THE PONTIFICAL ACADEMY OF SCIENCES

Scripta Varia

104

The Challenges for Science

Education for the Twenty-First Century

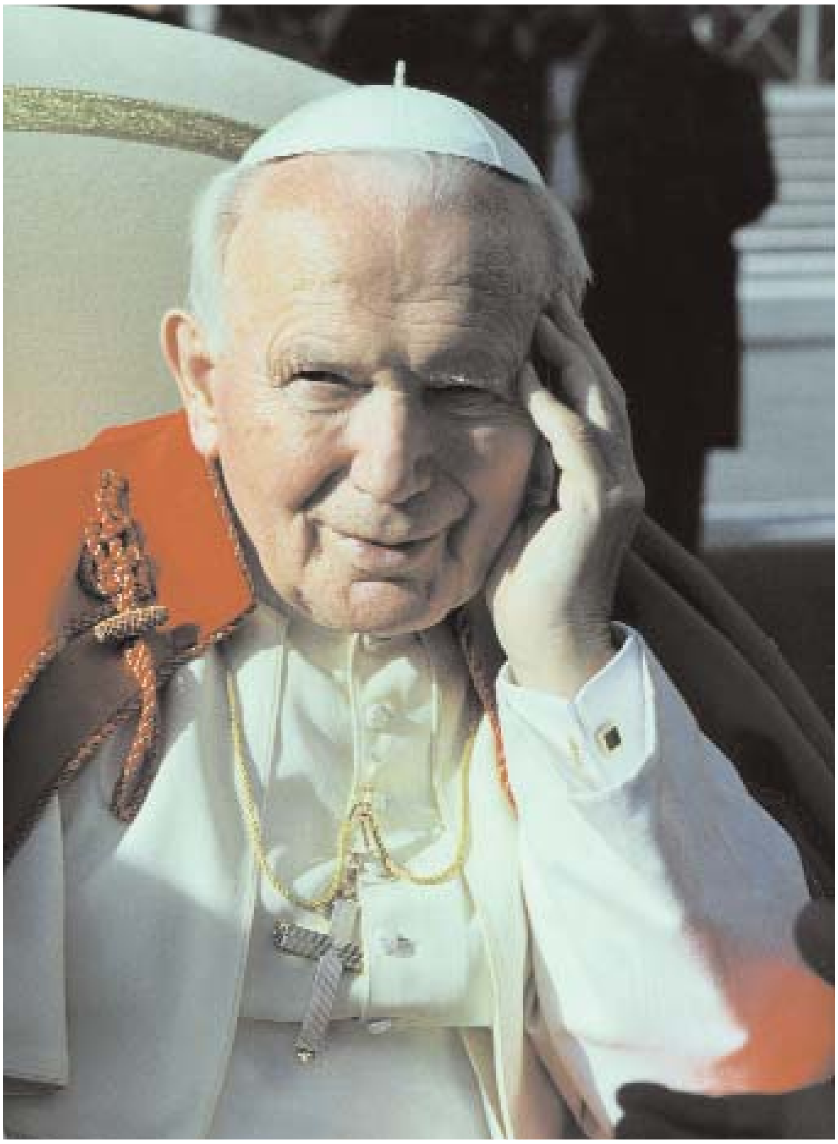
PONTIFICIA ACADEMIA SCIENTIARVM

VATICAN CITY
2002

Working Group
19-21 November 2001

THE CHALLENGES FOR SCIENCE:
EDUCATION FOR THE TWENTY-FIRST CENTURY

Address:
THE PONTIFICAL ACADEMY OF SCIENCES
CASINA PIO IV, 00120 VATICAN CITY



Joannes Paulus PP. II

The Pontifical Academy of Sciences – Casina Pio IV

The Participants of the Working Group of 19-21 November 2001

The Participants of the Working Group of 19-21 November 2001

PONTIFICIAE ACADEMIAE SCIENTIARUM SCRIPTA VARIA

104

THE CHALLENGES FOR SCIENCE: EDUCATION FOR THE TWENTY-FIRST CENTURY

19-21 November 2001

EX AEDIBVS ACADEMICIS IN CIVITATE VATICANA

MMII

The opinions expressed with absolute freedom during the presentation of the papers of this meeting, although published by the Academy, represent only the points of view of the participants and not those of the Academy.

ISBN 88-7761-080-8

CONTENTS

THE PONTIFICAL ACADEMY OF SCIENCES

Working Group on:

THE CHALLENGES FOR SCIENCE: EDUCATION FOR THE TWENTY-FIRST CENTURY

(19-21 November 2001)

Programme

Monday, 19 November 2001

9:00-9:05 *Speech of Welcome*
(N. Cabibbo, President)

9:05-9:20 *Introduction to the Workshop*
(P.J. Léna – P. Germain)

WHY SCIENCES/TECHNOLOGIES REQUIRE A NEW PLACE IN THE EDUCATION OF YOUNG PEOPLE

Chairman: N. Cabibbo

9:20-10:10 *Science and Education*
(R.L. Mössbauer)

10:10-11:10 *Science Education and Capacity Building in the Twenty-first Century*
(C.N.R. Rao)

11:10-11:30 Coffee-Break

Chairman: J. Allende

11:30-12:00 *Science Education in Brazil: Towards a New Proposal*
(C. Pinto de Melo)

12:00-12:40 *The Science of Education and Education in Science*
(S.L. Jaki)

12:40-13:15 *Science Education and Information Technology*
(M.G.K Menon)

13:15-15:00 Lunch

15:00-16:30 *Building a Vision of Inquiry-Centered Learning. A Workshop Demonstration*
(D.M. Lapp)

EXAMPLES OF SPECIFIC APPROACHES/SUCCESSES IN VARIOUS COUNTRIES

Chairman: R. Hide

16:30-17:10 *The Problems and Promises of Science Education in Chile*
(J.E. Allende)

17:10-17:30 Coffee-Break

17:30-18:00 *Closing the Educational Gap among Teenagers*
(A.S. Kashina)

18:00-18:40 *Science Education in France: 'La main à la pâte'*
(P.J. Léna)

18:40-19:10 *The Pontifical Academy of Sciences: a Historical Profile*
(H.E. Msgr. M. Sánchez Sorondo, Chancellor)

Tuesday, 20 November 2001

EXAMPLES OF SPECIFIC APPROACHES/SUCCESSES IN VARIOUS COUNTRIES (CONTINUED)

Chairman: R. Vicuña

9:00-9:45 *Experiences in Mexico in the Use of Hands-on, Inquiry Science Education Systems in Primary Schools*
(G.R. Fernández de la Garza)

9:45-10:30 *Science for Citizenship*
(J.F. Osborne)

10:30-11:00 *The Presence and Absence of Science in Italy's Educational Tradition*
(G. Tognon)

11:00-11:30 Coffee-Break

Chairman: G.V. Coyne

11:30-12:10 *Evaluation and Education in Science*
(B. Gueye)

12:10-13:00 *Strategies for the Improvement of K-8 Science Education. A Report from the United States*
(D.M. Lapp)

13:00-15:30 Lunch and Visit to the Vatican Museums

THE PLACE OF SCIENCES/TECHNOLOGIES IN THE EDUCATION OF TWENTY-FIRST CENTURY CITIZENS

Chairman R.L. Mössbauer

16:20-17:00 *The Computer in the School: a Tool for the Brain*
(A.M. Battro)

17:00-17:30 *Science and Society*
(Y. Quéré)

17:30-17:50 Coffee-Break

Chairman Y. Quéré

17:50-18:30 *Hands-on Science*
(R.L. Gregory)

18:30-19:15 *International Collaboration in Science Education*
(all Participants)

Wednesday, 21 November 2001

THE ROLE OF THE SCIENTIFIC COMMUNITY

Chairman: C.N.R. Rao

9:00-9:40 *The Responsibility of Scientists in the Education of Young People*
(R. Vicuña)

9:40-10:10 *The Scientific Education of Citizens*
(P. Germain)

10:10-10:40 *From a Static to a Dynamic System of Education in Science*
(A.V. Verganelakis)

10:40-11:00 Coffee-Break

11:00-11:40 *Modern Cosmology, a Resource for Elementary School Education*
(G.V. Coyne)

11:40-12:20 *The Importance of the History of Science in Intellectual Formation*
(J.-M. Maldamé)

12:20-13:00 *A Philosophical Platform for Proportion in Education: the "Scientific Subject" and the Creative Act of the Human Being* (A.-T. Tymieniecka)

13:00-14:30 Lunch

CONCLUSIONS AND RECOMMENDATIONS

Chairman: P. Germain

14:30-17:00 *General Discussion and Resolutions*

17:00 *End*

LIST OF PARTICIPANTS

Academicians

CABIBBO Nicola, President
COYNE George V.
GERMAIN Paul
HIDE Raymond
JAKI Stanley L.
LÉNA Pierre J.
LEVI-MONTALCINI Rita
MALDAMÉ Jean-Michel
MENON Mambillikalathil G.K.
MÖSSBAUER Rudolf L.
RAO Chintamani N.R.
SÁNCHEZ SORONDO Marcelo, Chancellor
VICUÑA Rafael

Experts

Prof. ALLENDE Jorge E., Director
Instituto de Ciencias Biomédicas
Facultad de Medicina
Universidad de Chile
Avenida Independencia 1027 – Casilla 70086
Santiago 7
(Chile)

Dr. BATTRO Antonio M.
Academia Nacional de Educación
Pacheco de Melo 2084
C1126AAF Buenos Aires
(Argentina)

Mr. FERNÁNDEZ DE LA GARZA Guillermo R., Executive Director
The United States Mexico Foundation for Science
Avenida San Francisco 1626
03100 Mexico, D.F.
(Mexico)

Prof. GREGORY Richard L.
University of Bristol
Department of Experimental Psychology
8, Woodland Road
Clifton
Bristol, BS 1TN
(United Kingdom)

Prof. GUEYE Babacar
École Normale Superieure
Centre de Recherche
Avenue H. Bourghiba – B.P. 5036
Dakar
(Senegal)

Dr. KASHINA Anna S.
1000, Spanish River Road # 3T
Boca Raton, FL 33432
(USA)

Dr. LAPP Douglas M.
3104 Hawthorne Street, N.W.
Washington, DC 20008
(USA)

Prof. OSBORNE Jonathan F.
Kings' College London
Department of Education & Professional Studies
Franklin-Wilkins Building
150 Stamford Street
London SE1 9NN
(United Kingdom)

Prof. PINTO DE MELO Celso
Universidade Federal de Pernambuco
Departamento de Física – Cidade Universitária
50.670-901 Recife, PE
(Brazil)

Prof. QUÉRÉ Yves, Foreign Secretary
Académie des Sciences
Délégation aux Relations Internationales (DRI)
23, quai de Conti
F-75006 Paris
(France)

Prof. TOGNON Giuseppe
Libera Università Maria SS. Assunta (LUMSA)
Facoltà di Scienze della Formazione
Piazza delle Vaschette, 100
I-00193 Roma
(Italy)

Prof. TYMIENIECKA Anna-Teresa, Rector
The World Institute for Advanced
Phenomenological Research and Learning
1 Ivy Pointe Way
Hanover, New Hampshire 03755
(USA)

Dr. VERGANELAKIS Antonis V.
26, Garyttou St.
153 43 Aghia Paraskevi
(Greece)

INTRODUCTION

PIERRE J. LÉNA

Observing the list of the last fifty years of Plenary sessions or Workshops held by the Pontifical Academy of sciences, we see that a number of them dealt with subjects which clearly have to do with education, such as Science and the modern world (1976, 1979), Developing countries (1979), Science and human culture (1990), Changing concepts of nature (1998), The future of mankind (Jubilee in 2000), but the word *education* did not appear in any of these titles.

Today, the concern for science and technology education blossoms in many parts of the world, in Science Academies, in Research organizations, in public opinions, no matter what the stage of countries development is. Why are we entering into this change, if this is really a change? In the last decades, accent has been placed on scientific *information*, and on the role of the media (press and television), in order to bridge the increasing gap, or even fracture, between the immense growth of scientific knowledge and technical achievements on one hand, and the understanding – or at least awareness – of the citizens on the other.

But *information* is not *education*: when a child leaves the school at ages which may vary between 12 to 16 or beyond, what understanding of science and/or technology does this boy, this girl have? An accumulation of mere facts, results, formula, an admiration for technological achievements of 'black boxes', or for the spectacle of nature, from atom to galaxies, put on stage by the media, do *not* build the basic roots of a scientific attitude towards the natural world, of a proper reasoning based on rationality, of a capability to use adequate words, to argument, to designate phenomena, concepts, causality, probability with a critical mind.

To many, it appears that such basic abilities, to be proposed to every child on the planet, not only are desirable for the world to be able to solve the many problems facing us (energy, water, etc.), but are part of human development, in order to properly assume the new and vast areas of freedom opened by the expansion of science and its applications.

And the correlative question is: how could or should teachers, during the 30-40 years of their practice, cope with this pace of change in science? How can we help them?

Hence the choice made for this Workshop has been to concentrate on science education issues at primary and secondary school levels, mainly ignoring other fundamental aspects (Universities and general public). The following points were selected as a focus of the Workshop attention:

– In order to mix global views and concrete examples, we have chosen to listen to presentations illustrating various experiments and original developments in a number of countries.

– Applying the fundamental precept 'by doing', we also have chosen to have a small 'practical workshop' with Douglas Lapp, former Director of the NSRC (NAS & NSF): it will hopefully trigger interesting discussions.

– To which extent information technologies modify the classical frame of teacher's training and children learning is a new question, which will be extensively adressed during this Workshop.

– As many of the successfull experiments indicate, the role of the science community – the people who actually do science or technology as a profession – is a key ingredient of change, especially at primary and junior high school level: this new role for scientists and engineers will deserve special attention.

– We have also tried to make the attendance as diverse as possible, yet it is unfortunate that still large cultural areas of the world are absent, as the Middle and Far East.

– We hope to be able to draw some formal conclusions and recommandations from the Workshop, to be discussed on Wednesday and printed with the Volume of your communications.

It was doubly unexpected for me to be at the same time receiving the honor of election in this Academy and placed in charge, with Paul Germain, of this first Workshop to be specifically devoted to education for the 21st century. I thank you all for your contributions and patience in the numerous exchanges we had in the last months and wishes as a good session.

WHY SCIENCES/TECHNOLOGIES REQUIRE A NEW PLACE IN THE EDUCATION OF YOUNG PEOPLE

SCIENCE AND EDUCATION

RUDOLF L. MÖSSBAUER

The problem is as old as the school itself. I became aware of this fact, when I went through the files in my records. There have been numerous articles written in the past, and numerous articles will be written on the same subject in the future.

Germany will be treated preferentially, because education is *also* a national problem. But the international scale of the problem will not be forgotten.

Already in 1983, the Süddeutsche Zeitung presented an article talking about our schools. In this article, the schools were considered to be rather remote from the world. The paper describes that modern pedagogy went into abstract regions, talking about structures which would present a more complicated system of life, with the result, that the kids gather less and less and become increasingly unenthusiastically. Has the reform of education maybe achieved the opposite it was supposed to do? The school is characterized by an often meaningless tenor of learning and very often school is advancing too much and too early, penetrating into things, which clearly are the matter of the university. To find explanations for this fact, you have only to take school books or curricula in your hands. It could seem that many of them have been written only with the purpose to embitter the youths, to make sure they will never enter the sciences or the humanities. Theodor Hellbrügge, a specialist in children's medicine, was formulating it like that: 'The problems of school, under which the entire population suffers, results above all that school advances without goal and that it does not even know, what the children suffer from. This is a grotesque and depressing development though it once was the high level goal of the reform of our educational institutions to free our population from such problems'. But this is largely a German problem, written on already in 1983. Since then, nothing essential has changed. Besides, teachers are burdened with the whole responsibility and they are considered the scapegoats for everything. In Germany, we have in some branches a lack of teachers, a fact, which has to be blamed on two main sources: Older teachers feel burnt out, get sick and try for early retirement. Young people, on the other hand, hesitate to become teachers, because they are then the scapegoats for all the problems of society. Besides, they don't get the necessary training in didactics and pedagogies for dealing with the youth.

We cite in the following a few of the items, which I consider of principal interest for schools:

1) It is crucial to have the right motivation for the pupils, i.e. one has to motivate the students when they have no motivation of their own. Children start grammar school being interested and curious, but later on they very often lack the proper motivation. It is especially at high school, which necessitates the right motivation. Universities are here much less concerned, because the students at universities usually are already having the right motivation, while it is at the high school level, where students are very often frustrated. Yet it is at high school, where they get selected for their future studies. Incidentally, high school in Germany should finish at least at the age of 18, instead of 19 or 20, but this is a special German problem.
2) It is essential that the students have their proper self-confidence, because it is only then, that they can get on with their life. A lack of self-confidence makes all kind of troubles. The children often feel very much under pressure at school. The notion of being 'cool' is a reflection of the lack of self-confidence, with the students simply putting away matters. I felt the pressure in my own case, when my father said if you are not doing well at school, you will be transferred to an apprenticeship. This notion was so impressive, that I thought for a long time, that an apprenticeship was the worst thing that could ever happen to me. But he never was putting me down, saying that I was bad or some similar notion, which lowers the self-confidence. Education means to escort somebody, not to pull him down. Trained and emotionally stable students are essential for the future of a modern society. Talented kids with a good self-confidence will always make it, but most pupils have to be motivated for a subject. This is leading to the next fundamental point:
3) The quality of teachers is also crucial. Much emphasis has to be put on this point. The selection and training of teachers is essential for the advancement of a country. The most important criterion for the

selection of good teachers is: He must be fond of kids, must be sociable and must be able to stand emotional and physical stress. A one-track specialist who cannot empathize with children will always deter from his subject, even if he is an expert in his field. Teachers must be continuously trained; this must be compulsory. The German civil service program is counterproductive to this point. Teachers should get a program in their own subject as well as in pedagogies and didactics. One learns a life long and this should also hold for teachers. In particular, high school teachers are not prepared for the job they are doing later on, not so much in their own subject, but especially in pedagogy and didactics. We have had in the German town of Dillingen a continuation seminar for teachers, which was exclusively limited to the field of natural sciences, but it was always the same 1.5 % of the teachers of the country which participated, irrespective of whether the training was in elementary physics or in solid state physics. This has to be changed. I remember in this context the case of two Hungarian high schools, where many famous people came from in the natural sciences, people such as Szillard, von Neumann, Caratheodory, Telegdi and so on. I talked this over with the Minister of Education of Hungaria, but he simply said: ‘Bring me the teachers’.

These points are the crucial ones. Yet there are others, which should be mentioned:

4) A solid education and possibly even enthusiasm should be prerequisite for a particular subject. Education here has two notions: First of all, it is instruction and training. But secondly, it is also the formation of a character and of mental powers.

   A school system, which does not educate people according to their elementary needs, remains unsocial. While it is the prime task of the schools to provide the youth with a human education, in some cases quite the opposite happens. A human education in this sense does not comprise, for instance, linguistics, the analysis of processes, molecular biology, mathematical set theory, elementary particle physics and so on. These matters are subjects for university studies; at high school level they serve largely the self-esteem of the teachers and their superiors, but they don’t serve the education of children.

5) Schools should provide an opportunity for practical work, for instance in banks, hospitals, industry an so on, in order that some pupils get sure about a subject of their interest.

6) There is the question of suicidal actions. It is a fact that in western countries suicide is on the second place in the statistics of the reasons of death of young males between 16 and 25. Often these are very gifted and sensitive young men. Teachers should be trained to see signs of crucial depression and should know how to offer help, as is already enforced by law in Sveden.
7) There should be psychologists at each school. These people should have experience in teaching, and should have special competence in advising youths, parents, other teachers and headmasters.
8) Children today have very often much distraction and the lessons are in clear competition to these distractions. By consequence, the children lack concentration. In my own case, I remember that the question of concentration was crucial for me: During my whole studies I pursued the goal how to concentrate.
9) We come to the point of mobbing at school. It is sad but it is a fact, that the weak ones – either physically or mentally – are teased by some other kids. A teacher should know how to intervene in this case.
10) We come to the role of parents in the education. Parents play a crucial role and many are not apt to that role and therefore tend to delegate their responsibility to school and other public institutions.
    Here I have to cite a special German problem: We have in Germany at the 'Hauptschule' large crowds of immigrants, who have lots of problems of their own. Prime problem is the German language, which a large share amongst them is simply missing, especially when their parents don't know German, too. Some of them are doing well at school, others lack completely an understanding of the lessons. This holds, in particular, for girls, who often are abused for taking care of the smaller ones, if the parents are both working.
11) The Abitur in Germany – it is called Matura in Switzerland and Austria – is like the eye of a needle, through which everyone has to go, if he wants to enter university. It is the exit examination of the high school. Parents often put pressure on the kids, because they think only with the Abitur the kids can finally have a good life. In other countries, there is an entrance examination at the university. It has to be seen, which one is better.

There are many other problems at our schools and I have cited only the crucial ones.

There is the question of the formation of an elite, a notion which in Germany will rise some eyebrows. The standard criterion of an elite should be only the talent of a student, which for ideological reasons is difficult to sell in present Germany, which is a socialistic country.

Already in 1981 we had a meeting at the Bavarian Parliament with the title ‘On the Position of Research’. The result was discouraging. The educational reform is the major domestic issue in Germany. But nothing essential happened.

It is probably not very far fetched to assume, that there is a connection between the defects of the school system and the quality of research. The advance of research within new scientific fields is hardly made any more in Germany, and this has its roots partly in the schools. Already the elementary school teacher often prefers fields other than science, because the natural sciences are considered to be very difficult and the education there is very abstract. It is even chic to present a lack of knowledge in the sciences, while it is an outrage against good taste to present such a lack in the humanities. This has to be avoided. Particularly in science children should have the opportunity to do concrete examples, involving illustrative and intuitive material.

It is a worldwide phenomenon that there is a drastic shortage in the number of students, who enter the natural sciences and engineering and this fact has its roots partly in the schooling systems. This matter is handled in the United States in the following way: There has always been a shortage of scientists at the universities, but it was coped with immigrants, which, incidentally, are also saving the expenses for the education of these urgently needed scientists. You have, of course, also set aside the necessary funds, but this has never been a problem in the U.S. In Germany, we are presently lacking both the proper scientists and the necessary funds and in addition we have the problem that many German scientists are leaving the country for other European countries and for the U.S. because of the superior conditions for research with respect to funds and also less bureaucracy.

Another German problem is the question of tuition fees at the universities, which largely is an ideological question. Education is supposed to be free, even if the ordinary worker with his taxes is paying for it. In my own case we had tuition fees, but we also had large scholarships, which meant, that I never paid anything for the tuition, even got some money for buying books. This system was abandoned in the meantime, but the present system is counterproductive to its goal.

One could add quite some more points, but I just wanted to show the main tracks.

Finally I want to point out my opinion, that we should make all efforts to establish an educational system, which helps children and youth to preserve their joy of life, their curiosity and their concern for one another. This should be the prime goal of every education.

SCIENCE EDUCATION AND CAPACITY BUILDING IN THE TWENTY-FIRST CENTURY

CHINTAMANI N.R. RAO*

1. Introduction

The relevance of science to the future of society is likely to be considerably more far-reaching than its influence on human affairs in the past. Some of the pressing problems of society today are related to the rapid decline in the quality of global environment, depletion of natural resources, increasing poverty, hunger and illiteracy in many countries and regions of the world. Solutions based on science and technology are likely to provide remedial measures to some of these problems, and yet science and technology as we understand today, are not available to a vast human population. It is essentially in the advanced world that science and technology have contributed to individual fulfilment, the well-being of communities, and to the health of nations. A high percentage of the human population does not understand science or its utility, and its potential for economic and social development. There is a tendency to get impressed with certain products of technology that may bring in superficial prosperity, but a proper understanding of technological innovation and of the way science and technology are related to society is important for real progress of all countries, particularly the developing ones. Such an understanding is retarded today by the barriers impending the sharing and the use of scientific and other knowledge necessary to make decisions and choices. They include poor education, lack of exposure to science in the formative years, inadequate grasp of science in the general public, non-availability of proper facilities

*President, Third World Academy of Sciences, Trieste (Italy).

for training, poorly endowed laboratories and teaching institutions (for those already trained) and isolation of scientists and teachers. Even in the advanced countries, science or specifically science education, is meeting with difficulties, disenchantment or absence or excitement being one of the factors. I shall address some of these issues in this presentation.

The changing global scenario has created unusual situations for most countries today. Those in the developing countries, face a formidable challenge in terms of problems related to poverty and illiteracy and at the same time, they have to compete with the advanced countries in science and technology. Thus, at no time in the history of mankind has a democratic country such as India faced such challenges where it has to feed the poor and at the same time, has to be at its very best in science and technology to be able to compete. This situation has direct impact on the strategies that one has to adopt for science education. I shall briefly outline what I consider to be the problems and challenges in science education and capacity building and indicate some possible solutions. I make this presentation with the fundamental faith that the mechanism to reduce global imbalance of development (or the gap in well-being) and to increase the stability of the world has to be based on knowledge.

2. The Changing Scenario in Science Education

What is happening in science education in the world at large, deserves attention. While dealing with science education, it is necessary to distinguish the problems and challenges faced at primary/middle school level from the college or university (tertiary) level. At the primary level, the main challenge is to deliver the core message of science to all children, while at the advanced level the challenge is to find ways of imparting the essential and crucial information/knowledge of a subject. However, the common question at both levels is, how do we interest young people in science and inculcate scientific temper in them. How can everyone benefit from a knowledge of general science and how can some of the bright students be made to take up science?

Computers have made a major impact on everything people do in daily life. Information technology is there to stay and most high schools in advanced countries are connected to the internet. Most children in the advanced countries are at home with computers, somewhat independent of their scholastic abilities and performance. Some of the developing countries have made moderate progress in the use of IT at schools and colleges, although much is yet to be done. IT for distance education is also being attempted.

There are other significant changes occurring in the science education scenario as well. Educational Institutions in some countries are trying to make education more broad-based and are trying to provide greater choice and flexibility. In Japan, tertiary science education is still traditional, imparting thorough in-depth training to science students. Unless one competes and work hard, there is little chance of succeeding in science in Japan. In the US, science subjects are taught along with many other subjects including social sciences so that the students can have a better alternative for their professions later. However, those who specialize in science, by and large, receive high quality instruction. In most European countries, science is generally studied only by those who specialize.

Excellent curricular material continues to be produced and constantly improved in most of the advanced countries, although they have not been used as effectively as one desires. Here again, the tools of educational technology available for instruction (specially self-instruction) have been remarkable. However, the use of paper or the need for teachers has not been affected (minimized) by the technology age. The various advances and efforts in science education made in the advanced countries do not readily reach the developing countries. Proprietary rights often prevent such diffusion. Unfortunately, many of the developing countries have also not made sufficient effort to explore various aspects of science education and the use of educational technology. They are still facing formidable problems of very poor infrastructure and teachers at most schools.

3. What do we teach? Chemistry as a case study

A thinking teacher inevitably faces the problem of what to teach. With the explosion of knowledge, how and what do we pick as the essentials that have to be taught at school or at college level? In order to understand the dynamics of science, today, I shall briefly discuss Chemistry (which is my field of interest) as a case study. I will first dwell on the nature of chemistry and its dynamic scope. Chemistry is an old subject with traditions, and it is also a mother science having interfaces with every possible discipline. The chemical cornucopia is truly impressive and it is difficult to see how there could have been much progress of humankind without chemistry. Human progress has indeed been closely intertwined with the progress in chemistry. Whether it is a fertilizer or a plastic, cough syrup or the chip, there is chemistry in it. And, Chemistry is growing all the time because of its serious concern with issues of vital importance to society, such as the environment. It is chemistry that showed the devastating effect of the chlorofluorocarbons on the ozone layer. The contribution of chemistry to the production of food and life-saving drugs, which are both basic necessities of humankind is well known. The way chemistry has contributed new ideas and newer dimensions to modern science may not however be common knowledge.

Broadly speaking, chemistry involves the study of structure, dynamics and synthesis. Chemists have made use of every possible means to study structure, properties, phenomena and processes involving atoms and molecules in various states. They have employed high resolution (~1.5Å in size and a fraction of a wavenumber in energy), a variety of time scales (down to a femtosecond), extreme conditions (high and low temperatures, high and low pressures, intense radiation) as well as theoretical methods of different degrees of sophistication in their investigations, the computer having added yet another powerful tool, simulation, to the chemists' arsenal.

The preoccupation of chemists with structure since the early part of this century has provided the basis to understand not only simple molecules but also the basis for modern biology. The saga of chemistry in synthesis is remarkable. In 1828, Wohler synthesized a simple molecule, urea, and in 1968, Woodward synthesized vitamin B12, a very complex molecule. Today chemists are able to synthesize molecules of highly complex shapes and structure.

Chemistry is generally based on the strong covalent bond (linking atoms in molecules). There is now an effort to build complex structures by using non-covalent, weak binding forces. The emerging area of supramolecular chemistry has indeed provided a new direction.

Chemistry has played a crucial role in some of the path-breaking discoveries related to advanced materials in the last decade. Discoveries in this area such as high-temperature superconductivity in 1986, as well as preparation of fullerenes in 1990 and mesoporous silica in 1992 have depended directly on chemical knowledge. All such contributions lead to major technological innovations. I see an unlimited future for materials chemistry which will not only serve the growth of new science but will also answer the growing demands of society such as cleaner technologies and alternative energy sources.

Chemists build bridges (bonds) between areas as well as ideas, the bridge between chemistry and biology being a notable one. While chemistry is characterized by its diversity and breadth, biology is characterized by its complexity. Chemists are now trying to understand and synthesize more and more complex systems, while maintaining the diversity. There will soon be an interesting meeting ground between chemists and biologists in the complexity-diversity plane, giving rise to exciting developments of great value.

Although science, as exemplified by chemistry, has progressed in various dimensions, the benefits of the progress and even a knowledge of such progress have failed to reach the students as well as a high percentage of the world's population. What we teach in schools has little to do with how we practice science in the research laboratory. While we are interdisciplinary in research, we become narrow and parochial in teaching. Furthermore, the way science advances today is so forbidding, that it is not possible to catch up unless one is already in it. The question that should bother teachers at all levels is "What exactly should we teach? Which are the essentials?" This has implications in education.

4. Some challenges of this century

In the 21st century, science will have newer venues and challenging opportunities, but we will also be facing unprecedented problems of human migration, accompanied by an increasing divide between the haves and the havenots. Scientists have an obligation to serve the entire humanity, keeping in mind the need for a cleaner environment and better quality of life for a vast majority of the population, which has hitherto been denied the basic needs. In so doing, there is much to be done in inculcating the right attitudes in the citizens of the world and in ensuring that they have the necessary capacity to participate in human endeavours. The few success stories in the developing world have shown that there can be social progress only with proper education and attitudes, specially amongst women. The real dichotomy in some of the developing countries is that, on the one hand, science has to be used to solve basic problems and on the other, it has to be employed on a competitive basis for developing technologies. Clearly, there is need for greater human understanding, tolerance, compassion and generosity amongst the citizens and the scientists of the world, specially those who have been more fortunate.

The proportion of the poor in the world is increasing and it is no wonder that the poorest fifth of the world's nations hold only 1.4% of the world's riches. Hardly 3% of the internet hosts are in the developing world. According to RAND's classification, there are 22 scientifically advanced countries, 24 scientifically proficient countries, 24 scientifically developing countries, and 80 scientifically lagging countries. The developing countries belong to the last three categories. The least developed countries (LDCs) are in the last category, mainly in Africa. Differences between the scientifically advanced and proficient countries can be readily seen. For example, India with a 1000 million population produces around 5000 Ph.Ds per annum while the US produces 100 per million of population. In most of the developing countries, specially the least developed ones, there are very few scientific institutions (of quality). In some of them, there are very few well-trained personnel as well. The common human being is by and large oblivious to developments in science and of the factors responsible for economic development, being mainly absorbed in day-to-day chores of seeking a livelihood. Illiteracy and obscurantism are dominant. Even in a country like India, prevalence of illiteracy is high. The question therefore arises as to how we can make the developing countries with such formidable problems become aware of scientific progress, of the effect of science on development, and the need for scientific attitude in everything that we do in daily life. Then, there is the cultural aspect. There is a tendency in developing countries to copy and imitate what has been done elsewhere. This is certainly not a healthy situation.

Scientists who work in laboratories or teach in educational institutions in most of the developing countries face immense problems. Even in the best of the developing countries, libraries are in a pathetic shape. Information technology has not made much headway. There is little computer capability in many of the institutions and people are not connected to the new information highway. The laboratories have poor infrastructure and outdated equipment. A recent international survey shows that 83% of the schools in the developing world do not have laboratories, 73% do not have proper buildings and 58% do not have science teachers. A large proportion of the schools (20-40%) have no facilities or teachers. Many are single-teacher schools and most teachers are not equipped adequately to teach science. The gap between the laboratories in the developing world and in the advanced world is increasing day by day. In fact, I do not know of a single college or university even in a country like India, which is comparable to some of the best in the advanced countries. Research facilities in most institutions are far from satisfactory. Minimum infrastructure facilities such as electricity and water are not available to a good portion of the laboratories even today. I compare a developing country to a man standing on the banks of a river whose width is changing everyday. There is no hope of ever constructing a bridge across the river and the other side of the river gets farther and farther. The other side of the river today represents the hope for better living and greater scientific progress through education and capacity building. Can there be a quantum leap, is a question that it is difficult to answer, with regard to most countries.

Let us look at the situation in a large country like India in the early part of this century. The population in India is one billion, a majority of which is young. India is one of the youngest countries in the world. The demands on the educational system are unprecedented, requiring major structural and organizational changes to be brought about with a sense of urgency. The situation in Africa is considerably more serious and offers many challenges.

Isolation of scientists and teachers in developing countries is a factor that deserves some attention. Even the best of us have great difficulty in keeping abreast in our fields. It is not ability alone that matters, but also the availability of information on the spot. How does one remain competent, let alone be competitive in a developing country, where information is not easy to get? In the advanced countries, most scientists and teachers no longer go to the library. They talk to friends, attend conferences and learn about what is happening to-date in the area of interest, more by informal means (or through the computer). Furthermore, in many of the developing countries, specially the LDC's, there would be a small number of scientists in any given area.

Another serious problem is the tendency in most developing countries to undermine the importance and role of science and education. This tendency for some reason seems to be encouraged by the new global economic scenario. Investment in these sectors is extremely low in most of the developing countries.

Besides the situation discussed above, there are other problems. Brain drain is one of them. This is an important, but controversial topic. It is interesting that the present trend is for greater migration of professionals from the developing countries with better education – a surprising dichotomy indeed.

5. What can we do?

While it is easy to be pessimistic, I would like to take an optimistic approach. I believe that it is possible to network at least some select colleges, universities and other institutions in the developing countries and connect them to the internet. It should not be too difficult to ensure that most of the institutions have e-mail and fax facilities. Regional (national) libraries and laboratories could be established in Africa and elsewhere. Good facilities in chosen areas could be provided to some of the better institutions and individuals.

Governments in developing countries will have to take full responsibility to support science and education because there is little industrial support available in these countries. Governments have to be the instruments of change. They have to be the catalysts and the providers. Besides the Governments, academies and professional bodies can contribute much in changing the attitudes of people and politicians. If at all this becomes possible, we may make some progress in science education in the third world. There would then be some capability in science and the necessary confidence in these countries to deal with the rest of the world. It will enhance the self-esteem if the teachers and scientists in the third world and enable them to take up challenging tasks. The language of modern science is so essential today even to have a conversation. While one may not develop a new technology, the language is necessary to buy technology, to be counted amongst the nations of the world. Science has become a currency and that currency has to be provided.

6. A possible international program in science education and capacity building

In what follows, I list some of the important measures that need to be taken. I owe some of the ideas to the Capacity Building Committee of ICSU.

6.a. *Improving primary/middle school science education and adult literacy programs*

There is considerable information on new and improved methods of teaching science to young children. It is profitable to assemble, filter and disseminate tested curricula which can then be transferred to all countries and to an international network.

– Decide on a set of agreed upon standards of primary/middle school science education (e.g. what should children know and understand at the end of the first, and the seventh or tenth years of school). Such material would be required for adult literacy programs as well. Identify core concepts, teaching materials and classroom experiences for primary science education and adult literacy programs. The purpose is to inculcate scientific temper and literacy amongst children and others independent of their professions in later life.

– Identify those aspects of science, which when properly presented would excite the imagination of young minds and find ways to promote creativity. Select stories of discoveries and scientists that may enthuse and interest children and teachers.

– Identify a world-wide network of scientist-teachers who are interested in promoting science education and connect them with sources of the latest materials and research in cognitive sciences.

– Design activities to encourage the participation of girls and women in science education and form partnerships with groups involved in such efforts.

– Examine and evaluate the role of science museums and hands-on science exhibitions in school education.

– Recruit, recognize and reward good and dedicated teachers.

6.b. *Minimizing the isolation of scientists and teachers and promoting excellence*

Isolation of scientists and teachers in developing countries is a crucial factor affecting science and education. Difficulties of travel and communication with colleagues and the absence of a critical mass of scientists often limit the growth of science.

– Promote co-operative activities by regional associations of teachers and scientists in the same field.

– Promote use of scientific facilities located in one country to scientists from other countries. Provide easy access to such facilities.

– Strengthen and promote South-South cooperation.

– Seek the establishment of regionally shared major facilities.

– Ensure that every school and scientific centre in the world has internet connectivity.

– Set up and support small units of excellence based on individuals or groups of individuals specially in LDC's in Africa.

– Develop sound scientific and technical man-power planning depending on the needs.

6.c. *A network for capacity building*

Information technology is introducing dramatic changes and may hold the key to our goals of building global capacity in science.

– Set up a mechanism to collect, evaluate, and arrange for suitable editions and translations of programmes in primary school science education and programmes that address public understanding of science. Exemplary programmes can be disseminated.

– Build a network of organizations and obtain their commitment to cooperate in the programme, and establish internet links with all parts of the network.

– Encourage national bodies devoted to capacity building in science.

6.d. *Promoting public understanding of science*

Today, in this striking world, there is the common language of science. It is the same everywhere. It is essential that all human beings, understand the essentials of this language, content and methodology.

– Seek the co-operation of professionals in the assessing the state of public science literacy.

– Obtain advice of media experts and scientists in the frontier of science communication. The role of television is especially crucial and much thought must be given to making use of TV for scientific literacy.

– Encourage science museums and hands-on science exhibitions (travelling exhibits) and other initiatives which bring science closer to the public.

6.e. *Making a case for science and education*

Science is by far the greatest force for change in the modern world and education is the only means to communicate and share knowledge.

– Pressurize or persuade Governments in developing countries to invest at least 1% of the GDP on S & T and 6% of the GDP on education (~2% on higher education).

– Help to organize national and regional meetings to make the case for science and education.

– Organize national and regional science weeks.

– Employ the media and the internet to build a case for science education.

7. Concluding Remarks

Whatever I have discussed here has to be accomplished in the next decade or so. Otherwise, in this highly competitive world, we may not have the time to think about the impoverished and the underprivileged in the future. As time goes on, it is possible that there will be new generations of citizens, who may be somewhat benign to real world problems. I feel that it is the responsibility of our generation to do something meaningful. To start with, we should repeatedly declare in various fora, such as the Pontifical Academy of Science, the importance of science and education and their role in society, and the need for support for science from Governments. We should make a case for science and science education in the developing world, a case for optimal support for science and education even in the poorest and the least-developed of the countries of the world. It is my earnest hope that enlightened citizens from the advanced world will make it their first priority to help in spreading knowledge. It is a great humanitarian activity. The removal of illiteracy and spreading knowledge are as important as the removal of poverty and hunger.

Let me close by stating that (scientific) knowledge is the common heritage of humankind. It is the only this treasure of humankind that can provide a possible remedy to conquer inequality and to bring about an acceptable quality of life and a purpose, for a majority of the people of the world. Let us make sure that it is available to all.

SCIENCE EDUCATION IN BRAZIL: TOWARDS A NEW PROPOSAL

CELSO PINTO DE MELO

Introduction

For the last two and a half years, a major wave of reform has swept the planning of science and technology (S&T) activities in Brazil, especially after the creation of the so-called Sectorial Funds. Associated to the opening of the Brazilian economy, mechanisms were established to assure that a small percentage of the revenues derived from some of those newly deregulated economic sectors should be dedicated to form S&T Sectorial Funds, each one related to a specific economic sector. (Among other measures, the free-market initiatives included the privatization of traditionally government-owned companies in the mineral, telecommunications and electrical segments, as well as the end of the state monopoly in the petroleum exploitation; the key idea was to approve laws that estipulate that a certain amount of the subsequent financial revenues of the newly created enterprises must be invested in scientific and technological programs).

As a consequence, for the first time the financing of basic science and the federal support of research and development projects in Brazil would not depend on yearly negotiations at the Congress and on eventual budgetary constraints of the public administration. (Contrary to the monotonically crescent pattern seen in the most developed nations, in Brazil the total federal expenditure in the broad area of S&T has a ‘saw-tooth’ profile when considered along the last two decades, since the few spasms of good-will were immediately followed by a return to almost the same levels of insufficient investments). Now, the amount of money to be collected will be mainly subject to the health of the Brazilian economy as a whole and, once allocated, it will be freed from yearly budgetary restrictions. Preliminary estimates are that when the entire set of fourteen expected sectorial funds enter in regular operation in 2002, over one billion reais will be added to the national S&T effort every year, more than doubling the current overall budget for the area. Such funds will have the additional advantage of representing money ear-marked to the end activities.

The promise of financial stability implicit in these new mechanisms has afforded the possibility of long term planning in Brazilian S&T. At first, some of the principal challenges to be faced were readily identified, such as a lack of competitiveness of the technologically based enterprises and an excessive geographical concentration of the S&T activities. Also, a high price had been paid for the decades of progressive strangling of financial resources to the basic sciences and academic activities, reflected by the dismantling of research groups, a fairly recent deviation from the traditional trend of Brazilian scientists remaining to work – even under adverse conditions – in the Country (as well as from the custom of the trained-abroad young generations to return home), and a general lack of confidence by the scientific and technological communities that this bleak picture could be changed in the short term.

A dramatic change in this landscape has been reached in these two and a half years. New programs were devised, the financing of basic science has been reinitiated, and the idea of launching immediate actions within a long-term view of strategic priorities became more pervasive. An opportunity to review those efforts, to correct identified distortions and to incorporate new challenges to the scope of priorities was effective during the process that led to a recent National Conference in Science, Technology and Innovation (CNCTI). At that moment, more than 1,200 professionals of the S&T community-at-large, key businessmen and high-ranked politicians spent three days in Brasília discussing the Brazilian Green Book of science, technology and innovation.[1]

During the Conference, among other relevant issues, several ideas of improving science education in Brazil were discussed, and alternatives for a far-reaching national program in the area were considered. In this communication, I will present a preliminary sketch of one of these possible programs now under consideration by CNPq, the largest Brazilian funding agency for science and technology.

[1] The Brazilian Green Book on Science, Technology and Innovation (in Portuguese) can be downloaded from www.mct.gov.br.

Science Education in Brazil

No new initiative in science education in Brazil could be successful if not based in a careful examination of the large amount of previous experiences in the area accumulated along the last fifty years. In fact, it is very rich the panel of different efforts, programs, and institutions dedicated to this general theme that were initiated in the Country. Museums of Science, experimental parks ("espaços-ciência") for the popularization of science, projects devoted to the production and mass distribution of pedagogical kits, and regional centers dedicated to science education are just some of the few examples of those initiatives that can deserve special analysis for having attained different levels of success.

However, under the present view none of these previous efforts (several of which very successful at their own time) could actually be considered a national program. Not only because in general terms they lacked an organic and integrated national coverage in their scope, but especially due to their inherent liability derived from the unstable guarantee of long-term financing, a characteristic of the entire S&T sector until recently.

The leitmotiv of the CNCTI could be understood as how to incorporate the access to science and technology benefits as a birth right of the 21st Century Brazilian citizens. Embedded in the contradictions of a complex society, with a mosaic of contemporary, modern and centenary needs, the social agenda of Brazil for this century must comprise a basket of priorities, where items typical of the 19th Century citizenry claims still need to be considered a par of contemporary requests. The average citizen nowadays face science and technology choices not only in the great ethical debates, such as those biotechnology and procreation issues, but also more homely in the origin of the food he or she buys, the quality of life in the cities where he/she lives, and (increasingly) in the preservation of his/her individual privacy rights.

This view helps in settling an ongoing debate on the appropriate focus of science education efforts. Should these programs search for the lone 'gold nuggets', i.e. the brightest youngsters with the right aptitude to science and mathematics that must be recruited to assure the quality of the future scientific workforce? Or, instead, should the energies be directed to a more universal coverage of the scientific information, trying to involve even those students that in their incoming professional lives clearly will require scientific information at most as subsidiary?

The technical evolution of the contemporary societies will naturally resolve the above dilemma between those two non-exclusive choices in favor of the second. To face the challenges of the education for the 21st Century one must begin by the recognition that the literacy indices have ceased to be relevant for the measurement of the aptitude of a society to the modern world.[2] The digital divide, the extension of the alphabetization concept to include the training in information and communication for the average citizen and the internalization of the democratic rights in an increasingly larger number of nations would make scientific education an essential factor of competitiveness in the economic scenario of the present century.

Towards a New Proposal

CNPq has traditionally not only supported individual scientists dedicated to science education but also financed several of the previous programs in the area along the last few decades. As part of these continuing efforts, CNPq has recently issued a call for proposals[3] concerning the production of pedagogical kits, the organization of national Olympiads in science and technology, and the establishment of a cooperative network among the existing science museums and science parks. These initiatives remain essential and must be continued on a yearly basis, as one of the strategic priorities in assuring the lifeline to the basal mechanism of the scientific and technological community. What is needed, and what had its urgency clearly identified in the recent CNCTI, is a national program for science education, an initiative of national coverage in its scope that could take advantage of the continuity of supply of money afforded by the Sectorial Funds.

