences dispose of systematic surveys and trustworthy databases that support vanguard research in the different subareas, in Brazil the situation is quite distinct. This deficiency represents a major problem to the country, particularly in the Amazon Region and in the backcountry. In a certain measure, this also represents a problem to the continental shelf. At the same time this situation constitutes an obvious limitation, it also offers opportunities for the development of studies of national and international interest. It is a responsibility of our scientific community to overcome the enormous existent gaps, transforming the available data into scientific information, qualifying and publishing it in the most different levels. This challenge imposes to the involved community an extra effort, since it will simultaneously have to acquire basic information and apply to it modern and innovative scientific treatment, in order to achieve international research patterns.

Human resources available in the area are, proportionally to the population, very inferior to that active in the above-mentioned continents and also in Eastern Europe and China. Therefore, there is a great need of expansion of the critical mass. In terms of quality, the expressive contribution of PhDs, graduated in the last two decades in the best universities abroad, oxygenated the institutions and significantly reduced, with a few exceptions, the endogenic effects. Since Brazil disposes of an immense and extremely varied natural laboratory in terms of environment, the country gathers very favorable conditions for the training of researchers in the area. This, together with the accentuated improvement in the quality of the graduate programs and the capacity building effort carried out by some state companies, particularly PETROBRÁS, propitiates to the area highly qualified professionals with competence similar to that achieved by the best programs in the developed countries. These professionals are qualified to face the challenges of the market and are adapted to the country's reality, being appropriately trained to work in the physical environment. However, it should be alerted that the chronic deficiencies of our public schools and the small demand for enrollment in the area in graduate courses are reducing the medium level of the undergraduate students to a level below the desirable. Another problem is that teaching in most of these courses is based on classic molds, which privileges specialization in detriment of a more integrated vision of knowledge.

The area gave an expressive leap in terms of equipment and laboratories in the last 15 years, approaching, although without reaching, the conditions available in the developed countries. Since no important technological revolutions occurred in the area, it has been possible to achieve a reasonable competitiveness in several subareas, although in many others this is still far from happening. On the other side, the accelerated technology advances imposes the need of continuous updating, renewal and amplification of the research laboratories. If this is not done, the risk is that in a period of ten years, Brazil might loose if not all, a significant part of what was obtained in the last years.

Considering scientific productivity, the area presents a specialization index in the continent superior to one, what is only achieved by Oceania, North America and Sub-Saharan Africa (Barré & Papon, 2000). North America's index is superior to that of the United States, certainly being positively influenced by Canada and, in particular, by the importance of space sciences, considered jointly with earth sciences by the mentioned authors. Such index is less than one in the European Union and of only 0.70 and 0.44, respectively, in China and Japan. This suggests a relevant role to be played by research in earth sciences in Latin America and, in general, in continents where the expansion of knowledge is being made on unexplored territorial domains.

Probably, when in comparison to developed countries, the largest current deficiency of the area is its low articulation with school education and the poor divulging of the generated knowledge (Campos, 1997). In a moment where this aspect constitutes a major concern in developed countries, we are still very far away from the desirable in the search for a Knowledge Society, which is pointed in the Green Book as one of our essential goals.

Another limitation of the area of earth sciences in Brazil is related to the fact that most of its research is developed in a disciplinary and segmented way, presenting very little interaction between the different subareas. Interdisciplinarity, inherent to the earth sciences area, has been demanded in a more explicit and embracing way, through the focusing on environment. At the International level, fostering agencies have been privileging interdisciplinary initiatives and many are the universities and research organisms that have centers on earth sciences congregating professionals with different academic backgrounds working on common themes. However, in Brazil there still are only a few courses and researches with this design.

