CHALLENGES FOR SCIENCE EDUCATION IN THE WESTERN HEMISPHERE:

A Brazilian Perspective

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The Social Impact of Science

Before the 17th century, scientific research was chiefly an activity in which scientists worked as isolated individuals. Scientists working in different places only occasionally communicated their discoveries to each other. Starting in the 17th century, the institutionalization of science developed gradually, and science was carried out at universities and other academic institutions such as the Royal Society (1660) in England, the "École Polytechnique" (1795) in France, and the Massachusetts Institute of Technology (1865), in the USA. By the mid-nineteenth century the consolidation of this process, which was almost circumscribed to Europe and USA, had given rise to an exponential growth in new knowledge, which resulted in unprecedented changes in daily life and major changes in the social organization of the planet (1,2). The technological development has been readily perceived and its advantages are present in goods such as household appliances, in faster means of transportation, and in the advances in medicine and sanitation, which have increased life expectancy. However, the positive impact of scientific and technological developments must be weighted against negative aspects such as unbalanced population growth, degradation of the environment and the production of weapons of mass destruction. The resulting beneficial and harmful aspects of science and its products produced tensions, and have led society to increasingly demand more information about science and a greater role in decisions related to science practices and goals.

World Distribution of Science and Young People: A Challenge for Science Education

Scientific Knowledge, scientists and science education

At present, over 700,000 papers are published every year in scientific journals indexed by SCI (Science Citation Index) (3). However, much as it began 200 years ago, most new knowledge is produced in only a few countries. Scientists from the USA, England, Germany, Japan, France, Canada and the countries which constituted, until recently, the Soviet Union, contributed approximately 75 % of the indexed scientific papers published from 1975 to 1989 (3,4), while the population of these seven countries account for only 13 % of the world population (tab. 1). In contrast, the remaining countries of the planet – comprising 87 % of the world population – produce about 25 % of the papers published each year, and their social and economic development is closely dependent on those countries where knowledge is generated (5).

Table 1. Production of New Knowledge and Worldwide Distribution of Young People.

	Major Science Producers*		Rest of the World	
	1979	**1989**	**1979**	**1989**
1) Published scientific papers (thousands) *(a)*	470	561	153	228
2) Population (thousands)				
0-24 0-24 years old *(b)*	306,000	340,000	2,065,000	2,318,000
3) Ratio (2/1)	639	606	13,497	10,167

(*) Canada, France, Germany, Japan, Britain, USA and Soviet Union.

Sources:

(a) Thomas Phelan and Stephen Cole (1993) Social influences of scientific productivity. Paper presented at the American Sociological Society Annual Meeting, Miami, USA.

(b) Estimate data from: PC Globe 4.0, 1990, PC Globe Inc., USA. Statistical Year Book, UNESCO, 1984.

One of the tasks of science education is to assimilate and distribute the knowledge that science generates. Scientists are not the only ones responsible for science education, but the small scientific community in countries like Brazil provides the local scientific competence for accessing the international pool of knowledge and information, and has the potential to forge links among science, technology and education (6). They have the responsability to make the huge amount of new scientific knowledge that is produced each year available to their countries, and intelligible to young people who have to be educated. Since developing countries have a larger proportion of young people in their population (82.6 %), than do the developed countries (7), the problem of distributing scientific knowledge represents, in fact, a great challenge for science education: most of the planet's young population lives in countries which have only a small scientific community to help promote science education.

Human resources for science

The uneven worldwide distribution of scientists and school-age young leads to a complex scenario that can be evaluated by comparing two countries in the same hemisphere, Brazil and the USA.

In Brazil there is increasing awareness of the need to develop science and to train new scientists as a necessary pre-requisite to deal with economic constraints of its society. In the USA science is developed and there is a large scientific community, but in recent years the USA has encountered difficulties in meeting the growing demand for capable new scientists to maintain its lead in science and technology.

In both countries the scientific community participates in the efforts to attract talented young people into science from the very beginning of the educational pipeline (8,9,10). In Brazil, this is not an easy task even though the number of scientists has increased more rapidly than the population as a whole (tab. 2). The number of Brazilians under 24 years old was about 78 million in 1988 (11). Given the small number of active scientists, each scientist would have to contribute to the education of 12,600 students (tab. 2). In contrast, the equivalent proportion in USA is 1 scientist to 44 young people (tab. 3).