In the context of major revisions of the planning of S&T, a strategic concept is the idea of establishing a chain of knowledge for each sectorial fund, so that all different scientific and technical aspects, as well as the concerning social, health and legal consequences of that specific economic activity could be thoroughly examined at the highest level of scientific expertise. With the operation of all sectorial funds, the corresponding chains will necessarily intermingle among themselves to generate a vital knowledge network for Brazil. Problems of strategic importance for the Country, and not object of any specific fund, such as the dichotomy preservation/development of the Amazon region – on its beauty and complexity – and the need

[2] A.B. Dias, Parcerias Estratégicas, 11 (2001), 151.
[3] More details can be found in www.cnpq.br.

for a rational exploitation of ocean and coastal resources, can then be included in their multidimensional aspects. By the same token, horizontal actions such as investment in the upgrade of the metrological and electronic instrumentation standards are of interest to several (if not all) sectorial funds, and can be by them financed within the knowledge network idea. Science education, for its long-term strategic impact on the competitiveness of the Nation, is one of those programs that should be prioritized in the new funding scenario in Brazil.

The Centers of Reference in Science

As part of the new approach for the planning of S&T in Brazil, a committee of specialists was invited by the Ministry of Science and Technology with a double mission of first reviewing the performance of the federal institutes of research in their role as strategic agents for the scientific and technological development of the Country and then pointing out new opportunities for their development and of the federal research system as a whole in the next decade. One of the suggestions of these specialists in their report, recently released,[4] was the establishment of an entirely new hierarchy of different institutions that could flourish into a mesh of interconnecting units: the legal existence of coexisting federal institutes, centers of competence, centers of reference, associated laboratories, and so on, will add a welcomed flexibility while increasing the efficacy of the federal system. An important additional recommendation is that a new unit should only be created once its mandate (i.e., the specific directives of purpose and scope of action) and its initial term of operation (number of years to accomplish its objectives before a major review of its current adequacy – that could even recommend the phasing out of the unit – is implemented) were clearly established.

Based on these general guidelines and in response to the universal diagnostic that an urgent action in science education is needed, CNPq has recently invited a team of experts to examine the opportunity of proposing the creation of a national network of Centers of Reference in Science Education (CREC's). While still on the preliminary stages of its work, that panel has already identified a few points that could serve as cornerstones of a new national program in science education, robust enough to grow and adapt itself to an environment of progressive complexity. A program of this

[4] Relatório da Comissão de Avaliação dos Institutos de Pesquisa, available for download from www.mct.gov.br.

kind must initially face the two not always convergent challenges of attending the increasingly sophisticated S&T based demands of a contemporary society, while not excluding itself of a solid national strategy of social inclusion of ever-growing fractions of the Brazilian population into the modern aspects of the 21st Century.

New technologies of information and communication, such as fast Internet links and those in support of distance learning, should be made available for this effort. In fact, in recent years Brazil has made striking progresses in providing Internet access to educational and research applications by the scientific community (which is concentrated mainly in the public universities and research institutes), through the physical backbone of the National Network of Research (RNP). Even so, the dreams of a national coverage of science education initiative by a point-to-point presence in the elementary (or even secondary) schools must face the crude reality that a large number of these institutions do not have the necessary infrastructure[5] of regular libraries, computer and/or science laboratories, or even Internet access (See Tables 1-4).

One should note, however, that concerning the latter issue it should be possible to take advantage of the recently created FUST, the Fund for Universal Access of Telecommunication Services: although not a 'sectorial fund' per se, this fund collects its money from a percentage of the revenues of all telecommunication companies and has the mission of significantly increase access of Brazilians to modern telecommunications tools, including the world wide web. Hence, FUST can offer the required financing for the connectivity of all public schools and libraries in the next few years.

A last hurdle to be passed constitutes a major hindrance to the success of a national science education program designed to reach universal coverage: the weakest link of any program of this kind resides in the lack of adequate training of the average science teacher. Also, once initiated on their professional lives they have few chances of a continuous updating of modern information, a problem compounded by the low wages offered[6] (see Table 5) and the reducing social respect for the teaching activity.

A coherent degree of compromise between efficacy in the near horizon and a national scope of this type of initiative can be reached with the CREC's, whose main role and mandate would consist in the education of the young generation, life-long training of the teaching professionals and

[5] All statistical data concerning the Brazilian educational system are available for downloading from www.inep.gov.br.

[6] Cfr. www.inep.gov.br.

the replication of successful initiatives. Through a cascade-effect, the multiplication of examples will in the end reach over the entire school system. For tactical reasons, at least in the first few years such program should be focused at the students and teachers of the 5th through 8th degrees. Each Center would be established in partnership with the state and local governments in medium size cities of recognized regional influence. A special team of professionals will staff in full time those Centers to provide a space of continuous re-training of science and mathematics teachers of the secondary schools of the neighboring region, and to offer an open-doors environment for the students of these schools. Large band Internet access must be arranged so that those Centers, while possessing a portfolio of activities and specific programs adjusted to the local reality, could actually operate as an integrated national network that will benefit from the support of the most preeminent Brazilian scientists.

Science experiments and computer laboratories that privilege a 'hands-on' attitude and stress the importance of developing a scientific reasoning to deal with the problems of the everyday world should be specially devised. New curricula that break the standards from the traditional isolated disciplinary approach and provide an integrated learning of mathematics and of the basic sciences in their relationship to the environment (both local and in a global scale) and quotidian aspects of life will have to be proposed. The integration of the different CREC's into a single network will make much more efficient the transfer of a locally successful experiment to the entire system.

The pervasive dissemination of pedagogical science kits could be an important part of the program. If a partnership with commercial publishing houses is established, the mass distribution of such kits could be based on an efficient double system in which the support of the Ministry of Science and Technology would assure the coverage of the public system, while a commercial venue space would subsist in the attending of the private sector. The CREC's would fulfill an essential role for the linkage between the two sub-systems, by offering universal training and assistance in the correct use of the kits and also by acting as advanced centers for the experimentation and testing of new concepts and for the development of the most appropriate kits.

A national steering committee will be required to provide the core leadership of the program. Recruiting and training of the full time staff of each Center will depend of how attractive their proposal will be to young professionals. A possible solution would be to establish a special fellowship program that will pay more than the average secondary teacher salary:

recipients will have the fellowships assured for a certain period of time, provided that two conditions are satisfied: first, a minimum performance level – to be established in due time – is to be required to all participants and, second, the selected cadres must assume the commitment to function as 'replicate agents' of the program at the neighboring schools after completing the training period. Besides the normal supply of university trained science teachers, a possible extra source of human power to occupy these positions would come from the early- or middle-carrier changes of professionals trained in the science and technological fields at large.[7] A special training period for all recruited personnel would be required, when identified deficiencies of formation and information could be alleviated.

Conclusion

The urgent need for a national program in science education has been identified. While there is a unanimous claim for immediate action, different and not necessarily convergent strategies for dealing with the problem can be formulated. At CNPq a national program devoted to the creation of centers of reference in science education is being devised, which for tactical reasons will be initially focused at the secondary level public (students and science and math teachers).

The recent creation of the sectorial funds for science and technology has opened a window of opportunity for the design of long-term actions within a strategic perspective for the S&T area. The ancient wisdom expressed by the Chinese proverb "The best time to plant a tree was twenty years ago. But the second best time for doing this is today"[8] translates the feeling of urgency of an immediate action in the subject. A network of integrated centers of reference that have as the baseline directive to transform scientific and technological information into a basic right of the 21st Century citizenship will offer an adequate response to the needs of reducing the regional differences in Brazil while preparing the incoming generations to deal with a progressively complex technology based society. The competitiveness of the Nation in the decades ahead will depend on the existence of a large basis of scientifically and technologically informed citizens.

[7] Some of these ideas have benefited from the proposals presented in the report "Before It's Too Late", The National Commission on Mathematics and Science Teaching for the 21st Century, Washington, 2000.

[8] Ancient Chinese proverb, cited in Ref. 7.

TABLE CAPTIONS

Table 1. Fraction of Brazilian schools at the Fundamental (a) and Secondary (b) levels with Internet access.

	Number of schools	**Internet Access (total)**	**Internet Access (%)**
Total	181.504	12.166	6,7
Rural	111.909	111	0,1
Urban	69.595	12.056	17,3

Table 1a.

	Number of schools	**Internet Access (total)**	**Internet Access (%)**
Total	19.456	6.764	34,8
Rural	679	98	14,4
Urban	18.777	6.666	35,5

Table 1b.

Table 2. Fraction of Brazilian schools at the Fundamental (a) and Secondary (b) levels with library.

	Number of schools	**With Library (total)**	**With Library (%)**
Total	181.504	45.221	24,9
Rural	111.909	4.664	4,2
Urban	69.595	40.557	58,3

Table 2a.

	Number of schools	**With Library (total)**	**With Library (%)**
Total	19.456	16.025	82,4
Rural	679	414	61,0
Urban	18.777	15.611	83,1

Table 2b.

Table 3. Fraction of Brazilian schools at the Fundamental (a) and Secondary (b) levels with computer laboratory.

	Number of schools	**Computer Laboratory (total)**	**Computer Laboratory (%)**
Total	181.504	16.173	8,9
Rural	111.909	306	0,3
Urban	69.595	15.867	22,8

Table 3a.

	Number of schools	**Computer Laboratory (total)**	**Computer Laboratory (%)**
Total	19.456	9.530	49,0
Rural	679	157	23,1
Urban	18.777	9.373	49,9

Table 3b.

Table 4. Fraction of Brazilian schools at the Fundamental (a) and Secondary (b) levels with science laboratory.

	Number of schools	**Science Laboratory (total)**	**Science Laboratory (%)**
Total	181.504	13.202	7,3
Rural	111.909	506	0,5
Urban	69.595	12.696	18,2

Table 4a.

	Number of schools	**Science Laboratory (total)**	**Science Laboratory (%)**
Total	19.456	8.956	46,0
Rural	679	178	26,2
Urban	18.777	8.778	46,7

Table 4b.

Table 5. Average monthly wage (in reais of 1997) of Brazilian teachers working at the 1st-4th grade of the Fundamental level (a), 5st-8th grade of the Fundamental level (b), and Secondary level (c), accordingly to the level of schooling. The salaries at the private system are substantially higher than those paid to public employees. (In 1997, the exchange rate was R$1,00 ≃ US$1.00, while nowadays – 2nd semester of 2001 – is R$2,60 ≃ US$1.00.)

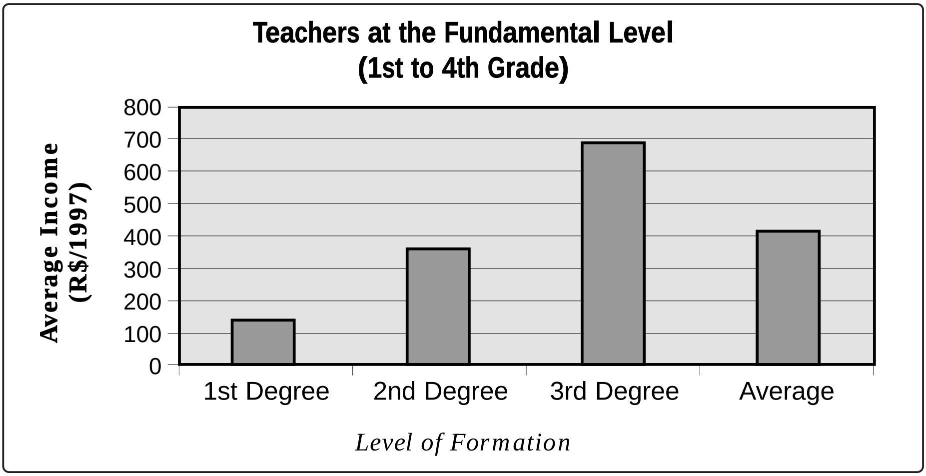


Table 5a.

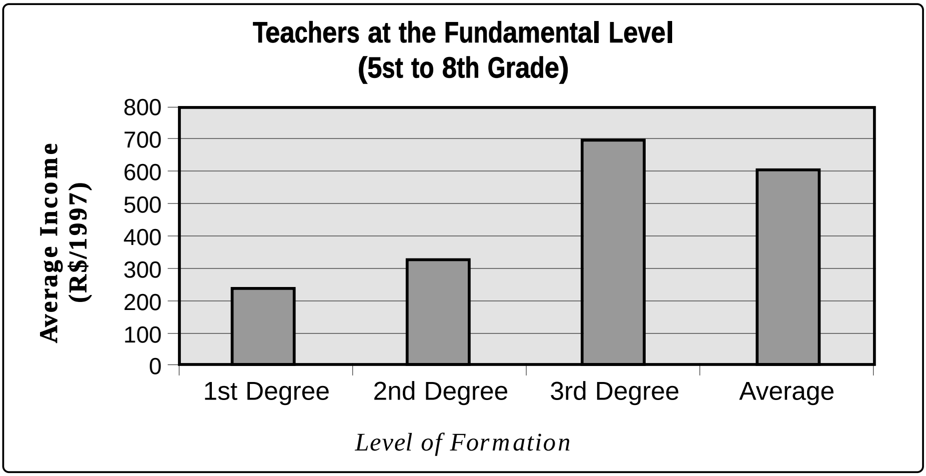


Table 5b.

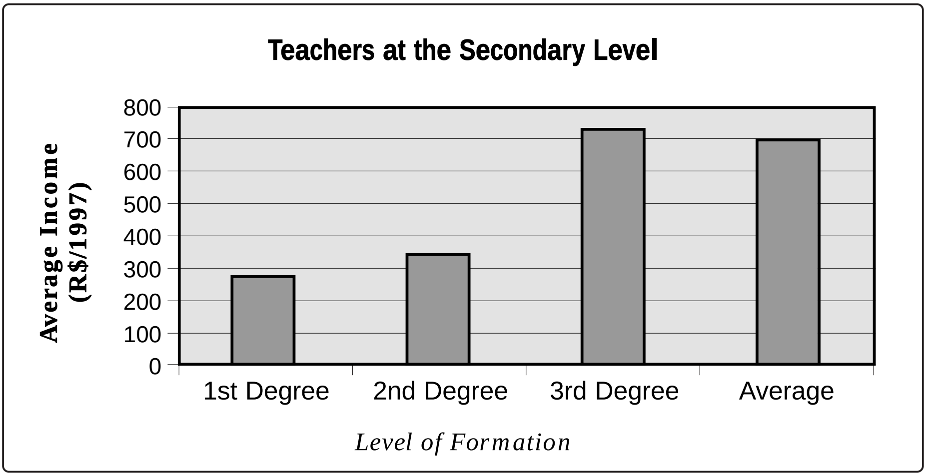

Teachers at the Secondary Level
Average Income (R$/1997)
800
700
600
500
400
300
200
100
0
1st Degree
2nd Degree
3rd Degree
Average
Level of Formation

Table 5c.

THE SCIENCE OF EDUCATION AND EDUCATION IN SCIENCE

STANLEY L. JAKI

Whenever science and education are the subject of a conversation, assumptions are readily made and by precisely those who should not make them readily. Such conversations usually take place among educated people, who just because they are educated are certain to know what education is. And, unfortunately, those with a scientific education seem to be absolutely certain that they know what science is. Almost all educated people have received their higher education in colleges or universities that boast of a department of education. There all faculty claim that education is a science. The situation would not be so bad if they merely claimed that the teaching of education can be a reasoned discourse. That there is plenty of unreason in that discourse may be suspected from the ever more rapid revisions of syllabuses issued by departments of education. Ever new courses are introduced and ever new methods are being invented about the most effective methods of educating. The result is that the science of education resembles ever more closely a machine devised to produce illiterates in ever larger number.

It has become an educational fad to ask those still in elementary schools to write research papers. Pupils now have access to limitless information through the Internet but their teachers show no concern whether their youthful charges can make an informed judgment on what they are expected to research. It has become a fashion to let children in kindergarten graduate in cap and gown. After high school attendance was made compulsory two or three generations ago, the level of instruction in high schools began to sink lower and lower, with inevitable consequences for college and university education.

Even the best schools are not immune to this process. About fifteen years ago a course in creative English writing in the graduate school of Princeton

University had to be supplemented by a remedial course in creative English writing. Efforts to expose science students to courses in the humanities remained as ineffective to produce balanced minds as were courses that offered physics for poets. The method did not alleviate the situation which Schrödinger described half a century ago. In discussing the results of "an all around good scientific education", Schrödinger spoke of "the grotesque phenomenon of scientifically trained, highly competent minds with an unbelievably childlike-undeveloped or atrophied-philosophical outlook".[1]

It is said that America is run by the graduates of its best fifty or so graduate schools. Its many thousands of colleges merely produce such who, once they are hired by business or industry, can be taught there how to do this or that. Big industrial firms are increasingly uneasy about this development as they realize that they cannot simply assume enough competence on the part of those whom they hire for higher than mere quasi-manual jobs. It even happened in various countries that large industrial firms had set up their own examination for those who looked for a job with a Ph. D. in physics or chemistry in their hands.

In 1888 the emperor of Germany urged that gymnasia there should produce not Romans and Greeks but Germans. Undoubtedly there was too much Latin and Greek in the curricula but whether it was better to drop these subjects entirely should seem doubtful. By 1888 two centuries had gone by since the first battle between the "ancients" and the "moderns" took place, with more such battles to follow. The "ancients" stood for the age-old classical education, the "moderns" for the study of the new sciences. In 1868 T.H. Huxley attacked literary education as being largely useless and extolled the usefulness of courses in the various sciences.[2] About the same time Herbert Spencer wrote the most lopsided praises of science as the sole security in every facet of life.

In the middle of the twentieth century C.P. Snow did the same though rather deceptively. He did so in his Reith Lectures broadcast by the BBC, lectures that came out in print under the title *The Two Cultures and the Scientific Revolution*. At that time few noted the deceptiveness of Snow's endorsement of both cultures, literary (or humanistic) and scientific.[3] Many

[1] E. Schrödinger, *What is Life? and Other Scientific Essays* (Garden City, N.Y.: Doubleday, 1956), p. 96.

[2] For details, see my essay, "A Hundred Years of Two Cultures" (1975), reprinted in my *Chance or Reality and Other Essays* (Lanham Md.: University Press of America, 1986), pp. 98-118, and its sequel, "Knowledge in an Age of Science", ibid., pp. 119-43.

[3] See my essay, "A Hundred Years of Two Cultures", as quoted above.

in a West overawed by Soviet propaganda, readily swallowed Snow's argument which ran along the following line: Of the two main branches of cultures, literary and scientific, the scientific is the voice of the future. To prove this, he first offered a few anecdotes about early nineteenth-century Oxford dons who failed to see the future so much as to deplore the running of trains into Oxford and certainly on Sundays. Since men of science did not make such objections to trains they had, according to Snow, the future in their bones, a strange argument to prove the positive from the negative. Snow then claimed that among scientists experimental scientists showed a better grasp of culture than theoretical scientists. Among experimental scientists engineers were the most alert to the needs of mankind. Finally, since the Soviet Union produced many more engineers than the West, the future belonged to the Soviet Union. Such was a stupefying Gleichschaltung of two cultures or of any culture for that matter and of any education worth being called education.

The only saving grace in Snow's lucubrations was that he avoided saying what he meant by education, whether literary or scientific. Had he considered the etymology of the word "education", Snow might have had some second thoughts, but probably none at all. The ideology he stood for relied heavily on the art of skirting the basic issues, even the basic meaning of words, which is often revealed by their etymology. The word education comes from the Latin verb *e-ducere*, which remains a mere word, unless we consider what is being "e-duced", or drawn out, and from what it is being elicited.

In other words, to make the word "education" meaningful one has to consider the subject and the object of the very act of educating. The subject of education is the pupil, presumably a human being, although nowadays they often behave like little beasts, overstimulated as they are by the marvels of technology. Whether they are humans or are beasts, education takes them for mere specimens of a species which is to be instructed by lessons learned from observing the behavior of this or that animal species. The object of education is what is being drawn out from the subject.

Compared with these two notions, the object and subject of education, quite secondary should seem the manner or the technique of the procedure, or the educational skill, which often passes for the art of education. As long as those two, the subject and the object of education, were in the focus, and not the technique or skill of educating, no one assumed that the student, the pupil has a built-in fund of information, a fund born with him, so to speak, that can be cajoled out of them. It became the dubious privilege of education in recent decades to take education for magic whereby one can prompt the student to rediscover the rules of mathematics and the rules of grammar, and even the skills needed for the various arts, such as drawing. Luckily they are not encouraged to compose music. They are, however, being taught that computers can take the place of composers. So they are hardly encouraged to care about learning music, which, however, was a principal branch of classical liberal education. Rock music is literally rocking our culture. Casettes with animalistic singing have become runaway bestsellers and this in university campuses as well. A brief walk by a typical college dormitory provides more than enough evidence.

At any rate there is much truth in the observation about the respective function of the three main branches of college education, the administration, the faculty, and the students. Now students want to teach, the faculty want to administer, and the administration is supposed to get the money for the farce of turning education upside down. Education is rapidly degenerating into the art of conveying all sorts of skill.

There can be no question about the fact that ever since Comenius, who is often taken for the first modern educator, much more emphasis has been laid on the technique of teaching than on what is being taught, and hardly any attention is paid to the subject of education, or the pupil himself or herself. This is even true of what was said on education by Pestalozzi, by Herbart, by Montessori, to mention only a few of the big names of the history of modern education. Fifty years ago anyone with a college degree in mathematics could apply for a job to teach it. The same was true of other subjects as well, such as Latin, or geography, or history. By the late 1950s it was required that applicants for teaching jobs have more courses in education than in the particular subject they wanted to teach. Skill nowadays wholly dominates substance.

Obviously it cannot be the purpose of education to draw out data of information that are simply not born with the student. Man is born as a "tabula rasa", although a very strange "tabula" or board or rather drawing board. Pieces of information can be drawn on that board which is very different from a purely material board. On a material board one can draw lines of various forms, but many such lines will appear on that "tabula rasa" as concepts corresponding to written or spoken words, all of which are universals. It is therefore most illogical to take the students for a purely empirical or material being, for just one specimen of a species which is just one among millions of species. It is illogical to try to educate little children in the manner in which animals are thought to learn if the human species, alone among all species, is able to form concepts (which comes from the

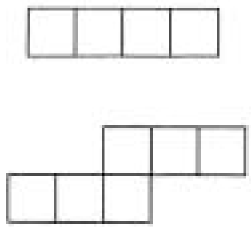
Latin word “con-capere”), that is, to grasp the universal in the particular. Each and every human word is a proof, including words uttered by professors of education who do not want to come clean on the issue as to what they take human beings for. And since they dissimulate, they would deserve to be dismissed from their chair. There is no tragic harm in holding any view, if the view is held openly. The irremediable harm is dissimulation that should be considered a form of crime committed against humanity.

But back to concepts which are very supple items and as such they wholly escape material representation. Only words corresponding to integers can be represented say by a figure of definite contours, such as a square. And these words represent only a minuscule part of words used in any developed human language. Integers are practically infinite in number, but it is enough to know numbers up to ten to know what is two hundred-twenty-four, or three million and twenty. Strangely enough, the drawing board, the “tabula rasa” of a human pupil will catch on readily with the meaning of a practically infinite number of integers, most of which have not been verbalized to him.

Now the meaning of a given integer can be imagined as the juxtaposition of the same number of squares. Not so with the visual representation of the meaning of any other word. Any such word is defined in terms of six or seven or more other words, and none of these have a meaning with a definite contour. Their partial overlap forms an area which is again without a distinct contour. Moreover, the meaning of words continually change, but, unlike amoebas, words do not have a membrane. For amoebas to live, they must remain within the membrane. Words live only as long as they are not given exact contours. Words may be best compared to patches of clouds. Looked at from a distance, they, or at least some clouds, may appear with a crisp contour, but as one gets close to them, say by flying, one does not know the exact place and moment when one enters them (see Figure 1).

Now classical education was in a sense the imparting of a skill to handle patches of fog. This perception is still to gain grounds. It first appeared, so it seems, in a paper I gave six years ago before the 10th World Congress of Optical Engineers held in Orlando, Florida. I doubt that more perhaps than a few of the tens of thousand of members who received the Proceedings of that Congress cared to read my paper there and consider the figure which I have just showed. Most of the three thousand or so attending that Congress showed interest only in technical solutions to problems arising in optical engineering. They work with quantities and they know that quantities work and do work marvelously. The Bible already said that God dis-

Representation by areas,
all with precise contours,
of the definition of the meaning of integers.



Representation by areas of the definition of the meaning
of non-numerical concepts when the definition consists of three words.
The area where all three overlap to define such a concept is marked 3.
Areas where only two areas overlap are marked 2,
and areas where there is no overlap are marked 1.
Note that no area can have a precise contour.

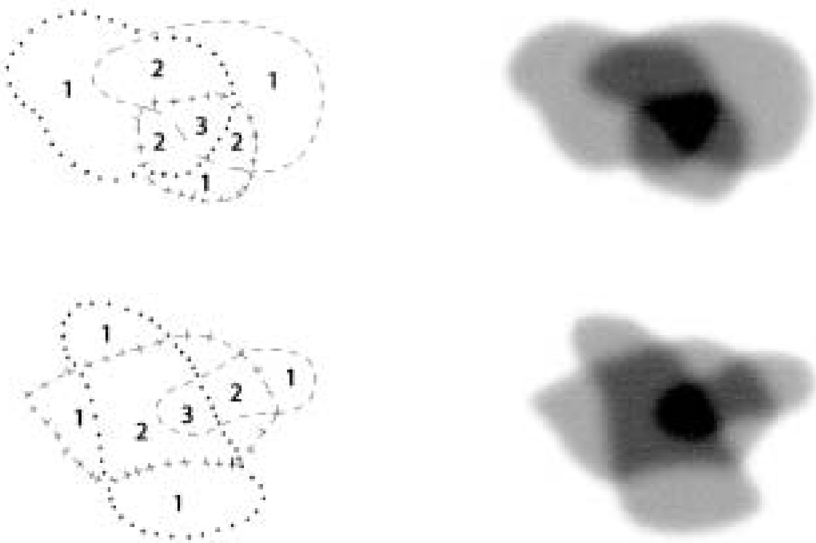


Figure 1.

posed everything according to measure, number, and weight. Tellingly, this phrase comes from the Book of Wisdom and was, during the Middle Ages, the most often quoted biblical phrase. Just one indication that those Ages were not so dark after all.

But one would look in vain in the Bible for a most fundamental point about numbers, or at least for a very challenging point about the realm of numbers. Well, the Bible is not a philosophy book, let alone an interpretation of the foundation of mathematics. The point is that one needs non-quantitative words, or words that are not numbers, in order to give the definition of even the simplest class of numbers, the integers. The proof of this is any dictionary of any language. Those who rather believe an eminent mathematician, there is Hermann Weyl, who wrote: “One must understand directives given in words on how to handle the [mathematical] symbols and formulae”.[4]

When we try to define imaginary numbers, we have to give up our imagination, which can imagine a square, or a circle, but not a number which is imaginary. This is not the only strange feature of the human mind, which is to be educated. Another is that we do not become irrational when we talk of irrational numbers, although they cannot be visually represented. We talk of the exact sciences and we are confident we know what we talk about: empirical sciences cast in the terms of mathematics. Still the meaning of the word “exact” cannot be given with an area of exact contours. The only way of coping with this conflict is to trust the ability of the human mind to have insights that are clearly non-empirical.

But before I say something of the importance of including some such considerations in scientific education, let me go back briefly to the classics or rather to classical education. It would be nonsensical to think that the story of the Horatii and the Curiatii was drilled in the minds of young boys as if they were ever to find themselves in exactly the same situation as those famous Roman heroes. Those stories were subtle patterns, consideration of which was to generate intangible insights.

Those stories were picked from a distance of many hundred years and as such they did not generate political animosities. Even today stories about Lincoln cannot be taken for a pattern because they are just too close to us. Lincoln is not a wholly uncontroversial figure in the Southern parts of the United States. Participants from other countries will find their own exam-

[4] H. Weyl, “Knowledge as Unity”, in L. Leary (ed.), *The Unity of Knowledge* (Garden City, NY: Doubleday, 1955), p. 22.

ples from their not too distant past to illustrate the need for going far back into history to find apparently uncontroversial patterns of behavior. But we must find them or else education will become the imparting of mere technical skill even in the humanities. In the sciences education has hardly ever been more than the imparting of such skills.

Communication is now a science, I would say the skill of misinformation. A journalist must know the technique of how to escape the charge of editorializing in the guise of reporting. The simplest form of that skill is to find somebody who agrees with the position of the newspaper and ask him or her for opinion. This then is reported as being representative of the thinking of society at large, but it reflects above all the view of the editor and perhaps also of the reporter. The technique is a skill in the art of lying about which most reporters and editors as well as professors in schools of journalism are not really concerned. No room there for an Augustine of Hippo, who on thinking ever more seriously about becoming a Christian realized that his profession, for which the State paid him, was to promote lies. This dawned on him when shortly before his conversion he was supposed to deliver an oration on the emperor's birthday. He knew that, like other rhetors paid by the State, he had to lie from both corners of his mouth by presenting a rascal as a paragon of virtues.

I am not saying that such an art is explicitly endorsed in our schools of education, but it is hardly met head on, because there everything has to be politically correct. There the chief aim is to make everybody feel comfortable with anyone else's views and pattern of behavior. The result is that modern society is coming apart at the seams. Statistics on crime, on deviant behavior, speak louder than words. The science of education has become an instruction in brazen pragmatism.

Education in science has hardly ever been more than the art of imparting computational skill and skills in experimentation. Most Ph.D. graduates in physics have never been asked to take a course in basic epistemological or ethical questions, although they meet them at almost every instance. They face up to them only when they pick up books by this or that prominent physicist who waxes philosophical in old age and all too often just rediscovers age old errors in philosophy. I cannot forget the surprise of my late dear friend Eugene Wigner who once showed a philosophical paper of his to a friend of mine who happened to know the history of philosophy. In that paper, of which Wigner was very proud, he had merely rediscovered the old system of Ockham and Malebranche, the system called occasionalism.

To his credit Wigner conceded the point of not having discovered anything new, but he would not admit that what he had rediscovered had long been refuted on purely philosophical grounds. He thought that science vindicated occasionalism. He merely confused the good science of quantum mechanics with the bad philosophy Bohr, Heisenberg, and others grafted on it. The two now form a unit about which it is not supposed to ask whether it is put together from two parts, one good, the other bad. The unit is being taught as an indissoluble whole, with some frightful consequences.

An instance of this is the rejoinder which a Caltech Ph. D. candidate in quantum cosmology voiced on hearing my remarks on creation out of nothing. According to him I was wrong in claiming that the nothing is nothing and not something. He claimed that quantum mechanics proved that the nothing at times was something and vice versa. I merely suggested to him that he should inform his bank about this astonishing development. The astonishingly facile style in which prominent quantum cosmologists claim that quantum cosmology enables them to create universes literally out of nothing, or that the metaphysical idea of creation out of nothing has now become a proposition to be experimentally decided by physics, is a piece with that rejoinder. Cosmologists would do well to take seriously an observation which one of them, L. Landau, had made about them: "Cosmologists are frequently in error but seldom in doubt".[5]

My question is then the following: In promoting scientific education what are we going to promote? Are we going to promote skill in solving nonlinear equations with or without the help of computers, or are we to promote the spread of insane non-scientific claims dressed in scientific garb? I carefully avoided the terms insane philosophical claims, because if a claim is insane, it cannot be philosophical, although this restriction is no longer allowed among professional philosophers. No wonder that philosophy has become almost a bad word. More than a hundred years ago it was customary to say in German scientific circles: "Philosophie ist die systematische Misbrauch einer eigens zu diesem Zwecke erfundenen Terminologie", or in English, "Philosophy is the systematic misuse of a terminology invented for precisely that purpose". What those scientists failed to notice was that the only way to avoid philosophy, indeed metaphysics, is to say nothing.

It should be obvious that it is very philosophical to make a judgment about insanity, whether of a person or of an enterprise. At the dawn of the

[5] Quoted by C. Humphreys, of the Department of Materials Science in Cambridge University, in his letter to *The Times* (London), January 10, 1994, p. 15.

third millennium it would be utterly insane not to see mankind's total dependence on science. Science alone can keep us well-fed and healthy, and take us quickly to long distances. Science is indispensable for securing peace for mankind, although it has to do this all too often by making war. The construction of the Twin Towers of the World Trade Center would have been inconceivable without science, which is also true of their wanton destruction. It has indeed been estimated by structural engineers that had those hijacked planes hit the Twin Towers at their ninetieth floor or higher and not at their eightieth floor, those towers might not have collapsed.

But before I say more about the real and imaginary abuses of science, let me recall a statement of Samuel Johnson, the great codifier of modern English in the late eighteenth century. At that time gentlemen still wore lace around their neck, on their chest, and around their wrist. Of lace, Samuel Johnson said, one can never have enough. I would say the same about science: of science no one can ever have enough. Scientific education is a matter of survival and progress, apart from being a powerful source of satisfying legitimate intellectual needs to understand the world we live in. But it should not be allowed to turn science into a potential curse. This may be the case if scientific education becomes merely an art of imparting scientific skills. The product will be a scientifically trained class that will not know what to do with science when it comes to crucial junctures. That class will merely feel a non-scientific pressure, without the ability to cope with it.

Let me give you some examples from scientific history, because even in the history of science it is true what was stated two thousand years ago about history in general: History is philosophy teaching by examples. A historian has to be selective for a reason far more important than that readable books cannot stretch beyond three to four hundred pages. So let me select some examples from the history of science, because of their philosophical or rather educational instructiveness.

Half a century ago, the challenge was whether to make or not to make the atomic bomb. Once the war was brought to an end by the explosion of an atomic bomb over Hiroshima, second thoughts began to surface, partly for political reasons. But other reasons too did surface in the answers given by atomic scientists. John von Neumann simply said that he and others were simply unprepared for the philosophical and ethical challenges. We were, he said, like little children. Other scientists said that by making the bomb they proved themselves to be, I am quoting, "sons of bitches".[6] Still

[6] For details see my *The Relevance of Physics* (Chicago: University of Chicago Press, 1966), pp. 395-96.

others, Fermi was a case, claimed that the atomic bomb was just a piece of superb physics. But I still find most instructive as well as most frightening the reply Oppenheimer gave on being questioned by a Congressional Committee about whether some ethical considerations had been weighed before the making of the bomb. Oppenheimer replied: "...it is my judgment in these things that when you see something that is technically sweet, you go ahead and do it and you argue about what to do about it only after you have had you technical success".[7]

The words "technically sweet" are unparalleled for their expressiveness. Today they are reworded by those biochemists and microbiologists who want legal protection and indeed public funding for their program of cloning humans. This they request on the ground that there should be no limit set to satisfying scientific curiosity. Or take Steven Gould, who twelve years ago spoke of the devastation of AIDS as simply the mechanism of evolution which eliminates specimens of a species that possess less survival value than the others.[8] Surely this view is fully logical if one agrees with James Watson that genes are the only thing to know.[9]

About half a century ago Herbert Butterfield gave a much publicized lecture at Harvard in which he spoke of the teaching of the history of science as the subject that would replace the teaching of the classics as a basic framework of education.[10] Classics have already been largely eliminated from the curricula, but nothing yet has been chosen to fill the vacuum. Suppose, Butterfield's suggestion will be taken up. But then the question arises about the examples we are going to take from the history of science. Surely, Galileo will be taken up. But are we going to make it a part of that educational course in the history of science that Galileo praised sky high Copernicus's courage to commit a rape of his senses? But will an empiricist education tolerate this praise which flies in the face of John Dewey's empiricism that still rules American teacher colleges, beginning with the one at Columbia University?

Einstein is surely another one who will be taken up. But what is going to be taught about Einstein? The cliche, according to which he proved that

[7] See ibid., p. 397.

[8] S.J. Gould, "The Terrifying Normalcy of AIDS", *The New York Times Magazine*, April 19, 1987, pp. 32-33. See also my essay, "Normalcy as Terror: The Naturalization of AIDS", (1987), reprinted in my *The Only Chaos and Other Essays* (Lanham, Md.: The University Press of America, 1990), pp. 144-51.

[9] In a lecture at Princeton University, reported in *The Trenton Times*, Feb. 25, 1995, p. 1.

[10] H. Butterfield, "The History of Science and the Study of History", *Harvard Library Bulletin* 13 (1959), pp. 329-47, especially p. 331.

everything is relative? Or is his admission also to be taught that it would have been much better to call the theory of relativity the theory of invariance? Or is another admission of his also to be taught that he failed to derive from science even a drop of ethical value? Or is it also going to be taught that according to him it was not the uranium but man's heart that needed to be purified? And if education is a task to set role models, can an Einstein be chosen, whose biography, *The Private Lives of Albert Einstein*, written out from the Einstein Archives,[11] surely makes for a titillating text? Or is the teaching of the history of science to become a means to create the belief that scientific expertise puts one above basic norms of human responsibility?

Of course, Darwin, too, would be taken as the one who proved that everything is evolving and that man descended from the apes and that there was no purpose. About man's descent I hold something even more drastic, namely, that man's ancestors were the rats or other rodents, hundreds of million years older than apes and monkeys. But if rodents were our great grandparents, the difference between man and his ancestors is even greater than ever. What then becomes of the marvelous precept which Darwin wrote on a piece of paper as a constant reminder for himself: "Never use the words 'higher' and 'lower'".[12] Every page of the history of evolutionary biology shows that neither Darwin nor his disciples obeyed this very sound rule, sound at least from the viewpoint of the scientific method. That history should also teach Whitehead's observation made in 1929 with an eye on Darwinists: "Those who devote themselves to the purpose of proving that there is no purpose, constitute an interesting subject for study".[13]

That history should also teach the hollowness of Tyndall's dictum that "a mind like that of Darwin can never sin wittingly against either fact or law".[14] Well, Darwin kept under cover the fact that he took his main ideas from two papers of Edward Blyth, but he hoped that from a distance of twenty years none of the readers of *The Origin of Species* would remember those papers. In fact almost nothing was said on the subject for another hundred years or so. Then the subject surfaced again, but also quickly

[11] See R. Highfield and P. Carter, *The Private Lives of Albert Einstein* (London: Faber and Faber, 1993). Less explicit, though still very revealing is Schrödinger's major biography by W.J. Moore, *The Life of Erwin Schödinger* (Cambridge University Press, 1994).

[12] Darwin's motto placed in his copy of Chambers' *Vestiges of Creation*.

[13] A.N. Whitehead, *The Function of Reason* (Princeton University Press, 1929), p. 12.

[14] Address to the British Association, 1870, on "The Scientific Use of Imagination", in *Fragments of Science* (New York: P.F. Collier, 1901), p. 135.

dropped by admirers of Darwin as the one who could not "consciously tell a lie". Such are the words of G.G. Simpson, the leading American Darwinist of the mid-20th century, who sought refuge in the lame claim that there "always remains something hidden [in Darwin's life and character] as there is in every life".[15] Yet, apparently only in some cases should this all-alleviating principle be applied. Even more revealing was the attitude, about the same time, of the geneticist C.D. Darlington, who said, in reference to the Blyth matter: "Among scientists there is the natural feeling that one of the greatest of our figures [Darwin, that is] should not be dissected. at least by one of us".[16]

Loren Eiseley was not really one of them, although he wrote well about paleontology and did so as befits an unstinting admirer of Darwin. In presenting the full evidence about the Blyth matter, Eiseley claimed that the mystery of Darwin's character cannot be solved.[17] In adopting this evasive stance, Eiseley simple reduced the amount of "new light", which his book, according to its subtitle, wanted to throw on a very touchy subject. When a courageous historian of science decides to set forth matters with no holds barred, scientists are apt to be very resentful. The scientific community, so ready to canonize some of its members, still has to emulate the Catholic Church, which canonizes some of her own, though only with the help of an office popularly called the office of the devil's advocate. About this, too, something should to be said in the education of scientists.

James Clark Maxwell, too, will be included in that list of great scientists, but hardly that Maxwell who wrote that "the most difficult test of the scientific mind is to discern the limits of the legitimate application of the scientific method".[18] The first to glimpse the depths of this remark was Heinrich Hertz, the first to demonstrate the reality of electromagnetic waves. But Hertz was concerned with something far deeper. He wanted to know what Maxwell's theory was. And here too a question that begins with the word "what" brought up philosophy. Hertz finally gave up the struggle saying: "Maxwell's theory is Maxwell's system of equations".[19] That system, those equations were differential equations. The same could be said of

[15] G.G. Simpson in *Scientfic American*, August 1958, p. 119.

[16] C.D. Darlington, *Darwin's Place in History* (Oxford: Blackwell, 1959), p. 57.

[17] L. Eiseley, *Darwin and the Mysterious Mr X* (New York: Harcourt, Brace, Jovanovich, 1979), p. 93.

[18] *The Scientific Papers of James Clerk Maxwell*, ed. W.D. Niven (Cambridge University Press, 1890), vol. 2, p. 759.

[19] H. Hertz, *Electric Waves*, tr. D.E. Jones (London: Macmillan, 1893), p. 30.

Newton's theory of gravitation or of Einstein's theory of reference systems moving at constant speed or accelerated with respect to one another.

But if one admits that science, in its most exact form, is merely a set of equations, then its limits come to the fore immediately. No scientist can avoid the use of universals, although mathematics gives no enlightenment on them, not even a handle on them. No scientist can avoid the use of the word *is*. To try to measure the *is* in centimeters or in nanoseconds is a patent absurdity. The scientist will then have to recognize that which Feynman did recognize, namely, that there is no philosophy of quantum mechanics, but there are only some quantum mechanical operators, all of them strictly mathematical. Bohr said pretty much the same, but he also said other things as well whereby he fully contradicted himself. Contradictions are bad enough, but not nearly as bad as plain hubris. Unfortunately when hubris is preached in the guise of science, few will protest. Protests from the scientific community are still to be heard about Bohr's claim that his complementarity theory will be the future form of religion and its only good form.[20]

Is education in science going to include some such points or will it continue to be an art of imparting skills in calculation and experimentation? The question is important in its own terms but also for a practical reason as well. That reason is simply the fact that to learn science demands today far greater effort and time than was the case fifty years ago, let alone a hundred or two hundred years ago. Even three hundred years ago, it was impossible for John Locke, surely an intelligent man, to master the latest in science, or Newton's *Principia*. As reported by Desaguliers, Locke asked Huygens whether the mathematics of the *Principia* was reliable. For if it was, so Locke thought, he could become "the master of all physics", by which he meant a Newtonian philosopher.[21] Today a mind of Locke's caliber has even less chance of mastering physics, unless he had been formally instructed in it. But the fact remains that only a fraction of educated men, with a good mind, can be educated in science.

The rest of mankind will have to take from scientists what science is. Is there going to be an education in science that would enable scientists to speak intelligently about science? Are there going to be enough scientists

[20] A recollection of A. Rosenfeld; quoted in R. V. Jones, "Complementarity as a Way of Life", in A.P. French and P.J. Kennedy, *Niels Bohr: A Centenary Volume* (Cambridge: Harvard University Press, 1985), p. 323.

[21] See the Preface by I. Bernard Cohen to Newton's *Opticks* (New York: Dover, 1952), p. xxii.

who would agree with Polykarp Kusch, a Nobel laureate in physics, who warned in 1963: “Science cannot do a very large number of things and to assume that science may find a technical solution to all problems is the road to disaster”.[22] Such a road was charted a hundred years ago by Marcelin Berthelot, a famed French chemist of his time. He served as minister of education, then also as a minister of foreign affairs. He must have felt qualified for all such jobs since he had made in 1897 in a public conference on “Science and Popular Education” the following declaration: “People begin to understand that in modern civilization every social utility derives from science, because modern science embraces the entire domain of the human mind: the intellectual, moral, political, artistic domain as well as the practical and the industrial”.[23]

Contrary to Berthelot and similar scientist worshipers of science, science does not embrace the basis of intellectual endeavor which is concept formation, nor many areas of that endeavor, that cannot be measured. Those who take the opposite view attribute to science wisdom which it cannot have in terms of its method in which the touch of proof and truth is measurement, a quantitative operation. To attribute anything more than that to science is the height of unwisdom.

Bernard Shaw once remarked that it took a monster to conceive of a Nobel Peace Prize. Unfortunately, there have become attached some monstrous aspects to the Prize in the field of hard sciences, among which I do not count economics. That such is the case is undeniable. Hardly remembered is the manner in which Eugene Wigner tried to keep at safe remove those monstrous aspects. On receiving the Prize in 1963 an army of reporters descended on him in Princeton, asking his view on questions that had nothing to do with his work in physics. He dismissed them by saying that the winning of the Prize did not make him “a man of wisdom” and that “it is a great danger if statements of scientists outside their field are taken too seriously”.[24] There is indeed a very good ground for saying that young men and women aspiring to become scientists might learn a great deal of good humanities from studying the human side of science and scientists. A good exposure to the history of science would help provided the history is not a recital of legends, although they had been long exploded by serious historical research.

[22] Address to Pulitzer Prize Jurors, reported in *New York Herald Tribune*. April 2, 1961, sec. 2, p. 3, col. 4.

[23] See my *The Relevance of Physics*, p. 399.

[24] *The Daily Princetonian*, Nov. 7, 1963, p. 1.

This kind of research will be kept out of the reach of science students by precisely those scientists who, like the British geneticist C.D. Darlington, would say, as was noted above, that Darwin's dissimulation concerning what he had learned from Blyth, should not be dissected by biologists themselves. Yet when such dissections, almost vivisections, are performed by a historian of science, he is resented or dismissed as one who shifted from science to the history of science for not being able to prove himself as a scientist. Steven Hawking fell back on that defense on finding that a historian and philosopher of scientific cosmology dared to point out the philosophical *non sequiturs* that grace his *Brief History of Time*. Little can, of course, be done with scientists who want to form a society of untouchables. In that case they should remove themselves from the task of educating, a task very different from transmitting mere skills, however arcane, over which they alone have a mastery.

Education in science must keep in focus good and valuable non-scientific insights by scientists, because the scientific class has at its disposal means far more powerful than any other class and therefore its voice will be much more listened to. Then the further question will arise about the principles needed for the proper use of the means. If, however, scientists would teach society at large that everything is relative, or would condone such a teaching, society will then see in this a scientific proof of the proposition that all patterns of behavior are equally good. Then society will not be able to perform a critical and controlling role even about the non-scientific statements of scientists. Then scientists will be left on their own in full practical control of the means they have produced and which they alone can handle. All of us then will be faced with Juvenal's question: "Quis custodiet ipsos custodes?".[25] which may be rephrased as follows: Who will control those who claim to control the rest? Those who make that claim can merely claim that they alone have the skill, the know-how of handling some controls without being able to prevent that everything would get out of control.