Socioeconomic impact

The strategic importance of knowledge on Environment

The strategic challenges, identified in the Green Book (Chapter 5), for Brazil's ST&I system in the next decade are divided into two major groups. The first group refers to knowledge and management of the national patrimony and among the seven items mentioned, six are directly related to areas of earth sciences: territorial surveying, meteorology and climatology, environmental management, sea resources, hydrological resources, and mineral resources. Among the action lines suggested for the strategic challenges (Green Book, p. 167) it is stated: "…mapping and knowing national reality... since without ample and trustworthy information on the real conditions of the country, in order to subsidize decision making by society, the risk is of improvisations as noxious as the problems intended to be solved." Recognition by the S&T system of the importance of basic information generated by professionals in the area is very opportune, because certainly it will bring a positive impact for the development of the area. The discreet and meticulous work of monitoring, map elaboration and structuring of databases and rock collections shall be more valorized. In the absence of consistent information, land planning and use become extremely speculative or even innocuous, many times implicating high economic and social costs for the country. Ecosystems depend on variables that involve environment and its knowledge, being this crucial for appraisals on the ecosystem's sustainability, considering modern environmental paradigms.

One of the most expressive examples of the socioeconomic importance of studies in the area is the result of the effort developed in the Brazilian continental platform, in the last twenty years, under the coordination of the Interministerial Commission on Sea Resources (CIRM) and of the Hidrography and Navigation Directory (DHN). Following the recommendations of the United Nations Convention on the Law of the Sea (CNUDM), CIRM, and gathering, among others, representatives from the ministries of the Marine and Mines & Energy, PETROBRÁS, oceanography research institutions, Geological Survey of Brazil (CPRM), and DHN promoted, since the 70's, several projects and programs: Recognition of the Brazilian Continental Shelf (Remac), Geology and Marine Geophysics Program (PGGM), Survey on the Continental Platform Program (Leplac) and Evaluation of the Sustainable Potential of Living Resources in the Exclusive Economical Zone Program (REVIZEE). The first three programs, besides conducting to notable advances on the geologic and oceanographic knowledge, made possible the precise delimitation of the Brazilian platform that extends itself through a submerged area of 3,500,000 km^2, equivalent to almost half of the country's emerged territory. With this, answering to the demands of CNUDM, Brazil assumed sovereignty rights for the exploitation and use of natural resources, both in the sea floor and on the underground of this vast area. Through this, Brazil legally assured, among others, the exploitation of vast oil and gas resources accumulated in the basins of the continental platform.

Meteorology and Climatology

In more recent times, interest on services and products of meteorology increased enormously due to larger sensibility of society to atmospheric phenomena. The accelerated populational growth in the big cities, which expanded, in a general way, without planning, brought to scene daily problems such as pollution, sliding of hillsides and urban flooding. There is also a larger divulging of the increase of the uncertainty degree as for the future due to climatic variations and changes that have been affecting the planet, particularly these related to anthropogenic causes. Due to this uncertainty, society and governments have the highest interest in augmenting researches in this field.

On the other side, the understanding by the productive sector and government of the economic and strategic value of hydrometeorological information has increased. In agriculture, irrigation operations based on weather forecasts allow great water economy and harvest operations and use of agricultural defensives can be optimized. Service sectors, such as food distribution and air transports, routinely use meteorological information to optimize their activities. In the energy area, planning of the hydroelectric sector depends on weather monitoring and climatic projections. In oceanography, besides the analysis of the favorable oceanic conditions for fishing, sanitation applications also developed significantly (construction and operation of underwater emissaries), together with the capacity of previewing tides and sea conditions, which is important to port operation. The study of large-scale atmospheric phenomena, as the El Niño and La Niña, has demonstrated its relevance for the forecasting of extreme droughts or flooding, which helps to define which measures must be adopted in order to mitigate their consequences.

Mineral resources and its industrial use

In spite of its huge territory, Brazil only started to invest in mineral exploitation in a more intense and planned way in the last 40 years. During this short period of time, the country achieved important progresses with direct effects over its economy, both by generating and saving foreign exchange and by amplifying the number of jobs and promoting the growth of ST&I. The most obvious example is that of the gas and oil sectors, where the lucid performance of PETROBRÁS propitiated great progress in the levels of production. This success was possible due to investments in professional capacity building and development of innovative technology, internationally recognized, that made viable oil drilling in the adverse environment of the deep sea continental platform.