Table 2: Resources for Science in Brazil

	1980	1988	Increment
1) Expenditures (U$ millions) *(a)*			
Industry	330	725	2.20
Government (*)	298	268	0.90
Total	628	993	1.58
2) Doctoral degrees *(b)*	554	925	1.67
3) Young population in thousands (0-24 years old) *(c)*	70,600	78,000	1.10
4) Employed scientists			
Industry *(d)*	–	139	–
CNPq (#) *(e)*	1,935	6,060	3.13
Total	1,935	6,199	3.20
5) Young population/scientists (3/4)	36,500	12,600	0.34

(#) CNPq: Scientists receiving research fellowships from the National Research Council.

(*) *Government expenditures were calculated as follows: Average annual income paid for active scientists (b) working at the Brazilian universities (1980: U$ 38 millions; 1988: U$ 118 millions) plus resources for science from CNPq (National Research Council; 1980: U$ 23 millions; 1988: U$ 47 millions) and FNDCT (National Fund for the Scientific and Technological Development; 1980: U$ 237 millions; 1988: U$ 103 millions)*

Source:

(a) Brisolla, 1993. Dados de MCT-CNPq/DAD/SUP/COOE. In: Science and Technology in Brazil: A new policy for a global world (preliminary version 3.1), p. 2. * MCT: CNPq; FINEP; INT; INPE; IMPA.

(b) CAPES – Coordenação de Aperfeiçoamento de Pessoal do Ensino Superior.

(c) Estimate data from: Anuário Estatístico do Brasil. IBGE – Instituto Brasileiro de Geografia e Estatística, 1992.

(d) ANPEI – Associação Nacional de Pesquisa e Desenvolvimento das Empresas Industriais: Perfil do Quadro de Associados. September, 1989, p. 9.

(e) MCT-CNPq – Séries Históricas, 1976-1993. Brasília, 10 de Fevereiro de 1993. Tabela: Evolução do número de bolsas/ano segundo modalidades - 1976/1993 (Pós-doutorado-PD + Pesquisa-PQ + Pós-doutorado no exterior-PDE).

Table 3. Resources for Science in USA

	1976	1986	Increment
1) Expenditures (U$ millions)			
Industry	26,997	83,562	3.21
Government and Educational Institutions	12,021	31,135	2.59
Total	39,018	114,697	2.94
2) Doctoral degrees *(a)*	32,946	31,770	0.96
3) Young population in thousands (0-24 years old) *(b)*	97,617	96,090	0.98
4) Employed Scientists *(a)*			
Industry	430,300	1,193,700	2.15
Government, educational institutions, and others	529,200	982,600	1.71
Total	959,500	2,186,300	1.98
5) Young population/scientists (3/4)	102	44	0.43

Source:
(a) National Patterns of Science and Technology Resources (1987). Survey of Science Resources Series. National Science Foundation, USA, pp. 39 and 71.
(b) Statistical Year Book, 1984, UNESCO.

Although the USA has a large scientific community, the mismatch between the increasing demand for scientists and the number of young people interested in scientific careers is making it difficult to provide the human resources needed to maintain the rate of development. From 1976 to 1986 the number of scientists and engineers employed in the USA increased by a factor of 2, from 2.3 million to 4.6 million. Meanwhile, the number of doctoral degrees awarded in the USA decreased from 32,946 to 31,770 (12; tab. 3). This discrepancy between supply and demand has led to an increase in the age of active scientists in the USA. The peak of the frequency distribution curve has shifted from 34 years old in 1976 to 44 in 1986 (12). The scientific work force in the USA has been renewed in part by foreign students enrolled in doctoral programs; this group increased from 34,400 in 1976 to 72,809 in 1986 (12). As a result the percentage of jobs going to talented foreign students has increased. This represents a high cost to developing countries, because Third World students who go abroad to obtain a doctorate, and do not return, cause an enormous economic burden to their home country, which paid for their education from elementary school to graduation (13).

Research and development (R&D) in industry

The shortfall in the scientific work force in developed countries can lead industry to establish new policies aimed at fulfilling its needs in R&D (14). Transnational industries may find it advantageous to transfer part of their research activities to developing countries that have a large young population and are eager for scientific development. Such a move might help to decrease the discrepancies presently existing in the Americas.

There are several requirements for a developing country to host industrial R&D. There should be universities to produce appropriately trained people, there should be enough human material to justify the investment, and the country should be interested in promoting of industrial modernization. This profile is fulfilled by a number of countries in Latin America, including Brazil, Argentina, Chile, Venezuela and Mexico. In the case of Brazil there has been an exponential growth in the number of industries that spend money on R&D (tab. 4). This is a new trend: before 1970, neither transnational nor local industries in Brazil spent a significant amount of money on research. However, their investment in this activity has increased from U$330 million, in 1980 to U$ 725 million, in 1988 (14). Two examples of this change in policy for research funding are the transnational companies Rhodia and Pirelli, which in 1988 applied 1.5% and 3.5% of the money earned from sales to research and development in Brazil (16).