Clearly, science will not give the answer, nor an education which is merely the skill of imparting knowledge, scientific or other. Education in science should therefore be much more than a technique of imparting skills. "Education is a high word", John Henry Newman said in his *Idea of a University*.[26] Only by rising high above the level of science, which is universally extended, though always on the same plane formed by quantitative

[25] Satire VI.
[26] *The Idea of a University* (Doubleday, 1959), p. 164.

relation, can we have an education in science which qualitative in a non-trivial sense. Newman was a theologian, whose business is to talk about God's ways of educating man. Here, before this Scientific Academy, it may be best to recall that nothing contrary, indeed something very similar, is contained in Schrödinger's observation: "Physics consists not merely of atomic research, science not merely of physics, and life not merely of science".[27] A perfect summary of what education in science ought to be. Otherwise, science may become one of the four S's of those universal wrapping papers which unable to sell anything. Three of those S's are Sex, Sport, and Smile. God forbid that science become the fourth of those dubious commodities, and also become the target of an unintended pun, as the plural of the letter s sound very similar to the sound of a word spelled a, s, and s. By trying to become scientific, theorists of education are removing an important barrier in the way of that disastrous development. Education in science has indeed a very great and serious task cut out for it, not only for man's sake but also for the sake of science.

In the wake of World War II, the Commission for University Reform in Germany, urged that each lecturer in a Technical University should have the following qualifications. The first two ought to be quoted verbatim: "1. To see the limits of his subject matter. ... 2. To show in every subject the way that leads beyond its narrow confines to broader horizons of its own".[28] On reading this, one would be prompted to state with Pascal: "All good maxims are in the world. We only need to apply them".[29] Unfortunately, qualification #1 is qualified with the following: "In his teaching [the teacher should display the ability not only] to make the students aware of those limits [but also] to show them that beyond those limits forces come into play which are not entirely rational, but arise out of life and human society itself".[30] There are, of course, forces at work in man and in society that are not entirely rational, but qualification #1 seems to suggest that reason is equal to science and science to reason and that whatever is not science is not entirely rational. This is, however, the number one danger to be avoided both in the science of education and in education in science.

[27] Unfortunately, I lost my reference to the provenance of this statement of Schrödinger.
[28] Schrödinger, *What Is Life? and Other Essays*, p. 115.
[29] *Pascal's Pensées*, tr. W.F. Trotter (New York. E.P. Dutton, 1958), #380.
[30] Schrödinger, *What is Life? and Other Essays*, p. 115.

SCIENCE EDUCATION
AND INFORMATION TECHNOLOGY

MAMBILLIKALATHIL G.K. MENON

The very first aspect of the purpose of this conference it is to consider how science and technology permeate the educational system. We have an educational system and we want to see how science and technology percolate into it, and of course we are only going to look at the school primary and secondary education system. But there is an aspect that has repeatedly come up for discussion. Prof. Osborne raised it in particular when he discussed scientific literacy and it was also referred to earlier when science education and its relationship to the scientific information for the public was discussed. One is referring here to the whole area of science communication, or science for all rather than for specialists, and I believe this is an equally important area that we should consider because it is part of what emerges from the primary and secondary levels.

I would like to start by saying that the main area I would like to deal with is the scale factor in primary and secondary education, and this is because I come from India, which is a developing country. Professor C.N.R. Rao discussed certain categories of countries in his report about scientifically advanced, proficient, lagging and so on countries. There are many areas of development in India where India might be regarded as an advanced country, but let me say that if one looks at the overall picture, India is certainly a developing country as far as the area of primary and secondary education is concerned and as far as science education is concerned. Professor Rao made a very forceful and impassioned speech about the problems of development and the developing countries, so I will not repeat a large part of what he had to say, but if we are going to discuss the future, if we are going to discuss primary and secondary education and science education, and as I said the principal purpose of my presentation is to deal with the question of scale, I want to say that there are a very large number of issues across the spectrum, and these are seen essentially in the developing countries.

First of all, I know that in my country there was a promise made to achieve universal elementary education; there was a promise made in the Constitution of India in 1950. We still, in 2001, have not fulfilled this promise. There is the question of literacy. I am not talking about scientific literacy; I am not even talking about the ability to understand the meaning of things. I am talking about literacy *per se*, and when talking about scale we have 400 million illiterates in India. There is the question of equity, and I think that this a very important term that we ought to consider; and I have seen it across the whole spectrum, whether in the rural areas or the urban areas. And Professor Pinto DeMelo showed that in the case of Brazil the difference between the urban and rural is sectors very evident.

There is also a high degree of gender inequality; there is inequality between the young and the old. In fact Professor Cabibbo referred right at the outset to Professor Alberts and the fact that he had talked about those about the age of sixty. But I would like to say that if we just take the age group between fifteen and thirty-five, where the bulk of the working population comes from today in India, we have 110 million illiterates. There is also the problem of what are called 'drop-outs'. A 'drop-out' is essentially a child who joins school and does not proceed through school. He drops out at various stages in class two, in class three, and so on. And the figures for India are that for every 100 children who join class one, only twenty-five get to class 8. Seventy-five drop out. This is a very major problem.

And there is of course the state of schools, I think Professor Rao gave some indication of what the schools are like: roughly 40% of schools do not have blackboards; only 30% have libraries or laboratory facilities; and 73% have no proper buildings. Now, we heard a great deal about teachers, and I think Professor Mössbauer hit the nail on the head when he said that the most basic question is the teachers and the training of the teachers. But Professor Rao also told us about single-teacher schools. One teacher looks after the whole school, all the classes, all the subjects, and I can tell you that I have been to practically every part of India, because I have dealt with this field for eight years, with the planning of the education sector, and in a large number of these schools there is no teacher; there may be a single-teacher school but there is no teacher. Teachers who are appointed live in the better towns. They do not come to the rural areas. And you have schools in places where the children have to walk as far as twenty kilometres to go to school and come back, often across difficult territory, including mountains. With all this, quite clearly, there are going to be drop-outs.

There was also a discussion on the question of teachers not joining this profession for a variety of reasons. First, in most developing countries today you find that they do not have any real position in society, or respect for scholarship. We have discussed the question of the importance of money and the other professions available. Reference was made to how a good mathematics student goes on to do other things, maybe in financial areas, rather than becoming a mathematics teacher, and I know that a very large number of those who are actually teachers instead of teaching in their classes give take private tuition outside – that is where they make their money. They go for coaching classes, as they are called, to enable students to pass examinations.

What I really want to point out is that we are really dealing with a different animal, dealing with a different problem in terms of the types of issues that come up in terms of the scale involved, and therefore I really asked myself when this workshop was planned: how can science and technology percolate into the educational system? I want to see in what way we can use our current scientific and technical capabilities to overcome this problem of scale, of distance, of access, of timing, because very often the problem that arises in developing countries is that schools are far away, they operate on fixed timings, and these are not the timings when students can go to school. Therefore they do not go to school or when they have other things to do they drop out. Can we therefore overcome the barriers of distance, the barriers of fixed locations and school buildings and the resources required? Can we overcome the barriers of time? And this is why I want to talk about science education and information technology.

Many here are probably familiar with the fact that one of the successful programmes conducted in India is what is referred to as the 'green revolution', the increase in food production. At that time television was just coming on the scene, and perhaps the first programme ever conducted in India on television was what is referred to as 'creshi dashan'. 'Creshi' is agriculture, and dashan is a view; and this was essentially to put across on television what was important to farmers in terms of seed varieties, what to sow, pest control techniques, and so on and so forth. This was a process of real education which was of value to them in terms of what they were actually doing.

This still continues. Later on, and this was really conceived by the person who envisioned the Indian space programme, Vikram Sarabhai, we had an experiment which is referred to as the satellite instructional television experiment. This programme essentially borrowed a US satellite, a dual stationary satellite, the ATS 6, moved it overhead from America to overhead India, and used it for education. Televisions were put in remote villages and there were programmes of relevance to these communities, not necessarily teaching them at a primary or a secondary school, but aspects which were related to the totality of what was relevant to them, relating to water, relating to health, relating to education, relating to general knowledge and so on and so forth, so as to open their horizons. This was a very successful experiment.

But since then has television has grown tremendously in the country, and today television is no longer regarded in information technology as being a separate entity. One has what one calls convergence, which means the totality of all aspects of information storage, dissemination, communication, computing and so on. Today computers, broadcasting systems and telecommunication systems converge. There is an IT convergence, and the question that I would like to really raise here is the manner in which one can use this. Dr. DeMelo referred briefly to the use of Internet. But I would like to say that we are not only dealing with the computer, but also with television, with all types of systems for storage and for the dissemination of information. There are now a variety of things happening which would enable this to take place. Let me give you just one small example of how slum children make use of computers. In Delhi one of the companies involved with computers installed a computer in a slum area with just a hole in the wall, so that the children could have access to it, and it was switched on. They came and looked at this new object or toy, played around with it, they were pressing buttons and so on and so forth, and they saw all sorts of things happening on the screen. They were illiterate street children, but they all learnt and they knew far more about computers than adults who had followed the manuals in which you go step by step.

Television today is essentially used within a consumerist framework. It is used by the news media for a whole range of things. How much information has been transferred to society on a real time basis, whether the September 11 WTC event or what is happening in Afghanistan, what happened when man landed on the moon or what was happening in Yugoslavia or anywhere else for that matter, or when a goal is scored in a world cup! All of it in real time is available to huge numbers of people, and they absorb it. This is the power of the television. And yet, because of the fact that it has been completely handed over, in a certain sense, to what are called market forces, education and health are rather neglected. Certainly we make the maximum use of business, of industry, of whatever they can do in the matter, but the primary responsibility in this sector will be that of government and of society, and therefore whatever means is available must be made use of by the public sector, and by that I mean government and society.

I would like to mention another area of information technology very quickly, and that is the area of languages. Reference is made to a whole range of issues relating to languages and Dr. DeMelo talked about various developments in Brazil. But if I ask myself in what way could I use them, the answer is: zero, except for kits, because they would all be in Portuguese. Elsewhere it would be in Spanish, and so on and so forth.

We have to realize that there are three thousand languages spoken in the world. Thirty-eight of these are spoken by more than ten million people. There are twelve which are spoken by more than a hundred million people. Language is a matter of great importance as we move into the future, if we want to have anything that is international, and not only international but also national. When we talk of India, we have eighteen constitutional languages in India, ten scripts, and about fifty dialects. Children, when we talk of primary education, grow up in their language groups with a mother tongue.

If you look at the way the human brain reacts to this, all information is essentially a process learnt in that idiom, that form of idiom. And in fact all records are kept in that fashion too. I mean, if you look at any farming records you will find that many records are kept in the local language, in that script. As we move into the future we have got to accept that language diversity is a basic trait of cultural pluralism.

There are different cultural identities, and hence a diversity, and on this rest the various forms of expressing feeling and thinking. Now, certainly it is true, and reference was made to the fact earlier on, that we have Internet. A very large part of it is in developed countries. I am not going into the detailed numbers on that. A significant part of it is in English, but if you take this very continent in which we are, Europe today, and take the number of languages in Europe, would one want to go over to an Internet based entirely on English? Or should we do what Professor C.N.R. Rao said and allow the gap to widen? He referred to standing on the bank of a river, a widening flooding river. Or are we going to have some mechanism whereby we can move over from one language to another with ease?

And I would like to just spend five minutes in telling you that this is possible, not just in a machine translation from language A to language B, but in moving across from any language to any other language, and that is something with which I have been connected, and it is called 'universal network in language'. This was something which was developed by a team of two individuals who originally worked on machine translation at Fujitsu and who then were at the Institute for Advanced Studies in Tokyo, the UNU. I will not go into the history of the whole development but what does it amount to? It amounts to the fact that you can express yourself in the language you know, English, or French, or German, or Hindi, or Gujarati or Chinese, or Russian or Arabic, and in the script that you know. It is then put on a computer in the way you normally put it on, it goes into the server, and then what you have is an electronic language which picks up the totality of it, the words, the syntax. It has an enormous dictionary for the purpose and resides in the server, in machine language, in computer language. This is the process of UN conversion. You can pick it up in any other language anywhere else. If I today send a message from here in Italian, it can be picked up in Beijing, in Chinese, or in Moscow in Russian, in those scripts and in those languages.

Here is an opportunity to go across all the languages and to break the barriers that exist today. Now, I could go into greater details on this but I do not want to because of a shortage of time. But what I wanted to point out is: first one has the power of the television, and a television set, particularly with cable television, and now there are powerful new techniques which are coming in including overcoming the last mile problem through wireless and local loop, a variety of things which exist, which display in a form which is absolutely explicit and clear. I am not now arguing that this can substitute the teacher, I do not say that at all. What I am saying, however, is that it is a powerful adjunct. In addition to that, you are not then dependent only on doing everything within that language framework. You can cross over from one language to another.

This can be done for all purposes that we are concerned with at this level, which is primary and secondary education. I am not talking of technical education in great detail, there will be special domain areas: if you are going into neurosurgery, if you are going into high physics, if you are going into molecular biology, then of course you require a whole range of new dictionaries and words and so on and so forth. But, on the other hand, if one is talking of two aspects, and that is what I would like to focus on, which is in the original definition of the purpose of the Conference, namely how science and technology percolate into the educational system, and how one can move over experiences across the world, and how one can relate this as science communication, namely the whole question of science and public understanding, then I think this too can be used in a very powerful way.

I can make a few clear suggestions about what should be done in this area. There has to be an immediate technological effort and an effort relating to lower costs. Efforts being made particularly in Brazil, in India, for instance, are bringing us down to the level of a hundred dollar PC, and I will make the prediction that soon we will have instead of the actual complex boards things printed on paper. You do not require all the elaboration required for the type of usage at this level. One would require systems that operate mechanically with battery systems, not only electrical systems. You have already seen Dr. DeMelo's projection on the availability of electricity; the situation in Africa is much worse; in the remote areas of India it is also very bad. My second suggestion relates to the increase in the number of languages connected to the universal network in language, because the universal network in language is the computer electronic language. But the language groups are working today on all the languages, all the standard languages of the UN system, plus a very large number of traditional languages, Hindi, Thai, Japanese, etc. which are not part of the UN system.

There has to be a commitment to the public sector and government funding of education, and particularly science education. There is I think the opportunity, and this is what Professor C.N.R. Rao in some sense hinted at, that there could be a declaration from here, particularly with the backing of His Holiness, on the importance of education for development, for values. I have not gone into this whole area which is a completely different area in its own right, but education is not purely technical, education includes value systems, and this of course finally brings us to a knowledge-based society which can use that knowledge effectively.

And of course I hope that we will also have the possibility of international programmes whereby very low cost science experimentation can be transferred, so that it can be used in much broader areas than presently. Indian experiments do not have to be confined to India, Brazilian experiments do not have to be confined to Brazil, Mexican experiments do not have to be confined to Mexico. One should be able to spread them around and make much larger use of them, and an international programme to make this possible is certainly called for. But I do believe that the very first part of the purpose of this workshop, namely how science and technology can percolate into primary and secondary education, is very important. It can be done, and I am not pessimistic about it, but it must attack the most single key factor in it: if you are going to deal with the world, scale is important.

BUILDING A VISION OF INQUIRY-CENTERED LEARNING
A WORKSHOP DEMONSTRATION

DOUGLAS M. LAPP

The National Science Resources Center (NSRC), a science education center operated jointly by the National Academy of Sciences and the Smithsonian Institution, has developed a series of workshops that can be used to demonstrate inquiry-centered science learning. These "jigsaw workshops" have been very effective, not only with teachers and educational leaders, but also with university scientists and corporate leaders, as a way of building a new vision of the benefits of teaching science by engaging learners in scientific inquiry.

At the meeting of the Pontifical Academy of Sciences Working Group on "The Challenges for Science: Education for the Twenty-First Century", the members of the working group had an opportunity to participate in a jigsaw workshop on buoyancy developed by the NSRC. This workshop is based on learning activities drawn from the *Floating and Sinking* curriculum unit, which is a part of the NSRC's *Science and Technology for Children* (STC) elementary science program.

Working in groups of three, the participants performed one of the following investigations, using the simple apparatus designed for the STC program.

(A) This group was given a set of sixteen objects, which included a fishing bobber, wooden bead, glass marble, lump of clay, nylon bolt, aluminum nut, and eight large and small cylinders made of wood, aluminum, acrylic, and polyethylene. They were asked to: (l) predict which objects would float and which would sink; (2) develop a statement that would describe the properties of the "floaters" and the "sinkers"; (3) test their predictions by placing the objects in a water tank; (4) record their results and compare these results with their predictions; and (5) identify the major concepts and skills that children might develop by engaging in these activities.

(B) This group was given an uncalibrated spring scale, a box of paper clips to use as weights, and a set of five objects which included a large fishing bobber, a small fishing bobber, an acrylic cube, a nylon bolt and nut, and a large metal washer. They were asked to: (1) without using the spring scale, develop a strategy to compare the weights of the five objects and to place them in order from lightest to heaviest; (2) use the paper clips as weights to calibrate the spring scale; (3) using the spring scale which they calibrated, weigh each object, and compare this with their earlier results; and (4) identify the major concepts and skills that children might develop by engaging in these activities.

(C) This group was given a tank of water, a calibrated spring scale, a hook with a small suction cup that could be attached to the bottom of the tank, a nylon string, and a set of three fishing bobbers of different sizes. They were asked to: (1) without using any measurement tools, roughly compare the weights and volumes of the three fishing bobbers; (2) investigate the buoyant force on each fishing bobber by pushing it under water; (3) use the spring scale to weigh each of the bobbers; (4) using the spring scale, the hook attached to the suction cup, and the string, measure the buoyant force exerted by each of the fishing bobbers; (5) discuss their observations in order to draft a statement about the effect that volume has on the buoyant force; and (6) identify the major concepts and skills that children might develop by engaging in these activities.

(D) This group was given a tank of water, a lump of clay, and a bag of marbles. They were asked to: (1) discuss together a strategy that might be used to modify the shape of the clay, without changing the amount of clay, so that it will float with a cargo of 25 marbles; (2) test and modify this design until the clay boat floats with the 25 marbles; (3) design and construct a boat that will float carrying as many marbles as possible; (4) discuss the variables that affected the performance of their boat designs, including the effect of changing the volume of the boat; (5) identify the major concepts and skills that children might develop by engaging in these activities.

(E) This group was given a tank of fresh water, a calibrated spring scale, and a set of objects that included a metal cylinder, wooden cylinder, polyethylene cylinder, acrylic cylinder, black plastic cylinder, and a hollow cylindrical plastic container (all of the same diameter and volume). They were asked to: (1) predict which objects would sink and which ones would float in fresh water; (2) test their predictions by placing each cylinder into the tank of fresh water; (3) use the spring scale to weigh each cylinder and record these weights; (4) fill the hollow plastic container with water, record its weight, and compare this weight with the weight of the other cylinders; (5) develop a statement that describes the relationship between the weight of each of the cylinders, the weight of the container of fresh water, and each cylinder's tendency to float; (6) identify the major concepts and skills children might develop by engaging in this learning experience.

(F) This group was given a tank of salt water, a calibrated spring scale, and a set of objects that included a metal cylinder, wooden cylinder, polyethylene cylinder, acrylic cylinder, black plastic cylinder, and a hollow cylindrical plastic container (all of the same diameter and volume). They were asked to: (1) predict which objects would sink and which ones would float in *salt* water; (2) test their predictions by placing each cylinder into the tank of salt water; (3) use the spring scale to weigh each cylinder and record these weights; (4) fill the hollow plastic container with salt water, record its weight, and compare this weight with the weight of the other cylinders; (5) develop a statement that describes the relationship between the weight of each of the cylinders, the weight of the container of salt water, and each cylinder's tendency to float; (6) identify the major concepts and skills children might develop by engaging in this learning experience.

After engaging in these activities, the participants discussed the "Focus-Explore-Reflect-Apply" learning sequence that is utilized in the STC science learning materials. The participants also discussed the special benefits that result from engaging children in inquiry-centered science learning as demonstrated in the *Floating and Sinking* demonstration workshop.

EXAMPLES OF SPECIFIC APPROACHES/SUCCESSES IN VARIOUS COUNTRIES

THE PROBLEMS AND PROMISES OF SCIENCE EDUCATION IN CHILE

JORGE E. ALLENDE

Chile is in a process of developing its science and technology capacity. Having worked as an active scientist for 40 years in my country and having lived through very difficult times, I am optimistic that now we are making some significant progress.

I will show you a few facts why I am optimistic.

Transparency 1 shows the number of scientific publications indexed by the ISI originating in Chile through the last decade. Presently there are more than 2000 publications per year. Per capita this is the highest number of publications for any Latin American country.

The number of publications is important, but the quality and impact is more important. The following transparency (2) shows the number of citations per publications and the ranking of the different countries with this criterion. We see that Chile occupies the 23rd position – the highest for any developing country and ahead of some European countries with long traditions of research such as Greece and Poland.

In transparency (3) I have included some new Programs for support of science in Chile which have been generated by the government and which

Transparency 1. ISI PUBLICATIONS FROM CHILE

	1990	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**
SCI SEARCH	1.220	1.197	1.306	1.404	1.412	1.629	1.739	1.770	1.843
% World Total	0.178%	0.170%	0.181%	0.184%	0.177%	0.190%	0.193%	0.189%	0.195%

Transparency 2. THE 30 CLASSIFIED NATIONS BY CITATIONS PER PUBLICATION (1992-1996)

Country		Citations by Publication	Number of publications	Total citations
1	Switzerland	5,66	55.213	312.564
2	United States	5,03	1.239.188	66.234.187
3	Netherlands	4,45	80.016	356.025
4	Sweden	4,38	61.072	267.685
5	Denmark	4,38	30.719	134.616
6	United Kingdom	4,19	330.677	1.259.427
7	Belgium	3,94	38.095	150.206
8	Finland	3,93	26.998	106.151
9	Canada	3,83	167.326	641.114
10	Germany	3,78	258.956	979.823
11	France	3,66	197.816	723.156
12	Austria	3,54	24.388	86.275
13	Israel	3,45	39.977	137.980
14	Italy	3,42	116.534	398.285
15	Norway	3.30	19.814	65.305
16	Australia	3,23	85.215	275.599
17	Japan	3,18	280.855	892.029
18	New Zealand	2,94	17.015	59.007
19	Ireland	2,78	9.233	25.630
20	Spain	2,72	73.224	199.443
21	Hungary	2,55	14.768	37.724
22	Portugal	2.40	7.135	17.097
23	Chile	2,31	6.666	15.366
24	Greece	2,02	15.216	30.666
25	Poland	2.00	32.728	65.610
26	Argentina	1,98	12.266	24.334
27	South Africa	1,94	17.418	33.737
28	Hong Kong	1,92	19.379	40.106
29	Mexico	1,91	13.043	24.962
30	Brazil	1,89	25.578	48.406

Source: ISI – Science National Indicators

Transparency 3. NEW PROGRAMS FOR SUPPORT OF SCIENCE AND TECHNOLOGY IN CHILE

FONDAP PROJECTS CONICYT *1999, 2001*	7 projects in Astronomy, Oceanography, Physics and new materials, Applied Mathematics, Cell Biology, Signal Transduction and Ecology 1 million USD/year for 10 years
MILLENIUM INSTITUTES WORLD BANK – MINISTRY of PLANING *1999, 2001*	3 in Biophysics, Biotechnology and Genomics 700.000 USD/year for 5 years 10 Nuclei 300.000 USD/year for 3 years
INTERAMERICAN BANK – MINISTRY of ECONOMICS *2000-2005*	100 million USD for Technology Development in Informatics, Biotechnology, Agriculture (5 million for Genomics)
WORLD BANK – MINISTRY of EDUCATION *1999-2002*	250 USD million for higher education From this, approx. 50 USD million are dedicated to support Doctoral training and expensive research equipment

are improving the situation for funding for science and technology research in our country.

President Lagos is truly interested in scientific research and understands the relevance of science for cultural and socioeconomic development. We must recognize that despite the present financial crisis which has hit our country very hard, he is trying to honor his promise to double investment in R&D from 0.6% of the internal product to 1.2% during his 6 year term.

This may sound very rosy to you, but despite our optimism, we recognize that we still have very big problems. The biggest of them is that our society in general is not aware of the importance of endogenous science for their own development and for the progress of Chile as a nation. For most people in Chile, Science is something magical, complex and expensive that is done in the United States, Japan and Europe and that results in new gadgets or medicines that eventually appear in the stores, supermarkets or pharmacies in Santiago. The general public does not realize that scientific research and knowledge generation is something that can and should be done in their own countries and that their future and especially the future of their children depends on this.

Unless the perception is definitely changed and a general consensus among our national and regional (Latin American) societies is achieved, our present rosy picture will be fragile and ephemeral and will be changed depending on whether we are lucky on the political lottery and draw a more or less enlightened President or Minister.

It is obvious that the most sure and efficient way of changing the situation and achieving a society that understands and values science is through science education of our children.

But our argument must not be the selfish one of improving science education because that way we will get more money for science, for our labs and for our students. We should emphasize that science education must be improved because the knowledge, the attitudes and the values of science are essential for our children to live a fuller, freer, more democratic existence in the 21st Century.

Unfortunately the level of science education in Chile is very low. This statement is objectively ascertained by international tests as well as by national measurements. Rafael Vicuña presents in his contribution the results of the TIMS international test in which Chile is very close to the bottom of the list. The same very negative results can be seen in the SIMCE, a national exam that also tests natural sciences. (Transparency 4).

The most disturbing factor of these test results is the great disparity between public education, attended by the poor and the lower middle class (70-75% of the people) as compared to the private education of the privileged part of society. This is disturbing because it indicates clearly that we are not providing an equal opportunity to the children of the poor, on the contrary, we are giving them a handicap in the competition to enter the University or to prepare themselves for their life work.

Transparency 4. RESULTS OF SIMCE NATIONAL EXAM IN NATURAL SCIENCES

4º Year of Primary Education – % correct answers

Year	Municipal Public	Private State Supported	Private Paid
1992	56.1	62.5	76.3
1994	64.3	67.4	78.0
1996	65.7	69.0	81.4

Average of 24.000 students in a National sample

8º Year of Primary Education – % correct answers

Year	Municipal Public	Private State Supported	Private Paid
1991	47.81	52.32	67.11
1993	50.87	55.03	68.33
1995	55.68	60.15	75.14
1997	59.26	63.05	75.42

The last two years around 150.000 students were tested

The key factor to explain this low level resides in the training and support received by those rather heroic individuals that teach science at the primary and secondary education.

The market economy and the low salaries and poor social recognition that teachers receive in our countries have made teaching in pre-university

Transparency 5. SECONDARY SCHOOL SCIENCE TEACHERS GRADUATING IN CHILE – 1999

Mathematics	78	[*only 7 graduated from a research University*]
Mathematics and Physics	4	
Physics	11	
Chemistry	37	
Chemistry and Biology	4	
Biology	44	
Total	178	

In the national entrance exams, the students accepted to train as science teachers were in the lowest 30% of those accepted to institutions of higher education.

education very unappealing. Despite incentives and fellowships recently provided for those that enroll in teaching careers in Education Faculties and Teacher Universities, the numbers of those graduating in science teaching are terribly low. (Transparency 5).

In addition to the low numbers, their performance in the national university entrance exam shows that the students applying to be the future science teachers have some of the lowest qualifications of any profession.

To compound matters, only a very small percentage of teachers graduate from the few research universities that we have in the country. Therefore, science teachers graduate without ever being exposed to the real active science and without having contact with working scientists.

Obviously this rather dismal picture has to be changed drastically if we are to improve science education.

We have to raise the salaries and prestige of teachers and have to get the research universities involved in teacher training. Those are national policies that imply major financial and political decisions.

Another area in which scientists and scientific institutions can and should directly participate is the area of working with science teachers and with the education institutions to update their knowledge of science progress and to provide them with materials and tools that can be used to transmit to the children the fascination and the adventure of science.

As will be stressed in a special session of this meeting, we, the scientists individually and collectively have a responsibility to work to improve the science education that is provided to our children and youth.

This responsibility arises from our contract with society, with our duty to inform society what we are doing and why our work is important for our countries and the world. We have to serve as antennae for our people to tell them what is happening in the world of knowledge and how new scientific discoveries impact them. We also have a responsibility to prepare the children and the young to grasp the opportunities of the Age of Knowledge.

I am pleased to report that in Chile the scientific community has become aware of this responsibility and has started to do something about it. (Transparency 6).

The Chilean Academy of Sciences and the scientific societies gathered around the National ICSU Committee have played a key role in organizing the National Association of Science Teachers, which now has close to 1000 members throughout the country. This association founded in 1994 as a result of an interacademy meeting held in Santiago in 1993 organizes a yearly Congress and stimulates many activities. Its headquarters are precisely in the premises of the Chilean Academy of Sciences and since its foundation it has been a joint effort in which scientists collaborate with science teachers in those areas in which they require support.

The Chilean Academy as a result of the meeting of the Interacademy Panel held in Tokyo last year, also decided to increase its concern with science education. We are organizing a meeting in January 2002 to which 15 other academies, from other Latin American country and from may other countries will participate.

The focus of this meeting is the design and use of simple experimental materials in the classroom to allow children to use their hands and do experiments and learn on their own important scientific principles. We have obtained support from the Andes Foundation and the Minister of Education to organize this meeting. More important than this, is the fact that both a group of scientists and the Ministry of Education are excited to start this kind of Program in our country.

Another very positive aspect is that the Ministry of Education is very much aware of the need to raise the level and equity of education in all areas but very specifically in the sciences.

Transparency 6. INVOLVEMENT OF SCIENTISTS IN SCIENCE EDUCATION ACTIVITIES

1) *Chilean Academy of Science and National ICSU Committee*
   - Foundation of the National Association of Science Teachers in 1994.
   - Organization of an International Meeting of Academies to discuss the use of experimental materials in inquiry based learning of science Santiago, January 9-11, 2002

2) *Ministry of Education*
   - Educational Reform together with a group of active scientists have defined a set of Fundamental Objectives and Minimum Obligatory Contents for Primary and Secondary Education
   - Detailed programs for each discipline for each year of basic and secondary schools
   - Massive training courses for teachers
     These programs provide examples of content and activities for teachers and "Benchmarks" for student attainment.

3) *The National Research Council (CONICYT) - EXPLORA Program*
   - has the objective of making science accessible to society and stimulating science education.
   - National Science Week (every year)
     1000 scientists in 1000 class rooms
   - Science interactive museum

4) *Research Universities*
   The Instituto de Ciencias Biomédicas, Faculty of Medicine, University of Chile
   - Teacher training courses in biology
   - Practical course on molecular biology
   - Adoption of schools in poor neighborhoods
   - Training of bright students to enable them to enter University careers

To achieve this, a very large and ambitious Educational Reform Program has been launched by the Ministry of Education a few years ago and in the framework of a large increment in the investment in education.

In the area of sciences, the Educational Reform as designed by the Ministry of Education has worked with a group of very active scientists to define a set of Fundamental Objectives and Minimum Obligatory Contents of Secondary Education. The publication of a book with these essential definitions has been a very important step which require an active debate, which in the case of Chile, was concluded with the decision to maintain the rather conservative idea of the large scientific disciplines, not the more revolutionary idea of integral learning of all sciences.

The group of scientists and educators in the Ministry has gone on further to provide Programs of content and activities for the teachers as examples of what they should be doing with their students to achieve the minimal standards. These Programs are books for each subject and each year of basic and secondary education and serve as teacher's guide and also as a guide for the authors of text books which are selected in an open competition. These Program books are extremely helpful to point at "benchmarks" of knowledge that the students should attain in these subjects.

I think this is a very positive example of how government policies can be implemented with the very active and decisive help of active scientists who are generous enough to give their time for this crucial task.

Another very important activity that is being carried out by our government with the help of the scientists is the Explora Program of the National Research Council (CONICYT). During the past 3 or 4 years this Program has greatly increased its activities of motivating children and science teachers to undertake projects and initiatives in science education. EXPLORA organizes a yearly science week that take place in our Spring. In that week there are many activities but the most important is called "1000 scientists in 1000 classrooms" in which that number of scientists visit and give lectures to primary and secondary school children about science, its fascination and its impact. Although this is a large part of the Chilean scientific community, there is no problem getting the scientists to agree to give these lectures because they find it a very rewarding experience.

A new interactive science museum build in Santiago is also a very positive aspect in this area.

A further example of what is being done by scientists in the area of education deals with University units.

I have stated that one of the most serious problems with teacher's training is that this is carried out in Education Faculties or even in "Teacher's Colleges" or Universities. These Faculties or Universities do not have groups doing scientific research. It can be concluded that science teachers are trying to convey to their students about the marvelous achievements of science without ever visiting a laboratory or talking to active scientists. This situation is made more serious by the celerity of scientific progress. It is very difficult for the scientists themselves to keep up with the advancement of the ideas and techniques in their specific field, obviously it has to be impossible for teachers to maintain abreast of a very wide discipline of knowledge about which news are coming out every day in the internet and in the news programs.

We can and should do something to remedy both situations. Scientific institutes and university departments that are research oriented should take part in organizing training courses for updating teachers.

In our Institute of Biomedical Sciences, Faculty of Medicine, University of Chile, we are actively working with biology teachers in the public schools of Santiago running courses on morphology, physiology, genetics and molecular biology.

In this last subject we have developed a practical one week course in which we have trained more than one hundred high school teachers. It is great to see the excitement of these teachers when they can clone genes and transform bacteria and isolate DNA.

We have the project of developing a mobile DNA laboratory that can visit schools and let the students carry out experiments of genetic engineering.

One of the most worthwhile programs undertaken by the Faculty of Medicine deals with the adoption of 3 high schools of one of the poorest neighborhood in Santiago, called La Pintana. This means that the teachers of those schools get the chance of a number of special training programs to help them raise the level of their teaching. In addition, 8 of the top students from that neighborhood are receiving special individual tutoring in the Faculty of Medicine with the objective to get them to do very well in the national entrance exam so that some of them can enter medical school or some other university careers. That was something unheard of in that neighborhood of La Pintana, its youth thought they had no future and were destined to increase the number of jobless or problem citizens. The fact that some of their own will be given a chance to escape this fate has had a tremendous impact in the morale of the whole school system of this poor municipality. It is something we should expand.

We are pleased because in the past few years, our scientific community has really started to understand its responsibility and has worked with enthusiasm on science education. However, it is a huge, massive task and there is a great deal to be done.

In this respect, I think that it is very important in this international meeting that we go further than the stimulating exercise of learning from each other what we are presently doing. In my opinion there is a need for generating international collaborative projects in this area in which we can synergize and complement each other and make full use of the resources and infrastructure available in various countries.

There has been a lot of discussions about the good and bad things of globalization. Well, whether we like it or not, science is a globalized area that was born that way, there is no folklore in science, international science is the only true science. We should make use of this in science education through international efforts.

Transparency 7. PROPOSALS

Academies and scientific institutions should generate one or many projects to carry out joint international activities dealing with pre-university science education.

1) International courses to train and update science teachers

2) A set of "benchmarks" of minimal required objectives for the attainment of children at an international level

3) Sets of experiments and materials that could be available to science teachers of any country

4) International science teacher prizes

These activities should be included in an international project.

For instance (transparency 7), we could organize international courses for updating science teachers. We could generate and agree on an international set of benchmarks for our children's science attainments. We could design sets of experiments and materials that could be available at minimum cost in all countries. We could institute international science teacher prizes for outstanding achievement. I am sure that you will have many other ideas, but it is certain that if academies with the prestige of the Pontifical Academy, together with TWAS and some of the National Academies, get behind such a project, we will be able to find funds to support this very worthwhile effort.

CLOSING THE EDUCATIONAL GAP AMONG TEENAGERS

ANNA S. KASHINA

Introduction

This paper focuses on science-specialized high schools – a highly successful educational experiment, initiated and carried out by Russian scientists, ranging from top-level scientists, including the famous mathematicians I.M. Gelfand and A. Kolmogorov, to graduate and undergraduate students. Such specialized high schools have been organized on the base of average schools with enhanced studies of one or several scientific subjects. In the rigorous educational system of the former Soviet Union they co-existed with a large amount of regular schools and foreign language schools.

The extreme success of this experiment, both in bringing up younger generations of top level scientists and professionals, and in increasing the general level of education, led to the development of a widespread system of schools in the scientific centers of Russia, such as Moscow, St.Petersburg, and Novosibirsk that succeeded the Soviet times in Russia and is flourishing up to this day. The first school was initiated in 1958 (Moscow School #2), the next few were started in 1968 (including the famous Moscow School #57). Currently there are over 30 specialized schools in Moscow alone.

While this experiment remains an example of an educational success, rather than a panacea for the educational problems in the world, a similar approach can make a valuable contribution to education in any country by creating a core of intellectuals that can serve as a foundation of the scientific community of educators. This core can be instrumental in setting up standards, principles, and traditions in general education and eventually in becoming leaders in the educational development of students, teachers, and parents, with whom the education really starts.

Principles and tools

Education in specialized high schools was based on four basic principles. First, it integrated learning with cultural and moral development, teaching, besides the scientific disciplines, a system of values that provided the necessary foundation for learning science. Second, it created an atmosphere of 'learning as an adventure', where the teachers assumed the roles of leaders and mentors, rather than simply delivering the information. Third, it made no distinction between students from different socioeconomic background. And fourth, it allowed each student to study at their own individual pace, without distinction between the initial performance of different students. Each of these principles is described in more detail below.

Specialized schools used a common set of tools. The first and most important tool was the core of highly enthusiastic university teachers, aided by graduate and undergraduate students. All of them in Russian specialized schools did this work voluntarily, without being paid. Second tool was the educational methods that involved, besides classes, a number of extracurricular activities, designed to create an atmosphere that encouraged students to learn. One of the most important extracurricular activities included educational field trips that, besides teaching, created an atmosphere of companionship, and bonding between students and teachers, and, as a result, turned learning into a collective game. Finally, the specialized schools used as their basic tool regular, average high schools, in no way special by any other criteria.

Here is how the specialized education fit into the regular educational system. All the high schools in Russia had 5 days a week (6 hours a day) of classes taught by a unified nationwide school program, and 1 day a week of vocational education, designed to give students some direction towards a simple profession, for example, a driver, or a seamstress. In specialized schools the basic program was the same, but the vocational education was replaced by the equivalent amount of hours a week (i.e., 6-8) of specialized classes, such as biology, mathematics, or chemistry. In addition there was a slightly heavier load of hours and extracurricular activities, such as field trips and cultural events. This specialized program was entirely up to the organizers in each school and thus it differed a lot between different schools. Therefore the specialized schools fitted naturally into the general education system, but added very important extra elements to it.

Selection process and curriculum

Selection into specialized classes took place in April-May for the upcoming academic year. It was directed at selecting students that were interested in the subject, were able to think independently, and were motivated to learn more. The grades attained in the previous schools were not a part of consideration, and the previous level of education was also generally considered unimportant. Specialized schools aimed at finding students willing to learn and compatible with their educational methods, not merely the top graded students.

For example, selection process into the biology classes at Moscow School #57 – one of the core specialized schools in Moscow – consisted of three rounds. The first round was a written test on subjects of general science within the school curriculum, which selected approximately 100 students out of the general group of applicants. At the second round the students underwent three one-on-one interviews with the members of the organizing groups. These interviews were usually conducted not by main class organizers, but by the university students helping them out, mostly the recent graduates of the same classes. They were aiming to determine the students' thinking abilities and compatibility with the program and therefore didn't restrict their questions to biology or even science (for example they could ask what is an applicant's favorite poem and why). This selected around 30-40 students for the final round. At the third round all the finalists had a 10-minute interview with the main organizer(s) of the class. These interviews, conducted in a format similar to the second round, selected anywhere between 15 and 20 students for the class.

An important addition broadened the implications of this educational experiment. 8-10 students from the neighborhood, for whom that was the closest school, were accepted into specialized classes without such selection, first-come, first-served, based on their willingness to join the class. This was done as an attempt of the program organizers to determine how applicable was their educational system to all students. As a result the specialized classes were very diverse, consisting both of top students from highly educated families all over Moscow, and of students below, often – much below average from common families in the neighborhood.

Contrary to expectations, having these two groups together in the same class didn't produce any problems or conflicts, because the general spirit, created by the teachers, was that of a participation in a special experiment, of blending together instead of emphasizing the differences between the students' socioeconomic or educational backgrounds. In addition to the spirit of enthusiasm and adventure, the rules were backed up by iron discipline, enforced by the peers through often unspoken disapproval.

Table 1 gives an example of specialized classes taught to the biology students in the Moscow School #57.

Table 1. CLASSES AND EXTRACURRICULAR ACTIVITIES IN THE SPECIALIZED BIOLOGICAL EDUCATIONAL PROGRAM (TWO LAST YEARS OF HIGH SCHOOL, 9TH AND 10TH GRADE, 15 AND 16 YEARS OF AGE, RESPECTIVELY).

Regular classes taught by enhanced program:

Mathematics	6 hrs/week of algebra and geometry
Physics	3 hrs/week
Chemistry	2 hrs/week
Russian and Literature	4 hrs/week
Biology	1 hr/week

Specialized biology classes, not taught in regular schools:

9th grade:

Zoology of Marine Invertebrates	1 hr/week lectures, simplified university program 1 hr/week practical course
Biology of Higher plants	1 hr/week, special course
Entomology	1 hr/week, special course
Cell Biology	1 hr/ week lectures, simplified university program 1 hr/week practical course
Ecology	1 hr/week lectures

2nd year (10th grade):

Genetics	2 hr/week full university course
Human Anatomy	1hr/week full university course
Cell Biology	2 hrs/ week full university course
Vertebrate Zoology	1 hr/week, special course

Extracurricular activities:	1-day field trips	1 Sunday/month
	1-week field trips	2-3 times/year, quarter breaks
	2-month field trip	between 9th and 10th grade
	Cultural events	once a month

In specialized schools some of the regular school subjects were taught by enhanced program. For example, biology students had, in addition to biology, enhanced mathematics, physics, and chemistry. All students had extra activities at other classes, such as literature, where they took time during the class to read and discuss their favorite poetry. On occasion the teachers even managed to include into classes the discussion of the Bible, which was very hard to do in the Soviet times, but in the teachers' opinion necessary to develop the moral values of the students.

The specialized biology classes were taught by volunteer university professors and students. During the first year heavy emphasis was placed on the 'old-style' biology, such as zoology and botany that was regarded as a necessary foundation for the future knowledge of more 'modern' subjects of biology. In the second year the emphasis was shifted to the 'modern' biology, with the curriculum for many subjects actually the same as taught to the first year University students (underlined in Table 1).

Teaching methods: individual pace for each student

A very important reason this education proved so effective was the following. In class teachers gave students the materials and allowed each of them to work at their own pace. At the same time, they were encouraged to ask questions, even if these questions concerned the program of previous classes, which the students were supposed to know.

The rationale, as given to the students, was that questions help not only the student but the teacher, and that the people who don't have questions can never learn anything. The teachers encouraged questions by pointing out that they themselves don't know everything and may very well make a mistake or not know the answer. To make it easier in some classes, along with the 'main' teacher several 'junior' teachers were present, who helped answer questions or refer them to the 'main' teacher if necessary.

As a result, an interesting thing came up. It turned out that most of the chronic non-performers, who used to have bad grades and were labeled as incapable of learning, in reality simply missed some previous parts of curriculum, and as a result lost hope to ever catch up. When they were allowed and encouraged to start from the previous parts of program, - 3 years behind, if necessary, - and ask any questions at all, they started to catch up very quickly, first doing problems at a much lower pace than others, but eventually becoming as good as the rest of the class, or, in some cases, better.

Other students had opposite problem – they finished their task much too quickly and were bored. Those students were always given an option to leave or to study more if they wanted. In the atmosphere of 'learning as a game' most of them chose to stay and keep studying. As a result those students who had a naturally slower pace of work didn't feel discouraged, and those who had a faster pace didn't feel bored.

An important conclusion from this is that *regular school education is directed at a non-existent 'average' student*: material is given at an average pace that is too fast for some students and too slow for others. As a result in regular schools some students are habitually bored and might eventually be turned off by the education process in general, and others never have a chance to develop their abilities. The education methods in the specialized classes dealt with this problem in a very efficient way. Even the original non-performers eventually became comparable with the top students in other schools.

Moral values and atmosphere

What was, in the end, so special about the specialized education? Definitely not the extra classes and extra material *per se*: such things are known in many educational systems and by itself they never have produced such striking results. It was not even the extracurricular activities by themselves, and not the unusual teaching methods. It was the combination of all these things and more: the atmosphere, created by enthusiastic teachers who wanted to apply their best effort to bring up a generation of students like them.

In a way these teachers approached the education as they approach the task of bringing up their own children, developing them morally as well as mentally, creating a group of people they themselves would enjoy being with. In such atmosphere the education came naturally, not so much as the result of lessons, but of this continuous interaction, where the most important thing was to come up with the true answer to each question, and searching for these answers in itself was what bonded the students together. This atmosphere bred intellectual hunger that was not confined to the specialized subjects. Students from these classes took turns to stand in line overnight for the tickets to the best art exhibits and plays; on one occasion a large group of students stayed behind after the literature class and spent four hours arguing whether Tolstoy had meant his Count Andrei to be a positive or a negative character.

What these students actually had in school was, on top of education, a life full of fun, companionship, and intellectual challenge, which taught them all the moral values, both in scientific research and in life in general. Many came to the school in search of this companionship, undergoing the tough selection process and often having to travel more than an hour each way to study there.

It is known that roughly around the time of high school teenagers start growing out of their family bonds and looking for a group of people to belong to. In some modern societies they often find only gangs, or rock groups, or extremists groups; or they find nothing at all and then become lonely and depressed. It seems feasible to attempt at providing alternatives for students, such as specialized schools that can give them a chance to belong to a wonderful group of people. It can give the teenagers a lot more, as taught by the example of the Russian specialized schools.