As a consequence of the investments, started in the 70's, in geologic-geophysical surveys and mineral exploitation, mining grew substantially in the country and several new mines went into operation. Here we emphasize the Mineral Province of Carajás, in Pará, where, besides the deposits of iron ore, manganese and gold, there is the expectancy that, in a short period of time, new mines will be operating exploiting copper deposits, with gold and other associated metals, and nickel. Brazil also is a big producer of bauxite, kaolin, tin, niobium, and gems, being today the fifth most important mineral producer of the planet.

According to Marini (2001), the total value of Brazilian mineral production in 1999 was of US$ 15.5 billion, of which US$ 8.0 billion correspond to ores and US$ 7.5 billion to oil and natural gas. A large part of the national production of ores is exported, having exports, there including primarian transformation industrial products, reached US$ 6.3 billion in 1999. Due to this, on that year, Brazil had a surplus in the trade of mineral goods around one billion dollars, which covered the deficit of the oil account in foreign trade. It is estimated that in 2000, products derived from the Brazilian mineral industry represented about 8.3% of the Gross Domestic Product (GDP). This clearly demonstrates the importance of the mining industry in Brazil. In 2000, the mineral extracting industry grew 11.48% and the average annual growth of mining, in the last five years, reached 8.2% (Marini, 2001).

A less visible economic sector of the mining industry concerns non-metallic minerals, which include carbonate rocks, sand, grits, pebbles, gravel, clay, and natural stones, of wide use and growing importance in the sector, for supplying indispensable raw material for construction and engineering enterprises. The economic importance of these mineral articles is very big, representing in many states the main income source of the sector. Any housing policy in the country that seeks the reduction of the current deficit of homes has to support itself on the availability of these raw materials, in adequate volumes and costs, under penalty of making itself unfeasible. The sector also generates many jobs and, frequently, serious environmental problems, mainly in urban districts, what need to be solved and avoided.

Water Resources

Superficial and ground water resources acquired high relevance in the international and national scenario in the last years. In the beginning of the new millennium it appears as one of the most important problems to be faced in the coming years (Tucci, 2001). The recent establishment of the National Water Agency (ANA) to coordinate the sector demonstrates this. Among the complex questions related to water resources, of great socioeconomic importance are: water pollution and shortage in big urban centers; hydroelectric energy generation based on big dams and the consequent environmental impact of these; water quality and its importance to sanitation, public health and level of human development; water availability in rural areas both for human and animal provisioning and agricultural use. Besides, the hydrological systems have great relevance for navigation and recreation, and are directly related to critical events such as lack of rain or flooding.

Ocean Resources

Oceans, besides their living resources, represent one of the last areas of the planet where the potentiality as a source of mineral resources still has not been entirely appraised. It is known, however, that these possess high concentrations of many elements or substances, which, in the future, depending on the increase in demand and technological progress, can economically be exploited (Fernandes, 1998; chapter IV). Oil and gas reservoirs in the continental platform are an example of this. Brazil, thanks to the its huge coastal extension and to the economic control of the continental platform, in the future may have to look to the Atlantic Ocean in search of certain mineral resources. The Evaluation of the Mineral Potentiality of the Brazilian Juridical Platform Program (REMPLAC) was created in 1998, with the objective of developing a more detailed evaluation of the mineral resources on our Exclusive Economical Area (ZEE).