Table 4: Research and Development (R&D) in Brazilian Industry

Year	Number of industries investing in R&D
Before 1950	2
1950-59	4
1960-69	12
1970-79	39
1980-88	81

Source: ANPEI - Associação Nacional de Pesquisa e Desenvolvimento das Empresas Industriais: Perfil do Quadro de Associados. September, 1989.

These are indications that, through the private sector, a dissemination of science from the First World is already taking place. Scientific research in Brazil is no longer restricted to *academia;* scientists are being sought by industry, which as an important productive sector of the economy has a strong influence on public opinion and government policies. Industry requires that money paid in taxes be recovered in the form of better education at primary and secondary school levels, and universities capable of providing capable graduates.

It has been pointed out (14) that countries like Brazil cannot sustain a rapid growth of science in industries without a certain risk. The interchange between universities and industries requires a careful balance in the distribution of investments and in wage policies. If the advantages offered by industry entice a significant fraction of the competent scientists to leave the universities and public research institutes, the formative system responsible for the training of new scientists could collapse.

The Role of Science Education

The data and comments presented so far point to important contributions of science education to contemporary society:

(A) The social impact of science leads society to depend increasingly on scientific research to fulfill its needs. Science education can help people to understand the nature and utility of science and contribute to developing informed and active citizenry.

(B) Human resources for the scientific labor force are necessary to support the pace of scientific development. Raising young people's interest in science and in pursuing scientific careers is a challenge for science education in both developed and developing countries.

(C) The unequal distribution of scientific knowledge and young population among different countries poses difficulties for development of science in both developed and developing countries. Science education efforts in developing countries can promote the spread of research in science and technology to these countries, and disseminate the associated benefits of new knowledge produced.

Scientists and Science Education Initiatives

Although production of new scientific knowledge production has grown exponentially during this century, research in science education has not progressed at the same rate as in other areas. This situation is exemplified by a comparison of the number of indexed journals that publish research in science education, 132, with the number of journals in other areas:1,729 in social science journals and 5,692 devoted to biomedical and exact sciences (medicine, biology, mathematics, physics, chemistry and engineering) (17). There is some evidence that insufficient efforts devoted to science education research have had a negative impact: (a) Low test scores and students' deficiencies in basic science skills, in USA (9,18,19); (b) Students' lack of interest in science, and the relatively small numbers of students being prepared for careers in science and technology (8,18); and (c) Common misconceptions among students about scientific facts and the stereotyped image of the scientists and the scientific activity that prevails among school-age children (20,21,22).

Scientists are aware that science education plays an important role, not only in attracting and channelling talented young people to scientific careers, but also in helping to prepare them to use new technologies and to become lifelong learners, in order to keep integrated in a rapidly changing society. There are numerous programs in different countries devoted to the improvement of science education. An important aspect of these initiatives is the growing involvement of active scientists in science education at primary and secondary schools. Some examples in the USA are: (a) The National Science Research Center (NSRC), an organization devoted to educational research and development, information dissemination and outreach, cooperatively sponsored by the National Academy of Sciences and the Smithsonian Institution. Since 1985, the NSRC has been developing science education, working in close contact with schools in USA (9); (b) The recent publication of the American Society for the Advancement of Science's *Project 2061 – Benchmarks for Science Literacy* - an outline of fundamental concepts of the teaching of science (23); (c) Projects in science education, sponsored by the American Society of Physiology (10) and the American Society of Biochemistry and Molecular Biology. These projects include hosting high school teachers who undertake laboratory research projects for 8-10 weeks during the summer; and promoting the development of science education materials.

In Brazil, universities and research institutes have been increasingly engaged in science teaching programs, including: (a) *The University and learning science in schools* a program undertaken by the Universidade de São Paulo-USP. This program was conceived with a view to improving science teachers' education (8); (b) The Instituto de Matemática Pura e Aplicada, in Rio de Janeiro, has organized courses aimed at improving the teaching of mathematics in Brazil, and also developing teaching materials; (c) The Universidade Federal Fluminense, in Niterói, runs a program, *Espaço de Ciências*, that promotes science courses for both primary and secondary-school teachers and students, involving scientists from the university's Institutes of Biology, Physics and Chemistry.

Among the programs mentioned above these are some, both in Brazil and USA, that favor institutionalized interdisciplinary collaborations among leading scientists and educators on research and development projects on science education. Such is the case at the Departmento de Bioquímica Médica of the Universidade Federal do Rio de Janeiro. Besides its usual research activities in biochemistry, the department has developed research projects in sociology of science and science policy. These projects are generated and carried out along- side those involving basic biochemistry and the mixture creates an interdisciplinary environment for research and development in science education. What follows is a description of the programs currently under way.