Above all these schools give students a head start, not only for professional science, but for other pursuits as well. Graduates of these schools are now working all over the world, and a few of those are leading scientists in their fields. Some of them have become engineers and doctors, artists and writers, or even military commandos. Several people chose to organize their own specialized classes at other Moscow schools.

Even more than that, such education gives students a broader and keener understanding of life and people, which really makes every aspect of human interaction a much better experience. And finally, for better or worse, it gives them independence of thought in a good sense, a quality – so necessary in a scientist – of questioning everything and arriving at their own conclusions, which in the end is making their convictions and sense of righteousness a much firmer foundation.

Implementations within other educational systems

The tools used by specialized schools exist in virtually any society and can be implemented within almost any educational system. Average schools – the foundation for specialized education described here – exist everywhere. There are certainly many ways to introduce additional classes into a regular school system. Many of those exist already, such as Sunday schools and honor classes. Similarly, there exist field trips for school students, such as scout trips and summer camps. Finally there are University Outreach programs, where scientists give lectures to high school students.

The new element, and the most important limitation of implementing the experience of Russian specialized high schools in any society, are enthusiastic volunteer teachers who would be willing to approach education with the same energy and responsibility as if they are teaching their own children.

Such people exist in any society, but are hard to find on a large scale. Perhaps they should be looked for initially not among the school teachers, but among the scientists, who are willing to bring their knowledge to schools. Tremendously important would be an effort to increase public awareness of science in general and science education in particular, since only then the students, the teachers, and even more importantly – the parents become aware of the necessity to learn science as a part of intellectual and moral development of a healthy individual, as well as a part of survival in the modern world.

While the example of the Russian specialized schools cannot be viewed as a total reform of educational system, but rather a useful addition to it, such an effort seems to be really worthwhile, since the results of such education have extended beyond just mastering the curriculum to the intellectual awakening and change in the value system.

SCIENCE EDUCATION IN FRANCE: ‘*LA MAIN À LA PÂTE*’

PIERRE J. LÉNA

1. *Education in science, a new concept?*

In France, the issue of the scientific litteracy of the society is most often raised in terms of *culture scientifique et technique*. Several studies have recently been published, showing the coexistence, in the public opinion, of a high degree of interest for science and technology, associated with a great ignorance and many fears. Within the scientific community, there is a lasting consensus that this situation is not satisfactory and requires specific actions. In the last two decades indeed, numerous efforts have been made by the public authorities, the research institutions, the science community through its professional associations in order to bridge this gap and amplify the transfer of scientific results to the public.

Some of these efforts aim to improve the information of the public through the media (press, television), others to stimulate the creation of centers (*Centres de Culture scientifique et technique*) which mediate the knowledge towards a large public on a local basis, others to open the scientific or industrial laboratories to the public in a yearly national *Science Week* which has now twenty years of existence. Most scientific research institutions (CNRS, INSERM...) have developed in-house special offices dedicated to communication, with the aim to make known their activity to the press and the general public. The emergence of science and technology into society debates (genomics, procreation, climate, etc.) now leads to new forms of exchanges, which go beyond a pure scientific information: *cafés scientifiques, conférences de citoyens* (citizens debates), Internet forums, which are reflected in the press.

While this *information on science* (and technologies) tries to cope with the pace of discoveries, their impact on society and the political debates they imply, another aspect began to emerge in the last decade, namely *education in science*. This is clearly an issue for the school system, which in France is strongly centralized, and deals with curriculum choices, teachers training, recruitment and evaluation. What should be the goals of a proper education in science, to be given to everyone during the school years, especially during the compulsory education, which in France lasts until the age of 16 and is in principle identical for everyone? does the change in the volume, the rapidity of development and the impact on society of science and technology force to reconsider the way science is taught in schools?

Education in science can be understood as the goal to share methods, history, values and results of the scientific and technological development. It is not to be conceived as a mere accumulation of facts, results, 'scoops' on discoveries, fragmentary knowledge, formulas or practical rules. It is a subtle access to this apparently miraculous ability of human intelligence, brain and hands together, senses and measuring artefacts together, to unveil the mysteries of nature and to become able to act on it, predict the future and develop new artefacts, in a cumulative process of development, specialization and cross-fertilization of disciplins. Achieving this *education* requires pedagogy, continuity, appropriate tools and methods, the partnership of a teacher and can not be confounded with *information*, which is needed but today appears as a volatile and often superficial product of the consumerist society. The ambition of education is to introduce everyone to this mixture of pure imagination and inflexible rationality leading to the scientific knowledge and subsequently to a power upon the natural world.

The transformation of the pace in science and technology evolution forces to reconsider entirely the ways through which the school system handles this challenge. The scientific community, the role of which has been essential in the development *of information on science* in the last two or three decades, as briefly discussed above, has to become involved also in this new issue, to a degree it ignored up to now. On top of its traditional *raison d'être* to create new knowledge and to disseminate it to the new generation to ensure a cumulative development, it bears a new responsability of *knowledge sharing*, which implies a more direct role and impact on the education system, and especially on teachers.

The central role of teachers for a good education in science is obvious. Yet, the community of science teachers (in *collège* and *lycée*), in the last two or three decades in France, became more and more separated from the mainstream of science and technology, became cut from active research and even organized in professional associations which have little or no relation with active scientists. One key issue is therefore to reinstall a kind of common interest and understanding between the two communities. An adequate place for this should be the pre-service and in-service training of teachers, since there is no hope for the science to remain the same during the several decades of duty a teacher will have.

2. *Evolutions in France*

It was progressively realized, by the mid-90s, that science was essentially absent from primary school education in France, as this education was instructed to focus on the so-called *fundamentals* requirements of reading, writing and counting. A movement called *La main à la pâte* was started in 1996 by Georges Charpak, Nobel Prize in Physics 1992, with the determinate support of the Académie des sciences, aiming at a rejuvenation of science teaching for children of ages 5 to 12. This movement is briefly described in the Appendix and its positive lessons are discussed below.

The lessons from *La main à la pâte* action and the worrisome recent decrease of science students in higher education leads now to a new question, i.e. the validity of the science/technology teaching achievements in the *collège*, namely the four years (12 to 16 in age) which end the compulsory school time in France. Since 1974, this *collège unique* is conceived on a uniform scheme for all pupils, no matter what their achievements, background and professional wishes or plans are. Although this formula has the merit to refuse former disparities, related to social classes, and to propose an equalitarian and uniform frame of learning for all children, it is more and more questionned in view of the problems encountered in classes.

The *collège* is today, certainly, the most difficult part of the French education system: teen-agers are in a difficult period of their personal development, teachers are submitted to strong but often contradictory pressures from the society and the parents, violence has irrupted in many classes, social integration of minorities is difficult. Science teaching is broken and parcellized in three independent disciplines (physics & chemistry, life & earth sciences, technology) which barely lead to a clear understanding of the nature of scientific knowledge and their role in society, not to speak of the relation of science with other disciplins such as language or history. Put in perspective with Gaston Bachelard's words '*For a scientific mind, every knowledge is an answer to a question. Nothing is obvious. Nothing is given. Everything is built up*', our science teaching gives answers long before the teen-agers are driven to ask questions!

Nevertheless mathematics teaching, a traditional strong point in French schools, remains good, possibly for unsatisfactory reasons: proficiency in mathematics continues to be considered, by the parents but also by the system, as a *sesame* for almost any career.

After the *collège unique*, while a small fraction of each generation goes directly to work or keep some kind of apprenticeship, a larger and larger proportion (78% in 1999) continues the school, eventually reaching the *baccalauréat* or going beyond. In these three years which terminate the secondary cycle, for six students, three go to the *lycée général*, two to the *lycée technologique* and one to *the lycée professionnel*. Of the whole system, these three years are probably the ones where science/technology teaching is the best, where transformations are relatively easy and require relatively less attention.

Another concern recently emerged from the other extremity of the education system, namely from Universities and Engineering schools (Grandes Ecoles). From 1995 to 2001, although the number of students selecting sciences or science related technologies in the last years of secondary education has not decreased, the *post-baccalauréat* choices towards scientific fields and, to a lesser degree, technological fields, shows a trend of decrease, especially in physical and chemical sciences.

These various considerations, indeed specific to France, point out to a single phenomenon: science education is in a deep crisis. First, although the system more or less continues to produce the scientific and technical *elites* the country needs, science is taught more and more as a technical collection of efficient recipes to the detriment of creativity. Second, this education fails to give to the ones who will not become scientists, engineers or technicians a proper background to understand the evolutions and to participate to the choices in a democratic society.

3. *Some lessons from 'La main à la pâte'*

This is a brief summary of the development of action in French primary schools:

– 1995: Less than 5% of French *maternelle* schools (age 3 to 5) and primary (age 6 to 11) practice any natural science.
– 1996: Georges Charpak, the *Académie des sciences* and the *Ministère de l'éducation nationale* begin a small scale experimentation called *La main à la pâte* (344 classes).
– 1998: Publication by the *Académie* of the 'Ten Principles' as a simple guide and reference for teachers. A high-quality Internet Site is developed as a resource/exchange basis.

– 2000: The experimentation has expanded as a grass-root movement and rallied over 5000 classes, with *Académie des sciences*, public and private support.
– 2000-01: Along with *La main à la pâte* and inspired by it, a new Plan for quality science/technology teaching in all schools (350.000 classes) is established by the Ministry of national education.
– 1995-2001: international developments go in parallel, in French speaking country first, then in other countries, through the network of Academies.

The Ten Principles were elaborated in 1998 and broadly diffused as a simple reference for teachers, supervisors or trainers:

- Children observe and experiment with their senses on real and close objects or phenomena;
- They are encouraged to argue and reason, to share ideas, to build knowledge;
- Proposed activities are organized in sequences, leaving ample space for children autonomy;
- A minimum science time of 2 hours/week is spent on the same theme, for several weeks. Continuity must be ensured over the 5-6 years of elementary school;
- Children keep their Experiment Notebook to write, draw with their own words and schemes;
- The goal is an appropriation of scientific concepts/procedures with language (oral & written) acquisition;
- Family & neigbourhood are closely associated;
- Scientific partners (scientists, students, engineers) accompany the teacher, but not substitute;
- The teachers vocational schools (IUFM) are involved;
- An Internet site is developed for resources and exchanges (mutualization).

Learning by doing, *Hands-on learning*, *hands & brain*, *inquiry* are parallel designation of this approach of science which *La main à la pâte* aims to develop. It is not necessary here to detail principles which are well known. It may be more interesting to quote some of the conclusions reached after five years of work, dealing with the teachers, as they represent the only real possiblity for evolution.

A few remarks need to be made here, in order to understand the background of science teaching: in the French primary schools, the teacher is polyvalent, namely he/she teaches, 26 hours a week, all the subjects, and children have only one teacher. Today, teachers are trained with 5 years after the baccalauréat, namely at the level of an engineer: their initial field may be science (a small proportion) or history, economics, litterature..., but beyond this, they all will have had two years of professional training, with barely some science (30 to 50 hours). Yet, older teachers may have had a much shorter initial training. Compulsory in-service training is limited to about 15 hours per year, while teachers are allowed to accumulate as much as 3 years of voluntary training over a 37 years career. Finally, 79% of the teachers are women. Here are a few of our conclusions:

– Teacher's attitude towards science itself is positive in principle, but often characterised by a great complex of ignorance;
– Teacher's attitude towards *teaching science* is very negative: fear, lack of knowledge, anxiety are often quoted as dissuasive obstacles;
– Teacher's are afraid, when questionned by a child, to be forced to say *I don't know*, while the child may have been exposed to scientific information on the media or in the family;
– Teacher's view on science is broken into narrow disciplines, without an integrated view of what is science and scientific behaviour. They completly ignore science history;
– Their attitude towards teaching technology is better, in the sense of 'building something which works', but they make little relation with an abstract content of the 'reasons why it works';
– They consider that science is made-up of formulas, and the mathematical expression of nature is considered as completly dissuasive of understanding what stands behind formulae;
– Best teaching sequences in science are clearly taught by teachers having no science background in their education. This is so often stated that it kills the common-sense opinion that, at this elementary level at least, science could only be taught by teachers having a strong scientific background;
– A thorough difference is observed when some kind of partnership is created and maintained between the teacher and a scientific partner (scientist, engineer, student). This partnership creates or increases teacher's self-confidence, solves difficulties about equipment or experimenting in the classroom, answers questions about scientific facts or phenomena (why is the sky blue? why is a bird flying and not falling? etc.).
– Main cognitive role of teachers is language education, as requested and easily evaluated by the parents and the system. Anything aside this

appears superfluous to the teachers. Therefore, connecting science education to language acquisition (especially the writing in the *Cahier d'expériences*, and the collective oral argumentation in discussing hypothesis or experiments) rehabilitates science as a mean, among others, to reach the language acquisition goals. Some teachers in difficult areas were quoting the fact that science writings were the longest texts children could produce!

– The number of teachers connected to Internet, either through the school or at home, is steadily increasing: developing a good site for teachers has proven to be a formidable tool for the development of science teaching. It allows exchanges of experiences, access to resources (the full 17 volumes of the *Insights* protocol, translated in French and free for dowloading, have been made available through this site). It allows also to question consultants from the scientific community or on pedagogy, and more recently cooperative work on specific subjects across the country or even worldwide (cf. the *Eratosthene* project on measuring the Earth's size with shadows). There are 350.000 teachers in French primary schools, and the *La main à la pâte* Internet site receives close to 50.000 connections per month; it handles more than 50 scientific consultants and has a forum discussion list of over 1000 teachers, while only 20% of the teachers population access Internet in 2001.
– Teachers appreciate, in very practical terms, universality of the questioning towards natural phenomena: science classes often prove to be the most efficient in giving the taste for knowledge to non-french born pupils or pupils with non-french mother tongue.
– Teachers are surprised to see that science can be taught in an integrated manner, not broken in disciplins which reminds them of their, often painful, secondary science education: dealing with *water* relates to physics, chemistry, meteorology, geology, biology of animals and plants.
– The best training of teachers is obtained, neither by giving them elaborate lectures on how to teach science, nor by step-by-step instructions which would eliminate their pedagogical initiative, but with a simple method: put them, in a collective manner, in the situation of the questioning, hypothetizing, experimenting, argumenting, writing child, and discuss with them their reactions, questions, a priori evidences, common sense, etc.
– Teacher's creativity can be trusted to enrich the initial material, draw on local resources (parents, museums, industries), improve by exchanges.

4. *Some conclusions*

The experiment started in France in 1996 is slowly progressing, and it is accepted that it may take more than one decade to seriously transform science education in primary schools. Generalization requires financial resources, a minimum equipment of 150 euros per class would lead to a total budget of 50 million euros, hundred times the 0.5 million euros spent to date in equipment. But even more, generalization requires to motivate and train the teachers. Experience shows that motivation is clearly obtained when scientific partnership breaks the teacher's isolation and fears: amplifying this partnership and finding ways to cope with the number of teachers (350 000 in France) is one of the main issues for the success. Initial training requires to thoroughly improve the academic context (vocational schools called IUFM or *Instituts universitaires de formation des maîtres*), which is not properly connected to the active science, and tends to substitute to this connection a discourse on didactics, valuable but too often cut from real and enjoyable science.

The involvement of the scientific community is also required to develop resources, create new themes based on contemporary science, relate learning to modern brain research and cognitive science (a growing field which has not been treated here, but should not be ignored), exploit the training and exchange capabilities of Internet: as a simple example the possibility to observe the night sky through a small telescope, during day time for a class, by remote observing (Hands-On Universe Project) offers entirely new perspectives to astronomy.

My conclusion is clear: improving science and technology education is in the hands of teachers, but teachers, even helped by manuals, can no longer cope alone with the pace of development. Leaving them behind means also one leaves behind whole generations of children. On the contrary, involvement of the science community and the Academies is demonstrated, through the modest effort carried in France, as a sure way to improve the situation.

APPENDIX

Note: *the following text is a short description, published mid 2001 by the French Académie des sciencies under Yves Quéré's supervision. It details the action undertaken by this Académie to rejuvenate science and technology teaching in French primary schools.*

LA MAIN À LA PÂTE (HANDS ON)

In 1995 Georges Charpak, joined shortly by Pierre Léna and Yves Quéré, launched the *La main à la pâte* (Hands-on) programme, intended to revitalize the teaching of the sciences in the primary school in France. This initiative received the unanimous support of the *Académie des sciences* in July 1996, which support has been unceasing since then.

In order to realize this objective, the Academicians have also the support of a team of around fifteen full time persons (Lamap team), of a *Scientific Council* composed of outstanding persons of research and education, and of a *Committee of partners* which is intended to give ideas and financial support to the action of the *Académie*.

What is 'La main à la pâte?'

The general idea of *La main à la pâte* is to cause children to participate in the discovery of natural objects and phenomena, to bring them into contact with the latter in their reality (outside of virtual reconstructions), directly through observation and experimentation, to stimulate their imagination, to broaden their mind and to improve their command of the language.

More precisely, here is a scenario of a typical *La main à la pâte* session.

A child has asked a question about his/her environment, inanimate or living. Instead of replying immediately, the teacher throws the question back to the class, 'And you, what do you think about it?', eliciting the hypotheses of the children and thus firing their imagination.

A simple experiment (observation, manipulation, measurement..., what you will) is then begun. Led by the children in small groups, it must in principle provide the answer, doubtless making them return to the initial hypotheses, and giving rise to the dialectic of reasoning and experiment which lies at the very heart of all research work.

Finally, the children will be invited to express their thoughts (short statements, writing in an experiment book) on the little adventure they have just experienced together, being thereby obliged to enrich their vocabulary and refine their logic and, hence, their syntax.

Of course, this is an ideal scenario which, in many cases, may be severed from one of its elements. For example, experimentation on living things (or on astronomical objects) raises specific problems. The experiment may even fail, in which case the teacher will give the answer to the initial question ex cathedra. Nevertheless, the fact remains that a personal engagement by the child, appealing at the same time to both his/her senses and intelligence, tends to encourage an enjoyment of science and bring it to life for him/her.

Hands on (and the eye in the microscope) in a school of Montreuil (Seine-Saint-Denis).

Based on these general ideas, a number of partners were sought, actions were initiated and tools created. At the same time, stimulating relations have been established with foreign colleagues working in the same vein, thus leading to collaborations and enriching comparisons. On all these points the *Académie* has contributed greatly to the progression of these ideas and to the facilitation of contacts between the partners in the operation.

The 'Académie's' partners

– The first of these has of course been the French national Ministry of Education. The launch of *La main à la pâte* in September 1996, was by Ministerial decision and involved 450 primary school teachers in five French *départements*. The number of teachers is currently more than 6,000.

Encouraged by the Department of School Education (*Direction de l'enseignement scolaire*, DESCO), the experiment led to the setting up by the Ministry, in June 2000, of a plan derived from *La main à la pâte* to revitalize the teaching of the sciences, in *all* French schools at *cycle 3* (final two years of primary school), the idea being to then extend it to all primary education, including preschools.

The *Instituts Universitaire de Formation des Maîtres* (IUFM) are essential partners because that is where the teachers are trained. The *Académie* has established excellent relations with the IUFM, concretized in the creation of a network of *La main à la pâte* 'corresponding members', with a presence in each Institute.

The *Institut National de Recherche Pédagogique* (INRP, national institute for educational research) has been involved from the beginning through research staff, IT support (see *The site*),...

The *Corps des Professeurs des écoles* (ensemble of schoolteachers) is a crucial interlocutor for the *Académie*. This dialogue is established at numerous sessions, conferences, education days..., when the promoters of *La main à la pâte*, invited to talk science, receive comments and ideas in exchange.

The *École Normale Supérieure* (ENS-Ulm) has thrown itself alongside the *Académie* in this approach, involving *agrégation* candidates (the highest competitive examination for teachers in France), and making offices available to the *Lamap* team.

– The Ministry of Foreign Affairs is an important partner of the *Académie* for the international part of the programme (see later).

– A number of the Grandes Écoles have joined the movement: l'*École des Mines de Nantes* , Director: R. Germinet, which is generating educational material, l'*École Polytechnique* some of whose students spend a few months in schools in difficult areas; l'*École de Physique et Chimie Industrielle de la* *ville de Paris*, whose Director Pierre-Gilles de Gennes has encouraged it to be involved in scientific support of a number of schools in Paris.

– Various Bodies and Associations, both public and private, support *La main à la pâte* in diverse ways, every one very effective.

The Department of Technology (*Direction de la Technologie*, DT) of the Ministry of Research, and the Interministerial Commission on the Town (*Délégation Interministérielle à la Ville*, DIV) have contributed to the financing of some of the *Académie*'s activities.

The *Fondation des Treilles*, with its hosting of seminars, and through the publication of books, has been a partner from the beginning, together with the *Société Française de Physique, EDF, France-Télécom,...*

Many Institutions are striving towards the popularization of science among children. *La main à la pâte* has positive relations with *L'explor@dôme* (Paris), *Ébulliscience* (Vaulx-en-Velin), *Science en fête, Les petits débrouillards...* and, of course, *La cité des sciences et de l'Industrie* (La Villette) and *Le Palais de la Découverte* (Paris).

In a less institutional way, many laboratories and research centres..., together with engineers and researchers (both active and retired), lend a valuable support, generally involving actions in schools or on the Internet Site (see later).

The educational tools

– The *Académie* has undertaken, with INRP, to provide French schools with an Internet network, enabling the teachers involved in *La main à la pâte* to link up with one another, and also linking them to the world of research.

The site (http://www.inrp.fr/lamap), which has three sections (information, resources, exchanges) has several attached networks:

The *La main à la pâte* network: a national site and departmental sites display locally produced resources and general information.

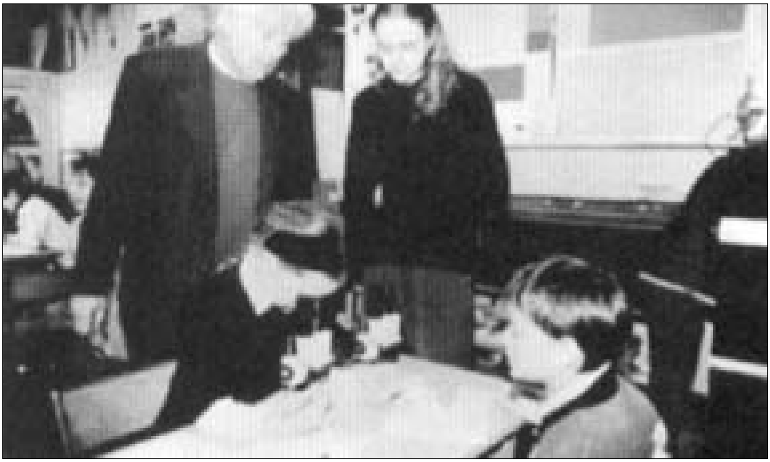
The network of *scientific consultants*: researchers and engineers answer science questions raised by teachers.

The network of *training officers/teaching specialists*: questions on teaching and education are dealt with here.

An international site in under elaboration

– Since, in the beginning, the availability of educational documents corresponding to the approach described here was only fragmentary, American *Hands on* texts have been translated and made available to teachers on the Site. Then, the generation of texts, books, experimentation packs,... has been encouraged. A ‘Seal of approval committee’ has been created. Chaired by Marc Julia, it examines documents seeking to achieve the *La main à la pâte* seal, which guarantees their good scientific quality.

– An Autumn university has been founded, with the support of the *Fondation des Treilles*, which brings together schoolteachers and researchers. The reports of the latter are published in the *Graines de sciences* collection.



La main à la pâte prize giving in the *Académie.*

– *La main à la pâte* prizes are awarded annually by the *Académie* to classes for high-quality achieve-ments in science teaching and learning.

– A travelling exhibition on the *History of the teaching of the sciences in schools* is planned. It will tour France from 2002.

International implications

Numerous countries, including both some of the richest and some of the poorest are also facing the need to revitalize their system for teaching the sciences.

The *Académie* has established a large number of collaborations on this theme, all the more so because the IAP (*InterAcademy Panel for interna-*

tional issues, see *International relations* sheet) has made this one of its priority tasks. Among these collaborations, it is particularly pertinent to mention those established with Brazil, China, Columbia, Egypt, Israel, Morocco, Mexico, the United States, Vietnam..., and, more generally, with the ICSU (*International Council of Scientific Unions*) through the CCBS (*Committee on Capacity Building for Science*).

One sign of this broad opening up is that the book *La main à la pâte* (Flammarion, 1996) has been translated into Arabic, Chinese, Portuguese and Vietnamese (translations in Spanish, Hungarian and Romanian being in preparation).

CONTACTS:

Académie des Sciences: G. Charpak, F. Gros, M. Julia, P. Léna, Y. Quéré, B. Ajchenbaum-Boffety, Chargée de mission, beatrice-ajchenbaum@académie-sciences.fr
Plan de rénovation: J.-P. Sarmant, Inspecteur Général, Jean-pierre.sarmant@education.gouv.fr
Comité des partenaires: M. Digne, Inspecteur d'Académie, mariedigne@yahoo.com
Equipe Lamap, 1 rue M. Arnoux, 92120 Montrouge
Direction: É. Saltiel, saltiel@inrp.fr
Le site: J.-M. Bouchard et D. Wilgenbus
david.wilgenbus@inrp.fr et jm.bouchard@inrp.fr
Le site international: D. Jasmin, jasmin@inrp.fr
La marque: Y. Renoux, yrenoux@inrp.fr

REFERENCES

La main à la pâte. Les sciences à l'école primaire. Présenté par G. Charpak. Flammarion, 1996.

La science institutrice. Y. Quéré, O.Jacob, Paris, 2002.

Enfants, chercheurs & citoyens. Dir. G. Charpak, O. Jacob, Paris, 1999.

Graines de science, Vols. I, II, III. Y. Quéré, P.Léna, J.M. Bouchard, I. Catala, D. Jasmin Ed., Editions du Pommier, Paris, 1999, 2000, 2001. Vol. IV in press, 2002.

EXPERIENCES IN MEXICO IN THE USE OF HANDS-ON, INQUIRY SCIENCE EDUCATION SYSTEMS IN PRIMARY SCHOOLS

GUILLERMO R. FERNÁNDEZ DE LA GARZA

Introduction

Since 1995, different activities have been undertaken in Mexico to explore the application of Hands-On Inquiry Centered Systems (HOICS) for Primary Schools with the support of the Mexican Academy of Sciences and in close collaboration with the National Academy of Sciences of the United States.

Twelve Units of the Science and Technology for Children (STC) curricula developed by the National Science Resources Center have been translated and adapted to Mexican conditions. Close collaboration has been established with several groups in the United States including school districts, universities and research institutions that have been working with HOICS in the United States.

As a result of the series of research activities, national and international conferences as well as pilot programs in different Mexican States, there is now wide interest in these systems and in the ways to insure their adequate application in Mexico.

A brief account of these experiences will be introduced in this presentation, considering their implications for other countries with conditions similar to Mexico.

An outline of possible international collaboration schemes will also be given based on the results of the International Conference on Research related to Science Education held in Monterrey, Mexico, in September 2001.

Adaptation of STC units to Mexican programs and schools

After the analysis, translation and modification of the initial 6 STC units that were selected for the pilot programs in Mexico in 1995, a research project was made applying one unit per grade of the STC in 8 schools in Mexico City.

In this research project, special care was given to the analysis of:

– The pedagogical strategies of teachers and the support they need to improve them.

– Techniques to use children's interest to cover several areas of the education programs.

– The evaluation of children's results.

There was great concern that the teachers would not be able to apply these systems in the classroom. Would it be possible for the teachers to feel confident teaching hands on, inquiry science? Would they be able to apply the pedagogical strategies needed to work with these systems? The main findings of this research are the following:

1) Teachers already have a good background in the pedagogical theories involved and are able to work effectively with these systems if they have adequate preliminary training in the details of the pedagogical objectives and scientific contents of each unit as well as continuous support during the application.

2) Teachers could easily relate important themes from other subjects like language, mathematics, geography and history with the work that the children were doing in each unit. It became particularly interesting to see that the notebooks with the written description of the children's experiences and ideas were a very good way to help them to improve their writing and communications abilities. In other cases, the use of measurements, comparisons, tables and graphs facilitated the introduction and use of mathematical concepts.

3) The evaluation of the children was seen as a very significant challenge. There was the need to go beyond the evaluation of the answers that the children could give to questions on the scientific content of the units. It was necessary to evaluate if the children had gained the thinking skills and developed the scientific attitudes that each STC unit had within its objectives.

4) Teachers require special professional development to be able to use the assessment methodologies and techniques that are appropriate for these types of science education. This is especially the case in the assess-

ment with the observation of the children in the classroom and with the tests which the children are requested to solve problems using the knowledge and skills that they have gained.

5) There was much interest to find which ways the teachers can use the pupil's interest in the STC units to deal with other subjects that are also important in the education programs.

A support system for STC applications was derived from the research results, including:

– Training workshops.

– In classroom support of a science assistant, in the first application of a Unit, to prepare and distribute materials and also to help the teacher in the review of the scientific content of the unit.

– Pedagogical advisory support to the teacher by an advisor who every two weeks visits the classroom, reviews with the teacher the work of the students and the teacher's pedagogical strategies.

– Complementary guides to facilitate the broadest possible coverage of the objectives and subjects of the official programs, linking them with the content of the STC units and the interest of the children.

The use of these support systems were found to be very important in reducing the fears of the teachers about teaching science or being exposed to questions that they could not answer properly. These support systems were also very important in facilitating the improvement of teacher pedagogical skills, especially through interaction with the pedagogical advisors, through cooperation among teachers and through additional courses and lectures that the teachers might require.

Application of the STC in Mexico

After the initial pilot applications were made in Mexico City in 1995, pilot programs were established in the states of Queretaro and Veracruz using the methodologies derived from the research project. In these cases, the local school for teachers participated in the preparation of the pedagogical advisors and in the follow up to the results in the classrooms. The science assistants were students of the last semesters of the science programs in the local universities. These assistants received training on the system, on the specific STC units that they were going to use and on the environment in the school to insure that they interacted properly with the school support system.

In the five years after 1995, STC has been applied by more than 2500 teachers in 210 schools. This has been done with the support of the local state governments and in some cases of Mexican business companies, like Resistol, Bacardi and PEMEX.

Some of the main results that have been observed are the following:

– The STC work in the classroom is curiosity driven and can be guided by the teacher to be really effective in the development of cognitive skills and scientific attitudes

– Children become enthusiastic about science and technology by exploring, discovering and making things work.

– Science taught in this way is a good support for teacher in helping students to write, to read, to deal with essential mathematics concepts and to learn about geography, history and other subjects in the general curriculum.

– Children and teacher share the need to explore, investigate and to build on previous knowledge and new experiences

– Children modify their previous schemes and enrich their possibilities to build new doubts and new knowledge that launch them to new challenges.

The STC has been used in rural areas with the same type of results and even with street children, ‘CHAVOS’.

Work with Street Children

It is important to mention that in the work with street children it has been found that:

– These types of systems help the children to recognize that the knowledge that they have already developed during their childhood and their street experiences is valuable and can be the basis for them to learn more and to be better.

– There is a cooperative and respectful environment that facilitates the sharing of ideas and the development of interpersonal skills.

– Children are stimulated to express themselves with confidence, both to express doubts and to communicate their ideas.

– The children assume a reflexive, critical, inquisitive and proactive attitude.

– They improve their thinking skills and their ability to use their previous knowledge as well as their resources and tools.

– Working with the Ecosystems unit, they identify themselves with other living beings and feel that they are part of an ecosystem.

The key element in obtaining these results were the 'facilitators', specially trained young professionals performing the role of the teacher and very committed to helping the street children to overcome this situation. The pilot work with street children was organized with specialized groups and with the support of the local Catholic Church programs.

There is the possibility to use these experiences with street children to design better programs. There is the pedagogical challenge to make the previous knowledge of the children and the knowledge gained with these programs a source of confidence, self-esteem and a basis for the Chavos to:

- Find new ways to live with young people and with the community
- Become responsible for guiding and building their own lives
- Have values to improve their life and to contribute to the community.

Recent application of the STC in private and public schools

Several private schools have started using the STC in a continuous way; however, most of the applications have been made in public schools as part of demonstration programs where the schools have worked with the STC only during one year. This has happened because there has not been a federal program to support the application of these systems and because of the limitations imposed by the existing education programs and working conditions.

In the last two years, with the participation of the United States-Mexico Foundation for Science and with the financial support of the Brystol Myer Squibb Foundation, several departments of education in Mexican States have become interested in setting up permanent HOICS programs and the federal education authorities have become interested in facilitating this process.

At the moment there are already continuous applications of the STC, including the operation of pilot Science Resources Centers, in the States of Tamaulipas, Quintana Roo and Querétaro and plans to establish more in the State of Nuevo Leon and in Mexico City.

Within the education research community in Mexico there is now better awareness of the importance of research in facilitating the work with these types of systems and to improve them according to the local conditions and experiences.

A Mexican Foundation, similar to the National Science Resources Center of the United States, has been proposed in order to facilitate the understanding and application of HOICS with support from the Federal Government, the Mexican Academies and several private foundations.

Dissemination and outreach of science education improvement opportunities

In order to facilitate the understanding of the essential elements and the benefits of the new HOICS, a series of meetings and lectures were organized with teachers, education officials, business leaders and other influential persons.

Two national conferences were organized, one in Queretaro in 1997 and the second one in Xalapa in 1999, to review the content, results and possibilities of HOICS where the U.S. experiences were also presented.

Especially important was the International Conference on Research Related to Science Education held in Monterrey, Nuevo León in September 2001. The Conference was organized by the Mexican Secretary of Public Education, together with the US-Mexico Foundation for Science, the Mexican Academy of Sciences and the Government of the State of Nuevo Leon. The support of the National Academy of Sciences and the National Science Resources Center of the United States were very important, as well as the collaboration with the Inter Academy Panel, and the Latin American Academy of Sciences.

The goals of the International Conference were to:

– Analyze and discuss cognitive research findings about how people learn and the implications of these findings for teaching science to students.

– Review and discuss research findings providing evidence of the impact of HOICS on student achievement.

– Recommend effective roles for the scientific and engineering communities in working with educators to improve science education.

– Identify strategies for international cooperation in research and implementing strategies for improving science education programs.

Some of the important conclusions derived from the conference are the following:

About research on 'How People Learn':

– There are very important practical consequences in the classroom of the research results about the relationships within mental structures, the way they evolve and function, and how they are applied to common problems.

– There are very important benefits for the students if the learning environments are centered on the development of learning capabilities.

– A well-structured curriculum emphasizes the children's acquisition of essential concepts (big ideas).

– It is essential to have evaluation methods that support learning.

On the results of the TIMSS Studies:

– A very significant factor in explaining the good performance of the students is that the curriculum should be presented with depth, rigor, coherence and should challenge the student to go beyond.

– International comparison is not important *per se,* but as a way to learn how to improve and to share experiences.

– Good science and mathematics education can be achieved with limited resources and has a very important role in the development of thinking skills and scientific attitudes essential for the future success of the student in the modern world.

– We all have the moral imperative to give the world's children the learning capabilities needed to build their future.

With respect to HOICS systems:

– They have an extremely important impact in the development of children's essential learning abilities.

– There is the need to have more comprehensive studies to assess the systems and to validate their success before the whole community.

– There are very good opportunities for international collaboration on these systems, both in research and in innovation projects.

On the role of science academies in the improvement of science education:

– They are a stable platform for the discussion and promotion of improvements.

– They provide continuity in science education research and innovation, which transcends political changes.

– They offer a direct and cordial link between scientists and educators.

– They symbolize a seal of excellence when they support research and development projects in science education.

Partnerships for science education improvements:

– The importance of linking both business and society in general with science education enhancement processes.

– Acknowledge the leadership role that the business community might have in science education innovation and reform.

Final remarks

The application of HOICS in the primary and secondary schools of Mexico is seen as a very important opportunity to develop the scientific attitudes and thinking skills of children as well as to help them construct essential scientific concepts and to be enthusiastic about science and technology.

It is not easy to introduce these types of systems. It is necessary to integrate them properly to the educational programs and to work with the education authorities, the teachers and the community to set up the systemic programs that are needed.

International collaboration is a very important support in facilitating the understanding, development and application of HOICS for children.

SCIENCE FOR CITIZENSHIP

JONATHAN F. OSBORNE

Science Education and its problems

It is Collins (2000) who most aptly points to the horns of a trilemma on which science education sits. That is that science education attempts to wrestle with three mutually contradictory requirements. On the one hand it wants to demonstrate the tremendous liberatory power that science offers – a combination of the excitement and thrill that comes from the ability to discover new knowledge, and the tremendous insights and understanding of the material world that it provides. Yet its mechanism for achieving this aim is to rely on a dogmatic, authoritarian and extended science education where students must accept what they are told as unequivocal, uncontested and unquestioned. Only when they finally begin practising as scientists and enter the inner sanctum will the workings of science become more transparent. Moreover, its foundationalist emphasis on basic concepts rather than the grand ideas of science means that any sense of its cultural achievement is simply forgotten. The consequence, as argued in the report *Beyond 2000: Science Education for the Future* (Millar and Osborne, 1998), was that:

> We have lost sight of the major ideas that science has to tell. To borrow an architectural metaphor, it is impossible to see the whole building if we focus too closely on the individual bricks. Yet, without a change of focus, it is impossible to see whether you are looking at St Paul's Cathedral or a pile of – bricks, or to appreciate what it is that makes St Paul's one the world's great churches. In the same way, an over concentration on the detailed content of science may prevent students appreciating why Dalton's ideas about atoms, or Darwin's ideas about natural selection, are among the most power-

> ful and significant pieces of knowledge we possess (Millar & Osborne, 1998, p. 13).

The outcome is that science education is, in a non-too trivial sense, science's worst enemy leaving far too many pupils with a confused sense of the significance of what they have learnt and, more seriously, an enduring negative attitude to the subject itself (Osborne & Collins, 2000; Osborne, Driver, & Simon, 1996). None of this matters for the traditional education of the scientist which demands a lot of routine and rote learning to acquire the basics of the domain.

The result, however, is that such an education ignores or neglects the third horn of its trilemma, the requirement to provide its students with some picture of the inner workings of science. Knowledge, that is, of science-in-the-making (Latour, 1985) – knowledge which is essential for the future citizen who must make some judgement of reports about new scientific discoveries and applications. Contemporary society, it is argued (American Association for the Advancement of Science, 1989; Jenkins, 1997; Jenkins, 1998; Millar, 1996. Millar & Osborne, 1998), requires a populace who have a better understanding of the workings of science enabling them to engage in a critical dialogue about such issues and arrive at considered decisions about the political and moral dilemmas posed by science. New developments in science will, for instance, require the ability to distinguish whether an argument is sound: to differentiate evidence from hypotheses, conclusions from observations and correlations from causes.

Another aspect of concern is the gulf between science-as-it-is-practised and science-as-it-is-taught in schools. The growing gulf between these two is well-illustrated by our recent research (Osborne & Collins, 2000). Many pupils expressed antipathy to topics such as the periodic table. Not only did they experience difficulty in memorizing the constituents of the table, but they also failed to perceive its relevance to their everyday lives at present or in the future for instance:

> Edward: It doesn't mean anything to me. I'm never going to use that, It's never going to come into anything, it's just boring.

Similar sentiments were expressed about the inclusion of the blast furnace in school science:

> Roshni: The blast furnace, so when are you going to use a blast furnace? I mean, why do you need to know about it? You're not going to come across it ever. I mean look at the technology today, we've gone onto cloning, I mean it', a bit away off from the blast furnace now, so why do you need to know it?

The lack of perceived relevance to pupils' lives of such topics was a recurring theme throughout these discussions in all groups, either for continuing education in science and/or career aspirations. For instance, it was argued by a boy not continuing with science post 16 that 'I won't need to know all the equations or the chemicals. Without the essential ingredient of relevance, sustaining interest is difficult, if not impossible.

The emphasis of school science on consensual, well-established science, means that there is no space for any consideration the science that dominates contemporary society-the science and technology of informatics, CD-ROMs, mobile phones, lasers, health and disease, modern cosmology, modern imaging systems using computerized techniques, advances in materials technology and polymers, and last but not least, advances in medical genetics. This is the science that interests adolescents and would be included if the curriculum was, instead, organized around the question 'what makes young people want to learn science?' Yet there is as much chance of finding any contemporary science on the curriculum as there is water in a desert. This is not to argue for a curriculum based totally on contemporary science but simply for some aspects to be included as a vital point of engagement.

More fundamentally, the question needs to be asked how this gulf between school science and contemporary science has emerged. My analysis is that, as currently practised, science education rests on a set of arcane cultural norms which inhibit change and adaptation. These are 'values that emanate from practice and become sanctified with time. The more they recede into the background, the more taken for granted they become' (Willard. 1985). A closer examination, and the insights of contemporary scholarship, expose these norms to be nowhere near the self-evident truths that we may think-what I might choose to call the eight *deadly sins of* science education. For in contemporary society, research would indicate that trust in science is dependent on developing knowledge not only of its basic concepts and ideas of science, but also *how* it relates to other events, *why* it is important, and *how* this particular view of the world came to be. Any science education which focuses predominantly on the intellectual products of our scientific labour – the facts of science – simply misses the point. Science education should rest, therefore, on a triumvirate of a knowledge and understanding of:

a) the scientific content;

b) the scientific approach to enquiry;

c) science as a social enterprise – that is the social practices of the community.

Evidence would suggest that in many countries, normative practice regards school science education as a selection mechanism for the few who will become the future scientists of contemporary society. Consequently, the predominant emphasis is on the content of science and consensual well-established knowledge. Contemporary science – the science that interests adolescents – is notable by its absence. The result is a curriculum with only marginal relevance and extrinsic instrumental value for a limited set of career aspirations rather than a discipline valued for its intrinsic interest. Western societies can ill afford the consequent alienation and disengagement with science that such courses generate. First on the economic front, the lack of recruits into science and technology is in danger of undermining economies which are highly dependent of the skills and knowledge of these disciplines. Second, the ensuing lack of engagement and ambivalence to science threatens science's relationship with its public. Indeed, and the growing distrust of scientific expertise is in danger of placing unwarranted restrictions on future research and technological development. Moreover, fear of the worst is leading the public to demand a naïve application of the precautionary principle to research potentially limiting the advancements that science offers for solving the plethora of problems that face contemporary society. In the UK, for instance, significant pressure groups have argued that all research on genetically modified food should be halted using highly questionable ethical arguments.

What then are the norms that hinder the development of current practice in science education obstructing the development an appropriate understanding of science, a more positive engagement with the fruits of scientific labour, and a critical but constructive, understanding of its strengths and limitations? The argument here is that the practice of science teaching rests on eight fallacious assumptions which are as follows.

The fallacy of miscellaneous information

All too many science courses have attempted to make students memorize a series of dry facts which no practising scientist knows, such as the boiling point of water, the density of various substances, the atomic weight of different chemical elements, conversion factors from one system of units to another, the distance in light years from the earth to various stars (and so on). However, an increasing body of work now shows that knowledge is only one component of the many competencies required of adults in their professional life and, unless it is constantly used, is rapidly forgotten (Coles, 1998; Eraut, 1994).

The foundational fallacy

This is the fallacy that because scientific knowledge itself is difficult and hard won, learning and understanding science requires a similar process where the student's knowledge and understanding are assembled brick by brick, or fact by fact. As a consequence, only those that reach the end ever get to comprehend the wonder and beauty of the edifice that has been constructed. Current practice, therefore, is rather like introducing a young child to jigsaws by giving them bits of a one thousand piece puzzle and hoping that they have enough to get the whole picture, rather than providing the simplified 100 piece version. In effect, although the pupils can see the microscopic detail, the sense of the whole, its relevance and its value-the things that matter to the pupil (Rowe, 1983) are lost. Chown (1998) offers a good example of a tale which the foundationalist approach offers only to undergraduates or postgraduates taking courses in stellar nueleosynthesis – the grand ideas of science which are reserved only for those who complete the course.

> But if all these examples of our cosmic connectedness fail to impress you, hold up your hand. You are looking at stardust made flesh. The iron in your blood, the calcium in your bones, the oxygen that fills your lungs each time you take a breath – all were baked in the fiery ovens deep within stars and blown into space when those stars grew old and perished. Every one of us was, quite literally, made in heaven (Chown, 1998, p. 62).

Yet there is nothing about such a story which is intrinsically difficult. The failure to communicate such ideas in compulsory science education simply reinforces Claude Bernard's, the famous 19th century philosopher, view that science is a 'superb and dazzling hall, but one which may be reached only by passing through a long and ghastly kitchen'.

The fallacy of coverage

School science is suffering from a delusion that the science we offer must be both broad and balanced. The result is an attempt to offer a smattering of all sciences and to cram more and more into an oft-diminishing pot. Quite clearly, as the bounds of scientific knowledge expand from evolutionary biology to modern cosmology, more and more knowledge vies for a place on the curriculum. However, just as those teaching literature would never dream of attempting to cover the whole body of extant literature, choosing rather a range of examples to illustrate the different ways in which good literature can be produced, has the time not come to recognise that it is our responsibility to select a few of the major *explanatory* stories that the sciences offer'? And surely it is the *quality of* the experience, rather than the quantity, which is the determining measure of a good science education?

The fallacy of a detached science

Science education persists with presenting an idealized view of science as objective, detached and value free. This is wrong on three counts. First the public, and particularly young people, do not distinguish between science and technology. Second, science is a socially-situated product and the language and metaphors it draws on are rooted in the culture and lives of the scientists who produce new knowledge. Thirdly, those that engage in science are not the dispassionate, sceptical and disinterested community that Merton (1973) portrays. Science is a social practice, engaged in by individuals who share a 'matrix of disciplinary commitments, values and research exemplars' (Delia, 1977). Within the contemporary context, where scientists are employed by industrial companies with vested interests, it is hard to advance a case that science is simply the *pursuit of truth* untainted by professional aspirations or ideological commitments. For these days scientists are:

> judged as much by the company they keep as the data they may gather (Durant & Bauer, 1997).

Finally, the separation of science from technology eliminates all consideration of the societal implications for society. For, as Ziman (1994) argues, if science education fails to make the small step from science to its technological applications, how can it take the much larger step to the implications for the society in which it is embedded?