PERSPECTIVES OF DEVELOPMENT OF THE AREA AND ITS VULNERABILITIES

Earth sciences in Brazil presently dispose of a considerable critical mass in several of its subareas and of a significant number of modern laboratories routinely working. Among the five subareas, geology is the most consolidated. It is fairly distributed throughout the country and gathers the essential conditions to continue growing in the next ten years. The atmospheric sciences subarea has been presenting expressive scientific contributions, discussing themes of high international interest. Nevertheless, it still needs a better regional distribution since most of its research is concentrated in only two institutions. The physical and geological oceanography subarea follows the trend of oceanography as a whole, demonstrating, due to the priority received from fostering agencies, a clear tendency to increase its critical mass. Keeping the pace, the perspective is that in ten years the area will reach full consolidation. However, the expansion of the subarea must be followed by the strengthening of the existing research centers. Geophysics has a big linkage to mathematics and physics, and plays an important role since it introduces a more quantitative view of the geological processes and for its familiarity with computer and modeling techniques. Despite its modernity, the subarea currently faces a delicate moment. At the same time that the demand for geophysics in Brazil is expected to increase, undergraduate courses in the subarea suffer from high evasion indexes and graduate programs did not expand significantly in the last decade. For representing the most solid connection link between the several branches of earth and human sciences, physical geography plays an important role in the area, but it also faces difficulties, maybe needing to reconsider its area of action.

One of the most important challenges to the several subareas is the maintenance of the consistency in the training of new researchers in the different traditional specialties, and the courageous expansion towards the new subareas of knowledge, where interdisciplinarity will be the dominant topic. Very probably the vitality of the area by the end of the next decade will depend on the answer to this challenge. This is a very complex challenge for it demands deep changes in the way that teaching and research is structured, what already has been discussed at different levels (Green Book). Currently, certain interdisciplinary domains, such as, for example, those addressed to environmental subjects, water resources, remote sensing, or others with more access to financial resources, as petroleum programs, attract a big number of graduate students. Such tendency can lead to the undermining and vanishing of specialties that are still important to the framework of the area. This may represent a threat, since two aspects must be considered: on one side, the development of consistent interdisciplinary researches will only be insured through the effective interaction, inside a same program, of researchers with different specialties. On the other side, the search for a holistic vision of the different processes that act over the environment, influencing men and nature, will not be effective without a solid scientific basis on the different involved disciplines.

Earth sciences have been slowly advancing towards interdisciplinarity, and will certainly continue doing so in the next decade. The current trend is evidenced by several programs: those dedicated to global changes, where the atmospheric sciences and oceanography subareas standout; those dedicated to the characterizing of the continental platform and its resources, where various specialties of oceanography, geophysics, geology and atmospheric sciences are important; programs on water resources, which increasingly integrate specialists in hydrology, geophysics, geology, civil engineering, atmospheric sciences, and agronomy, differently from what occurred in the past when these professionals worked separately (Tucci, 2001); in geology, in a more strict sense, the interaction between researchers in isotopic geology, mineralogy, metallogenesis, geotectonic and regional geology have made possible expressive progresses in the understanding of the crustal evolution of the country's Precambrian terranes; on environmental studies, the participation of geochemists, limnologists, meteorologists, specialists in engineering geology, geophysics, geographers and hydrogeologists, working together with biologists and ecologists, has also been a reality. The *Atlas Ambiental de Porto Alegre* (Menegat et al., 1998) is an example of successful integration involving several subareas, representing an important contribution towards Knowledge Society.

The understanding that climatic variability depends not only on the atmosphere but also on the interaction between the atmosphere/ocean/biosphere systems is one of the clearest examples where scientific progress depends fundamentally on multidisciplinary researches. The comprehension of the dynamics of this process is a big challenge that already is being faced by Brazilian researchers in meteorology and oceanography, and shall continue to be pursued in the next decade. Research in meteorology related to agriculture represents another example. The participation of Brazilian scientists in international programs, such as the Intergovernmental Panel on Climate Change, subordinated to UN, that produces updated information on climate change, its impacts and mitigation of its effects, shall be maintained in the future. Another big challenge to research in environment and climate is the construction of integrated numeric models on the physical environment, there including aspects related to the physical-chemical composition and evolution of the atmosphere and its interaction with the terrestrial surface. Brazil's contribution to the reduction of the emission of greenhouse gases must be estimated with much rigor, in order to determine effective actions. The understanding of physical-chemical processes associated to energy, water and carbon change between tropical forests and the atmosphere represent another enormous challenge for the scientific community.