Students Come to the University:

1) *Laboratory Projects* – Graduate students tutor undergraduates and high-school students at bench. Undergraduate students attending the university's regular biochemistry courses, and high-school students attending vacation courses (see box) are invited to participate in research projects that are in progress in the department. Students who are interested are interviewed and selected by graduate students, who become their advisors and oversee their projects, which are usually related to the senior students' thesis research. Presently there are over 100 undergraduate students working in the department's laboratories and over 50 graduate students engaged in tutoring. Acting as tutors also helps to prepare graduate students for the future when they in turn will supervise thesis research.

Some of the high school students are talented youngsters from low-income families, and they receive work-study fellowships. Although few in number their presence in the labs tends to focus the attention of the senior students on the problems afflicting Brazilian society.

2) *Vacation courses* – High-school teachers and students attend two-week intensive courses at the university, during vacation months. During the last six years vacation courses have given both teachers and students a chance to develop a closer view about the science process of inquiry, within the scientific environment of the university. More than 60 secondary level teachers and 1,000 secondary level students have attended the courses, which are intended to emphasize how scientific inquiry is used in generating knowledge. The course helps students to increase their comprehension of the nature of scientific activity at a time when they are about to choose their professional careers, and also influence the science teaching approach teachers use at schools.

A brief description of the vacation course – *The classes are directed towards creating an environment where students are stimulated to formulate hypotheses, propose, plan and execute experiments, and finally report the work done and draw conclusions.*

Teachers enroll for two weeks and students for one week. During the first week the teachers are the "students"; during the second week they work supervised by the instructors, coordinating the high-school students' activities.

The same structure is adopted for both weeks. On Monday the theme proposed for the week's work is introduced, with a brief historical account. Students are encouraged to raise their own questions related to this theme, guess about possible answers (hypotheses) and suggest experiments to check them. There are no lectures and no printed experimental protocols. The discussions are coordinated by graduate and undergraduate students in the first week. During the second week they are assisted by high-school teachers. Materials for carrying out the experiments proposed by the students are assembled beforehand or rounded up on the spot when unexpected proposals arise. The first experimental results obtained are discussed by the students, guided by the instructors, and then the students propose new hypothesis and experiments, based on the first round. This sequence is repeated many times during the course. On Friday, students present the results of their experiments to the students of other laboratory classes that worked on the same theme.

The experimentation variety and breadth can be illustrated by the experiments done from working out the following students' question (Q) and hypothesis (H): (Q) ***How does light enter plants?****; (H)* ***Plants have a pigment that absorbs light****. Experiments included: extracting from a purple leaf pigments of different colours, using different solvents, and separating them by paper chromatography.*

The main goal of the vacation courses is to involve students in actually doing experiments to answer their own questions; information content is secondary. By the end of the course students should realize that producing scientific knowledge, which they have previously encountered only in books, involves an enjoyable and continuous process of creating, testing and discussing ideas about natural phenomena.

Science Goes to School: *Long-term project activities carried out at schools, during the whole year.* The teaching approach used in the vacation courses is currently being adapted for use inside the schools. Science teachers are considered as partners and multipliers of the department's science education programs. They are encouraged and given continued support (tutorial and materials) to use the experience acquired during the vacation courses, in the schools they work. At present, there are 5 long-term projects under way in Rio de Janeiro high schools involving teachers who have taken part in the 2-week vacation courses. The aim is to encourage high-school science teachers to replace the traditional "cook-book" approach to laboratory classes with a format that emphasizes the scientific process of inquiry. That means asking the students to propose their theme-related questions and designing their own experiments to answer their questions. Finally, teachers are also expected to develop more comprehensive assessment strategies to evaluate the impact of such a science teaching approach in order to identify students' achievements related to their: (a)ability to inquire; (b)scientific understanding of the natural world; and (c) understanding of the nature of science.

Teachers Work in Department's Laboratories: Teachers are invited to engage themselves on research activities at the department's laboratories, both on biochemistry projects and on science education and sociology of science projects. However, they keep their links with the schools allowing a permanent bridge to be established between the university and schools. The projects on science education and sociology developed so far encompass areas of: scientometrics and science policy, the learning process in science, and the social impact of science (5,13,14,22). Projects that are under way include development and evaluation of science teaching strategies.

Graduate Program: *Several of the programs described have been structured into* a graduate studies program in the department that is run side by side with the traditional course in biochemistry. This course has 11 students, about 10% of the total master and PhD students in the department, and it can be considered an effective institutionalized and interdisciplinary environment for developing collaborative work among leading scientists from different areas of knowledge and educators.

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