The fallacy of critical thinking

This is an assumption that the study of science teaches students reflective, critical thinking or logical analysis which may then be applied by them to other subjects of study. It is based on the fallacious assumption that mere contact with science will imbue a sense of critical rationality by some unseen process of osmosis. It is also an assumption questioned by the Wason 4 card problem and the Wason 2, 4, 6 problem

(Wason & Johnson-Laird, 1972) both of which require a standard scientific strategy of falsification to determine the correct answer and, which very few, including scientists, use.

Secondly, the notion that science develops generalizable, transferable skills is also an assumption questioned by the body of research which suggests that people's use of knowledge and reasoning is situated within a context (Carraher, Carraher, & Schliemann, 1985, Lave, 1988; Seely Brown, Collins, & Duiguid, 1989) and that detached knowledge is of little use to individuals until it has been reworked into a form which is understood by the user. More fundamentally, the dogmatic and authoritarian training required for future scientists only permits original and critical thought once its noviciates begin to engage with original research. Prior to this point, there is little to incentive to engage in critical enquiry.

The fallacy of the scientific method

This is the myth that there exists a singular scientific method whereas the record of those who have made the important discoveries of the past shows not only that scientists rarely attempt any such logical procedure, but that the methods vary considerably between the sciences. The methods deployed by the palaeontologist working out in the field are about as similar to those used by the theoretical physicist as chalk and cheese.

Yet the science that increasingly confronts the individual in the media, with its focus on environmental or biological issues, is predominantly based on correlational evidence and uses methodological devices such as clinical trials with blind and double-blind controls. Yet where, and when, is there any treatment of the strengths and limitations of such evidence (Bencze, 1996)? Is it not time to give up any notion that there is such a singular entity and turn instead to presenting a range of ideas about science and its working. Moreover, when so much of the science reported in the media is based on epidemiological research and associative findings – probability and likelihood rather than causal relationships and certainty – is it not time to teach about such data, its interpretation and evaluation?

The fallacy of utility

This is the myth that scientific knowledge has personal utility-that it is essential to the mastery of the technology; to remedy its defects; and to live at ease in the culture of technology that surrounds us. For as machines become more intelligent they require less care and thought for their effective use. Even its economic utility is questionable as current employment trends, at least in the UK and USA, suggest that, although we will need to sustain the present supply of scientists, there is no indication that there is any need to significantly improve the number going into science, which remains, as ever, a small minority of the school cohort of around 10-15% (Coles, 1998; Shamos, 1995).

The homogeneous fallacy

Increasingly, in many countries, science education labours under the fallacy that its clientele are an entity who, whilst they might differ in aptitude and ability, nevertheless are best served by one homogeneous curriculum. With their devotion to pure science, a foundationalist approach, and a high-stakes assessment system, the result is a pedagogy based on transmission (Hacker & Rowe, 1997). By the onset of adolescence, the imperative of relevance increasingly challenges the delayed gratification on which such a curriculum rests leading to a lack of motivation and interest (Osborne, Driver, & Simon, 1996). Pupils, therefore, need to be offered a diversity of science courses to meet their disparate needs.

What then are the methods, practices and components of a new vision of science education that might meet these concerns? The broad framework of such a vision has been developed in the report *Beyond 2000: Science Education for the Future* (Millar & Osborne, 1998). In this report, we argued for 10 recommendations, which we saw would address many of the aforementioned criticisms. These were:

1) Science education should be for the majority and should be for scientific literacy.

2) An element of choice should be allowed at age 14.

3) The curriculum needs aims to ensure that its primary purpose is well understood and shared by all.

4) Scientific knowledge can best be presented as a set of explanatory *stories* that would provide a holistic overview of the great ideas of science.

5) Technology can no longer be separated from science as the former is what interests pupils.

6) The science curriculum must give more emphasis to key ideas-about science.

7) Science should be taught using a wide variety of teaching methods and approaches.

8) Assessment needs to measure pupils' ability to understand and interpret scientific information.

9) Change in the short term should be limited as radical change is undermined by teachers.

10) A formal procedure needs to be established for the testing and trialling of innovative approaches.

This report has been read widely and positively received influencing some of the changes in the new version of the English and Welsh science national curriculum and requiring greater exploration within school science of the relationship that exists between ideas and evidence (Department for Education and Employment, 1999). It has also led to the development and piloting of a new course for 14-16 year olds which will have a specific focus on science for citizenship. Perhaps, more significantly, the report has the support of the UK Deans of science committee who stated recently that:

> 'Broadly we agree the analysis presented in the report Beyond 2000: Science Education for the Future ... We are acutely aware that the style of specialist school science curriculum has not changed for many years. We thus have to recognise that an approach that worked satisfactorily in the past as a preparation for higher education no longer does so in the changed social and communications environment of today ... From a higher education science perspective, therefore, we l would happily see the general approach advocated in the Beyond 2000 report applied to the entire secondary science curriculum'.

For this report to gain acceptance from the representatives of the academic scientific community is a major achievement for it is this community that are the major stakeholders in the science curriculum. That they too seek change is an important recognition of the failings and inadequacies of the current system.

However, reforming the science curriculum to meet the challenges of the contemporary society faces a number of obstacles that must be addressed and met. These are the limitations of the qualifications and abilities of the science teaching force; the problems with developing appropriate modes of assessment; the resistance of well-established stakeholders., and the culture of science teaching.

Curriculum Reform

Any new curriculum which gave more emphasis to developing an understanding of the nature and processes of science, would require teachers themselves to have some understanding of these dimension of science. Yet science teachers are the products of an education which has paid scant regard to history, or any examination of its social practices. And for good reason-the dominant ideology within science is one of dogmatism and authority where the tentative nature of the roots of scientific knowledge is excised to present science as a body of certain knowledge which has been the successful, linear progression of the work of isolated great men, devoid of any cultural context. The outcome of such an education is a body of science teachers who have naive views of the nature of science-seeing it as an empirical process where scientific theories are inductively proven (Koulaidis & Ogborn, 1995; Lakin & Wellington, 1994).

Similarly, Donnelly (1999) has shown how science teachers see their work as one which is dominated by content rather than process, as opposed to the contemporary treatment of history where the history teachers seek to develop an understanding of what it is to do history, The significance of empirical work to science, and in the teacher's practice, is such that teachers are endowed with distinctive status by the provision of specialized laboratories. Laboratories in their turn become rhetorical artefacts where the scientific world-view can be used to illustrate the predictability of nature and inspire confidence in the scientific world view (Donnelly, 1998). Asking teachers to teach more about the nature of a subject which they themselves only have a limited understanding of will inevitably be problematic.

Attempts to introduce change under the umbrella of the National Curriculum – particularly when those changes were later shown to be based on fallacious models of science – have met with substantive resistance and modification. The 1991 version of the English and Welsh science curriculum introduced a model of practical based investigatory work which was unfamiliar and resented by teachers who failed to share or understand its intentions. The result was a long period of adaptation whilst teachers reworked the curriculum to put into practice work which was a distorted representation of the intentions of the national curriculum document. Many teachers were alienated or disaffected by the process (Donnelly, Buchan, Jenkins, Laws, & Welford, 1996).

The lesson of these problems is one that was clear from previous research on educational change (Fullan, 1991; Joyce, 1990). First, teachers must he dissatisfied with the existing curriculum if the arguments for change are to be heard. Second, if change is to occur, teachers must be supported in developing new practices, new bodies of knowledge and new pedagogic methods. At the very least, that requires the rewriting of curriculum support materials which should seek to provide exemplary illustrations of the ideas to he taught and suggestions for how it can be taught. More substantive support would require a programme of professional development delivered by individuals who are themselves competent and effective teachers who have a good grasp of any new initiative. At the very best. there would be *in-situ* training provided for all teachers who required it.

Assessment

The second problem lies with reform lies in the role of assessment within existing national and international frameworks. Within the past twenty years, political imperatives have led to the necessity to measure the performance of the educational system. The consequence has been the rise of national systems of assessment based on testing at certain key ages – in the UK these are age 7, 11, and 14. Internationally, we have also seen the rise of comparative assessment between countries which have been used as a measure of the overall quality of education (Beaton et al., 1996). Thus rather than assessment serving as a tool to benefit the child, providing either a formative or summative judgement of their capabilities, it has become a servant of a bureaucratic mentality that seeks to monitor the performance of the system. Whilst, it could be argued that these two aims are not incommensurable, the reality is different.

Similar problems have beset attempts to provide performance indicators in the Health Service, in the privatized railway companies, and in a host of other public services. In each, a variety of indicators are selected for their ability to represent the quality of the service, but when used as the sole index of quality, the manipulability of these indicators destroys the relationship between the indicator and the indicated. Directing more and more attention onto particular indicators of performance may manage to increase the scores on the indicator, but the score on what it indicates are, in reality, relatively unaffected. Thus whilst measures of children's achievement show year on year improvement, the actual quality of their education remains much the same.

The lesson of history then is that in seeking to make the *important measurable*, only the *measurable* has become *important*. The second problem is that within school science, assessment items are commonly devised by those that have been, or still are, practising science teachers. Just as it is often said that you teach only that that you can teach, so assessment is often based on the normative values of what it is considered possible to assess. Hence the assessment of students' understanding of the processes of science, or its social practices, are not considered because there is no established body of knowledge of how to assess such items. At worst, assessment experts will simply assert that it is too difficult, time-consuming or expensive to assess such understandings and, at best, that they do not know how to do so. Thus, within such a context generated by the importance of measuring performance of students, teachers and schools, the clear message to teachers is that the lack of any assessment of a given topic implies that it is an extraneous item of no significance.

The single most important message that emerges from this analysis is that curriculum reform without a commensurate change in the assessment will be ineffective. Change must be attempted holistically and not in a piecemeal fashion for the intended curriculum is read as much, if not more from the assessment as much *as* it is from the curriculum. In conclusion, what *is* evident, is that *science* for all requires a curriculum for all. The current flight from science by contemporary youth would suggest that anything else would be a price that neither science or society can afford to pay.

REFERENCES

American Association for the Advancement of Science (1989). *Project 2061. Science for Americans*. Washington, DC: AAAS.

Beaton, A., Martin, M.O., Mullis, I., Gonzalez, E.J., Smith, T.A., & Kelley, D.L. (1996). *Science Achievement in the Middle School Years: IEA's Third Tnternational Mathematics and Science Study*. Chestnut Hill, MA: Boston College.

Bencze, J.L. (1996). Correlational studies in school science: breaking the science-experiment-certainty connection. *School Science Review, 78(282)*, pp. 95-101.

Carraher, T.N., Carraher, D.W., & Schliemann, A.D. (1985). Mathematics in the streets and in the schools. *British Journal of Developmental Psychology*, *3*, pp. 22-29.

Chown, M. (1998). The cosmic connection. *New Scientist*, *2159*, p. 68.

Coles, M. (1998). *The Nature of Scientific Work. A study of how science is used in work settings and the implications for education and training programmes*. Unpublished PhD, Institute of Education, London.

Collins, H. (2(M). On Beyond 20M. *Studies in Science Education, 35*, pp. 169-173.

Delia. J. (1977). Constructivism and the study of human communication-*Quarterly Journal if Speech, 41*, pp. 66-83.

Department for Education and Employment (1999). *Science in the National Curriculum*. London: HMSO.

Donnelly, J. (1998). The place of the laboratory in secondary science teaching. *International Journal of Science Education, 20*, pp. 585-596.

Donnelly, J. (1999). Interpreting differences: the educational aims of teachers of science and history, and their implications. *Journal of Curriculum Studies, 31*, pp. 17-41.

Donnelly, J., Buchan. A., Jerkins, E., Laws, P., & Welford, G. (1996). *Investigations by order-Policy, curriculum and science teachers' work under the Education Reform Act*. Nafferton: Studies in Science Education.

Durant, L., & Bauer, M. (1997). Public understanding of science: The 1996 survey. *Paper presented at a seminar at the Royal Society*, Dec 8, 1997.

Eraut, M. (1994). *Developing professional knowledge and competence.* London: Falmer Press.

Fullan, M. (1991). *The new meaning of educational change.* (2nd ed.). London: Cassell.

Hacker, R.J. & Rove, M.J. (1997). The impact of National Curriculum development on teaching and learning behaviours. *International Journal of Science Education*, *19*, pp. 997-1004.

Jenkins, E. (1997). Towards a functional public understanding of science. In R. Levinson & J. Thomas (Eds.), *Science today: Problem or crisis?* (pp. 137-150). London; Routledge.

Jenkins, E. (1998). *Scientific and technological literacy for citizenship: What can we learn from the research and other evidence?* Available: http://www.leeds.ac.uk/educol/documents/000000447.doc.

Joyee, B. (Ed.). (1990). *Changing school culture through staff development. 1990 Yearbook of the Association for supervision and curriculum development.*

Koulaidis, V., & Ogbom, J. (1995). Science teachers' philosophical assumptions: how well do we understand them? *International Journal of Science Education, 17*, pp. 273-282.

Lakin, S., & Wellington, J. (1994). Who will teach the 'nature of science'?: teachers' views of science and their implications, for science education. *International Journal of Science Education, 10*, pp. 175-190.

Latour, B. (1985). *Science in action: How to follow scientists and engineers through Society.* Cambridge, MA: Harvard University Press.

Lave, J. (1988). *Cognition in practice: Mind, mathematics and culture in everyday life.* Cambridge: Cambridge University Press.

Merton, R.K. (Ed.). (1973). *The sociology of science: Theoretical and empirical investigations.* Chicago: University of Chicago Press.

Millar, R. (1996). Towards a science curriculum for public understanding. *School Science Review, 77(280),* pp. 7-18.

Millar, R., & Osborne, J.F. (Eds.). (1998). *Beyond 2000: Science education for the future.* London: King's College.

Osbome, J.F., & Collins, S. *(2000). Pupils' and parents' views* of *the school science curriculum*. London: King's College.

Osborne, J.F., Driver, R., & Simon, S. (1996). *Attitudes to science: A review of research and Proposals for studies to inform policy relating to uptake of science.* London: King's College.

Rowe, M. (1983), Science education. a framework for decision making. *Daedalus, 112,* pp. 123-142.

Seely Brown, J., Collins, A. & Duiguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher, 18*, pp. 32-42.

Shamos, M.H. (1995). The *myth of scientific literacy.* New York; Rutgers University Press.

Wason, P.C., & Johnson-Laird, P.N. (1972). *Psychology* of *reasoning: Structure and content.* London: Batsford.

Willard, M.H. (1985). The science of values and the values of science- in]. Cox, M. Sillars & G. Walker (Eds.) *Argument and social practice: The fourth SCA/AFA* summer conference on argumentation (pp. 435-444). Annadale, VA: Speech Communication Association.

Ziman, J. (1994). *The* rationale of STS education is in the approach. In J. Solomon & G. Aikenhead *STS education: International perspectives on reform* (pp. 21-31). New York, Teachers College Press.

THE PRESENCE AND ABSENCE OF SCIENCE IN ITALY'S EDUCATIONAL TRADITION

GIUSEPPE TOGNON

Italy is a country that boasts a fine scientific tradition and vast technical experience, yet Italian society still has difficulty in recognising itself in this picture. The basic education offered by Italian schools is good, indeed among the best in the world. The level of university education is up with that of other major nations. Italy no doubt suffers more than most the shortcomings typical of Europe as a whole: few investments in Research and Development, a small number of researchers, fragmentation in terms of organisation, few patents. This state of affairs is however in line with the general 'European paradox': a continent where the scientific base is sound, where the network of universities and laboratories is excellent, where there is a high concentration of theoretical expertise, but also where scientific discoveries and technological applications are not at the same level as those of the US or, until a few years ago, Japan.

Why then in Italy do we find it particularly difficult to accord science its rightful place? Perhaps because Italy has been the 'Catholic' country most chastised by the Church? But we know that this has not been the case for the past two centuries. Perhaps because its economic and industrial development was delayed somewhat? This is true, but it was then exceptional, and Italy managed to catch up. The causes are more complex. They are concerned with the tricky relationship between knowledge and Italian society, and have been compounded by the schooling model, adopted in 1860 when the country was unified and confirmed by the reform of the schooling system inspired by the neo-idealist philosopher Giovanni Gentile in 1923. This model is based on supremacy of the culture of the written classics and on the clear-cut distinction between literary and durable education for the emerging bourgeoisie and practical, accelerated education for the masses. The Gentile reform was important in many ways, and cannot be criticised just because it was effected during the period of fascism. The origins of this reform went back a long way, and were accepted by the majority of Italian intellectuals, including liberals and socialists. At the beginning of the 20th century in Italy, as in France and Germany, there was a revival in a philosophical movement whose aim was to establish unity around spiritual values that might overcome those of materialism and positivism. There was a violent confrontation between different schools. The neo-idealistic current came out victorious, partly because of its ability to represent the need for social emancipation of the lower middle classes that sought employment in the public sector and liberal professions. We know that a sound basic classical education, centring on the study of the arts and languages, actually helped rather than hindered the career of major scientists. The main limit of that cultural model was rather the intent to write off science categories as ‘pseudo-concepts’, as B. Croce said. Unfortunately such a purely instrumental conception was enormously successful, partly favoured by a certain naive Positivism. The stories of positivism-inspired science illustrated the slow but inexorable rise of scientific observation and experimental verification over religious prejudices and traditional abstract knowledge. Positivist literature stressed the benefits that the new rigorous scientific method would have on humanity, not only in cultural but also in civil, political and social terms. Such stories had dramatic contrasts: light against darkness; rationality opposed against credulousness; the truth clearly distinguished from error.

In light of these and other conditions that I cannot name here, contemporary Italian society has systematically distinguished between the ‘two’ cultures, theoretical and experimental, thus refuting the specific nature of its tradition. Above all, it has constructed the image of the cultured man around the model of the jurist and man of letters and the image of the influential man around the model of the politician. Notwithstanding the efforts of some pioneers, 20th century Italian society gave priority to ethical-political issues over scientific research. In Italian universities the chair of history of science or scientific techniques has existed only since 1980. The first national programme for the divulgation of a scientific culture got under way only in 1989. Hostility towards the sociology of science has meant that scientific research has been removed from national awareness.

This national weakness may also be explained by the absence of a policy defending and enhancing Italy’s historical and scientific heritage. Everybody knows for instance that Italy is the nation of museums and collections *par* *excellence*. But among the thousands of public and private museums and institutions, which are cited as proof of the absolute excellence of our country, scientific museums and technological and industrial collections are rarely mentioned. After the Unity of Italy little or nothing was done in this sector to catch up with Great Britain, France, Germany or the United States. A significant breakthrough in this direction only came in the 1920s and 1930s, a time of great modernisation for Italian society. Fascism embarked on a series of initiatives to valorise Italy's scientific heritage and to disseminate a technical-scientific culture, from which all the institutions still operating in our country originated. This interest was not selfless. The Regime aimed to finally give Italian culture as a whole 'virile' and powerful guidance. It saw Italian 'supremacy', in both civil and scientific terms, as being effective for the regime's propaganda and for the celebration of Italian science. Many of the best Italian scientists were forced to emigrate. It was in this climate and with these intentions that the scientific institutions and museums that still constitute the basic framework of Italy's research system, first and foremost the National Research Council, were founded. The issue that should be stressed here is that after World War Two the new Republic basically preserved the same system. It did change internal set-ups, create new laboratories and new faculties, but it was unable to change the collective mentality. For decades Italian scientists have had to 'struggle along', being forced to perform miracles, often to emigrate or spend a great amount of energy in search of resources, available almost only from public sources. Many researchers have become – or generously turned themselves into – 'politicians', with results that have not been spectacular either for science or for politics.

We can no longer carry on this way. The world's scientific and social scenario has changed, but the problem remains that of the educational roots of science. Psychological and social sciences have shown us the importance of the cognitive and emotive mechanisms that rule the life of individuals and communities. We all know too the way in which major technological and scientific challenges have been brought to the attention of the public at large by the media. Government and non-government committees dispensing ethical-scientific advice have sprung up in all countries. The majority of general discussions are now concerned with ethical controversy born out of scientific research. And with globalisation, moratoriums just do not work in 'sensitive' areas. We are unable to ascertain whether the moratorium is universal or only affects with some countries; whether it is possible to overcome the pressure of lobbies and industrial interests; whether researchers can be persuaded to prefer prudence to speed and private interests.

Rhetorical solutions can no longer be proffered. It is always possible of course to alter teaching methods, organise more training activities, create foundations or prepare major exhibitions. Positive transformation can clearly only result from a series of coordinated actions in schools and universities. One of the basic school functions that has almost totally lost its positive influence in recent decades is the scientific laboratory. A large number of schools were and still are endowed with such laboratories. But with current research trends, the lack of funds and competent technicians and limited equipment, there has been a gradual abandonment of laboratories, and they have been sidelined from teaching activity. I personally am aware of the attempts to reform educational systems in all industrial countries over the past twenty years: too often they have fallen victim to the 'engineering' of school curricula that has failed to yield good results. As Einstein said: 'I reject the idea that schools must directly teach the specialist knowledge that will have to be used in later life. Life's needs are too many and complex for such specialist teaching to be possible. The aim of schools should always be to ensure that youngsters leave school with a harmonious personality. The general ability to think and judge independently should also take first priority'. If this is not possible for the masses, then at least we have to try to invent the new figure of 'mediator' beside the figure of pure researcher: the mediator, an invaluable scientist whom the community of researchers entrusts with the job of seeking consensus, explaining and pre-empting objections. In university departments it is necessary to re-evaluate the role of those studying and teaching the history and didactics of science, a function often assigned to second-rate scientists.

The general problems is that of educating our societies to be able to choose while the machine is running, and to select the level and nature of knowledge that such choices require. If there is an alphabet of science, consisting of specific and specialist knowledge, then there is also a 'grammar' of knowledge, which extends beyond specific areas and is concerned with the overall behaviour of men in relation to knowledge and its history. There was a time when life's choices were few, and it was often other people that decided for us: what to study, who to live with, who to do business with, who to spend time with, who to vote for. Now we are called upon to make choices about everything, every day. These are almost always simple or false choices, regarding market-oriented consumption choices. When we come across real choices, we try to brush them to one side, because we have got out of the habit of considering knowledge as the basis for choices and of encouraging mutual trust. We are no longer living at a time when the models of scientist are those of Einstein or Fermi, alone and faced by terrible alternatives, but still very cultured men alert to ethical problems. The problem with our system of specialist teaching is basically: it does not teach scientists about responsibility, it does not help the layman to appreciate scientific progress, it does not provide scientists with the tools to defend these breakthroughs when they are called into doubt.

To develop the educational roots of science, therefore, we must work on several fronts and ‘from the bottom’, namely at the level of individual scientists. The number of scientists should however rise well beyond the number of professionals, and scientific intelligence should become a mass phenomenon. We do not have to create a mass of researchers, but it is important to get whole populations to understand something about science, enough to be able to choose and to give or deny consensus to professionals, to involve them in the community rather than confining them to the laboratory. Without a popular scientific base, scientists too tend to intensify their individualism, and when they have to choose between cynicism and responsibility, they are torn by what are often futile internal conflicts. And without the understanding of public opinion, it is almost a waste of time calling upon scientists to reflect upon their responsibility with regard to the results of their action.

Human beings play a part in scientific research in three ways. Through the personality of the individual scientist, through the personality of scientists brought together in a community, and finally through the history of the society they are a part of. Science is not just a two-sided game, theory against nature, it is more complex, with the individual playing at least three roles: scholar, researcher, citizen. The more the person delves into science and acquires knowledge, the more responsibility and ethics circulate around the world through him.

Today science and technology are ‘current money’, but if the successful model of ‘scientist’ continues to be that of extreme competition between nations, between lobbies, we cannot hope to make of scientific research something more than other marketable occupations. If moreover public opinion continues to consider scientific research only as a means to an end, the scientist will continue to be viewed only as an economic entity, and it will attempt to unload the causes of evil onto society. There is the danger that what is happening against financial globalisation will be transferred to scientific and technological globalisation, which is the essence of the former. Then no one will be able to call himself simply ‘a free scientist of a free science’.

EVALUATION AND EDUCATION IN SCIENCE

BABACAR GUEYE

1. Introduction

Be it explicit or not evaluation always comes along with teaching (oral and written tests, exam papers, etc.) That is why it may have a central position in all well-thought of curricula.

However it is common knowledge that the evaluation part is the most difficult curriculum component to set up. That is why in Education Science it has been considered as a special field of investigation for so long.

Docimology – a subject that concerns itself with evaluation in order to disclose good and bad practices and then consolidate the former and improve the latter has gradually gained ground into evaluation research.

If many researchers have tried in the past to define the evaluation concept in a more or less successful and appropriate way, today we must agree that most of them put evaluation at the service decision making (STUFFLEBEAM 1980, De Ketele 1993).

For De Ketele, evaluation means to

– collect a set of adequately appropriate, valid and reliable information

– study the adequacy rate between this set of information and another set criteria suitable to the assigned objectives from the onset or streamlined on the way, in order to make a decision (De Ketele, 1993).

This definition corresponds to an epistemological change as if nowadays a fully documented decision making seems to be the stated objective of evaluation, the unique will to pass a value judgement from measures had seemed to overrate any other considerations for a long time.

As a mather of fact value judgement and decision making are the two stages of the same process. Any decision making stems from a value judgement on the people's actions or performance in relation to implicit or explicit objectives.

Another definition of evaluation considers that it should help determine congruence between performance and objectives that is Tyler's definition stated as follows.

"The evaluation process mainly consists in determining to which extent the education objectives principally aim at changing human beings, that is the objective is to cause desirable changes in students' behaviours, whereas evaluation is the process consisting in determining to what extent these behavarioural changes are actually occurring (Tyler, 1950)".

Therefore it could be stated that the evaluation issue is mainly rooted on the following questions

What is to be evaluated?

When and why evaluate?

How to evaluate?

Our paper which is focusing on the teaching of sciences develops within that range.

2. The Traditional functions of Evaluation

2.1. *What is to be evaluated?*

The usual answer to this question is provided by the school conception that stages the following steps in the design of any programme.

– Determine the objectives that should be aimed by the course or the programme

– Choose the learning experiences that will help reach those objectives

– Organize those learning experiences

– Determine to which extent those objectives are attained (FURST, 1964).

The point is then to evaluate the objectives, more precisely the objectives in terms of behavariours if Tyler's (1950) and FURST'S (1964) definitions are brought together.

The basic task is, therefore, to assess the objectives and categorize them. All this resulted in the already familiar taxonomies (Bloom, d'Hainaut, etc) which have, each attempted to assess, describe and categorize what the learner should be able to achieve what ever subject content may be used as support.

The first taxonomy, that of Bloom published in 1956 lists six levels (knowledge, comprehension, application, analysis, synthesis, evaluation) was used in Quebec as early as 1964, then in Belgium in 1972 for evaluating learners.

Such a method had a strong point as it rationalized systematized and evaluated an educative action which had too long been left to intuition, sensibility and common sense (De Landsheere, 1975).

However that has been a major criticism against it. The use of taxonomies entails too strong a focus of evaluation and teaching on atomised behaviours which do not take into account the initiative and desire of the learner who is thus compelled to quasi inactivity.

2.2. *When and why evaluate?*

It is customary to evaluate while learning is in progress (oral & written quizzes, progress tests, etc) or on completing a syllabus (exams, contests). Those two evaluation forms use to be kept apart by SCRIVEN (1967) who calls the first on while Training Evaluation and the second End of Training Evaluation. They are different not only in terms of the time when they are administered, but also in terms of the reason for their administration in the application of teaching programmes.

The while-training Evaluation (Progress Test) may be defined as a continuing evaluation process aiming to ensure every individual's progress in a learning strategy in a view to alter the learning situation or the rate of that progress in order to improve on remediate (if applicable) it.

The end-of training Evaluation (achievement test) which tends more and more to be referred to as Certification Test is defined as the one that leads to a binary decision for a pass or fail in relation to a learning period, for granting or denying someone a promotion, for continuing or stopping an action (De Ketele et Roegiers, 1993).

2.3. *How to evaluate*

In many countries it up to the teachers in charge of one course who design the evaluation (progress and achievement) tests and the learner is supposed to demonstrate his/her competence through a written production: it is the well-known "per and paper" test.

The oral tests are indeed administered, but writing is a given more focus with a higher coefficient.

Two main techniques are usually employed in school tests

– The so-called objective test when the learner has to choose the one correct answer from others which are not. This kind of test resulted from the early applications of taxonomies, namely in Canada in 1964 and in Belgium in 1972 as far Bloom's taxonomy is concerned.

– The composition, an answer in a written form which allows the learner to produce some more elaborate response, presented in an organised or an original free way.

In the field of sciences, the composition has developed from a traditional form in one question, one sentence or one word alone to a more structured form with several questions requiring more or less complementary answers extracted from provided documents.

That change occurred while the methodological procedure was being introduced in the teaching of sciences which allows both discovering and understanding phenomena.

3. Contributions of Didactics to Evaluation

Subject areas Didactics seems to me more comprehensive and systematic to report on the impact of evaluation on the teaching of Sciences, which is the reason why I have chosen it as a scope for this discussion.

If Didactics was originally, indeed, a new approach to educational issues, it has to be noticed that it has presently expanded beyond the school field. Now it deals with all the communication settings, be they formal, non formal or unformal.

Coming back to the school setting which the object of our concern, let us consider that the Didactics of a given subject area both looks at classroom proceedings and at what happens in the learner’s mind.

In short, it has to do with the way messages are encoded and transmitted, in priority, but most principally with “how learners learn” and how they interact with the learning contents and the teacher’s strategies.

Didactics positions itself at the crossroads of the three following domains.

– The subject area domain (programme – contents – objectives)

– The psychological domain

– The pedagogical domain

It calls upon each of these domains if need be, to give a definition and meaning to the school tasks, depending on the obstacles facing the conception and acquisition of knowledge and skills. Today, didactics has identified two short comings in the teaching of Sciences.

First school has generally restricted evaluation to the sole field of learning.

Second, the quality of the evaluation battery in use is so poor that it has negative consequences on the whole curriculum

Be it in the form of a progress or an achievement test, evaluation in the teaching of sciences is only geared towards learner acquisitions. However, as far as the teaching field is concerned there are other contests which require the collection of reliable and valid data before decision making.

– First, it is now common knowledge that actual teaching is preceded by the teacher's awareness of his learner's ideas. Which will help him take into account libely problem areas when planning lessons.

– Second, the teaching tools used as supportive materials learning bear information and values that are worth disclosing for optimal efficient use.

– Third the different evaluation results also include useful information on learner behaviour and how it operates.

As mentioned above, evaluation in the teaching of Sciences is today confined to the results of acquisitions. Given this situation, the Didactics of Sciences, through its research results has revealed thanks to a more systematic vision of the teaching act, other fields, other instances when evaluation may play an important role in the quality of learning of teaching aids and reinforcement that may be granted as shown in the grid below.

EVALUATING MEDIATION

Mediator	What to Evaluate
1. Knows the targets	Characteristics, questions, interest, conceptions, thought procedures
2. Has objectives	Knowledge Know-how Attitudes
3. Has communication resources	Teaching aid Films Books Posters Teaching modules
4. Has constraints	Space Time Funding, etc…

3.1. *Diagnostic evaluation*

If the teacher pays some attention to "errors" made by learners on such or such a concept or scientific reasoning, he realises that some of those are made again and again on a regular basis.

It was logical for didactics to look closer at errors. This is how researchers discovered that prior to a course on a given topic learners had a number of ideas on it, their own explanations of some phenomena and interpretation of the environment surrounding them. Those prime ideas, those rough elements in the learner's brain that most often opposed to settled scientific knowledge are referred to as conceptions or representations. The sciences didacticians started evaluating those conceptions. If the learners' conceptions issue has been raised since the works of Piaget, its systematic study started in France only with the works of Pr. Giordan (1975, 1977, 1978) who came to realise like other researchers that learners tended to forget most of the scientific knowledge acquired at school or in other terms the "pedagogic yield" that is the amount of knowledge acquired in relations to the time spent at school is very weak, even non existant, at times. Presently over (W) three quarters of studies published in sciences didactics deal with conceptions they fall into three categories.

– *Descriptive researches*

They assess learners' conceptions and draw up questionnaires, etc, kinds of catalogue. Unfortunately, they wank, I believe, as the most numerous.

– *Explanatory researches*

They go beyond mere categorisation of conceptions, they aim at identifying the mechanisms that generate them and how they operate.

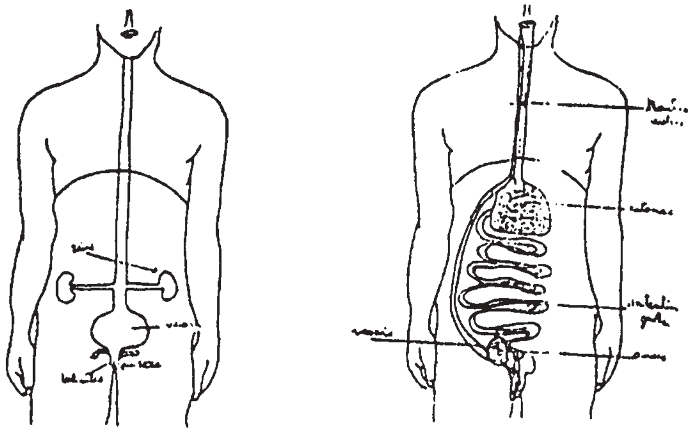
– *Applied researches*

They are few however they seems very important to me as they try to install teaching strategies usable in class and taking into account learners' conceptions.

All these researches are credited to put the lear back at the beginning and end of the education act and have made obvious what follows.

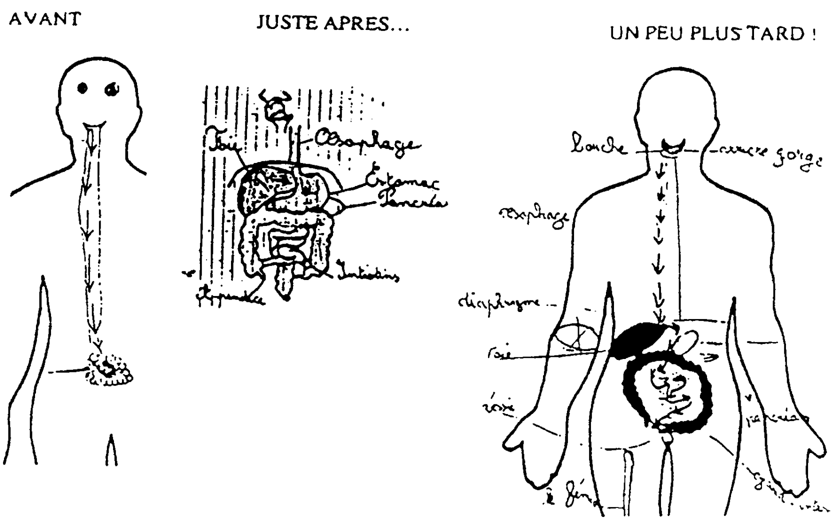
– *Before any teaching* learners have conceptions, ideas or reference framework allowing them to capture the different messages.

Here are a few examples about the digestive apparatus (Giordan, 1988).



1 2

Document 1. Two different conceptions of the digestive apparatus. In Case 1 There is a confusion with the excretion apparatus and the continuing part of the oesophagus leading to the bladder. In Case 2. Two canals (one of them would represent the trachea) One for solids – This shows that the learner is always active he always functions with prime ideas at back of his mind. Conceptions are extremely difficult to eradicate. If the teacher does not take them into account what is taught will only transit, as shown in the example below still about the digestive apparatus (Giordan, 1988).



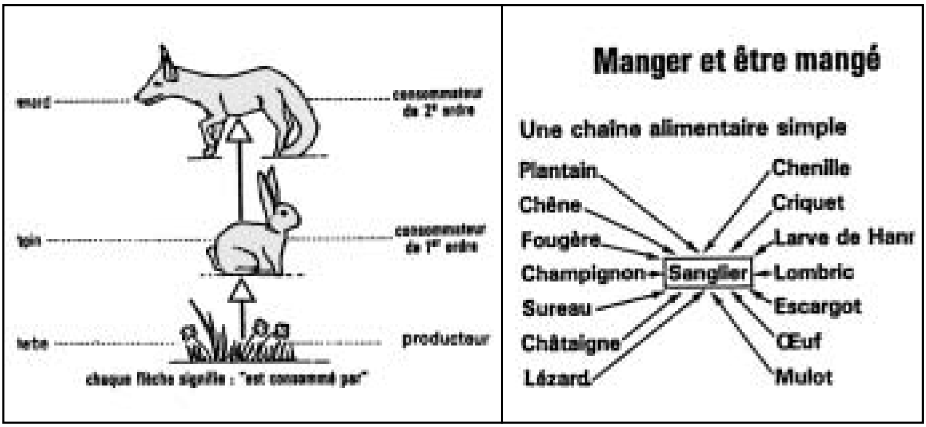
Document 2. Evolution of a conception of the digestive apparatus after the lesson.

3.2. *Evaluation of Teaching aids*

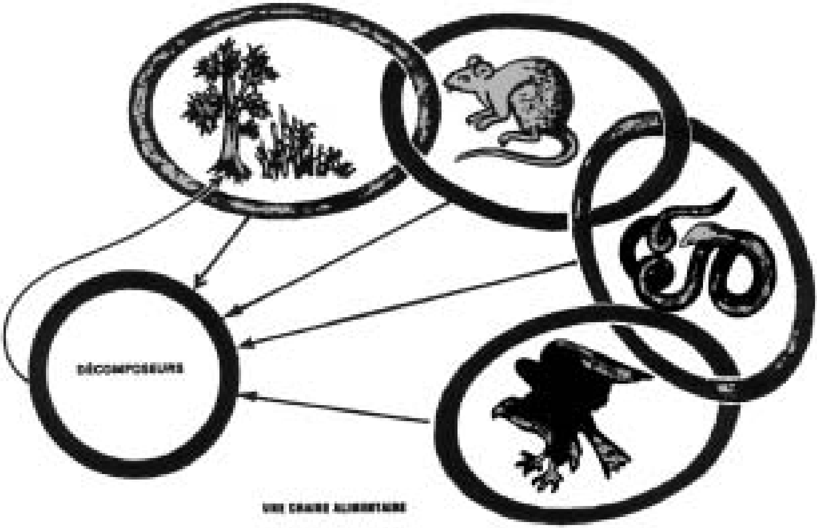
In the teaching of experimental sciences, the teacher often resorts to aids of icaried kinds in order to create situations that favour actives learning. This how he moves from exposure to demonstration at to problem solving at times. In such situations they help the teacher reach move easily the targeted objectives allowing learner to build up knowledge by themselves. They also permit to engage into activities which would not be possible, other wise.

For a number of years now, teaching research has been stressing the fact that teaching materials (books, films) carry information and even values that deserve evaluating before use not only avoid embarring situations but to assess their efficiency. Here are a few examples taken from school text books.

EXAMPLE 1.

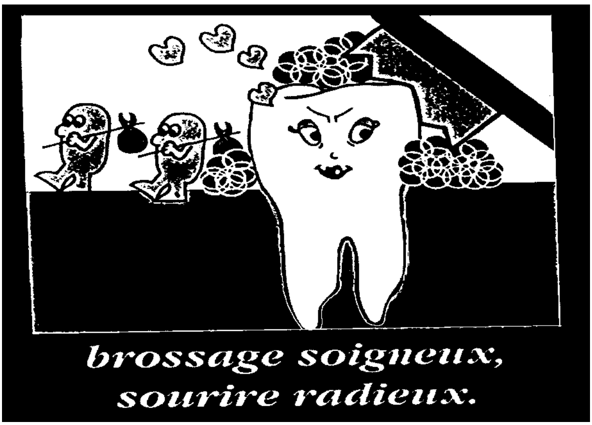


Document 3. The food chain in ecology. If the drawing on the left may be receivable for its simplicity, that on the right is hardly acceptable. Moreover, judging from terminology familiar to learners, this has nothing to do with a "chain" – "Chain" refers to a sequence of rings as shown below.



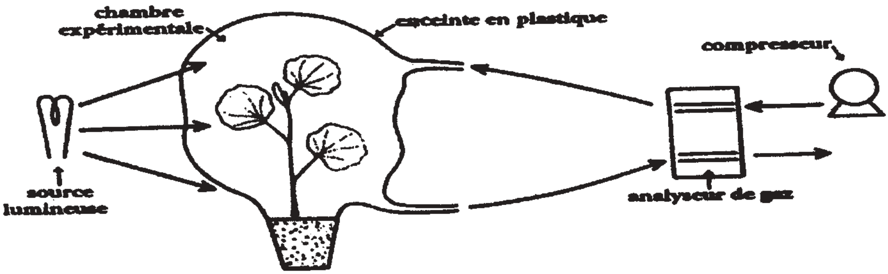
Document 4. Another representation of the food chain concept. But here, the arrow does not mean “is consumed by”. This is a semantic and conventional puzzle which needs to be evaluated and straightened up for a better understanding of the food chain concept.

EXAMPLE 2. Information about tooth hygiene.

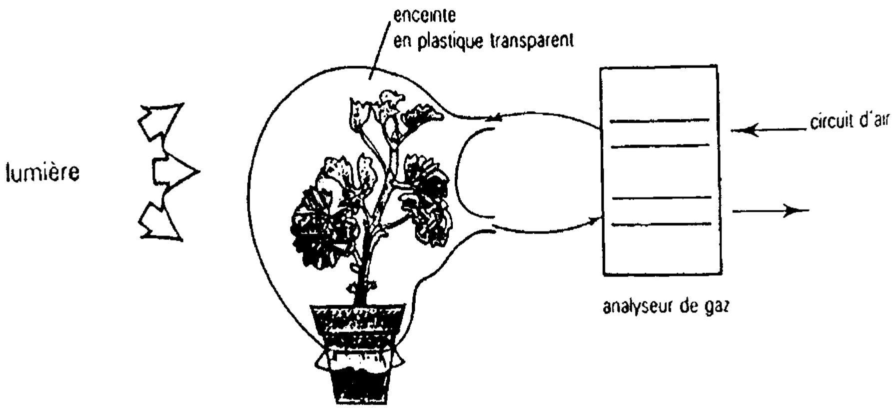


Document 5. Children-geared information.
– The adjective “delightful” is not part of the 8-10 year old children’s lexicon.
– The tooth brush is spotted by less than one child out of two.
– Bacteria are not identified by 75% of children.
– Worse most children even cannot identify the tooth.

EXAMPLE 3. Measuring gas photosyntetic exchanges.



Document 6. Graph of principle of the gaz photosynthetic exchange measure.



Document 7. Another graph of the principle of the gas photosynthetic exchange measure.
First of all, it can be said that despite a few symbolic differences the two graphs taken from different text books seem to represent the same experiment.

However a closer does not take into account of all sorts of gazes which might due to the numerous organisms of the soil, be emitted and disturb the composition of air within the cover. Little cause in the teaching materials great effects on the reasoning and rigorous, procedure which are characteristics of experimental action.

3.3. *Evaluation of evaluation tools*

If one goes beyond the good wishes expressed by official texts on the evaluation of learning in science in search of habits settled and the very practice of the different tests designers, one discovers that in the whole, the pathology of evaluation in sciences goes beyond the long-critised subjectivity of judgements passed by examiners. It is founded on its chronical lack of validity relative to the stated contents and objectives, validity being defined by the extent to which tests evaluate what they are supposed to evaluate.

In many countries, teaching is centred around acquired knowledge. The starting point is university knowledge already built up, then, a list of themes followed by a list of teaching contents which rank high on the programmes of the educational system.

In the case of achievement Evaluation in Sciences, when a categorisation by themes of topics suggested over a fairly long periods is carried out and compared to the prescribed programme, it can be noticed, that in most cases in practices, all the programme, it can be notices, that in most cases in practice, all the programme chapters are not given equal treatment.

This allows to find out that there is a sort of an implicit value scale according to which certain chapters are more frequent. Others occur from time to time while one category never appears. A times a clear cut discrimination between the different notions and concepts can be notices within the same chapter.

A systematic study of objectives from the questions usually asked in sciences tests shows that contrary to the state and documented desire to move science teaching towards experimental procedure and scientific attitudes

Questions that require the use of acquired knowledge are the most frequent, in spite of the misleading appearances of the different instructions used by designers in setting questions (Analyse, Interpret, Deduce).

In fact learners are asked to show what follows:

– specific knowledge

– mastery of one (or more) problem solving (strategy[ies]), type(s)

– (exceptionally) skills to analyse a situation under study (Johsua, 1983).

Let us take the example of the evaluation of the learners' skill to form hypothese. It is noticed that the existence of familiar laws whose demonstration has necessitated hypothese known to the learners after they have been taught in class does not leave much room to questions evaluating their skills to form their own hypothese.

Indeed, when learners are faced with such questions, they look back into the set of explanations they already known for those that can fit, as they are never asked to exclude any hypothesis, but to choose the best.

Ultimately, the whole issue is only related to constructed automatisms solely for the monitoring of knowledge in the frame word of a closed systems whose importance is nothing else than success at the exam (Johsua, 1983).

As for the affective objectives, they have not all been evaluated (it must be agreed that they are difficult to evaluate in the framework of a “pen and paper” test).

The consequences are that, after a certain time, the examination turns round typical questions which are the object of swotting such as the exam tasks of analysis, interpretation or even explanation will require declaratives or procedural knowledge transfer.

This is mainly explained by the fact that all the given exercises are put forward in the frameworks of a pen and paper test, which does not allow learners to face a real problem, that is a more or less new situation whose answer must be built up not retrieved automatically.

Moreover, in the countries where, for sometime, people have cherished the idea of making learners acquire, about the themes on the programmes, certain basic concepts and procedures from one or two examples, then to make them show during the evaluation what they have learnt though a transfer to a context not dealt with in class, have waken up from that dream.

It is noticed rather an insidious knowledge inflation phenomenon in the chapters focused on at the exam, as every time a new example came up at the tests, it was systematically swotted on the following year in class on teachers’ more initiative finally, overwhelmed by a mass of observations, subjects or definitions, most learners have no other solutions than learn as many of them as possible by heart. The sequence observation-memorization.

Monitoring and oversight becomes frequent practice instead of the opposite: observation-use of concepts-interpretation-relation with wider concepts-problem solving (Novak, 1970).