The Large-Scale Experiment on the Biosphere-Atmosphere at the Amazon Region (LBA), an international research initiative led by Brazil, generates the knowledge necessary for the understanding of: the climatological, ecological, biogeochemical and hydrological functioning of the Amazon Region; the impact of the changes of soil use on this functioning; and the interactions between the Amazon Region and the planet's bio-geophysical system. Programs similar to this will be fundamental in the next decade. Other priority themes for research will be: estimation of the balance of solar energy via remote sensing; direct estimates of the flux of carbon in ecosystems; contribution of the burning of sugarcane plantations, *cerrado* and forests to the production of greenhouse gases; impact of burning in different ecosystems; improvement of techniques for monitoring the burnings, using remote sensing; role of the burnings in the emission of gases precursors of ozone; and, emission of methane by bovine.

Researches on meteorological forecasts and climate have been developed in Brazil, being important the maintenance of the achieved quality patterns. Such researches depend essentially on numeric methods for the solving of partial differential equations. These evolve with the availability of new processing structures and cannot prescind of highly qualified human resources. For this, it is indispensable to guarantee their continuity through, among other things, fixation methods that will avoid brain drain. A larger decentralization of research in the area shall also be a goal.

The importance of characterizing the national physical environment and the high importance of the mineral sector to the country's economy demands the expansion of investments in geological mapping, aerogeophysical surveys and remote sensing. By the end of the next decade, Brazil will need geological maps of the Amazon Region with adequate scales, due to the region's mineral potential, and also of the backcountry. This must constitute one of the area's priorities. Such maps, associated to studies on the major mining districts, the obtaining and dissemination of products of geophysical aerial surveys and remote sensing, and stimulus on investments in mineral exploitation shall make viable the amplification of the existing mineral deposits and mines. It will also contribute to the generation of new jobs, income and foreign exchange. It is worth mentioning that there is already clear evidence demonstrating that mining undertaken by commercial companies, when developed with responsibility, has a much smaller impact on environment, in comparison to other economic activities, as for instance, extensive cattle raising, and can more easily be controlled by the public organisms. Therefore, it represents a valid economical alternative to the Amazon Region.

One of the fragilities of the sector is derived from the fact that researches in mining, mineral technology, extractive metallurgy, mineral policies and economy still are little developed in Brazil (Marini, 2001). Mining companies prefer to answer in an isolated way to their technological demands, usually appealing to foreign advisory. Partly responsible for this is the fact that only recently the number of mines operating in the country increased. As a result, the country exports most of its mineral production without any processing, consequently with low market values. Since this is a very complex and highly competitive market and, in the moment, most of its raw materials are with their prices at a very low level, careful studies on the market and its evolution are necessary in order to make possible the definition of consequent strategies. A correct evaluation of the opportunities of verticalization of the industry is also indispensable.

Considering that the Mineral Province of Carajás is affirming itself as the most important in the country, it would be opportune to promote the local installation of a research institute aggregating from basic geology to the different branches of mineral technology and economy. Studies on the mineral resources existing in the Amazon Region should be emphasized, indicating its appropriate economic use and providing a fair social return to the region.

Earth sciences shall also expand its contribution on studies related to water and problems involving hydrological resources. Among research topics that shall be privileged are (Tucci, 2001): evaluation of the effects of climatic variations and anthropic modifications over hydrological basins and its possible consequences; evaluation of the potential of the aquiferous for provisioning urban and rural areas; improvement of climatic and hydrological forecasting techniques; contamination of springs, treatment and disposition of sanitary, industrial and solid residues sewage; flood risks in urban environments; long-term sustainability for populations from the semi-arid region, regarding water.

The area gave an expressive qualitative leap in terms of equipment and laboratorial training thanks to PADCT. However, this effort, far from being definitive and sufficient, shall be maintained and augmented throughout the decade. The speed of current technological evolution does not allow any type of accommodation, under penalty of increasing even more the existing distance that separates the country from developed countries. The installation, in a first moment, of a laboratory with an ionic microprobe and later, of a second, is indispensable to assure competitiveness to the area and amplify its capacity on studies on geochemicals and isotopes. The adoption by these laboratories of SHRIMP methodology (Sensitive High Resolution Ion Microprobe), developed by Australian researchers, will allow notable acceleration in the obtainment of geochronological and isotopic data. This will consequently bring important progress to stratigraphy and to knowledge in petrology, metallogenesis and crustal evolution of our Precambrian terranes. Progresses achieved through the installation of several electronic microprobes in the country shall proceed until the fulfillment of the goal of at least one microprobe per different region of the country. Scanning electronic microscopes, of regular use in any research of international level, shall be a part of the permanent equipment of all of the main institutions with programs consolidated in paleontology, mineralogy, petrology, metallogenesis and geochronology. The area still presents significant deficiencies in experimental petrology and mineralogy, which, beside their scientific interest, can establish bridges with the industrial minerals and new materials sector. The establishment of at least two laboratories in this area in Brazil along the next decade would be highly desirable. Oceanographic and climatic research equally depend on appropriately equipped ships and aircrafts, capable of serving the research programs under development. In spite of the praiseworthy and permanent support of the Brazilian Navy on this matter, this has been a critical strangulation point that needs to be overcome. Finally, financial resources for maintenance and updating of the already installed laboratories shall be assured, together with support for the training and fixation of qualified technical personnel.

In the geology subarea, the positive investments in the different specialties realized in the last decade will have to be continued. Simultaneously, new laboratorial capacity shall be installed, in order to guarantee further expansion of the subarea. Among the scientific goals for the next decade are: clarification of the models of crustal evolution and delimitation of the tectonic provinces in the Brazilian platform, emphasizing those in the Amazon Region; establishment of links between tectonic evolution and genesis of mineral deposits; elaboration, through the use of seismic data, of geophysical models on the lithospheric structure of our territory; give continuity to the geological and geophysical studies of the continental margin, as well as of the geology and geomorphology of the coastal area.

However, several subareas will essentially depend on the continuity of the current capacity building policy, on the creation of effective mechanisms of fixing junior researchers and of new incentives to researchers in a general way. The generation of researchers that started working in the 80's approaches retirement and the system will quickly begin to lose their most experienced professionals. The low tax of renewal in the research groups in the last years will lead to the exhaustion of the existent competence if energetic measures are not adopted, making possible the absorption of new PhDs. On the other side, to face the present challenges, the maintenance of the current level of professionals will not be sufficient, being necessary the amplification of this number. The significant growth in the current number of professors at graduate programs is also expectable. Similarly, research productivity scholarships shall reach levels compatible to the existent competence and potential of the area. Summarizing, the guarantee of the increase in the number of professionals in the area and of opportunities to junior researchers constitute another big challenge to be faced by the area throughout the decade. This will reduce the risks of brain drain, which already occurs in the atmospheric sciences subarea.

Programs of fixation of human resources shall also help do diminish the existing regional inequalities, stimulating the absorption of new researchers preferentially in areas where specific subareas or specialties are more necessitous. However, attention must be paid to avoid the isolation of these researchers. Any policy destined to reduce regional inequalities has to be centered in fixation of human resources, being also associated with the allocation of financial resources to research activities. The dissociation of these two induction factors leads, unavoidably, to results much below the desirable. The Profix Program represents a laudable initiative that, if it considers the regional unbalances, can contribute to its reduction.

The geophysics and physical geography subareas shall deserve a special attention. Still at the beginning of the decade actions shall be adopted to correct the existing debilities. Similarly to oceanography, geophysics should be considered a priority subarea for the fixing of junior researchers. As geophysics has a tradition in the training of PhDs, the renewal of the subarea shall be facilitated. However, it would still be adequate to train some PhDs abroad in order to assure the scientific oxygenation of the subarea. Geophysics shall be stimulated to a larger integration with the other subareas, overcoming its isolation and enlarging, through this, its scientific contribution. This subarea will also need to reconsider the existing alternatives for its undergraduate courses, in order to surmount the present difficulties and to answer to the foreseen increase in demand for professionals in the subarea.