4. Conclusion

At the end of this analysis I think to have widely proved that it is quite possible and useful, and even urgent and compulsory to widen the evaluation field in the teaching of sciences to the differentes questions that underlie the evaluation issue and the need to make decisions only when fully informed widely claim for such expansion. The adoption and the practice of such a systemic vision in scientific teaching will without any doubt, allow to improve it qualitatively. This improvement is dependent up on the quality of it's the learning evaluation tools.

In the teaching of sciences, as it seems presently, achievement testing is more debatable than progress testing.

Indeed the pseudo-democratic centralism used to administer in a more transparent an fairer way the evaluation of objects resources does not permit, during the achievement test, to muster all the didactic available to the scientific disciplines in their every day teaching in every school institution, owing to the number of candidates and the limited time allowed to the exam.

To solve this problem of evaluation in the teaching of sciences it is desirable to remember that whatever the philosophy and the content of a syllabus, its actual efficiency is largely determined, after a number of years, by the exam format for which the teacher has to train his learners (Guinier, 1980).

I believe that, for a project aiming to encompass all the ground aspects of the evaluation in the teaching of sciences to be likely to get off the it is necessary to tackle the problem through teachers' initial and continuing training.

Indeed teachers' straight forward training in theoretical, but mainly practical and critical training is the challenge to meet for evaluation to occupy its rightful position in the teaching of sciences.

BIBLIOGRAPHY

Bloom *et al.* (1969). *Taxinomie des objectifs pédagogiques*. Lavallée trad; Montréal: Edition nouvelle.

De Ketele, J.M., Roegiers, X. (1993). *Méthodologie du recueil d'information*. Bruxelles, De Boeck, p. 74.

De Landsheere, V. et G. (1975). *Définir les objectifs de l'éducation*. Liège, Thone, p. 15.

Giordan, A. (1975). "Analyse des attitudes scientifiques et des représentations des élèves". *Bulletin INRP*, n° 11.

Giordan, A. (1977). "Libération et conceptualisation". *Revue française de pédagogie*, n° 40.

Giordan, A. (1978). *Une pédagogie pour les sciences expérimentales*. Paris, Centurion.

Giordan, A., De Vecchi, G. (1987). *Les origines du savoir, des conceptions des apprenants aux concepts scientifiques*. Neuchatel, Delachaux et Niestlé.

Giordan, A., De Vecchi, G. (1989). *L'enseignement scientifique, comment faire pour que ça marche?* Nice, Z'Editions

Giordan *et al.* (1993). *Evaluer pour innover.* Nice Z'Edition

Guinier A. (1980). "A propos du contrôle des connaissances". *Bulletin de l'Union des physiciens*, n° 627, pp. 29-72.

Johsua S. (1983). "Contrôle des connaissances en fin de second cycle (baccalaureat) et nouveaux programmes de physique". *Revue française de pédagogie* n° 64, pp. 55-73.

Novak, J.D. (1970). *The improvement of biology teaching*. New York, Bobbs Merill and Company.

Scallon, G. (1988). *L'évaluation formative des apprentissages*. Québec, Presses de l'Université LAVAL.

Scriven, M.S. (1967). *The methodology of evaluation* (AERA Monograph series on curriculum evaluation, book I). Chicago, Rand Mc Nally and Co.

Stufflebeam, D. *et al.* (1980). *L'évaluation en éducation et le prise de décision*. Ottawa, Edition NHP, p. 48.

Tyler, R.W. (1950). *Basic principales of curriculum and instruction, Syllabus for Education 360*. Chicago, University of Chicago Press.

STRATEGIES FOR THE IMPROVEMENT OF K-8 SCIENCE EDUCATION A REPORT FROM THE UNITED STATES

DOUGLAS M. LAPP

The National Science Resources Center (NSRC), operated jointly by the National Academy of Sciences and the Smithsonian Institution, works to improve the quality of science education in elementary and secondary schools. The NSRC advocates an inquiry-centered approach to science education that challenges students to expand their understanding of science concepts, skills, and attitudes through hands-on explorations. Through its science materials development, information dissemination, and leadership development programs, the NSRC assists science education reform efforts in school districts across the United States. Scientists and engineers from universities and industry, as well as teachers and school district leaders, collaborate in the development and implementation of NSRC programs.

Building on fifteen years of experience working to improve science education, the NSRC has developed a model to guide school districts that are seeking to establish an inquiry-centered science education program. The NSRC model involves five complementary elements that are needed to create and sustain an inquiry-centered science program:

I. *Research-Based Curriculum Materials*

Carefully crafted, comprehensive, inquiry-centered curriculum materials lie at the heart of an effective science education program. Such curriculum materials should be developed collaboratively by teachers and scientists, field tested with students, and carefully evaluated before being published. The learning materials must provide developmentally appropriate opportunities for children to expand their understanding of science concepts, acquire skills, and develop positive attitudes toward science. Lessons must challenge students with a variety of learning styles and give them opportunities to apply what they have learned to real-life situations. The lessons must also offer opportunities for teachers to integrate science learning with other areas of the curriculum.

II. *Professional Development*

Carefully designed professional development programs are needed to prepare teachers to teach inquiry-centered science. These professional development programs need to focus initially on helping teachers become familiar with fundamental science concepts, learn how to use inquiry-centered science materials, and develop effective classroom-management techniques. Later, attention can turn to helping teachers acquire in-depth science content knowledge, perfect an inquiry-centered approach to teaching and learning, develop appropriate methods for student assessment, and integrate science with other subject areas.

III. *Materials Support*

Students who engage in inquiry-centered science need a variety of science materials – from hand lenses to magnets to organisms. A materials support system is needed to ensure that science materials are ready for classroom use throughout the year. Materials support staff take charge of ordering new supplies, refurbishing science kits, and ensuring that they are delivered to teachers when needed. Centralizing these materials support functions for an entire school district can make materials support more efficient and cost effective.

IV. *Student and Program Assessment*

Inquiry-centered science requires teachers to use new assessment strategies. Pre-assessment activities to assess students' knowledge before beginning a learning sequence can provide information to help teachers plan learning activities. Additional assessments need to be integrated throughout the learning process to provide both teachers and students with a way to evaluate their progress. Final assessments should be designed to assess what students know and are able to do as a result of their inquiries.

In addition, periodic program assessments are needed to determine whether the science program is meeting its goals and to guide curriculum selection, professional development, and other activities.

V. *Administrative and Community Support*

Planning and implementing an inquiry-centered science program require the support of a broad range of stakeholders. These individuals should share a vision of what is needed to create an effective inquiry science program. Equally important is the need to establish an infrastructure that will support this shared vision.

To be effective, science education reform efforts needed to enlist the support of school and community leaders. A broad range of community organizations can become effectively involved in the reform of K-8 science education. They include colleges and university faculty, business and industry, museums, philanthropic foundations, parent-teacher organizations, and other educational organizations. Scientists, engineers, and corporate leaders can be especially effective in building support for science education reform. Scientists can also team with teachers to lead professional development programs and parents may volunteer time to help replenish science kits in science materials centers.

Working together, these individuals can form partnerships that will ensure a sustained commitment to science education reform.

* * *

The NSRC has developed a book and a videotape to assist those who are working to improve science education in the schools. *Science for All Children: A Guide to Improving Elementary Science Education in Your School District* provides concise and practical guidelines for bringing about science education reform. Designed for school leaders, scientists, teachers, and community leaders who are committed to improving science education for all children, the book and videotape explain the philosophy and research underlying inquiry-centered science teaching and describes in detail the five elements that are essential to science education reform. The book also proves information on how to organize, plan and implement a new science program. *Science for All Children* is available from the National Academy Press (Telephone 1-800-624-6242), or can be accessed online over the internet at http://www.nap.edu.

THE PLACE OF SCIENCES/TECHNOLOGIES IN THE EDUCATION OF TWENTY-FIRST CENTURY CITIZENS

THE COMPUTER IN THE SCHOOL: A TOOL FOR THE BRAIN

ANTONIO M. BATTRO

The information world in science education

The impact of the information world in science education begins in elementary school. When a child sends an electronic message to a friend he is using a set of powerful computer tools: word processing, dictionaries, machine translation, digital images, audio, etc. These are "new tools for the brain", that transmit and amplify many feelings, emotions and cognitions in a totally new way. These instruments can work as "intellectual prostheses" for our mind.

I would present a case that illustrates this view. It is related to the emotional impact of the terrorist attack of September 11th in New York and Washington, on Nico, a 11 year-old child living in a remote place from the terrible events. Nico, who is at school in Argentina in his 6th grade, sent the following e-mail in Spanish to his friend, a university professor in the United States:

> "Hola, soy Nico. quería decirte que siento mucho lo que pasó allá en Estados Unidos espero que si tenías parientes ahi en NY que no les halla pasado nada. me dan muchas ganas de volver a verte. te mando un beso grande y mi mamá tambien. NICO".

He did not use the spelling software in Spanish to find some errors in his message, but we can leave the English translation to a machine:

> "Hello, I am Nico. wanted *decirte* that I feel much what happened back in the United States I hope that if you had relatives *ahi* in NY that does not find last anything to them. they give many desire me to return to *verte*. I also send to a great kiss and my mother to you. NICO".

Machine translation, in spite of its current and evident limitations, can be used with great profit in schools – it inspires linguistic criticisms and lively discussions – and will continue to improve. Children enjoy using this powerful tool to check their own proficiency in a foreign language and love to engage the machine in “linguistic loops”, i.e. translating an expression from language A to B, and then the translated sentence B into A, and so on. My point is that we are dealing here with a message transmitted by the web that eliminates many practical obstacles such as writing the letter on a paper, addressing the envelop, looking for stamps, going to the post office, etc. Also the e-message has the advantage of reducing the affective distance between both partners, we can even talk of a “distance zero” between them. Moreover we can feel that this information technology is closing the gap between the child and the adult, and the novice and the expert, in a very profound sense.

Even more so because Nico is a hemispherectomized boy and he is using the computer as a “prosthesis”, he is hemiplegic and his writing by hand is impaired (Fig. 1). He was given a right hemispherectomy when he was three years old to control intractable epilepsy, and he is successfully performing in life since his surgery using only his left hemisphere. He has compensated his devastating loss and became a regular student at school and a remarkable example of rehabilitation (Battro, 2000).

Figure 1. Two images of Nico’s brain showing the loss of the right hemisphere at the age of three.

Another related and striking example is Louis Pasteur. As one of his biographers stated: “Le lundi 19 octobre (1868), Pasteur, bien que souffrant d'un étrange malaise, d'un fourmillement dans tout le côté gauche, eu le vif désir d' aller présenter â l'Académie des Sciences, le travail d'un italien, Salimbeni". (Vallery-Radot, 1922). In the following hours "Pasteur suffered a cerebral hemorrhage on his right side... It has been said that after his injury (at the age of 46) 'he had only half a brain'. Nevertheless, after this injury, he did some of his best work" (Wiener, 1948).

These extreme cases of people working normally or being superbly creative in the sciences after the loss of a significant part of their cerebral cortex open, at least, two challenging questions: How much "brain power" do we need in order to learn and create knowledge? We have some 10^{12} neurons in our brain; how many do we actually use in a specific cognitive task? Perhaps this is not a quantitative but a qualitative problem related to the plasticity of our neuronal networks, of what is called "activity-dependent plasticity" (Sharma *et al.*, 2000). We also know that growth of the brain is closely related to growth of action and thought and that both brain activity and optimal cognitive functioning develop in fits and starts (Fischer and Rose, 1997). Modern education should take into account the results of neurocognitive research, and one task would be to understand the biopsychology of computing.

The click option and the cortical shift

Pasteur did not need a computer in order to make the remarkable discoveries that have improved our life, but one hundred years after his stroke children all over the world were starting to use the computer to calculate, to write and to draw, to make music and to control elementary robots and sensors (Papert, 1980). Many disabled persons also began to profit from and to enjoy the power of digital machines to learn and to work. Now the computer has conquered, definitely, its place in education. This is the result of many coincidences between the brain and the computer, which seems to bring an incredible expansion to our mental capacities. Everyone, for instance, can agree that the child has an astonishing talent to use a computer, even before he or she can read or write, but few have asked why this is so. This extraordinary matching of the child and the digital machine is both a gift of nature and of culture.

The biological reason is because our brains, and the brains of many animals, are naturally adapted to make "single-option decisions", by yes or no. In fact, ever since the nineteenth century experimental psychologists have intensively used the very simple device of a mechanical or electronic switch to study animal and human behavior. A simple click on a button can produce a cascade of effects in an experimental setting that can reinforce or inhibit a well-defined sequence of tasks. On the other hand, the computer is the cultural artifact that has led to the modern state of globalization of our society. The modern computer, with its flashing screen, its astonishing sound equipment, its keyboard and mouse, its modem, is the right instrument to make interesting things happen, in our own environment or at a distance, with a simple click. What we call the "click option" is only the final step of a *cognitive decision process*, which can be of great complexity. Think about the moment we decide to buy a book through the Internet, it is just a click at the end of a long search on the screen, browsing the digital shelves, reading excerpts and reviews, etc. All this search is part of a *digital heuristic* that belongs to the new *digital skills* developed by a citizen of our global society. Perhaps we are witnessing the unfolding of a kind of *digital intelligence* for the new digital culture of the twenty-first century.

Children of a very young age, even under a year (Bruner, 1883), can learn to make clicks on the computer and produce some significant results. The user's motivation is very high because of the immediate feedback; the answer is automatic and facilitates further exploration. It is a happy coincidence that contemporary technology has produced such a powerful tool that fits so well with children's interests. It would be difficult to imagine the conquest of our world by the computer without children's extraordinary capacity to play with it. A computer industry restricted only to adult experts would be unsustainable. As Nicholas Negroponte rightly says "each generation will become more digital than the preceding one" (Negroponte, 1997, p. 231). This cultural fact is substantial to our understanding of modern education, where, for the first time in history, the pupil may know more than the teacher does. In a sense, the mastering of the new digital field is very similar to the acquisition of a native language. No child needs to read a manual to use a computer or take grammar lessons to speak. Moreover, the computer is a machine that can simulate any particular machine; it is a tool of tools (Minsky, 1967). Equipped with the right interfaces the computer can perform multiple tasks. And this is one of the reasons why we need computers in education, in particular in the teaching of science. As I said before, the most elementary action with a computer is the "click option", wich every child uses with remarkable ease; even those who are severely disabled can learn to produce a click, if properly assisted by an expert (Rose and Meyer, 2000).

In my opinion the computer enables us to expand our brain-power because it might activate some brain areas that were not used to perform some specific tasks in a traditional pre-digital culture. Let us take an example: drawing by hand or drawing by computer. The skillful analogical movements of the arm, the hand and the fingers, which help to make a drawing: this is a very complex sensory-motor process that is controlled by specific areas of the cortex and the cerebellum. But the user can shift to a digital modality that by-passes hand-drawing: the machine will do the drawing and the user only the programming. In this case, the brain makes a "cortical shift" from the analogical task of drawing by hand to the digital task of producing a computer program as in Figure 2. We can also obtain interesting functional magnetic resonance images fMRI to monitor this cortical shift (figure 2, see page I).

Writing a computer program needs linguistic and logical skills, while drawing needs spatial skills, and we can perfectly separate the cortical areas and cognitive modules involved in language and in drawing (Gardner, 1983, 1999). The artist can even *dictate* the drawing procedure to the machine (with a voice recognition device) instead of writing it down on the keyboard (Battro, 1991). It is of great theoretical and educational importance to identify the different cortical areas that are involved in analogical and digital tasks. In the case of Nico, because of his right hemispherectomy both tasks take place in the left hemisphere. I understand this remarkable compensation following brain injury as a proof of *the expansion of the natural neural plasticity with the help of a computer.* The same neurobiological argument favours the use of computers in children in general: new digital tasks will require new digital skills and the exercise of new patterns of brain activation. This opens a new field in education which way be called *neuroeducation*.

We may have a glimpse of some future applications of neuroeducation in the paper published by Stanislas Dehaene and his colleagues (1998) concerned with arithmetic (number comparison). In this experiment, the (adult) subject pressed a key with the left or right thumb to decide whether digits presented visually were larger or smaller than 5. We know that the precentral right and left brain areas control, respectively, the left and right hands. This fact enables the experimenter to make very accurate inferences about the cognitive tasks performed by the subject by a kind of "reverse neurology" which predicts the behavior (the number comparison) from the (right or left) brain activation. As the authors say: "Once we understand the function of a given brain area or network of areas, it should be possible to use on-line activation measurements to infer what kind of task the subject was performing". This very interesting experiment opens many intriguing questions about the validity of what might be some day a "reverse education assessment", i.e. the evaluation of a given cognitive performance from the corresponding brain pattern produced during the task. To sum up, neuroeducation can be understood as a bridge – under construction – between the neurosciences and the sciences of education.

The dual world (real/virtual) of science education

We are living in a dual world, where many things have a double representation: the newspapers are printed on paper, and, at the same time, are published in the Internet; a molecule is produced in the laboratory and is simulated in the virtual space; a museum has real visitors but also as many, or more, virtual visitors on the web; a surgeon performs a hemispherectomy but also can simulate it by virtual surgery, etc. As a result, many human activities can be projected in two dimensions, real and virtual; the result is a path on a 2D cognitive space defined by these two orthogonal coordinates. Many people believe that the virtual is taking the place of the real, but this is a misunderstanding. It is just another, independent, dimension of our world. What happens is that the virtual dimension of journalism, chemistry, the visual arts, medicine, etc, is acquiring increasing relevance in our cognitive world. This is why the use of digital devices, of computer hardware and software, is also of increasing importance in education in general and in science education in particular.

The interaction with a computer enhances the child's cognitive field: learning to read hypertexts enriches the mental process with new perceptual modalities and new links, programming a robot develops new skills, simulations and animations open new windows to imagination and action (Resnick *et al.*, 2000). The enlarged (digital) educational field is, certainly, changing science education. In a celebrated paper entitled 'Unlearning Aristotelian Physics', Andrea diSessa (diSessa, 1981) used a computer to provide new insights about the notion of force. He programmed a dynamic object that could be directed to a target using very simple commands on the computer, such as Kick, Right and Left. The game was to hit the target with a minimum speed, like a landing on the Moon (Abelson and diSessa, 1981; Battro, 1986). Many children and young adults were tested and most of them failed in an "Aristotelian manner", because they used the intuitive strategy: aim and shoot. They rotate the moving missile towards the target and then a Kick was given following the common intuition that "objects move in the direction you push them", i.e. that force correlates with changes in position. This is what diSessa calls now a *phenomenological primitive* or *p-prim* (diSessa and Sherin, 1998). The result is that the missile makes an “Aristotelian corner” and continues its movement without hitting the target. Only a few students applied the Newtonian idea that force correlates with changes of velocity (F=ma) and one of the preferred strategies (a “Newtonian corner”) was to produce a turn and a Kick to stop the missile, then turn again and Kick to finish.

The important point is that the new brain imaging techniques can be used to test some cognitive changes produced by current education. For instance we can study the changes from Aristotelian to Newtonian performances in the subject’s brain in the same way we can analyze the different cortical processes in reading strategies in English and Italian (Paulesu, *et al.*, 2000). We are moving from the general notion of “embodiments of mind” (McCulloch, 1968) to the study of specific “embrainments of science”, a new task for the twenty-first century.

REFERENCES

Abelson, H. and diSessa, A. (1981). *Turtle geometry: The computer as a medium of exploring mathematics*. Cambridge, MA, MIT Press.

Battro, A.M. (1986). *Computación y aprendizaje especial.* Buenos Aires: El Ateneo.

Battro, A.M. (1991). Logo, talents et handicaps, in *Logo et apprentissages*. (Ed. J.L. Gurtner and J. Retschitzki). Neuchâtel: Delachaux et Niestlé, pp. 167-173.

Battro, A.M. (2000). *Half a brain is enough: The story of Nico*. Cambridge, Cambridge University Press.

Bruner, J. (1983). *In search of mind: Essays in autobiography.* New York: Harper and Row, pp. 148-149.

Dehaene, S., Le Clec’H, G., Cohen, L., Poline, J.B., van de Moortele, P.F., & Le Bihan, D. (1998). Inferring behaviour from functional brain images. *Nature Neuroscience*, 1, pp. 549-550.

diSessa, A. (1981). Unlearning Aristotelian physics. A study of knowledge-based learning. *Cognitive Science*, 6, pp. 37-75.

diSessa, A. and Sherin, B. (1998). What changes in conceptual change? *International Journal of Science Education*, 20 (10), pp. 1155-1191.

Fischer, K.W. and Rose, S.P. (1997). Dynamic growth cycles of brain and cognitive development, in *Developmental neuroimaging* (Ed. R. Thatcher *et al.*). New York, Academic Press, pp. 263-279.

Gardner, H. (1983). *Frames of mind: The theory of multiple intelligences.* New York: Basic Books.

Gardner, H. (1999). *Intelligence reframed: Multiple intelligences for the 21st century.* New York: Basic Books.

McCulloch, W. (1968). *Embodiments of mind*. Cambridge, MA, MIT Press.

Minsky, M. (1967). *Finite and infinite machines*. Englewood Cliffs: Prentice-Hall.

Negroponte, N. (1997). *Being digital.* New York, Knopf.

Papert, S. (1980). *Mindstorms: Children, computers and powerful ideas.* Cambridge, MA, MIT Press.

Paulesu, E. McCrory, F. Fazio, L. Menoncello, N. Brunswick, S.F. Cappa, M. Cotelli, G. Cossu, U. Frith (2000). How native language affects reading strategies. *Nature Neuroscience*, 3 (1), pp. 91-96.

Resnick, M., Berg, R., Eisenberg, M. (2000). Beyond black boxes: briging transparency and aesthetics back to scientific investigation. *Journal of the learning sciences*, 8 (1), pp. 7-30.

Rose, D. and Meyer, A. (2000). The future is in the margins: the role of technology and disability in educational reform. CAST.

http://www.cast.org/udl/index.cfm?i=542

Sharma, J., Angelucci, A., Sur, M. (2000). Induction of visual orientation modules in auditory cortex. *Nature*, 404, pp. 841-847.

Vallery-Radot, R. (1922). *La vie de Pasteur*. Paris, Hachette.

Wiener, N. (1948). *Cybernetics*. New York, Wiley.

SCIENCE AND SOCIETY

YVES QUÉRÉ[1]

When an ordinary caveman, 100 000 years ago, set about chipping a flint to form a tool, he was already celebrating the wedding of Science and Technology: Science, because he was using knowledge learnt from his ancestors about nature (i.e. the hardness and brittlness of silicon dioxide); and Technology since this particular utilization of scientific notion was aimed at a precise and practical purpose (to cut wood or meat, or fight an enemy).

The long story of interaction between science and human societies is precociously contained in this tiny episode. Most evolution of societies is due to a mixture of science related technological progress (of course including agriculture, medicine, navigation...) and of ethics-related behaviours (linked to religion, philosophy...). In other words, Science and Technology have always progressed hand in hand, and societies have used both for better and for worse with regards to human dignity and happiness. However entangled Science and Technology may appear in this perspective, we can separately describe their possible influence upon societies, having in mind that our understanding of both depend strongly o the scientific education which we have received as children.

1. Science, a learning model for societies

The development of societies demands one absolute prerequisite: the intellectual and moral development of Man, and here science may play a def-

[1] Co-Chairman of IAP (*InterAcademy Panel for international issues*) and Foreign Secretary of *the Académie des sciences*, 23 quai de Conti, 75006 Paris (*international @academie-sciences.fr*).

inite role. Indeed, science is tirlessly educating us, decreasing our ignorance, and addressing not only our intelligence but also our personal and social behaviour, shaping our outlook on the world and even our character or our public spiritedness. From this viewpoint, a precocious education in science particularly along the lines of Hands-on or *La main à la pâte* approaches, should be of great help for developing this sense of civic responsibility which is highly requested in our times of hatred, racism and violence.

If we leaf through the large volume that this learning method represents for all of us and in particular for those who are not destined to practice Science, we might select some of the following chapter headings.

1.1. *The idea of freedom*

Science being par excellence a space for liberty, it constitutes a kind of humus for the spirit of freedom. How could societies develop, in the long term, with men held back by prohibitions or curbs on their thought, on their liberty to circulate, or publish? Science, its history and practice, teaches us liberty: that of a postgraduate who starts on his subject and soon frees himself from the orders of his supervisor; or that of an engineer who invents a new process, often well beyond, or in contradiction with, established ideas and his manager's directives.

Either lodged in the depths of human conscience, or expressed through visible institutions charged with preserving it (learned societies, academies, ethical committees, and so on), the spirit of freedom establishes these two virtues of mankind, *creativity* and *dignity*, two ingredients undoubtedly crucial for a development (or capacity building) of societies which will be sustainable and will escape to the deadly hold of dictatorships and various dependences, as well as to specious illusions of easy money and unbridled consumption.

1.2. *The virtue of humility*[2]

With Galileo, at the revolutionary time of Renaissance, Science becomes humble in that Man decides to seek the answers to his questions at the very heart of Mother Nature, by questioning her directly, via experi-

[2] Let us make it clear here that, while considering this virtue as consubstantial to Science, I do not pretend that scientists practice it all the time! In fact, some are arrogant, some are humble, and most lie in-between. I just claim that, whenever they flout humility, they put themselves in contradiction with their own discipline.

mentation rather than by extracting the fruits of his own thought. The law of falling bodies is no longer what Aristotle declared – however great a genius he might have been – but is rather based on what experimentation reveals: in fact, what Nature says about herself. Henceforth, the man of Science is no longer a god-like figure who decides on what is, or should be, but a simple decoder, a sort of interpreter with the job of transcribing for other men what nature unveils about herself, and in the language that she herself has chosen ("Geometry", as Galileo put it).[3]

This modesty, taken on by Science, is one of the hidden forces (generally we celebrate more its power than its humility) that should influence societies. It is this patient observation, often inglorious indeed, of nature, the renouncement by Science to explain everything and its capacity to draw the demarcation line between knowledge and ignorance which should teach us to respect the facts, to test permanently our thoughts against them, to mistrust preconceived ideas, to hate arrogance and to increase our tolerance towards fellow human beings, a necessary condition to put an end to conflicts.

1.3. *The spirit of research*

By unveiling some of the great fundamental laws that govern nature, Science teaches us the immensity of what we do not know, or do not yet know. It is these *not yets* which generate the spirit of research, and thus the endeavour for undertaking it and therefore the ability to progress. This is one of the major reasons for favouring a sound, open-minded (i.e. non dogmatic) scientific education for children.

Those for whom a scientific education has imbued both the sentiment that there is a "blank page" open in front of them and the necessity of rigorous thinking, should undoubtedly have more respect for facts than for ideas, more respect for ideas than for certainties. They should be inclined to think with honesty and resist the *more-or-less*, the *preconceived*, and also the *ready-to-wear* (including sectarian and superstitious) types of behaviour. Without a doubt, if this education has included elements of the multidisciplinary harmonics of our environment (physical and social), they will be attentive to the many different – possibly complementary – approaches we have to the world, and their minds will be tuned to sub-

[3] We would now rather say "Mathematics", the only language, together with music, being universal.

tlety. Here, Science is indubitably providing a space, a priviledged theatre, for imagination, creativity, open-mindedness, and thus for a harmonious development of our societies.

2. Technology, a debated path to progress of societies

As previously recalled, Science and Technology are consubstantial with each other each benefiting from the advances of the other. However, we generally consider Technology (in the broad meaning of the word) as the real visible link between Science and Society.

The unbelievable and astounding progress of recent decades in well being, health, life expectancy, agricultural output, comfort, travel, communication... due to Science and Technology is so obvious that it is useless to elaborate. It also looks so normal that we have to force ourselves never to forget, or to underestimate, it. Nonetheless, hunger, extreme poverty, infectious diseases... still exist in many parts of the world, while environmental degradation, global trends in climate change, growing economic disparities, dreadful injuries inflicted to nature, not to forget more and more sophisticated weapons, may be counted at the debit of Technology.[4]

A necessary (if obviously non-sufficient) condition to tackle these dramatic questions is to invite social and human disciplines (demography, sociology...) to enter the scene. In particular, it has become clear that if Science and Technology are imposed on societies without a minimum of respect for local customs and the social, religious and moral principles that these are founded on, there is a great danger that the graft will not take. Instead of anticipated smooth development, mass rejection may occur, and even social regression, generated by migrations of populations, chaotic urbanization, feelings of frustration... This is where the reference to Ethics has become, in the last decades, more and mor explicit, as a natural mediator between Technology and Societies.

2.1. *Ethics and the Golden Rule*

The purpose of Ethics is to set forth principles that can guarantee basic human right by repressing the priority instinctively given by each individual,

[4] See, in particular, the Proceedings of the IAP Conference on Transition to Sustainability (Tokyo, 2000) and the subsequent *Statement of the World's Academies*.

group, nation, to its own interests to the detriment of all others. In a word, Ethics is an attempt to establish as much equity as possible in a society. Although morality differs from one civilization to another or from one era to another, it has universal characteristics. One cannot deny that all men rally, around a few major prescriptions. One of them, the so-called Golden Rule, has the advantage of summing them all up in an expression known on all continents: “Do not do unto others a you would not like them do unto you”.

Regardless of whether the reference is secular or religious, we are seeing a widening of its applicability even as the men that it commnends to our sollicitude retreat from our field of vision, in space and in time. From the clan to the village, from the village to the nation, from the nation to the planet, but also from today to tomorrow, the duties given us become increasingly abstract because we are increasingly unfamiliar with the recipients of our grace. We can imagine the assistance given to the strangers in ancient societies: the foreigner, the traveller, who is protected even if he does not return the favour to his benefactor.[5] This succour given to all and sundry is doubtless more meritorious than services rendered to our close ones. It is the sign that we bring those who are distant into our midst, that we give them the substance, attributes and privileges of true brothers.

The first duty which the Golden Rule gives to Technology is of course not to harm men of today. This is the root of so many present debates on what should be done, or nor done, in an increasing number of Technology-related problems: genetically modified crops, chemical pollution, internet-favoured pedophilia, mad cow desease (and social struggle)... But aside from this rather classical duty, new types of problems arise concerning men of tomorrow. In this case Technology helps Ethics to open a new chapter of its history: this is the signification of the Golden Rule concerning a very far future.

2.2. *Problems and duties for a far tomorrow*

New problems appear like those raised by greenhouse gas production, by chemical or nuclear waste accumulation, or by frenzied consumption of natural resources, which are more detrimental for future than for present generations. If we consider nuclear waste, the potentiality of the danger which we create now may last tens of millennia. In the case of some chemical waste, the period of danger has no known limitation in time.

[5] This is well illustrated by the parabola of the Good Samaritan.

These long term harmful effects that we generate and leave as an inheritance for others prompt us to introduce not just the man from elsewhere but the man of the future in our ethical field of vision and to ensconce him there. How can one fail to recognize that this intrusion is profondly unprecedented? The obligation just described, to provide hospitality and fraternity was less abstract than it appeared. The meeting of contemporaries, one man to another, was still possible. In this new scenario, it becomes unthinkable. No cordiality will ever reign between beings hundreds of centuries apart. Henceforth, we find ourselves confronted with this new anxiety: expanding the Golden Rule to include men of the far future obliges us to consider hopelessly faceless human beings, whereas it previously applied to outsiders who, as different as they might be, were at least contemporary and capable of communicating with us.

Not that this ethical tie that links us to our remote descendants is a new idea: doubtlessly, the carpenter or stone cutter never existed who built a bridge without somewhat vaguely meditating on his responsibility to future rnen who will cross this bridge, with a confident step, for centuries to come. But this ethical duty takes on a unique dimension in our time due to our increased capacity to harm, sharpening our sense of responsibility for our descendants. We have learned to regard the intensive mining of the planet's riches as pillage to our descendants' detriment, and the accumulation of waste from our industrial activities as flagrant injustice in their regard. We would be guilty of gross negligence not to heed this widening of the Ethics. With the risks that we subject them to, come the special duties of elder brothers.

Before, time frames were quantified in terms of generations: "I want to leave my great nephews an Earth where they can live in peace and well being". Now, human beings who are totally unimaginable to us enter the scene, beings whose customs, knowledge and rapport with nature we cannot even imagine. Will they be supermen, through natural or artificial evolution? Or will dreadful cataclysms return them to the caveman state? Will they be able to decipher our messages? Will they have any awareness of their distant ancestors? Does it even make sense to try to penetrate the mists of time to ponder their situation?

Given the impossibility of finding answers, what purpose is served by asking ourselves questions about future humankind? Let us instead see in the production of greenhouse gas or in the disposal of long-lived radioactive or chemical waste, an ethical command of unforeseen magnitude. It is this injunction that we must consider: we have no right to leave behind a heritage of risks for generations in the distant future, and we cannot dodge the issue by postulating that scientific progress will protect them. At least, our contemporaries profit from the beneficial effects of our activities, which is not the case of future generations. These should not assume the responsibility for dealing with the harmful effects accompanying the benefits that we ourselves have gained. Among all the unknowns that torment us, at least one certainty remains: that our negligence will cause harm, and that our present behaviours have acquired the formidable power of exercising influence that is practically unending in time. The magnitude of the harm sets the tone for the breadth of the vigilance required and for the crucial importance of the research to be done in this field.[6]

As a conclusion

Let's be honest. Our generation would probably not have mapped out this "new ethical frontier" so unwavenngly had it not been driven by fear. Accidents such as those of Bhopal or Chernobyl have created a new mistrust of industrial operations that generate pollution and immediate or eventual fallout. Because of those accidents, ecologists have found added justification for their warnings, denouncing the wounding of nature, as much as the harmful effects to man. In this mistrust, let us salute the part that is well-founded, therefore spurring our research on safety and environmental protection, and also sort out the part that may be irrational and subjective.

In this regard, we may note that many other tangible risks – airplane crashes, smoking... – are more or less accepted because they are part of daily life and therefore commonplace. In front of the above-evoked long term and global dangers, the public's lack of familiarity with complex technical issues, the affected community's feeling of powerlessness, the quasi-infinite duration of potential harmful effects, and above all the original sin represented by Hiroshima and Nagasaki urge us to re-examine some of our asumptions about Science and Technology. We have also, in this broad field, to create a renovated dialogue between policy-makers and the

[6] Large scale programs of research have been launched in countries like Canada, France, Germany, Sweden, Switzerland, USA, to assess the long term reliability of various types of nuclear waste repositories. In France, customers participate, via a percentage of their electricity bill, to this effort.

public.[7] The latter must remain conscious of the immense benefits which we derive from Science, for the shaping of our minds, the intellectual stature of mankind, and the increased well being of many societies. But, at the same time, the former should be prepared to evaluate properly the dangers – those rooted in reality, not in obsessive fears – in which we live, be they natural or manmade.

To so do requires a minimum of education, understanding, judgment and solidarity.

[7] See for instance: Sir Robert May, "Bringing Science into Governance", *Science and Governance*, Brussels, October 10, 2000.

HANDS-ON SCIENCE

RICHARD L. GREGORY

Presenting science and technology, Hands-on to children and the general public, is not a new idea. It was clearly expressed nearly four hundred years ago by Francis Bacon, in his unfinished book *New Atlantis* (1626), which describes how the technology and science of his day could be made available to everyone. Francis Bacon describes his House of Saloman, as having:

> Perspective Houses, where we make demonstrations of all lights and radiations; and of all colours; and of things uncoloured and transparent, we can represent unto you all several colours; not in rain-bows, as it were in gems and prisms, but of themselves single. We represent all multiplications of light, which we carry to great distance, and make so sharp as to discern small points and lines; also all colourations of light... We procure means for seeing objects afar off, and things afar off as near; making feigned distances... We have also engine houses... We imitate also flights of birds; we have some degree of flying in the air; we have ships and boats for going under water, and brooking of seas; also swimming girdles and supporters. We have diverse curious clocks, and other like motions of return, and some perpetual motions. We imitate also motions of living creatures, by images of men, beast, birds, fishes and serpents....

We have also a mathematical house, where are represented all instruments, as well as geometry and astronomy, excuisitely made.

Bacon saw that science could, and should, be a social activity with all kinds of contributions according to individual abilities and personal interests. He emphasized *methods* of enquiry and discovery, and stressed the importance of useful inventions deriving from questioning and research. It could be claimed that he invented planned organized research and the use of science for practical ends. Bacon's *Novum Organum* of 1620 set up rules for scientific method, which inspired the foundation of the Royal Society in 1660; but nothing came of his *New Atlantis* dream – though then as now the future depends on children coming to appreciate how science works, and what it does and fails to do.

The principal modern pioneer of Hands-On science is Frank Oppenheimer (1912-1985), who founded the *Exploratorium* in San Francisco in 1969. Oppenheimer wrote (1976): 'I suspect that everybody – not just you and I – genuinely wants to share and feel at home with the cumulative and increasingly coherent awareness of nature that is the traditional harvest of scientists and artists'. He said of his exhibits (Murphy 1985), 'We do not want people to leave with the implied feeling: "Isn't somebody else clever"'. Our exhibits are honest and simple so that no one feels he or she must be on guard against being fooled or mislead'. Yet, though he was a physicist, Frank Oppenheimer loved the subjective phenomena of illusions of perception. He saw them as a way to introduce the observer – us – into science's account of the universe.

Three and a half centuries earlier, Bacon included in his *House of Salomon* – in which as we have been there were to be Houses of Mathematics, Engines, Instruments for measuring, and all the science and technology of the time – demonstrations of perception and illusion:

> We have also Houses of Deceits of the Senses; where we represent all manner of juggling, false apparitions, impostures, and illusions; and their fallacies. And surely you will easily believe that we have so many things truly natural which induce imagination, could in a world of particulars deceive the senses, if we could disguise those things and labour to make them seem more miraculous.

The recent popularity of Exploratory Science Centres, shows that a significant proportion of the public of all ages find direct experience of science entertaining and interesting (Pizzey 1987). For example, generally following the *Exploratorium* in San Francisco, there are the unusually well endowed Toronto Science Centre, and the astoundingly ambitious Parc La Villette in Paris. The first in Britain was the *Exploratory* in Bristol, which after twenty years was to be superceded by Lottery-funded *Explore*; then *Techniquest* in Wales, in Cardiff; and now some forty Centres and Galleries in Britain including Birmingham, Manchester, Sheffield, Liverpool and Glasgow. There are science and technology Centres in almost all European countries and around the world, including: Italy, Australia, India, Singapore, Switzerland, South America and so-far small Centres in Africa;

though not yet in Russia. The physicist Professor Paolo Budinich has been striving for many years to make his “Laboratory of the Imaginaton” a major Centre open to the public in Trieste, and is gradually succeeding. A large Science Centrte has openrd recently in Naples. This is now a widespread rapidly growing movement, with the coordinating organization ASTC (Association of Science and Technology Centers) in America, and the European ECSITE (Consortium of Science Industry and Technology Exhibitions) co-ordinating all European countries.

An important question is: Do interactive, hands-on Science Centres, really convey science? With their necessarily quick and easy demonstrations are they much more than Fun Fairs? Certainly there are similarities. But it is interesting that even when there is similar apparatus (such as almost zero-friction pucks on an air table, for a Fun Fair’s game and in Science Centres to demonstrate Newton’s First Law of motion) they are handled differently and apparently are seen differently, by children and adults.[1] The context and ‘atmosphere’ is very important for how things are seen. Possibly though, as suggested by Michael Shortland (1987), we have been too free with phrases such as “Science is Fun”, for much of science is tedious, difficult and sometimes dangerous. And science has social and moral implications which it is most unwise to ignore. This charge of triviality is important. It needs to be met with evidence of what people do get from Hands-On learning, but unfortunately hard data on this is not readily available and is difficult to obtain.

But it is hard to believe that learning can’t be fun. There are experiments with children showing that games, and active involvement of many kinds, aids learning (Hodgkin 1985). There is strong evidence that babies and children learn to see by hands-on (and mouth-on) experience, especially from the germinal work of Jean Piaget (Piaget 1929, 1952, 1955).

Perhaps most dramatically, the power of Hands-on experience as the basis of visual perception is shown by some rare cases of adults who were blind at birth, or at infancy, then recovered sight by eye operations when adult. Some of these people see, almost immediately, things that they had learned through their early touch experience; but are effectively blind for objects they knew nothing about before the operation (Gregory and Wallace 1963, Valvo 1971). For Gregory and Wallace’s patient ‘S.B’, upon first being shown an object (in the Science Museum in London) which for years he had wished he could use – a lathe – S.B. was frustrated. For

[1] This is rather like a frame affecting how a picture is seen.

although it was there in front of him, he could not *see* it. It was meaningless, until he shut his eyes and ran his hands over it. Then he stood back, and said: "*Now I've felt it, I can see*". He then described the lathe he saw for the first time, with considerable accuracy.

The importance of hands-on experience for learning and discovery is of course very clear in the history of science. This is generally accepted for modern science; but it now seems that there was an infra-structure of surprisingly sophisticated technology behind Greek science and philosophy (Sarton 1952, Clagget 1957, Sambursky 1987).[2]

It seems that both the development of science, and individual perception and understanding, require interactive experience with objects (including working models that can be constructed and handled) to approach and appreciate abstract theoretical principles. But unfortunately much generally available hands-on experience is misleading. The genius of Galileo and Newton was to select appropriate experience – as in Galileo's apparatus in the Florence Science Museum – which is perfect for today's hands-on Science Centres.

The importance of active touch precedes humans. There are many studies on animals showing the importance of active touch exploration for learning to see, such as the ingenious experiment of Richard Held and Alan Hein (1963), on a pair of kittens in baskets which were free to move but linked together. One of the kittens was free to move as he wished; but the other, could only follow passively n his linked basket – so he had similar visual inputs, but lacked voluntary control of where he moved. It was found that the 'active' kitten learned normally; but the linked 'passive' kitten did not learn to see, remaining effectively blind.

It is sometimes claimed that young children do not start with a 'blank sheet', but rather from very early on have their own explanations – which

[2] This is shown most dramatically with the discovery of an elaborate Greek astronomical computer c. 80 BC, found by pearl fishermen in 1900, in an ancient ship that sank near Greece off the island of Kythera. The American historian of science Derek de Solla Price describes an elaborate geared calendar mechanism designed to represent with remarkable accuracy astronomical cycles, especially of the Sun and Moon. The existence of this mechanism (and there are references to such mechanisms of several hundred years earlier, on public display in Greece) shows an active technology of metallurgy and applied mathematics, with remarkable mechanical skill. This suggests that Ptolemy's system of epicycles for explaining planetary movements was almost certainly built, with working models used as thinking tools for explaining the science of their day. As shown by the remarkable work of Joseph Needham (1954-) much the same is true for China.

are remarkably Aristotelian, and they may be very hard to shift (Driver, Guesne and Tiberghien 1985; Matthews 1980). Presumably children's '*naive theories of science*' (as sometimes called), derive from their everyday hands-on experience from infancy. The conclusion is inescapable, that although hands-on experience is effective – indeed essential, for learning to see and understand – it can hardly be adequate for arriving at *scientific* understanding. More is needed, if only because many basic principles and phenomena are normally masked, by for example 'poluting' friction. The normal world is not a good hands-on Science Centre! So children are quite largely misled by their everyday experience. Designers of toys might do a lot to improve matters.

One might say that Aristotle's, rather than Galileo's physics, is suggested by everyday hands-on experience of pushing objects and so on. Specially designed Science Centres can, for example, (almost) remove friction from moving objects, to reveal Galileo's principles, for children's individual discovery.

Is it possible that children *need* to live for years with an Aristotelian view of physics? Is there perhaps some kind of innate structuring, and inborn development, that we may upset with risk of harm? Also, where facts are concerned, is it perhaps best to let children learn facts isolated from interpretation – so they can build up their own cognitive structures, in their own ways, appropriate to their generation? There is certainly a danger of teachers imposing out-moded unhelpful ways of seeing and thinking. The alternative, is to promote originality in children, and expect them to develop in their own, largely unpredictable ways.

If we are able to stimulate originality through individual experimenting, how do we know that children will be better off, than when given at least a basis of accepted knowledge and beliefs? Surely we should try to assess effects of Hands-On experience with controlled experiments, comparing effects of interactive experience with other ways of presenting phenomena and ideas to children. But, for such educational research on how understanding may be be gained – how can we measure understanding?

Perhaps the greatest danger for a Science Centre open to the public, is switching visitors off by appearing intimidating. For the habits of mind needed for entering the Magic Circle of science, are intimidating for many people – perhaps because Science Centres were not be available for them, when they were children! It is well known that mathematical formulations are generally incomprehensible and scary. Indeed, looking for logical structures in ordinary arguments can be seen as rudely challenging; so the problem goes beyond mathematics, and is very general. Research is needed on how to introduce effective rigorous science-thinking into Science Centres.

It is remarkable how little science there is in traditional Science Museums. It is generally impossible to find concepts of force, energy, Relativity, Quantum physics, or computing in museums. There are motor car museums that do not show how an engine works; computer museums which do not show how mechanisms can represent and handle numbers. Conventional museums should gain with Hands-On experience. For without it, visitors are blind to the most significant collections of fossils, engines, or even the apparatus of science, presented in glass cases.

Returning to perception itself, Frank Oppenheimer said (1983):

> The Exploratorium introduces people to science by examining how they see, hear and feel. Perception is the basis for what each of us finds out about the world, and how we interpret it – whether we do so with our eyes or develop tools such as microscopes or accelerators.

Paradoxically, perhaps the most effective way to see our own role and limitations as observers and 'understanders' is through the intriguing phenomena of *illusions*, of vision and the other senses. These are wild and wonderful deviations from the physical world: deviations which may seem closer to fantasies of art, than to verities of science; yet they illuminate *us* as observers and so as scientists.

However curious this may be, phenomena of illusions reveal the tenuous links of perception, by which we appreciate ourselves and our relation to the world. Apart from their own interest they serve to warn us that we must check our perceptions, and question even what may seem most clearly true. As Frank Oppenheimer found (and I helped him in this at the start of the Exploratorium), these 'subjective' though often explainable phenomena help the visitor to be aware of what it is to observe and understand – through recognising failures to observe and understand.