With the consolidation of many doctorate programs in the country, the area will be confronted with increasing risks of endogeny along the decade. A salutary alternative to minimize this tendency is the increment of doctorate mixed fellowship or co-orientation, involving institutions from other countries. Another alternative is to stimulate to the maximum the interchange among national institutions, not only involving institutions with unequal levels of qualification, but also among those with similar levels.

As already mentioned, another important challenge to the area is to stimulate the interaction between researchers and school education, in order to assure the dissemination of the generated knowledge and to contribute to the establishment of the foundations of Knowledge Society. Among the immediate necessary actions for the achievement of such goal is the establishment of licentiateships in Earth sciences in the several regions of the country. These may be gradually expanded as experience is acquired. Equally important is the involvement of museums, research institutes, universities and the Geological Survey of Brazil (CPRM) in the permanent effort to develop effective means for disseminating information. This shall be done not only aiming the directly involved sector, but also targeting different segments of the population, such as entrepreneurs and public administrators. We believe that these actions will be of extreme importance for the development of the area on the next decade.

On what concerns the scientific production of the area, among the measures to be taken in the short-period is the publication of one or more journals containing editorial bodies aggregating professionals with international prestige and with articles written in English. This could much contribute to the international disclosure of Brazilian research and researchers. Such periodical publications should have ensured financial resources to guarantee its regularity, thus creating effective conditions for it's indexing. This suggestion should be seriously considered by the scientific societies.

As in the other sectors of S&T in Brazil, the interaction with the business sector is still far from being the ideal. Investments from this sector in research, contrarily to what happens in developed countries, are still very limited (Green Book). Among the exceptions is PETROBRÁS, which has always been characterized by heavy investments in the development of technology (for gas and oil exploitation) and for the training of human resources, both internally as through partnerships with universities. With the opening of the sector to multinational companies, there is the risk of decrease in investments in the area, since it is very probable that now PETROBRÁS concentrates its efforts essentially in exploitation. This function might now be occupied by the National Petroleum Agency (ANP), which is responsible for the planning and regulation of the sector. The only thing that cannot happen is the discontinuity of investments, what would threaten the expressive results obtained and jeopardize the future of research in the area.

Conclusively, it is important to emphasize the growing need of interaction with professionals of the computer sciences area, in the attempt to create friendly interfaces and applicatives that use modern visualization techniques. Geophysicists working in universities develop their research using limited computer resources. As a result, programs adequate for research are developed, but these are completely inappropriate for the stage of industrial production. It is believed that companies use less than 20% of the geophysical knowledge generated in universities. To surpass this deadlock, it is determinant that fostering agencies support researches dedicated to the transformation of intellectual product into technological product.

ACKNOWLEDGEMENTS

Many colleagues contributed with comments on their personal vision of the area or transmitting documents and papers that were of great value. We here express our gratefulness to all. A special thanks goes to Maria Assunção Faus da Silva, who helped in the revision and with critics to the initial manuscript.

BIBLIOGRAPHIC REFERENCES

ADIMB (Agência para o Desenvolvimento da Indústria Mineral Brasileira). Desenvolvimento metodológico para exploração mineral na Amazônia – Proposta Síntese. Brasília, ADIMB. 2000. 39p.

BARRÉ, R. & PAPON, P. The state of world science. Nature Yearbook of Science and Technology. 2000. p. 2051-2059.

CAMPOS, D.A. Ensino das Ciências da Terra. In: Academia Brasileira de Ciências (Ed.) A Importância da Ciência para o Desenvolvimento Nacional. Rio de Janeiro, Academia Brasileira de Ciências. 1997. p. 41-48.