Then pendulums, locks and keys, clocks, pucks floating on air, elliptical billiard tables – almost *anything* – takes on richer meaning. But to see these as meaningful phenomena of science considerable help may be needed. It takes genius to read phenomena without help from the past. Indeed, the history of science can be most revealing and helpful.

Even without knowledge of the ways things work, it is wonderful to experience the surprising forces of gyroscopes, magnets, inertia, patterns of spectral lines in glowing gasses – to discover the same patterns in light in stars. To go on, for example to appreciate the Red Shift, and how this tells us the Universe is expanding and that we can see billions of years back in time, it is necessary to understand abstract principles such as the Doppler shift. Additional sources of information are needed. Then Science Centres can be useful resources for schools, and are symbiotic with schools.

Handling Explanations

Following initial *hands-on* experience, there are various kinds of understanding. There are what we might call '*Hand-Waving*' explanations, which though satisfying and useful are not strictly justified or proved. Then, there are mathematical accounts – generally preferred by scientists – that we might call, '*Handle-Turning*', They capture computing and mathematics, with the essentially mechanical processes of algorithms.

So, we have a handy terminology:

HANDS-ON	Interactive experience	Explorations
HAND-WAVING	Common sense	Explanations
HANDLE-TURNING	Mathematics	Computations

Commonly accepted Hand-Waving assumptions may be hopelessly wrong, and misleading. The assumption here, is that initial hand-waving explanations may be corrected by selected hands-on experience, and refined and quantified by Handle-Turning scientific methods of mathematics.

Hand-waving explanations (in spite of science) remain important. An interesting example is understanding the gyroscope's tendency to turn ('precess') at right angles to tilt, and vice versa. For some scientists, a mathematical account is essential. But with no mathematics one can see what is happening, directly from Newton's First Law of motion, (that moving bodies resist imposed changes of direction or velocity. This applies to each 'point mass' of the spinning wheel).[3]

[3] Consider the changes of direction of its point-masses, composing it. When the spinning wheel is tilted, say to incline to the right, the point-masses at the wheel's front and back are forced to change direction – which they resist by Newton's Law – though the point-masses at the top and bottom are shifted sideways but not changed in their direction of motion. So they hardly resist the wheel being tilted. The resistance to change of direction of the vertically moving point-masses produce a force at right angles – horizontal – which turns the wheel right or left, according to its direction of spin The opposite happens when the wheel is turned right or left – then it 'precesses' at right angles to tilt to one side. Once one 'sees' this one understands the essential principle of

Signs of Understanding

How can we measure effects of Hands-On experience for gaining understanding?

There are well-established ways of assessing knowledge in schools. These include the written questions of formal examinations. They may also be open-ended essays, or multiple-choice questions. The latter are easily run by computer; the former is more revealing but requires skilled assessment, so is expensive. If only to prevent Exploratories looking like schools, which they are not, we should develop different kinds of assessment – which may useful for research into effects of hands-on experience.

1) *Surprise*: A powerful technique is to set up situations for *predicting* – where correct prediction requires and so demonstrates understanding of what is going on. Clearly defined and usually simple situations should be set up. False predictions can be clear evidence of inappropriate mental models of the situation. A classical example is Aristotle's rejection of the notion that the stars appear to move because the earth spins round. He jumped up – and landed in the same place – so how could the Earth have been spinning under him? What Aristotle lacked was the concept of inertia. This shows how important concepts are, and how soon we depart from common sense in science.

2) *Analogies*: A further test of understanding at a more-or-less deep level is ability to see analogies. If one understands, for example resonance, then similarities and deep identities are seen between what on the surface are different-appearing things or phenomena, such as: musical

gyroscopes, and one can predict which way it will precess for any turn or tilt, with either direction of spin – with no mathematics. And having seen it in this way the mathematics takes on meaning. By experiencing these forces interactively, for building informal hand-waving intuitive conceptual models in one' mind, one is set up to understand the mathematics – which allows precise generalizations even to all situations and is essential for *designing* for example gyro-control systems. I suggest that the major aim of interactive Science Centres, after stimulating interest and curiosity should be setting up Hand-Waving explanations giving useful intuitive accounts. They are vital for meaningful seeing, and for going on to rigorous Handle-turning mathematics which is so important for much – though not all – science and technology. It is interesting that almost all scientists use Hand-Waving mental models, images, and analogies for their creative thinking. The greatest, Newton, was skilled at Hands-On model and toy making; thinking up rich working Hand-Waving accounts of light, gravity and much else before attempting to arrive at his wonderfully broad and powerful Handle Turning mathematical formulations of Laws of nature.

instruments; the divisions of Saturn's rings; tuned radio circuits; the positions of spectrum lines given by resonances within atoms. It is clearly important to have *many examples* of different-appearing phenomena to practice seeing analogies.

We may look at *increased power* to see analogies for assessing effects of hands-on experience Here again the importance of a rich variety of examples is clear, for this allows not only discovering basic principles common to many examples (which is surely the key to creative intelligence) but also is a means for setting up on-the-surface surprising predictions – which by succeeding or failing *surprisingly* can test understanding. (Sir Karl Popper emphasizes failures of prediction as necessary for gaining knowledge; but surprising positive predictions are, surely, just as effective though perhaps rarer).

3) *Inventing*: We may look for ability to fill in gaps, and invent novel solutions – where gap-filling or inventing requires more-or-less deep understanding. An example would be filling in or inventing hidden parts of mechanisms. One can only see into black boxes by understanding them.

4) *Jokes*: With increasing spread of understanding of science and technology we may look for more widely shared humour – which will surely enliven literature and life. Ability to see and to make jokes is clear evidence of relevant understanding. Science Centres should have humour and be run with a sense of humour. Here again the 'Explainers' or Guides or Pilots or very important.

5) *Small effects*. Appreciating significance of small effects or phenomena shows they are appreciated as *conceptually* important though they are not *perceptually* dramatic. (Thus the Photoelectric Effect heralded Quantum Mechanics, and the precession of the perihelion of the planet Mercury was a key to Relativity. Though conceptually dynamite they are physically tiny. There are many such examples.)

6) *Nothing: happening*. Perhaps the most dramatic evidence of understanding is seeing significance in *nothing*. This is the point of experimental controls. We should widen the notion of *experiencing* phenomena, for in science a great deal comes from significant small effects and *nothing* happening. But only when the situation is understood; for it is essential to appreciate what should (or should not) have happened on alternative hypotheses to appreciate nothing.

We have suggested, that to assess effects of hands-on experience we may look for: (1) Being surprised by predictions that turn out wrong; or against the odds, are right; (2) Ability to draw analogies, or see links between what on the surface look like different kinds of phenomena; (3)

To fill in gaps, of mechanisms or whatever, and invent what could be there but hidden; (4) to appreciate relevant jokes; (5) To appreciate *conceptually small* but *perceptually significant* effects; (6) To appreciate significance of *nothing happening*.

Beyond Hands-On Exploratories?

We have admitted a danger of exploratory Science Centres trivializing science, and unfortunately many do just this. Should we, indeed, speak of a '*Science* Centre' that lacks the rigour of science? For as we have said science is a slow, often tedious and sometimes dangerous business

Explanatories

As we have said: looking at the traditional museums of science, we find remarkably little science. There are very few explanations or examples of *methods* of science. It is hard to find Kepler's or Newton's Laws; or how spectral lines may be related to atomic structure; or concepts of Quantum Physics or Relativity. This general lack extends to technology. It is quite hard to find explanations of how motors, or radios, television or freezers work. Yet, technology can be exciting as *successful* experiments that reveal general principles.[4] Is it simply that science museums seldom attempt explanations because this is not their traditional aim or purpose? Or have they have found it almost impossible to present ideas in a museum context? Are the concepts and principles just too hard to present, without the kind of background knowledge instilled over years in courses in schools and universities? This is an important question. It may be answered by seeing how far Hands-On science can be pushed towards explanatory concepts. But can we interact with *abstractions*, hands-on? Perhaps we need to add to Exploratories, somewhat separate more thoughtful '*Explanatories*'.

Possibly existing schools and universities *are* the Explanatories we need. But in schools and universities explanations are built up gradually, on

[4] To give a recent example; it is a most imaginative concept to use a microscope *backwards* to shrink design drawings into working integrated circuits (and even minute motors and tiny geared mechanisms) with components as small as nerve cells of the brain. And now we can actually see electron charges moving through the logic gates of micro-chips, with a beam-switched scanning electron microscope, strobing repeated signals to slow things down to speeds we can see – which takes us right inside Alice's wonderland by technology.

a carefully planned slowly growing basis of knowledge. Can we speed this up? Can we introduce sometimes difficult and counter-intuitive concepts, of physics, chemistry, life, symbols or whatever – in *minutes* rather than years? This is the challenge. Possibly only a few people will wish to take the step from the familiar assumptions of every day life into the non-intuitive, even bizarre concepts of science. But surely many people, of all ages, will find it incredibly exciting; even to giving new meaning to their lives.

How can we explore *abstract* concepts hands-on? Some essential principles can be experienced directly by removing contaminating effects. Indeed, this is how many experiments have lead to discoveries. Less direct, but vital for moving from particular instances to principles, is providing a wide variety of examples – so that *general principles* emerge. Perhaps familiar technology can help to introduce unfamiliar, strange ideas of science.

New technologies of data search could be useful for Eplanatories. Interactive computer-video disc technology can provide explanations, and allow individual journeys through facts and abstract concepts. But even apart from the expense there are problems to solve. For example, it is important to approach the same facts or ideas from different starting points – when they may appear in a different light – or remain dark! For this and for reasons of economy, many of the same pictures and descriptions will appear in different 'journeys'.

"Handle-Turning" mathematics

Finally, should interactive Science Centres introduce what is for many people difficult and intimidating: *Handle-Turning* mathematics? Here, computers can come to the rescue. They remove so much of the sweat and tears of 'handle-turning', and their graphics reveal to the eye abstract principles and functions, with great beauty. Then, computers can be linked to actual experiments, to show mathematical functions and underlying principles operating beneath appearances in real time.[5]

It has even been suggested – by Philip Davis and Reuben Hersh in *The Mathematical Experience* (1980) – that computer interaction allows dimensions beyond the three of space and one of time, that we normally experi-

[5] This is the basis of Seymour Papert's work (Papert 1980) on Logo, in which the computer controls a mechanical tortoise which interfaces the object world with the symbolic world of mathematics.

ence, to be visualized. A Rotating, computer-generated hypercube looks meaningless; but upon taking up the controls:

> I tried turning the hypercube around, moving it away, bringing it close, turning it around another way. Suddenly I could *feel* it! The hypercube had leapt into palpable reality, as I learned how to manipulate it, feeling in my fingertips the power to change what I saw and change it back again. The active control at the computer console created a union of kinesthetic and visual thinking which brought the hypercube up to the level of intuitive understanding'.

This is truly turning minds on hands-on.

Conclusion

For some people making decisions by methods of science is alien, even dehumanizing. Perhaps they see scientific method (which objectifies judgements) as conferring a kind of *artificial* intelligence to human beings; even to turning us into machines. Although it may be admitted that science and technology transcend political and racial boundaries, and confer many undoubted benefits, this is not how many people want to see the world. Is this because science has been inadequately presented? Or is it because science is unable to answer questions that people see as important for their lives? Scientific method can be too slow to provide reliable answers in real-time, for individual and government decisions. These may all be true; but most people simply lack the understanding to have a comfortable, intuitive feel for science and their every day technology.

It may be that formal mathematics has too much prestige and over-dominates science education; as it intimidates so many people, to put them off science. Although "Hand-Waving" non-formal accounts generally have a rather low standing, it may be that they are very important for giving context to facts; for remembering and structuring experience into knowledge.

Discovering how to help children and adults explore phenomena, and appreciate principles effectively, must keep Exploratory Science Centres re-inventing themselves – to become viable mutations in futures they help to create. In our 'handy' terminology, surely they will succeed richly when they stimulate curiosity with *hands-on* experience, and give understanding through useful though informal *hand-waving* explanations – leading a few to *handle-turning* skills of mathematics.

This is introducing science, by shaking hands with the Universe.

REFERENCES

Bacon, Francis (1620) *Novum Organum* (ed. F.H. Anderson). Indianapolis, 1960.

Bacon, Francis (1627) *New Atlantis*. Oxford: OUP [1915].

Churchland, Paul M. (1989) 'A Neurocomputational Perspective: *The Nature of Mind and the Structure of Science*'. Boston, MIT Press.

Davis, Philip J. and Hersh, Reuben (1980) *The Mathematical Experience*. Boston, Houghton Mifflin.

Driver, Rosalind; Guesne, Edith; Tiberghien, Andrée (1985) *Children's Ideas in Science*. Oxford, OUP.

Gregory, Richard. L. and Wallace, Jean (1963) 'Recovery from Early Blindness: A Case Study'. *Exp. Psychol. Soc.*, *Monograph II*, Heffers, Cambridge. Reprinted in: Gregory, R.L. (1974) *Concepts and Mechanisms of Perception*, pp. 65-129, London, Duckworth.

Gregory, Richard L. (1970) *The Intelligent Eye*. London, Weidenfeld.

Gregory, Richard L. (1983) 'The Bristol Exploratory – A Feeling for Science' *New Scientist* (17 November), pp. 484-489.

Gregory, Richard L. (1986) with contributions by James Dalgety and Francis Evans, *Hands-On Science: An Introduction to the Bristol Exploratory*. London, Duckworth.

Gregory, Richard L. (1988) 'First-Hand Science: The Exploratory in Bristol', *Sci. publ. Affairs*, *3*, pp. 13-24. London, The Royal Society.

Held, Richard and Hein, Alan (1963) 'Movement-produced stimulation in the development of visually guided behaviour', *J. Comp. and Phys. Psychol.*, *56*.

Hodgkin, Robin A. (1985) *Playing and Exploring*. New York, Methuen.

Matthews, G.B. (1980) *Philosophy and the Young Child*. Cambridge Mass. HUP.

Murphy, Pat (editor), (March 1985) *The Exploratorium*. Special Issue.

Needham, Joseph (1954-) *Science and Civilisation in China*. Cambridge, CUP.

Oppenheimer, Frank (June 1979) 'Everyone is you... Or me'. Reprinted in: Murphy op. cit.

Piaget, Jean (1929) *The Child's Conception of the World* (J. and A. Tomlinson transl.) London.

Piaget, Jean (1955) *The Child's Construction of Reality* (Margaret Cook transl.) London.

Piaget, Jean (1952) *The Origins of Intelligence in Children*. New York.

Papert, Seymour (1980) *Mindstorms: Children, Computers, and Powerful Ideas*. Basic Books.

Pizzey, Stephen (1987) 'Interactive Science and Technology Centres'. *Science Projects Publishing, 67.* Eccles Road London. SW 11.

Price, Derek de Solla (1974) *Gears From the Greeks: The Antikythera Mechanism*. A Calendar Computer from ca. 80 BC, New York.

Sambursky, S. (1962) *The Physical World of Late Antiquity*. London, Routledge and Kergan Paul Antiquity.

Sarton, G. (1952) *Ancient Science Through the Golden Age of Greece*. New York, Dover.

Shortland, Michael (1987) 'No business like show business'. *Nature, 328*, pp. 213-214. London.

Valvo, Alberto (1971) *Sight Restoration Rehabilitation*. American Foundation for the Blind, 15 West St., New York.

THE ROLE OF THE SCIENTIFIC COMMUNITY

THE RESPONSIBILITY OF SCIENTISTS IN THE EDUCATION OF YOUNG PEOPLE

RAFAEL VICUÑA[1]

We live in a world in which scientific discoveries follow one another with ever increasing momentum. Rarely have we the time required to reflect on the cultural, social and economic consequences of these findings, not to mention their ethical implications. It has become increasingly evident that science has ceased to be an exclusive bastion of the specialist, since it has entered the public arena and now relates to all sectors of society. In relation to this perspective, the scientific community has an inescapable obligation to both transfer this knowledge to the classroom in the teaching of the basic sciences and to participate in regulating the quality of this distribution. A good grounding in the basic sciences during the informative school years will not only produce better prepared candidates for higher education, but will also establish a society with more scientific understanding and thus enhance public participation in the ethical implications that may lie ahead.

Some of the strategies that the scientist will apply in fulfilling these criteria will be universally applicable, whereas others will depend on the level of economic and educational development within each country. Either way, to approach the subject of the responsibility of the scientist in the scholastic education of sciences, it seems advisable to take an individual country as a model. I will concentrate specifically on Chile, a country that has a population of about 15 million inhabitants and a per capita income of US$ 5,000 dollars (US$ 8,400 corrected according to purchase power). In Chile the percentages of the population that undergo primary, secondary and higher education are 98.6%, 90.0% and 31.5%, respectively. In regard to sci-

[1] E-mail: rvicuna@genes.bio.puc.cl

ence, Chile possesses a small but effective community. Currently there are about 3,000 active investigators who annually publish close to 2,000 articles in mainstream scientific journals. This statistic of productivity is ranked fourth in Latin America, although it would be placed first if calculated on the number of publications per investigator.

It is just over a year (November of the 2000) – since the results from the Third International Mathematics and Science Study (TIMSS) were announced by the International Association for the Evaluation of Educational Achievement (IEA). The TIMSS, which was established in 1995, surveyed students of primary and secondary education from 41 countries. In the third version undertaken in 1999, Chile participated for the first time next to 37 nations, with a sample of 5,907 students of 14 years of age originating from 185 schools of differing socio-economic backgrounds. The selection of participating schools was made at random, as were the groups of students (all 14 years old, Chilean 8th grade of primary education) within each establishment.

Tests in Mathematics and Sciences both consisted of 30 questions and each student was given 90 minutes to respond to each section. The questions of the test, that were of multiple choice and written format, were processed by participant countries according to a pre-determined rigorous procedure designed to safeguard the universal validity of the test. Once the answers were obtained, the results were grouped in five categories, those including the top 10%, 25%, 50% and 75% population of students and a fifth category which included the lower 25%. It is hoped that those students who had been exposed to a curriculum content of basic Mathematics and Science would be grouped in the upper half, that is to say, in the first three categories.

The results obtained by Chilean students are dramatic, as much in Mathematics as in the Sciences. Chile occupied position 35 of the 38 participant countries, surpassing in both cases only the Philippines, Morocco and South Africa, and thus locating far below the general average (Table 1). In Mathematics, the three superior categories included only 15% of the Chilean students (1%, 3% and 15% in categories 1, 2 and 3, respectively). The fourth category included an additional 33% of students, those that according to the characteristics of the test possess a level of knowledge equivalent to that of an average 10 year old (Chilean 4th grade of primary education). The fifth category included 52% of the Chilean students. According to the definitions, this category includes students who do not even satisfy the requirements of the average 10-year-old. In simpler terms,

Table 1. INTERNATIONAL STUDENT ACHIEVEMENT IN TIMSS

Mathematics

01.	Singapore	604
02.	Republic of Korea	587
03.	Chinese Taipei	585
04.	Hong Kong	582
05.	Japan	579
06.	Belgium	558
07.	Netherlands	540
08.	Slovak Republic	534
09.	Hungary	532
10.	Canada	531
11.	Slovenia	530
12.	Russian Federation	526
13.	Australia	525
14.	Finland	520
15.	Czech Republic	520
16.	Malaysia	519
17.	Bulgaria	511
18.	Latvia	505
19.	United States	502
20.	England	496
21.	New Zealand	491
Average		**487**
22.	Lithuania	482
23.	Italy	479
24.	Cyprus	476
25.	Romania	472
26.	Moldova	469
27.	Thailand	467
28.	Israel	466
29.	Tunisia	448
30.	Macedonia	447
31.	Turkey	429
32.	Jordan	428
33.	Islamic Rep. Iran	422
34.	Indonesia	403
35.	**Chile**	**392**
36.	Philippines	345
37.	Morocco	337
38.	South Africa	275

Science

01.	Chinese Taipei	569
02.	Singapore	568
03.	Hungary	552
04.	Japan	550
05.	Republic of Korea	549
06.	Netherlands	545
07.	Austrialia	540
08.	Czech Republic	539
09.	England	538
10.	Finland	535
11.	Slovak Republic	535
12.	Belgium	535
13.	Slovenia	533
14.	Canada	533
15.	Hong Kong	530
16.	Russian Federation	529
17.	Bulgaria	518
18.	United States	515
19.	New Zealand	510
20.	Latvia	503
21.	Italy	493
22.	Malaysia	492
23.	Lithuania	488
Average		**488**
24.	Thailand	482
25.	Romania	472
26.	Israel	468
27.	Cyprus	460
28.	Moldova	459
29.	Macedonia	458
30.	Jordan	450
31.	Islamic Rep. Iran	448
32.	Indonesia	435
33.	Turkey	433
34.	Tunisia	430
35.	**Chile**	**420**
36.	Philippines	345
37.	Morocco	323
38.	South Africa	243

85% of 14-year-old Chilean students show an unsatisfactory proficiency in Mathematics.

In the Sciences, the results were somewhat better, as the average mark was closer to the international average. The three first categories included 22% of the student population, (1%, 5% and 22%, respectively). The fourth category included an additional 33%, which means that 44% of the Chilean students are located in the fifth category that could not not even answer the most elementary questions. In other words, 78% of the 14-year-old students have not reached a satisfactory level in the Sciences. Figure 1[2] (see page II) illustrates the performance of Chile in the TIMSS according to the designated categories.

Figures 2 and 3 (see pages II and III) enable better comparisons with other sample countries that are deemed representative of the five continents and different performances in the test. As it is evident, the countries with better education have the majority of their students in the upper three categories. In addition, these countries possess a high proportion of their students in the first category. In Mathematics, this is clearly the case of Singapore (46%), Taiwan (41%, not shown), Korea (37%) and Japan (33%).

Surprisingly, the TIMSS showed that diverse factors that commonly are associated with exam performance, such as the economic resources of the school, the number of students per class, the duration of the class, the style of management of the educational system, schooling of the parents, etc..., are not directly determining in the results obtained. The observation that only 1% of Chilean students are located in the highest classification category despite nearly 10% of the Chilean educational establishments being private schools is an eloquent representation of this phenomenon. Table 2 relates to the lack of correlation between the hours of education and productivity in the TIMSS. The socio-economic situation of the countries also failed to significantly influence the results, as demonstrated in the Mathematics test, where 14 countries that have a product to per capita ratio inferior to that of Chile, obtained better results.

What therefore, are the fundamental factors that affect education? The answer to this question is of vital importance for those teachers and scientists who wish to assume the responsibility of a collaborative role in the teaching of science. Possibly this is the variable that the TIMSS

[2] Figures 1 to 4 are adapted from the document entitled *The quality of Chilean education in numbers*, by B. Eyzaguirre and C. Le Foulon, Centro de Estudios Públicos, Saptiembre 2001, Santiago, Chile.

Table 2. YEARLY TEACHING HOURS AND PERFORMANCE

	Yearly teaching hours of Mathematics (a)	Average score in mathematics (b)	Productivity per hour (b)/(a)
Indonesia	222	403	1,81
Morocco	207	337	1,62
Chile	161	392	2,43
Czech Republic	139	520	3,74
Australia	138	525	3,80
Slovak Republic	137	534	3,89
Japan	127	579	4,55
Chinese Taipei	126	585	4,64
Singapore	126	604	4,79
Finland	93	520	5,59
Netherlands	94	540	5,74
Average	129	487	3,77

regrettably does not measure, that is to say, the quality of teaching. TIMSS only reflects the confidence that the teacher possesses in his or her preparation and ability to teach the subject. More than 40% of the mathematics and science teachers in Chile feel that they possess an insufficient level of preparation. Given this precedent, what can be asked of the students? Or, phrased in a more eloquent manner, what would be the outcome if the teachers in Chile took the test?

As anticipated, with this quality of primary science education, the level of knowledge in students who progress to higher education is insufficient. Several pieces of data serve to illustrate the magnitude of this problem. In Chile, since 1967, a system of national examinations has been used to gain entrance to university. The main exam is the Academic Aptitude test, which is obligatory and designed to evaluate verbal and mathematical ability. The mathematics section is composed of 60 questions that include direct operations, deductive logical reasoning, symbolic interpretation, data analyses, etc., with a degree of difficulty similar to that of the TIMSS for students of the same age. In the year 2000, more than half of the participating students (53%) failed to correctly answer 50% of the questions asked, with only one quarter of these students achieving a score of 60% or more which is representative of the ability to handle basic level mathematics.

Other important components of the national testing system are the Specialised Knowledge Examinations, which are based on the common curriculum and elective courses from the general education system. Close to 50% of university careers require these exams, at last half of which request Mathematics while only 5% request Chemistry. In the Specialised Knowledge Examinations the number of questions varies from 40 to 60 and the level of difficulty is regarded comparable to that of the TIMSS for students who have taken the advanced courses from the general curriculum education. Table 3 demonstrates these tests and the percentage of students undertaking them. In the sciences, the number of applicants ranges from 29% in Mathematics to 4% in Chemistry. As it is possible to observe, the results are clearly superior in the areas of History and Geography of Chile and in Social Sciences. The average number of correct answers per question in these last disciplines borders 45%, whereas in the sciences this figure varies between 34.2% in Chemistry and 18.3% in Mathematics. In the same vein, the percentage of students with a score equal or superior to 60% is extremely low, reaching only 1% in the case of Biology. Finally, a high number of students have negative scores in the tests, achieved by the cancellation of one correct answer by four incorrect answers. This statistical information paints a clear picture of the remedial work that must be undertaken once the students arrive to the university. Usually a large percentage of the curriculum during the first year of higher education is targeted at removing the deficiencies left by the Chilean primary and secondary schooling system.

Table 3. STUDENT ACHIEVEMENT
IN THE SPECIALIZED KNOWLEDGE EXAMINATIONS

	History and Geography	**Mathem.**	**Physics**	**Biology**	**Social Sciences**	**Chemistry**
% students taking SKE	63,0%	29,0%	6,0%	20,0%	17,0%	4,0%
Correct answers per question (average)	45,6%	18,3%	24,3%	23,8%	43,7%	34,2%
% students achieving at least 60% in the SKE	26,0%	6,0%	9,0%	1,0%	14,0%	13,0%
% students with negative achievement in the SKE	1,0%	33,0%	17,0%	6,0%	0,2%	9,0%

In Chile, this flaw is not unique to the education of science. Systematic studies also demonstrate deficiencies in respect to reading comprehension within the population. As illiteracy indicators no longer give sufficient information relating to the level of the education within a country, other techniques have been developed to achieve this aim. For example, the Organisation for Economic Co-operation and Development (OECD) has been conducting an international survey (IALS, International Adult Literacy Survey) for the last six years in an attempt to evaluate the reading comprehension of a country. A population age between 16 and 65 years was surveyed in a variety of countries with the aim of obtaining an accurate reflection on the literacy of the population and the country's education system. In 1998 this test was applied, for the third time, to a sample population composed of 18 member countries of the OECD, along with Chile and Slovenia. In Chile a sample population of 3,583 people was co-ordinated by the Faculty of Economy at the University of Chile. The test measured the ability to comprehend prose and written documents and to interpret quantitative data. Within each of these three areas the answers were grouped into five classifications. At the extremes, level 1 included people of low ability, incapable for example, to determine the dose of a medicine from the information printed on the package. In the highest group, level 5, the occupants demonstrated the capacity to integrate information from several sources and an enhanced capacity to process data. Level 3 is regarded the minimal grouping for those people who can participate successfully in the so called 'The Information Age'.

The results of this test were disappointing for Chile. More than 80% of the sample population was located in lower levels, 1 and 2. Level 3 included 13% of the sample with only 2% of Chilean population being classified in the upper levels 4 and 5. The statistical distribution was roughly the same in each of the three areas measured by the test (Figure 4, see page III). It is important to emphasise that extraordinary abilities are not required to reach levels 4 and 5, merely the ability to interpret what is being read. It is surprising that with close to 11% of the Chilean population possessing a completed university education, only 2% of Chileans are located in the higher levels of this test. Deplorably, Chile occupied the last place among the 20 countries evaluated.

Although every scientist must have a preoccupation in relation to basic science education in his or her respective country, in a country that possesses a diagnosis as I have just described, this preoccupation takes on an added ethical imperative. We could ask therefore, what can scientists contribute in this regard?. The answer to this question is not a simple one, as the demands of academic life do not leave much time for extracurricular activities. Further hindering this situation is that participation in this field generally does not yield economic reward, nor does it yield recognition in terms of academic merit. Despite these obstacles a varied range of alternatives are available, those that are of an institutional or individual nature. Without pretension of being exhaustive, I would like to elaborate on some of these alternatives.

Institutional activities include those that involve the establishments of higher education, private companies, scientific societies, scientific academies and other organizations, all of which – of course – requiring the active participation of scientists. As part of their dedication to teaching, the universities should be naturally inclined to contribute to improving the quality of science education. Perhaps the most obvious and available contribution in this respect are the university courses that are offered to school teachers during their vacations. For example, for several years the Pontifical Catholic University of Chile has been offering such courses. These courses rely on a professor in charge with the participation of several colleagues of the respective Faculty. It has been interesting to observe that it is the same schoolteachers that periodically return to the university to attend these courses and thus replenish their knowledge. Along similar lines, 'Project Seed' will be established this coming January at the University of Chile as an initiative of the Millennium Institute of Advanced Studies in Cellular Biology and Biotechnology, incorporating contributions from Fundacion Andes and the World Bank. This Institute will offer an 18 month course in Education and Tools in Modern Biological Sciences to 120 schoolteachers of secondary education from all over the country. In order to gain entrance to the course, each teacher must possess a personal computer and a network connection to their respective school. A fundamental part of the course will be the analysis of the scientific developments that are reported by the press, with the objective of learning the best methods to transfer this knowledge to the classroom.

Academic institutions may also offer stimuli to enhance teaching quality, such as the Father Molina and Michael Faraday Awards which the Pontifical Catholic University of Chile offers annually to teachers of Biology and Physics, respectively. Both awards recognise educational innovations, the search of quality in educational methods, creativity, personal contribution and commitment to enhancement of education, among other criteria. The awards are financial, with the purse divided between the teacher and as financial assistance in the purchase of educational equipment for the institution to which the recipient belongs. The press announces the call for candidates and the presentation takes the form of a formal ceremony performed in the presence of the University Rector and the Deans of the respective Faculties of Science, during which time a lecture is presented by a professor from either the Faculty of Biology or Physics.

Further institutional participation could consist of inviting teachers to do investigation in the university laboratories during the summer months. Although the level of university investigation is extremely different from the type of experimental demonstration used by the schoolteacher, the temporary exposure and experience of investigation may well increase the enthusiasm by which science is then taught in the classroom. In Hungary a program of this type, for students of 14 to 18 years of age began in 1995, with the participation of mentors of the highest scientific merit and with the support of both the government and private institutions.[3] Currently this program encompasses nearly 600 mentors, 68 of which belong to the Hungarian Academy of Sciences. Every year, a national student conference is organised and 20 to 30 student presentations are made. During this conference the mentors talk about their passion and approach to science. To date, the university laboratories and institutes of investigation have trained more than 1,400 talented young Hungarians from all the regions of the country. This same program has lead to the establishment of almost 100 science clubs in Hungarian schools, where more than 1,000 students are introduced to scientific research by established scientists who visit the clubs and speak about their own experience or summarise recent advances in their research fields. The operation of the program has also lead to the formation of a network for schoolteachers, who met for the first time in 1999 to exchange experiences and ideas. Further information about this program can be found at http://kutdiak.kee.hu .

Using somewhat different criteria, the Educational Program for Children with Academic Talents (PENTA UC), was offered by the Pontifical Catholic University of Chile for the first time this year. This program aims to deliver the opportunity of enhanced education to young people between 13 and 14 years of age who possess a talent which cannot be developed to its full potential in the student's current socioeconomic environment. The Program relies on a Directorial Committee incorporating professors from the Faculties of Chemistry, Physics, Biological Sciences, Social Sciences

[3] P. Csermely, G. Halász, G. Jeney, J. Máthé, L. Mikló, D. Solymary, A. Szekeres, G. Tamás. *Biochem. Educ., 28*, 132-133, 2000.

and the Humanities. During the semester classes are given on Fridays in the evening and on Saturdays during the morning, in conjunction with two-week summer courses. All courses are presented by professors who are of a recognised standing in each of the disciplines. The students, who at the moment number 80, also rely on the support of two psychologists, who act both as their tutors and serve as a link with the schools where they study. Further details on this program are available at http://puc.cl/pentauc/

There is another institutional participation that requires a special collaboration from scientists, which is to improve the basic formation of the future science teacher. It is traditional for teachers to be educated in schools of pedagogy in an environment removed from the world of science. The courses that the future teachers take typically include History of the Education, Philosophy of the Education, Sociology of the Education, Curricular Design, etc, and like an appendix, at the end of the university career, some courses of sciences are added. Normally, these courses are given by university professors who do not belong to the Faculties of Science. Fortunately, the main universities in Chile introduced a fundamental reform in this respect, allowing that students who have a degree in any discipline can obtain a teachers degree after taking some courses of pedagogy given by the Faculty of Education.

It is also probable that industry may be interested in contributing to the improvement of scientific education. Perhaps in this case, its main contribution would be in the form of funds directed to the financing of the different programs. In this scheme, scientists must contribute not only to the design of the programs, but also will be required to obtain resources from the companies to finance them. On this theme, I wish to draw your attention to the 'Program in Science Education', a very interesting initiative that is being supported by GENER, an international electric power company with headquarters in Santiago, Chile. This Program is oriented to students between the ages of 6 and 14 from low-income schools. It is a 'hands on' educational scheme in which students are given the opportunity to gain knowledge through discovery, according to a carefully designed sequence of activities based on selected topics in the natural sciences and mathematics. The Program was developed by Chilean university professors who have extensive experience in scientific research and in both international undergraduate and graduate teaching. These professors train schoolteachers during the first two weeks of summer vacations. The training procedure involves confronting the schoolteachers with exactly the same research problems that will be presented to their students and thus advising the teachers on the problems and questions which may arise. Under supervision from these schoolteachers, the students have weekly 90 minutes workshops for around 35 weeks each year. The participating schools are provided with the same computer generated transparencies, lab instruments and other teaching aids used during the summer training sessions. To support the work of schoolteachers throughout the year, members of the university staff make weekly visits to each participating school and interact with teachers and students during the workshops. Staff members report weekly to the Program Director, who in turn reports monthly to GENER officials. Students participating in ‘Program in Science Education’ have demonstrated enhanced performance in both national and international proficiency tests. For example, a test consisting of three different problems taken from an earlier version of TIMSS was applied to six schools involved in the Program. Their scores were compared with those obtained by students from all countries that took this same test. Considering the schools as independent entities for each problem, they achieved places which would have ranked in the top thirteen countries which participated in TIMSS. Obviously, this is a considerable improvement, which is further enhanced by the observation that some of the students were two years younger than those from the other countries. The participating students also performed better than older students from the same schools who had not taken part in this Program. This Program started its operation in the summer of 1995 and since then over 200 teachers and 25,000 students from more than 40 different schools have participated. The Director of this Program is Dr. Sergio Hojman, a PhD in Physics from Princeton University and full professor at the University of Chile and at Andrés Bello University.

A summary of the participation of institutions in scientific education must also include those that form the scientific societies and the academies of sciences, a subject to which Dr. Jorge Allende has already referred to in this workshop.

Although all the previous institutional activities require the active participation of scientists, there are other possible approaches that can be performed based on their own initiative. An obvious participation would be to present classes in primary and secondary schools. In Chile such an action is currently not possible, since teacher’s union regulations prevent those who do not possess a university title in pedagogy from presenting classes. Paradoxically then, scientists and academics who present lectures at both undergraduate and graduate levels in universities, cannot present a class within the school system.

Despite this obstacle, scientists can use other forms of participation in the classroom. For example, maintaining contact with teachers and acting as scientific mentors. They can advise on the form of presentation of theoretical concepts and in the design of experimental demonstrations. Scientists could provide support material such as experimental software, videos and kits that would be of great benefit to teachers. With respect to presentation design, classes could be organised based on questions that will stimulate the students to think, instead of the simple regurgitation of information. Simultaneously, the laboratory exercises should be more than mere demonstrations. They should encourage the active involvement of students, and as far as possible, be oriented towards data processing to enable an understanding of the scientific logic involved in the experimental process and not simply the reporting of results.

Scientists could also incorporate the schoolteacher into their environment, inviting them to their meetings and providing connections to the scientific community as a whole. Additionally, the access to journals, catalogues and instruments that are not commonly available in the school system could be of great help to teachers. Through the channel of the electronic mail and electronic networking the interaction between the schoolteacher and the scientist can be quick, continuos and effective.

The fore-mentioned examples do not exhaust the alternatives of interaction between scientists and schoolteachers. Far from it, these ideas provide the stepping stones and building blocks that will ultimately provide the framework of a fully integrated scientific community. What is important, is to find the manner in which to harmonise the demands of academic responsibility with the fulfilment of a true ethical obligation, which is to enhance scientific education – and with this – enhance the participation of society as a whole in the ethical dilemmas which science will present. In the long term, better scientific development of our youth will enable society to not only value science on the socioeconomic benefits that derive from its applications, but instead regard science as an integrative, stimulating and everyday part of our culture.

Acknowledgements

I am indebted to Barbara Eyzaguirre for supplying me with valuable data concerning science education in Chile, to Dr. Mario Quintanilla for his stimulating comments and to Dr. Gareth Owen for his help in the preparation of this manuscript.

THE SCIENTIFIC EDUCATION OF CITIZENS

PAUL GERMAIN

This paper attempts to show that the best answer to the challenges of science for the Twenty-first Century lies in the scientific education of the citizens. The education of future scientists and engineers to prepare them for their job is, of course, crucially important and has to be improved. The papers of this workshop were right to emphasize this point, to highlight the difficulties and to give some interesting suggestions. Such improvements are necessary. But I am not sure that they would be sufficient to meet the present challenges of science. I think that a scientific education for the citizens should not be just a diluted form of the education given to future scientists. In order to express the main theme of this paper, I will consider, first, the present challenges of sciences, then, the place and the character of science within a modern culture and, finally, the third and principal part of this contribution, how to achieve this scientific education for citizens and who would be involved in such a project.

The present challenges of science

It is not necessary to emphasize again what has been told clearly many times, the last few days: science has been one of the most important factors in the evolution of our world for at least three centuries. For people it has provided new knowledge and for societies, many new possibilities of action which have made the life of the people easier. The speed of this change and improvement of conditions has been steadily increasing, especially at the present time with the appearance of what is called today modern technology. That is the art of building new machines, systems or equipment with fantastic performances by application of many new scientific results of various fields, especially through communication and computing sciences and techniques. This explosion of new products is developed by the market and what is called the new economics. This process will probably continue.

For any nation, the first challenge is to survive and, consequently, to develop its own ability in science and technology through effective education of its future scientists and engineers. However, it is not an easy task for many reasons. One major problem is the 'brain drain' which incites bright young people to do their advanced studies and to work in a country which offers better conditions that those they might get in their native land. We must also confess that at the present time, science and technology appear less attractive than they were in the past. In particular a gifted boy or girl may generally find today a more gratifying job by becoming a good lawyer or a good manager. Another reason is that science and technology are becoming more complex. Even a scientist cannot have a very precise idea of the scientific fields which are not close to his own domain of competence. Moreover at this time, the ordinary citizen doesn't understand what the scientists and engineers are doing. A social fracture appears between the people involved in the progress of science and technology and the other citizens. In the past, it was clear for most of the people that science and technology were working for the benefit of mankind. Today, it is not so obvious. The citizens see the damage caused to the environment by some modern industries or by certain new methods of modern agriculture. The globalization of the economy which is generated by the worldwide application of scientific achievements sometimes has had very serious social or ethical consequences. Moreover, the advances made by miniaturization thanks to electronics open up to terrorists the possibility of using chemical and biological arms. The people are frightened and sometimes get made. Finally, recent progress gives humanity the possibility to influence or reorient or modify its future. But who will be able to make the choice of what to do? Science alone cannot do this. That is why it must be deep-rooted in the overall culture.

Science within culture

It is clear that science provides new knowledge by processes very different of those, which are involved in many other disciplines; in particular those which belong to what are called 'humanities'. It is the reason why it is often found convenient to admit the existence of 'two cultures'.

We will not follow this view. We will consider that any body of knowledge and inventions belongs to culture if it might help a human being understand himself and understand, enjoy and make beneficial his relations with his physical and social environment. With such a conception, science obviously belongs to culture. But it remains to analyze and to clarify its place and role within culture.

Let us first consider the statements emanating from the classical sciences mathematics, physics, chemistry, astrophysics, geophysics and biology. They will be called scientific statements. The proof of such a statement – a theorem in mathematics, a law in physics or in chemistry, the existence and the properties of the cell in biology – when given by a professor in a lecture in front of students or by a scientist in a paper published in a scientific journal – is completely independent of the political, philosophical or religious views of its author and of his nationality. That means that all the scientists, if they are in agreement on the starting assumptions of the reasoning or on the conditions of the experiment, will agree on the conclusion. That is why one may say that such a statement belongs to the 'world of complete agreement'.

It is then quite evident that it is impossible, strictly speaking, to derive any philosophical or ethical conclusion from statements which belong to the 'world of complete agreement'. Nevertheless, that has been done sometimes in the past, and, as that world is ever increasing, it was thought that, in the future at any rate, the other kinds of statement would lose their validity. Even now such a temptation has not completely disappeared. An ideology may claim to be the sole global conception compatible with the world of complete agreement and, then, on the strength of this claim, it might disable the validity of a traditional culture, any other conception of humanism or a philosophical or religious belief. That was the case with the communist ideology in the Soviet Union. Is it not the case today with some capitalist conception?

What is clear is the increasing interactions of sciences and technology with social, political and ethical situations and problems. Great efforts have been made in order to introduce scientific methods and reasoning into the treatment of such problems. As a result, one finds in a modern culture human sciences, social sciences, law sciences, historical sciences and political sciences. However the 'scientists' working in these fields reach conclusions which have not in general the same kind of validity as those obtained by the classical sciences because the personal view or opinion of their author affects them. Nevertheless, they are very useful for the decisionmakers and cultivated people who want to increase the information available to them and stimulate their thought.

When science and technology come into interaction with a culture, they induce changes in this culture, some of which may be profound, but the foundations of the culture are not necessarily affected. It is important that the culture offers the possibility in any situation of keeping a critical standpoint to discover what is scientifically valid and what depends on a personal opinion or belief.

Means of providing scientific education for the citizen

In the first section it was shown that, in order to face its challenges in the present century, science has to be deep-rooted in overall culture. In the second, that in any situation faced by the society, the culture of this society must offer it the possibility of deciding what is appropriate for scientific analysis and what is not. The best means of satisfying this requirement is to provide every citizen with a suitable scientific education. This last section aims to indicate some ways towards reaching this goal. Three points deserve to be considered: what the pupils and students have to gain; the contributions of teachers; the contributions of scientists.

Advantages for the pupils and students

The most important element out of all the instruction they must receive is training to recognize the specific character of a scientific statement. This training might favorably start in the primary school with simple experiments children can do themselves. If one asks them to write the properties they have found or the result they have obtained, they will immediately note that it is completely independent of their age, their nationality, whatever they live in a city or in the countryside. The initiatives of my colleagues of my Academy Georges Charpak, Yves Quéré and Pierre Léna who lead up the operation: 'la main à la pâte' show that it works very well. When they are in junior high school – a secondary school – they will see, with some very simple examples, what is a proof in mathematics and what is a physical law. For those who want to enter a professional career which does not require an extensive education in science or engineering it is not necessary to give them too many statements of theorems or laws they will soon forget But it would be good for them to get an idea of what science is and of is its place and role in the culture, in a Western culture and in other cultures, in China for instance. That implies they may receive some elements of the history of science. There is some chance they will recall that science has a history, that it is a conquest of humanity, that it was developed for the benefit of mankind. It would be good also if, during their schooling, they could see examples of some contemporary places devoted to sciences and technologies by visiting laboratories, factories and science-museums. It is essential that all these activities be led by the science teachers, under their responsibility and with their comments.

The teachers' contribution

Teachers in sciences in high school receive a special education to obtain the necessary knowledge in the field they will have to teach and also a training to develop their teaching ability. They are selected by some process which check that they have the required capacities. That is good. That is necessary. Is it sufficient? In many countries the answer is affirmative. But, if one agrees with what was said in previous sections, it is not. Future teachers must receive in addition some elements of the history of sciences, even elementary ones, and must be prepared to increase their knowledge when necessary. Their attention must also be drown to the importance of the interactions of scientific and technical developments with many modern problems of society. These complementary additions to the program of the purely scientific disciplines are useful to provide future teachers with the sound resources needed to fulfil their job. Of course, it is a controversial point which deserves to be discussed. The position taken in this paper is that the scientific education has to be given by a teacher of science who must receive everything that might help him to convey to any of his students a correct conception of science so that he or she might be an enlightened citizen. It is highly desirable that this teacher makes the teachers of the other disciplines aware of what he is trying to do in order to obtain their agreement and perhaps their support.

The scientists' contribution

Scientists must, of course, firstly feel concerned by all that might be done towards providing citizens with a good education and be ready to contribute to the operations undertaken for this goal. They may contribute to the education of the teachers of science, be aware of the problems and difficulties they encounted, and give them help and support. They can make suggestions which may be useful.

But they must also understand that if science today does not attract enough young and bright people, it is because public opinion has lost the confidence it have in the past. The arguments for science which worked a few decades ago do not now have the same impact. It is up to the present scientists to discover the new formulation of the scientific ideal, one which will be more appealing and fit present expectations. It seems to me that it would be necessary to assert and to prove the relevance of fundamental research to modern society, as did the report of ALLEA – the association bringing together the European Academies of sciences and humanities – in 1996. Scientific statements are universal. The interpretation which can be given to them depends on the culture of the society where they are received, in particular on its ability to take on board new results without losing its basic values. Consequently, scientists are encouraged to participate actively in the cultural life of society. That will make education of the citizens easier and more successful. As it was noted by some of you, Academies have a special duty in this respect. As it is written in the statutes of the French Academy of sciences, the Academy must work in order that the cultural values of sciences may be integrated in every human culture. Let us note also that such a scientific ideal is necessary if one wants to avoid domination of scientific activity by industrial and commercial forces.