CAMPOS, D. A., CORDANI, U. G. & KELLNER, A. W. Earth Sciences. In: BRAZILIAN ACADEMY OF SCIENCES (Ed.) Science in Brazil an overview. Rio de Janeiro, Academia Brasileira de Ciências. 1999. p. 79-88.

CLÜSENER-GODT, M & SACHS, I. Introduction. In: CLÜSENER-GODT, M & SACHS, I. (Ed.) Brazilian perspectives on sustainable development of the Amazon region. Paris, UNESCO & The Parthenon Publishing Group (Man and Biosphere Series 15). 1995. p.1-7.

CORDANI, U. G. Geociências. In: SCHWARTZMAN, S. (Coord.), Ciência e Tecnologia no Brasil: a capacitação brasileira para a pesquisa científica e tecnológica. Rio de Janeiro, Fundação Getúlio Vargas. 1996. V.3, p. 239-261.

FERNANDES, L. P. C. (Coord.). O Brasil e o Mar no Século XXI: Relatório aos Tomadores de Decisão no País. Rio de Janeiro, Comissão Nacional Independente sobre os Oceanos. 1998. 408p.

FONTES, S. L. Diagnóstico da Geofísica brasileira – contribuição preliminar da SBGf ao PADCT III. Revista Brasileira de Geofísica. 1996. V.14, p. 69-76.

KRIEGER, E. M. & GALEMBECK, F. A capacitação brasileira para a pesquisa. In: SCHWARTZMAN, S. (Coord.), Ciência e Tecnologia no Brasil: a capacitação brasileira para a pesquisa científica e tecnológica. Rio de Janeiro, Fundação Getúlio Vargas. 1996. V.3, p. 1-18.

MARINI, O. J. Sugestões de diretrizes para o Fundo Setorial Mineral (CT-Mineral) Documento Básico. Brasília, Ministérios de Ciência e Tecnologia. 2001. 23p.

MENEGAT, R., PORTO, M. L., CARRARO, C. C. & FERNANDES, L. A. D. (Coord.). Atlas ambiental de Porto Alegre, UFRGS. Porto Alegre, Editora da Universidade. 1998. 228 p.

SBG (Sociedade Brasileira de Geologia). Diagnóstico da SBG ao Subprograma Ciências da *Terra e Tecnologia Mineral do PADCT*. Brasília, Sociedade Brasileira de Geologia. 1996. 84p.

SUSLICK, S. B. (Org.) *Regulação em petróleo e gás natural*. Centro de Estudos de Petróleo, UNICAMP. Campinas, Editora Komedi. 2001. 528p.

SUSLICK, S. B. Geociências: um ensaio preliminar de avaliação e perspectiva. Rev. IG, São Paulo. 1992. Vol. 13, p. 69-81.

TUCCI, C. E. M. Desafios em Recursos Hídricos. 2001. 14p. (inédito).

AUTHORS

Roberto Dall´Agnol *(Coordinator)*

Member of the Brazilian Academy of Sciences (ABC); PhD from the Université Paul Sabatier (France); and professor at the Center of Geosciences of the Federal University of Pará (UFPA).

Ari Roisenberg

PhD from the Federal University of Rio Grande do Sul (UFRGS); and professor at the same university.

João Batista Corrêa da Silva

PhD from the University of Utah (USA); and professor at the Federal University of Pará (UFPA).

Pedro Leite da Silva Dias

Member of the Brazilian Academy of Sciences (ABC); PhD in atmospheric sciences from the State University of Colorado (USA); and professor at the Astronomical and Geophysical Institute of the University of São Paulo (USP).

Reinhardt Adolfo Fuck

Member of the Brazilian Academy of Sciences (ABC); PhD in Geology from the University of São Paulo (USP); and professor at the Institute of Geosciences of the University of Brasília (UnB).

This book was composed in
ITC Franklin Gothic 9,5/11,
printed in off-set paper 75g with
cover in Supremo paper 250g,
in September of 2002.