FROM A STATIC TO A DYNAMIC SYSTEM OF EDUCATION IN SCIENCE

ANTONIS V. VERGANELAKIS

Introduction

Four years ago I was invited by the teachers of an elementary school in Athens to speak about microcosmos to its pupils who had already been exposed to interactions and changes, as well as conservation principles from their activities at school.

While I was speaking about atoms, a little boy, not more than nine years old, asked me: “But why the electron in the atom does not stick to the proton?”

What a profound question!

I had to give an answer, caring to use the appropriate language for a child of that age.

My answer, as I can recall, was:

“The electron does not stick to the proton because it resists to the confinement, it resists to being shut in, it does not like the confinement as yourselves do not, therefore it reacts”.

From the expression of his face it was clear to me that the boy was happy with my answer.

Later on I started to tell the story of Big-Bang Theory concerning the creation of matter.[1] After having said a few things about the creation of the existing matter in the Universe, according to the theory, another pupil of the same age, asked me: “It means that my body comes from a recycling process?”

[1] You see I have confidence to the capability of children to assimilate new findings. I always remember the famous physicist Cecil Powell, many years ago saying that when you try to teach new things to a child it is as cultivating a plane. When you do the same with an adult it is as cultivating a desert.

I was surprised to hear that comment from a child nine years old.

Considering the number of questions the pupils of that school asked me that day, it was apparent that they were receptive, curious and imaginative. Furthermore, if they were exposed to some of the major conceptual schemes in science as they were at that school, they could be able to shape patterns of thinking and reasoning, which could help them attain a level of understanding and appreciation of new knowledge in science. This would serve them through their adult lives. This has been for me a very useful lesson.

Having said that, let us now go to the main part of my presentation.

Dealing with new scientific knowledge

The title of this paper could also be: "There is a need for continuous incorporation of the new scientific knowledge to the body of primary and secondary education".

But in what sense is there such a need?

We know that one of the basic principles which the various physical phenomena seem to follow is:

"No change occurs without interaction and interaction implies change".

When man interacts with *Nature* it is implied that *Nature* acts upon him and he, in turn, acts upon *Nature* resulting in mutual change.

All interactions of man with *Nature* have their limits, boundaries, rules and laws dictated by it, and this is something we should remember.

In the last decades man has started to interact with *Nature*, in most cases through the products of the application of sciences, in a novel *unnatural* way. The earth is forced by man to "live experiences" that have nothing to do with those in the past during the entire course of the human evolution and history. In that way man has modified his environment to such an extent that he has lost touch with his biological and ecological base.

Due to these novel interactions with *Nature, mankind now lives in phase of unprecedented and continuous changes of his environment* and nobody can foresee the consequences of these changes.

Among the consequences of the new interactions, there is one connected with the question: how far the new physical environment formed little by little on the Earth's surface will continue to be consistent with life processes, and, in particular, with human life?

There is great danger that at a certain moment this environment will no longer be consistent with life processes as long as, man continuously violates the boundaries, the rules and the laws that he should be followed when interacting with nature, *and this is something that Nature does not tolerate; one either respects the principles of Nature and he survives, or violates them and is rejected as a foreign body*.

This problem, due to the tremendous and continuous accumulation of new scientific knowledge, becomes every day more and more complicated. The new scientific knowledge brings new applications and one has to be continuously aware of their cost. Of course, many times the cost of the application of new knowledge, is usually deeply hidden and, even with the best of all prior assessments, not predictable.

Nevertheless, predictable or not one should fight hard for the survival of mankind, complying with the limits and laws of *Nature* in his everyday interactions with it. Towards this goal we need continuous incorporation of new scientific knowledge to the body of primary and secondary education, since at that level the foundations of society's knowledge are built.

Regarding the problem we are discussing, the incorporation of new scientific knowledge described above is not enough. Science by itself has not helped to bring a balance between man and nature. Apart from knowledge of science we need *wisdom* as well.

Now let me mention some of several other reasons that continuous incorporation of new scientific knowledge to the body of primary and secondary education, is required.

– Delayed dissemination to general public or, worse, its total missing of new knowledge would perpetuate the society's ignorance and blindness to science and technology.

– Science is the major force shaping the world today. The new knowledge in science and its applications support and determine the economy of a country, creating new products, a new human ecosystem, new concepts of the surrounding world, new modes of thought, and even new societies.

– The new scientific knowledge renders existing professions marginal (reason of unemployment) but at the same time it creates new professions.

The society continues to act, knowingly or not, according to the old concepts of previous centuries, although the new scientific knowledge has established new concepts that should have led to a new system of values governing our everyday life.

Examples of such new concepts are:

– The world is that of universal interconnection
– The world is that of universal interrelationship
– The world is that of universal interdependence
– Globalization

– Complementarity
– Fragmenation of knowledge – Unification of knowledge

The public should know the foundations and the meaning of them and act accordingly, however nothing of the sort has happened.

The education system is at fault

Whatever the reason for all the above problems is, it is evident that our education system is at fault.

For many years the system has remained unchanged. Although last century an unprecedented conceptual revolution took place, which logically should have led to a completely new education system, nothing has really changed. It has remained and still remains in many countries static and closed.

The newly acquired knowledge has not provoked a revision and re-evaluation of older ideas and thoughts that are part of the existing teaching material. The teaching methodology of the physical sciences has missed the experience of research procedures and the acquisition of new knowledge.

As we see schematically in Fig. 1, the higher, secondary and elementary schools have no interaction with sources of new knowledge. Furthermore the knowledge offered is codified and static. The teaching material, with unrelated facts and details, is always the same, sometimes recycled. The classification also is the same for all levels.

Thus with time, while the frontiers of knowledge were being continuously pushed higher thanks to international scientific contributions, the level of schools has remained the same.

The result of that was, and in many cases still is, the continuous increase of the gap between the various levels of education and the frontiers of knowledge. In the last thirty years it has become apparent that if this gap continues to grow it could be disastrous for education.

In some school programmes there has been an attempt to include some of the new findings but to no avail. There are scientists that still believe that the whole can be described and understood as the sum of its parts, but that is a great mistake. *Science is more than a collection of isolated facts.*

So if not by addition how could an educational system incorporate the fundamental results embodied in the new scientific knowledge and develop the educational methodology continuously, so that the system is dynamically developed? *How can we make the most general ideas of modern science part of our culture?*

CLOSED – STATIC EDUCATION SYSTEM

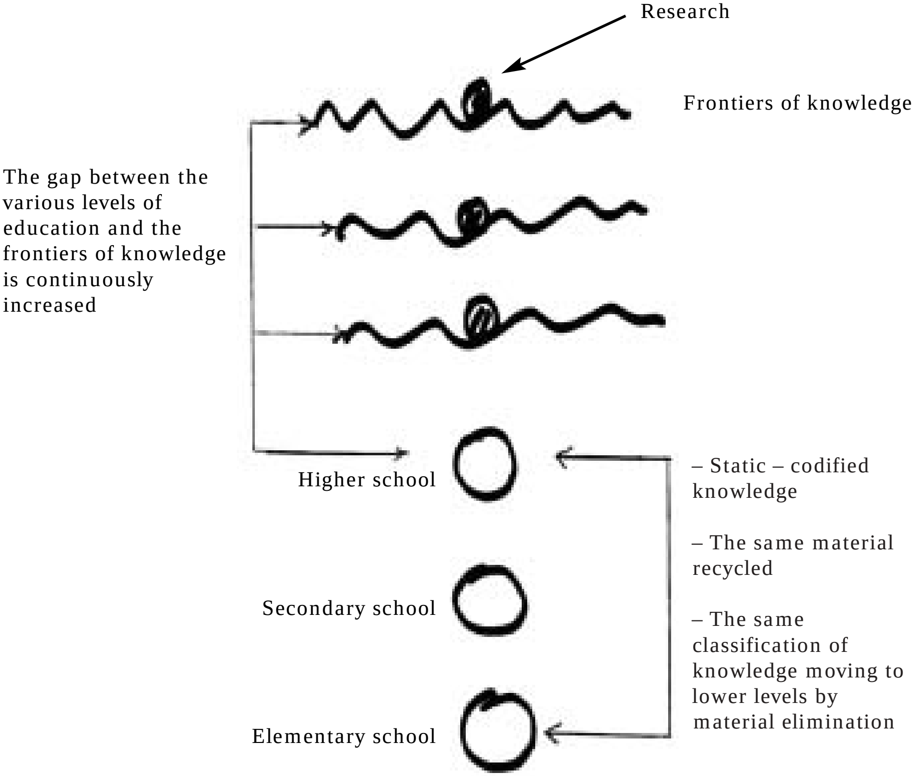


Fig. 1. The Higher, Secondary and Elementary Schools have no interaction with sources of new knowledge.

Presupposition for the dynamical development is that the system allowes, an immediate and continuous flow of new knowledge from the producing sources (research institutions) to the various grades of education.

The path of the flow of new knowledge in a dynamic system

Fig. 2 shows the path of this flow. It forms an expanding triangle. At the top there is the source (research institutions) of new knowledge, which moves on the frontiers of knowledge. At base there is the elementary education and at its sides the higher and secondary education.

By using the appropriate language and mechanisms and if the existing conditions allow it, the knowledge is going from the top to the higher and from the higher to the secondary and from the secondary finally to the elementary level.

As the new knowledge is passing through the various grades it is absorbed and in that way the system is refed.

This way, the foundations of the base (elementary school) are strengthened and they contribute to the elevation of all other levels on the right side of the triangle. The result is the top of the triangle goes higher, raising the frontier of knowledge as well. From its new position the source of knowledge gives new findings etc.

OPEN DYNAMIC EDUCATION SYSTEM CONTINUOUSLY REFEEDED

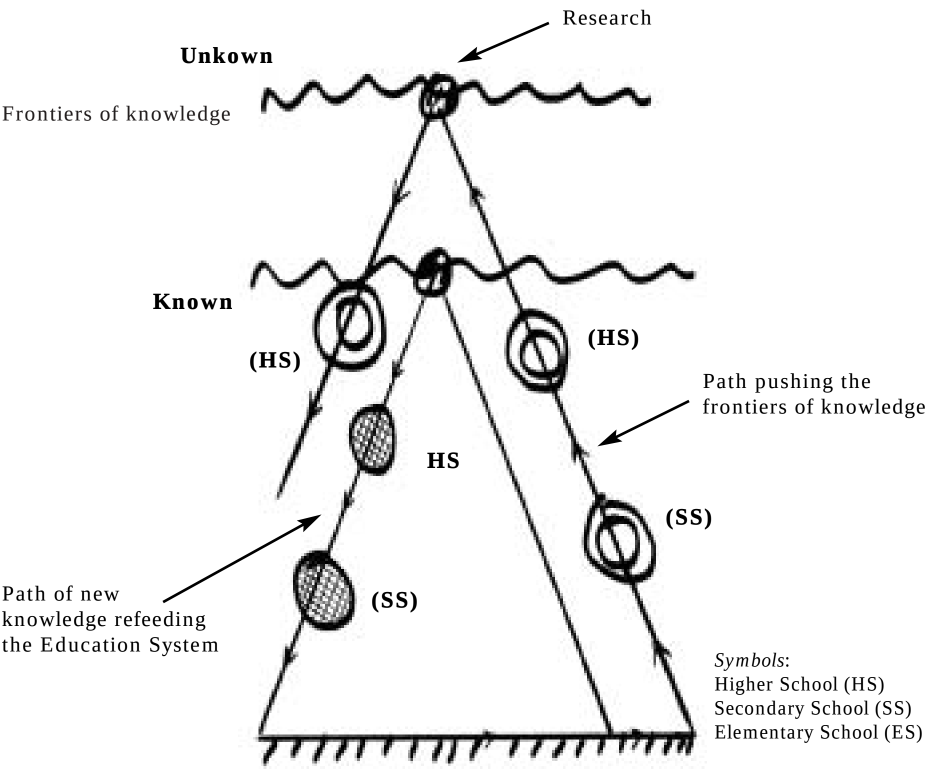


Fig. 2. The path of the flow of new knowledge.

The above flow procedure presents two serious difficulties:

1. How to insure the prerequisites for passing the new findings through the system and have them absorbed by it, or in other words how to keep the system in dynamical conditions.

2. How to find the mechanism to fulfil the above prerequisites and transmit effectively and quickly to the students of all grades the new findings.

Prerequisites for dynamical development

As it is known, every education system creates patterns of thinking and reasoning. These patterns constitute a kind of filter for the minds of the students. From that filter the general ideas of new knowledge may pass through and be absorbed by their minds.

In Fig. 3 this filter is presented schematically. Its characteristics are shaped by the patterns from which have been created.

FILTER FROM THE PAST

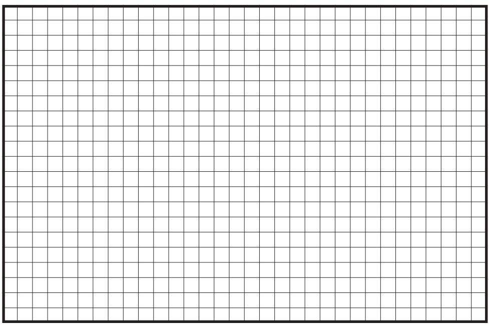


Fig. 3. A Schematic filter through which the new knowledge has to pass.

As is also well known physics taught in schools still today is based on nineteenth century science. At that time the only sources of information were the human senses.

In Fig. 4 you see an example. The observed phenomena were classified according to the way they were sensed. Thus sciences have been developed with the names: Acoustics, Mechanics, Optics, Thermodynamics, Electromagnetism, with little or no connection between them. This fragmentation of Physics, is so deeply ingrained in the minds of teachers of

Physical sciences that is difficult for them to adapt to different ideas of how to teach Physics.

In general man is not always prepared to have the foundations of his knowledge changed by new experience.

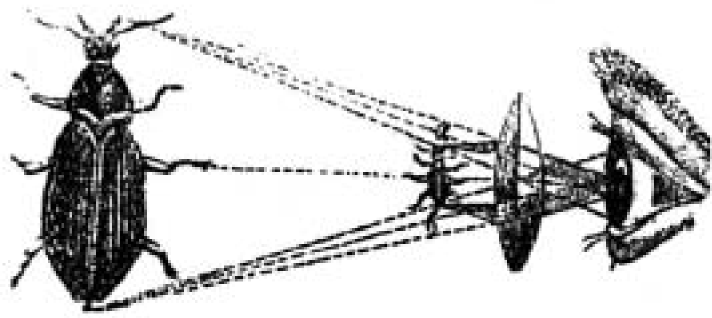


Fig. 4. Simple microscope.

The teachers of physical sciences usually transfer to their students the above “classical” model of physics and based on that they create to them patterns of thinking and reasoning for the physical world. With that “classical” pattern the students shape in their minds the filter through which they absorb or reject new scientific knowledge.

Today, in order to push the frontiers of knowledge further, our senses cannot play any more the role that used to play in the past. Nowadays in research we use instruments that go well beyond the capabilities of the human senses. In Fig. 5 you see a detector which is used in research of microcosmos. The comparison of the past and the present is given by Figs 4 and 5.

This detector reveals a new world in physics. Can we teach these revelations to the students? Will the filter that students have in their minds allow these revelations to pass through and be absorbed? The answer is negative. For pupils with the “classical” filter the new knowledge will be a “foreign body” and it will be rejected. Their basic concepts, their language, and their whole way of thinking are inadequate to understand atomic phenomena.

What should we do?

Obviously we have to take into account the revelations of the new detectors. The analysis of these revelations has led us to a conclusion: The new

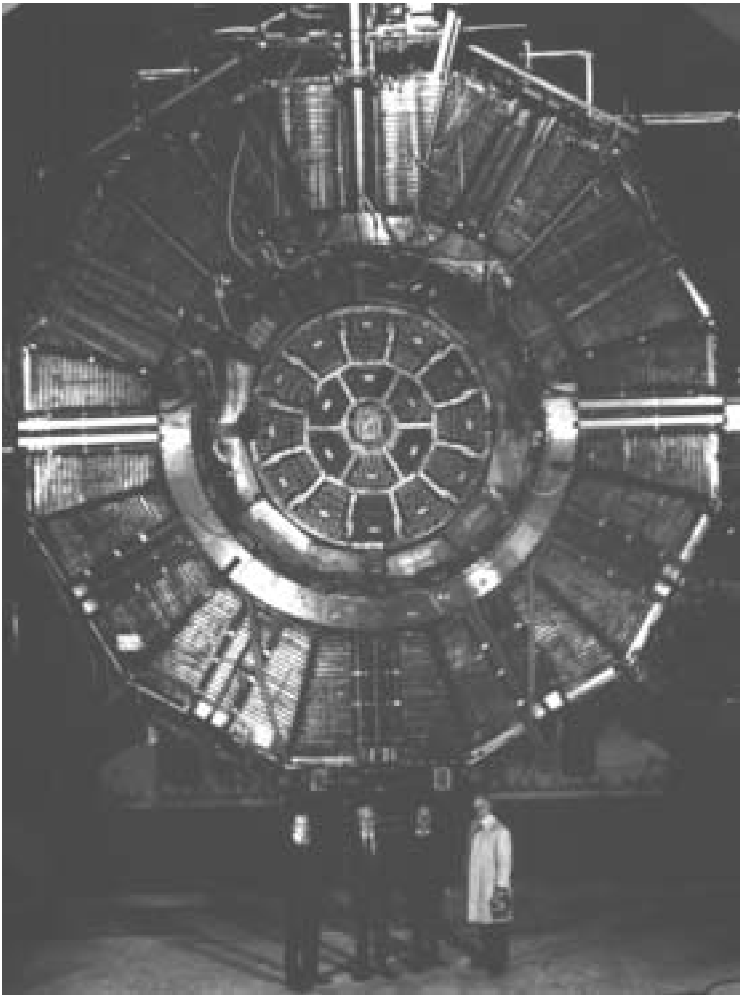


Fig. 5. A detector revealing the secrets of microcosmos.

phenomena that have been discovered follow some fundamental concepts which are valid in both macro and micro levels of the description of nature. If these concepts can be made meaningful to elementary and secondary school children, then with that equipment the children long after leaving school may retain some understanding of new findings.

From the same analysis we have learned that nature is not made up of a multimedia of objects, is not fragmented, but has to be pictured as one dynamic *whole*.

From Fragmentation to Unification

Nature forms a unity, which means that from fragmentation we have to pass to unification.

It is interesting to notice that this result turns us back to some centuries ago when our ancestors tried to understand the world as a whole, reveal the secrets of the Universe, and establish a relationship with their fellow men and their gods.

But after finding themselves unable to answer some questions convincingly, they discarded the attempt of discovering all the mysteries of the Universe and concentrated on certain isolated phenomena.

The success of this isolation rendered marginal the original problem of the relation of man with "nature" and his gods, and favored a false separation of man from nature. At the same time it influenced all aspects of human cultures, led to a fragmentation of their content, and gave a new direction to human thought and to the growth of knowledge.

This situation may have contributed to a certain progress, but at the same time it created boundaries and impasses. The separation of particular knowledge and concepts from others proved more and more dangerous.

Now in the light of accumulated experience we see that we are forced to review our course and change some aspects and the direction of our culture going back to its roots. A very nice result!!

Today the new knowledge is not in most cases a product of analysis but of synthesis of different phenomena. In order to have the necessary background to understand them we have to pass again from the fragmentation to the unification of the teaching of physical sciences.

If we want to prepare our pupils for this unification we should have the new science curricula focus on fundamental concepts that as we showed before, are valid in both macro and micro levels of the description of Nature.

If an educational system, since the primary school years, helps pupils assimulate the meaning of those fundamental scientific concepts, then it can provide them with patterns of thinking and reasoning which allow the incorporation of every piece of new knowledge into it. It helps to transform the education system from static to dynamic.

This solution is an answer also to the following five problems:

– The research is never ending, what we know today is inevitably just a small piece of what we are going to know in the next century. In our times it seems that the store of human knowledge doubles every five years, so there is a question how we would be able to teach all this material since the teaching hours at schools are always limited. One presupposes that the new knowledge should not remain “foreign body” for the next generations.

– The school has to provide the bases and the foundations for a “life-long education”. What do we have to do to achieve that?

– How to provide teachers and students clearly defined goals, as well as a cohesive picture of science?

– How to ensure that schools produce competent students?

– Since science is more than a collection of isolated facts, how to unify broad ranges of experience?

From all the above we may conclude that prerequisite for an educational system to function dynamically is that the schools, instead of filling the minds of pupils with unrelated facts and details, must focus their attention on certain fundamental concepts of science that form the bases for all explanations of physical phenomena.

In the next two tables a set of such fundamental concepts is presented for elementary and secondary schools respectively:

Fundamental concepts for Elementary School

1. *The Universe is composed of Distinct Units*

2. *Interaction and Change*

3. *The Conservation of Energy*

4. *The Degradation of Energy*

5. *The statistical view of Nature*

   (Nature is predictable only by the play of large numbers)

Fundamental concepts for Secondary School

1. *The Universe is composed of Distinct Units*
   Particles, Properties

2. *Interaction and Change*
   There are only a few distinct fundamental interactions
   In all interactions certain quantities are conserved

3. *The Conservation of Energy*
   The conservation principles are related to certain symmetries observed in the Universe

4. *The Degradation of Energy*
   The laws of thermodynamics
   Direction of energy changes
   Entropy, The spontaneous evolution of a system

5. *The statistical view of Nature*
   (Nature is predictable only by the play of large numbers)
   Uncertainty, Probabilities, Distribution Laws

6. *The Quantum behavior of matter*
   Uncertainty principle, complementarity

These schemes[2] were selected years ago by the COPES (Conceptually Oriented Program in Elementary Science) of the New York University, "because they include most of what is fundamental in science and because they provide the basis for a logical, sequential development of skills and concepts through the elementary grades".

As you see, in booth elementary and secondary school, the same fundamental concepts are used. With the appropriate language they can be meaningful for both. As one goes to higher grades the topics under each concept, progressively expand.

[2] See also M. Alonso, E.J.Finn, Physics Today 50, 140 (1997).

Mechanism to fulfill prerequisite

Let us go now to the problem of how to find the mechanism to fulfill the prerequisites for keeping the system in dynamical conditions and to transmit new findings effectively and quickly to students of all grades.

There are some facts relative to this problem.

– Equipped and suited to teach fundamentals are the scientists.

– The sources of new knowledge are the research institutions. These institutions are the central transmitters of the new “message”. In particular the specific producers of new knowledge are the best for transferring the substance of their findings in a simplified way. They have that substance in their “blood”.

If so desired the new scientific findings to be disseminated quickly and precisely to students of different grades of education and to the public, the research units have to play a new role in education, complementary to that of Universities.

With these facts in mind, one has to adjust the hole education activity.

The scientists that produce new knowledge have to transfer, their findings to the teachers and then the teachers to their students in the appropriate way and language.

In order to have a good communication during these steps the “transmitter” and the “receiver” must function well and be “in tune”. The first “transmitters” (the researchers) have to show “receivers” (teachers) how and what to transfer to their students. It means that the teachers should be scientifically trained in the spirit of fundamental concepts.

The whole problem is the education of teachers, in particular of teachers of elementary schools.

MODERN COSMOLOGY, A RESOURCE FOR ELEMENTARY SCHOOL EDUCATION

GEORGE V. COYNE

Introduction

The wisdom which has already come to light in this symposium has reinforced for me the following ideas which I would like to collect, if possible, into a single argument which I will try to establish by providing an example of teaching an actual class to elementary school students. You assembled Academicians and invited scholars are to be my class.

The ideas which I have garnered are the following: (1) we should start teaching children from where they are at present, their current knowledge, interests, fears, and so on; (2) all of us humans, those who teach and those who are taught, "have been made in heaven", it has been said. This refers to the well known need for stellar nucleosynthesis to provide the chemical abundances required for life in the universe. It has been indicated that one of principal goals of teaching children should be an awareness of this birth of ours from star dust, if only at an elementary level. I would suggest that the didactic order be reversed and that this awareness should be the beginning point of elementary school education; (3) the aim to develop "scientific literacy" has been a recurrent theme but I have not heard it defined. I propose an elementary definition which suits the purposes of my presentation: To be scientifically literate means to have an understanding of ourselves in the *physical* universe (the emphasis being on *physical,* but with the implication that I am speaking of all of the natural sciences: biology, physics chemistry and their derivatives); (4) Much has been made of the distinction between the methodology and the content of teaching. I would like to suggest that these two aspects of elementary school teaching find a unity in an ideology, a guiding theme, a single dominant perspective on ourselves in the physical universe.

"Being" versus "Doing"

My aim in this presentation is to show by a living example that the unifying theme of our birth from star dust can serve as an effective and entertaining way of introducing children to the elements of science. So let me begin, but first I must share with you an important but hidden conviction of mine which may not become apparent to you as I teach. For many years I have taught a general astronomy course to college freshman. In an evaluation of the course after about one month I received a recurrent refrain: "This course is fascinating and full of very interesting and new ideas, but it is useless". After many attempts at trying to refute that remark, I finally realized that it is correct. The course is "useless", if that expression is understood correctly. Philosophers distinguish, I am led to understand, between "being" and "doing". A knowledge of astronomy helps us to "be", not to "do". It shares, in that regard, with the visual arts, with music, with sports. Astronomy will not help me repair my car or make better toothpaste, but it will help me be a more interesting person, to myself and to others. It will help me to participate in a richer way in our adventure as beings in the physical universe. Many of the other sciences, of course, share in this "useless" nature of knowledge, but astronomy, I hesitatingly assert, does so in a preeminent way. So that is why I have chosen to teach it to children. I would never, of course, admit to my class of elementary school students that this year's course is useless. Children are already convinced of that without realizing it. They are quite content to grow in "being" and surrender the doing to "adults". Let us begin. Remember I am teaching you a year-long course in fifteen minutes. This is an introductory class to elementary school students in which many themes are only introduced and will be elaborated on during the year. These children are somewhere between the ages of 8 and 14. I am afraid my inadequate understanding of this age group will cause me to wander a bit in the range of difficulty of the ideas to be comprehended. I repeat, you are my class, at least for the next fifteen minutes.

A Class Taught to Children

Welcome, children. This year we are going to study about the world in which we live, mostly about the world way out there. But we will also be studying about ourselves, because, as you will see, we are part of the world and, although they are a long way out there, the stars are in some ways very close to us. It is going to be fun to see how close we are to the stars, even more fun than taking a picnic to the seaside or to the mountains. At least, I am going to have fun and I think you will too. And as we have fun, we will also see how important science is because science is one of the ways in which we can bring all of those objects way out in the universe close to ourselves.

You know how much fun it is at night to look up at the stars and try to see how, when we tie them together with lines between them, we can imagine various faces and animals and soldiers and our heroes. Take Orion, for example. Our ancestors, thousands of years ago linked up those stars and saw one of their great heroes, the hunter Orion, up there in the sky. And in front of him they saw the bear he was hunting and behind him his little hunting dog. These are what we call constellations and we will study about them this year.

But let's begin to think like astronomers think. Are all of those stars at the same distance from us? The answer is NO, but it took many years to find that out and it will take us this year some time to understand that NO. But let us begin by doing a simple experiment. Hold a pencil up a little bit in front of your nose, close your left eye and with your right eye look at my head. Now close your right eye and look with your left eye. Now blink your eyes like that many times. What is happening? Yep, the pencil is sliding to the right and to the left of my head. Now hold the pencil at arms length. What happens? Yep, the shift of the pencil with respect to my head still occurs but it is smaller. Now let us go out to the playground. Hold up the pencil again but now look at that tree down the street and then look at the top of that mountain out there? What is happening? Yep, we have noticed two things. When I look at a distant object the closer I hold the pencil to my nose the larger the shift and, if I keep the pencil at the same distance from my nose, then the shift is less for more distant objects. We have just discovered what astronomers call "parallax" and we will study this year how we can use it to measure the distances of the sun, the moon, the stars and even galaxies. We will soon talk about all of those objects.

Now we are becoming scientists so we have to ask more questions. Why is there the shift we have observed and why is the shift different for different distances of the pencil and the distant objects I am looking at: my head, the tree, the mountains. What would happen if your two eyes were together in the middle of your head, like those big giants in fairy tales? You guessed it! There would be no shift. It is because our eyes are separated that we see the shift. But the stars are so far away that the small distance between our eyes will not allow us to see them shift. What if we could separate our eyes by very large distances? Well, astronomers have found a way to do that. Can anyone guess how? We will find out later in the year.

When we study "parallax" later on in more detail, we will really become astronomers and will know that the stars we see in Orion are at various distances from us, some of them thousands of times further away than others. They only appear to be at the same distance because our eyes are too close together. In fact, we see everything beyond the Earth, even spaceships, as if they were at the same distance, on what astronomers call the "plane of the sky". Now that we have discovered this, let us look back at the stars in Orion.

With big telescopes – and we still study about telescopes later on – let us look at the belly of Orion. What we see is boiling gas and dust and, if we look very carefully, we see that some of the gas is red and some is blue and that the red and the blue are separated. Remember as scientists, when we see something like that, we have to find out why. Actually the red gas is the result of energy being transferred from stars to the gas, where that energy is swallowed up and then sent on to us. We will study about this later on. The blue gas is the result of starlight being reflected towards us, not swallowed up, just like light is reflected from a mirror; but the mirror in this case is the cloud made up of millions of gas and dust particles. Do you know why the sky is blue? It is for the same reason: sunlight is reflected from the particles in the Earth's atmosphere. But let us return to the discussion of the red gas.

Deep inside that gas new stars have been born. Yes, that is one of the marvels of the universe. Stars are born. They have a very long lifetime and it takes them a long time to be born. But we will learn later on that a star like the sun – yes, the sun is a star like all of those we see in the sky – was born more than twice as fast as we are, if we consider how long it lives. (I would introduce here the concept of the relative measures of time and distance, to be discussed in more detail later on. The sun was born in about 2×10^7 years and will have a total lifetime of about 10^{10} years; we are born in about 1/100th of our lifetime). The stars are very far away, so we do not see them being born, but we will see how astronomers can know about their birth. In fact, the red light that we receive gives us a clue to the birth of stars.

But what is light and what do we mean by swallowing up energy? Light is energy and, in this case, it comes from the stars. We will study about different kinds of energy. Light is one kind. It is called radiant energy and it travel in waves. Let us now do an experiment to show how light travels in waves. (See Appendix I for an experiment which I would now do with the children to introduce the wave nature of electromagnetic radiation. I would do this experiment in this introductory lecture so that the children could have fun and realize that the course will have many other experiments and not consist only in lectures). In order to understand what we mean by energy from the stars being swallowed up by the gas, let us do another experiment. (See Appendix II for a second experiment that I would do with the children on the absorption and reradiation of electromagnetic energy).

Stars are born in the following way. A big cloud of gas and dust in the universe begins to break up and the pieces begin to collapse. As a gas collapses it heats up and as it expands it cools down. We will study about why this occurs later on this year. The piece of the cloud that collapses weighs many times more than the sun and so it heats up to millions of degrees in its center so that it creates a kind of atomic bomb by turning hydrogen into the heavier elements. (Here I would introduce the difference between weight and mass with the promise to study it in more detail later on). This is a kind of nuclear energy. Later on this year we will study what we mean by nuclear energy and by light and heavy elements, but I can tell you right now that the gas in the star that was hydrogen will eventually become carbon and then finally iron. So a star is born when it turns on a nuclear furnace and it lives by making heavier elements.

Eventually, however, a star dies, just as happens to everything else in the universe, even to you and me. It is not very nice to think about dying, but in the universe, if stars did not die, you and I would not be here. In order to have the chemicals necessary to make our toe nails and ears and everything that lives in the universe, stars had to make up the heavier elements and spew them out to the universe as they die. Why does a star die? Because it finally has no more fuel for the nuclear furnace and it collapses and then explodes to spew out to the universe many of the heavier elements that it has formed during its life time. We are born of those elements; we are made of star dust.

As we study astronomy this year we will come back time and time again to understand what it means to say that we are born from the stars. We will see that the sun is one of a hundred billion stars in our galaxy, that we call the Milky Way and that there are billions of galaxies like the Milky Way. But one star is very special to us and that is the sun, because planets formed around the sun and one of those planets is our Earth. The planets formed because some of the matter from the piece of a cloud that collapsed to form the sun was left over and, after the sun was born, this material had to collapse into a disk. Why do I say “had to?” The laws of physics, which we will study this year, are the same for the stars as they are for us and for any other object in the universe. The material around the star had to obey a certain law of physics. (I would introduce here with examples the conservation of angular momentum). Do you think planets formed about other stars in the universe? Why do you answer "yes" or "no".

A marvellous thing has happened on our Earth. We can put the universe in our heads and that is what we are going to do during this year of studying astronomy. Some hundreds of years ago people like us discovered physics and mathematics and the other sciences and now we can use those sciences to find out how the universe works. Let me give you an example. When you go home I want you to weigh yourself and measure how tall you are. Tomorrow I want you to tell me what your weight is and what weight means. And then, without measuring your father's height, I will want you to tell me how much taller than you he is: two times; 1.3 times? Then we are going to talk about weighing a star and a galaxy and also measuring its size, even though we cannot touch a star or a galaxy. That is the marvel of being able to put the universe in our heads. We can measure the mass and size of stars and galaxies by knowing physics and the other sciences. We are going to have fun doing that this year.

Conclusions

Thank you all for being my elementary school class. What I have tried to establish is that, by using the central idea of our origins in an evolving universe, the principles of physics can be taught in an interesting way by introducing them at a time when the curiosity of the student has been aroused by the search for an answer to a real problem concerning his or her place in the universe. Here is a summary list of some of those real problems and the principles of physics to which they direct the attention of the student, as I have discussed them above:

1. Problem: What are constellations? Principles: distances, parallax, geometry, trigonometry.

2. Problem: how to see further in the universe than our eyes can see? Principles: optics, telescopes.

3. Problem: increasing the distance between our eyes. Principles: think like a scientist.

4. Problem: What is the difference between red and blue gas? Between emission and reflection nebulae? Principles: nature of light, reradiation of energy, reflection of energy, black body radiation and absorption.

5. Problem: How long does it take for a star to be born? Principles: numbers are relative, use of mathematics in science, powers of ten for large and small numbers.

6. Problem: How is a star formed? Principles: difference between weight and mass, gas laws.

7. Problem: How does a star shine? Principles: thermonuclear energy, atomic and molecular nature of matter.

8. Problem: Why does a star die? Principles: hydrostatic equilibrium, metal enrichment of the universe.

9. How do planets form? Principles: rotation, conservation of angular momentum.

I surmise that other sciences might also be able to find a central fundamental thesis which would allow a course development such as the one I propose for astronomy and physics. I leave it to the reader to judge as to whether the four ideas listed in the *Introduction* have been successfully incorporated, in a preliminary way, into the class I have taught.

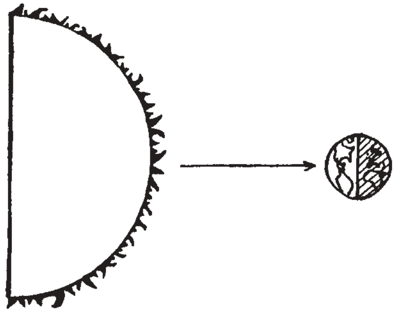
The Vatican Observatory has prepared two booklets of hands-on experiments which would be a key instrument for such a course as the one I envision. They are respectively for grades first to third and fourth to sixth (*Long Eyes on Space: Astronomy and You*, Designed and Developed by the Kino Learning Center [Tucson, Arizona: Vatican Observatory Foundation, 1991]). Samples of two experiments from those booklets are given in the appendices.

Appendices

APPENDIX I. *Long Eyes on Space: Astronomy and You*, II, p. 1.

DOES LIGHT TRAVEL?

People, animals and cars travel through space. Does light travel too?



Light travels from a ***source***, such as the Sun, through space and arrives at Earth in the form of sunlight. Light from ***stars***, other suns in the galaxy, also travels through space and eventually arrives at Earth as starlight. Some starlight comes from so far away that the light arriving at Earth has actually been traveling for millions of miles aver many years.

Light travels in ***waves***, much like those found on the ocean. To discover how light travels, use a simulation, or a model, to see how it works.

Make your own wave simulator to demonstrate how light travels.

Materials needed:
- large tub or pan
- marble
- water
- stop watch
- meter or yard stick

Procedure:
1. Fill the large tub with water, bringing the water level to within one inch of the top of the tub.
2. Drop the marble into the tub from approximately one meter (or one yard) above the water's surface.
3. Observe and record the movement of the water.

Draw and describe your findings

Light waves going through space move much like water waves in the tub. Energy from the Sun is released in the form of radiation, some of which is heat, so sunlight is warm. Starlight does not feel warm because stars afe so far away that the amount of energy that actually reaches Earth is very slight.

APPENDIX II. *Long Eyes on Space: Astronomy and You*, I, p. 11.

LIGHT MEANS ENERGY

Visible light is energy that you can see with the naked eye. The Sun, at the center of our solar system, ***radiates*** or shines this energy in all directions through space. Some of this light energy comes to Earth where it affects everything it touches.

Which is hotter in sunlight, a black object or a white object? To find out, conduct this experiment.

Materials needed:

- 3 large jars of the same size
- 3 thermometers
- black and white construction paper
- sunlight
- water
- clear tape
- aluminum foil
- 3 paper towels

Procedure:

1. Place one crumpled paper towel in the bottom of each jar.
2. Cover the outside of one jar with black paper, one with white paper, and one with aluminum foil. Tape the paper and foil in place.
3. Add equal amounts of water to the jars.
4. Place a thermometer in each jar. Make sure the thermometer rests on the paper towel so it does not touch the jar bottom.
5. Place the jars in direct sunlight.
6. Record the temperature of the water in each jar at the beginning of the experiment and every 15 minutes far an hour.

Record your observations on the chart below.

	Temperature				
Jar type	Beginning	15 minutes	30 minutes	45 minutes	60 minutes
White paper					
Black paper					
Foil					

Which jar had the warmest temperature?____________________

Which jar had the coolest temperature?____________________

Why do you think there were differences in temperature?____________________

____

If you lived in a desert, what color would you want your house to be in the hot summer?____________________

In the cold winter? ____________________

 Page 11

THE IMPORTANCE OF THE HISTORY OF SCIENCE IN INTELLECTUAL FORMATION

JEAN-MICHEL MALDAMÉ

What we call 'scientific knowledge' has two distinct facets. In the first place, the term 'science' refers to a collection of known facts which taken together give mankind a great power over nature. This is the side of science which is at once most visible and best-known. It allows us to carry out a vast range of projects, and it is thus part of the foundation of the modern global economy. Science in this sense has a place at the heart of our civilisation, a place which it will without doubt retain in the century which is before us.

The second aspect of science is something less well-known to politicians and to the public at large, but of great importance in the formation of scientists, namely, the scientific method. The scientific method is what allows science to develop successfully and to be put to practical use. Thus it is not enough for trainee scientists to gain a knowledge of what has already been scientifically established; they have above all to gain an understanding of the methods which will permit them to establish new truths and to envisage new technological applications of what they already know. This means developing a certain mentality, which we can call the scientific mind. A person with a scientific mind will know how to make the most of his rational gifts, yet at the same time be able to evaluate critically the use which he does in fact make of them.

This is the background to the remarks I shall be making about intellectual formation. There is one point in particular which needs to be stressed, namely the place which history must have in the teaching of science. The history of science is a branch of history which should not be neglected.

1. What is the 'History of Science'?[1]

1. The study of the history of science developed very significantly during the 20th Century. The work that has been done in this area allows us to determine more precisely what we mean by the history of science, and what ground this discipline covers. It is in practice the history of the natural sciences plus the history of mathematics. It is only rarely that the human sciences come into consideration in this connection. Some people would give the term 'history of science' a stricter sense, and mean by it just the history of the natural sciences. Nevertheless, the human sciences and mathematics share a common method with the natural sciences inasmuch as they are also rational acticivities.

The history of science as it has developed in the 20th century has two principal concerns. The first is to understand the way in which scientific knowledge progresses. The second is to understand the notion of science itself, which involves the questions of what methods are truly scientific and what kind of knowledge science actually offers us.

The studies that have been carried out in this field show how hard it is to separate the history of science from other branches of history. For example, medicine is at once a science, a technique and an art, and its history is bound up with the development of many different sciences.

2. The history of science obviously includes many different facts about things which happened at various times in the past. Yet simply compiling a list of such facts does not suffice for genuine history. For this, it is necessary to bring out the relationships between facts, indicating where there is continuity and where there is a break with the past. The history of science has thus to take into consideration the process by which science comes into being, that's to say, the various stages of its development. It's sometimes necessary in this connection to take into account the personalities of scientists themselves, in order to understand how they came to their various conclusions.

Not only must the history of science talk about 'facts', it must also talk about 'results', or about the diffusion within the wider scientific community of a particular piece of research. What happens here is that something which was the property of one individual becomes a sort of 'common good', and in the process gains a certain 'objectivity'. As soon as a result is published, it no longer belongs exclusively to the man who discovered it: it is now in the public domain.

[1] Cfr. François Russo, *Nature et méthode de l'histoire des sciences*, Paris, 1983.

What does this imply? It implies that other people may now find a significance of their own in what was discovered. They can adopt a given result for their own purposes and put it to uses which were not those of the original researchers.

3. This gives rise to a third consideration, namely the way in which the very notion of science changes as its methods evolve. What precisely is the sort of knowledge at which scientists are aiming?

Studying the history of science makes us see a dimension of intellectual work which is sometimes neglected, namely the cultural and spiritual context in which work is done. What appears to be insignificant at one moment can be of great importance later on. Thus Darwin would certainly have known about the work done by Mendel, but he didn't take it into account. Mendel's work didn't answer the questions which Darwin was actually asking, as their approaches to their subject were so different.

2. The Development of Science

One of the benefits of studying the history of science is that it helps to free us from a naïvely 'progressive' understanding of science. According to this view, science is supposed slowly but surely to have gained possession of the whole field of human knowledge; everything solid or well-founded in human knowledge is supposed to have come about thanks to the scientific method. In fact, history shows us that the development or progress of science is far from being a peaceful or uninterrupted affair. It is on the contrary an *adventure*, a human enterprise which is subject to the same vicissitudes as any other human endeavour.

2.1. *The Development of science: a fitful affair*

If the development of science were perfectly regular and harmonious, it would be a continual advance in which every result allowed one to proceed still further in the same direction. In reality, we find on closer inspection that science necessarily implies breaks with the past. This is what gives rise to the expression 'scientific revolutions', though the phrase is perhaps overly strong. Furthermore there is sometimes a long gap between the moment when a new discovery is made public and the moment when it is actually taken into serious consideration. For example, Saccheri published his work on non-Euclidean geometry at the beginning of the 18th century, but it wasn't looked at seriously for another hundred years. His work was easily available and yet it simply failed to generate any interest.

Another aspect of the fitfulness of scientific progress is that some periods seem much *richer* than others. During certain periods there is a great creativity about scientifc research; at other times science seems as it were to be in hiding. For example, in the first few years of the 20th century, we find Planck's work on quanta in 1900, and in 1905 the three principal theses of Einstein, namely those on Brownian motion, special relativity and photons. Likewise, between 1925 and 1930 we find the development of quantum mechanics, whilst in 1932 some very successful investigations are made into the nature of matter, with the discoveries of the disintegration of matter and of the neutron. What is is that makes one short space of time so extraordinarily rich? It is hard to say. Sometimes, of course, it can be the opposite which happens. In the Middle Ages, for example, there was not a great deal of scientific discovery: that was to come in with the 17th century, during which the foundations of modern science were laid.

Again, not all disciplines advance at the same rate. Biology, for example, developed much more slowly than physics, and even within a given discipline, the various parts do not always progress at the same pace.

A final point: the progress of science is also fitful in a geographical sense. We find that certain great centres of science – Athens, Alexandria, Bagdad, Seville, Oxford, Paris, Padua etc – flourish for a while and then decline.

2.2. *The search for greater precision*

Scientific discoveries, when they are first made, are not always so clear-cut and precise as they may appear to be later when they have found their place in a well-defined system. This causes problems for the historian of science. In the initial stages, ideas are often vague and ill-defined, and perhaps ambiguous, both in the mind of the scientist and in the experimental application which he makes of them. Yet it is precisely these ideas which turn out in the end to have been fruitful. Even when they are made more precise later on, we shouldn't forget what a rich significance they had originally, as it was precisely this that led scientists to interest themselves in them and to benefit greatly as a result.

Now scientific precision is acheived only gradually and often clumsily. The history of science shows us many a strange mixture of truth and error. True and false ideas are found together not only in the same science and in the investigation of a given question, but even sometimes in one and the same scientist. The founders of modern science themselves, men such as Kepler, Galileo, Descartes, Newton and Leibniz, were not immune from this law. The erroneous views which they all held on various matters didn't stop them from greatly furthering scientific knowledge: but their erroneous views had eventually to be criticised. Thus Newton, for example, sought to give a scientific account of the stability of the solar system, but at the same time put forward a whole host of speculations about divine activity at particular points in the world. It was not until the end of the 18th century that Laplace was able to give a fully satisfactory account of the planetary movements. Obsolete ideas can sometimes get in the way of scientific progress – witness Galileo's attachment to the idea of circular motion or Sadi Carnot's belief that calories were a certain kind of liquid.

2.3. *Conflicts of approach*

The history of science also shows us that one and the same question can be approached in quite different ways by different scientists, though this doesn't necessarily stop them arriving at the same conclusions. The best example of this is perhaps that of quantum mechanics. The formalism worked out by Louis de Broglie was quite different from the one worked out by Werner Heisenberg, but both of them give the same results. Planck and Einstein, likewise, approached the question of the quantum from very different perspectives.

Sometimes this varierty of approach causes conflict. One thinks of the battles between geocentrism and heliocentrism, or again between the followers of Descartes and the followers of Newton. Later on there were the battles between evolutionists and those who maintained the stability of species, and later still between the realist view of science and the conventionalist view. This raises the question of how a theory is to be proved.

We find in the development of science two opposing forces. On the one hand there is the urge to gain a fuller understaning of one's subject. On the other hand there is always a certain resistance to what is new. This resistance to change no doubt arises from the scientist's own attachment to certain opinions. He is used to thinking in a given way, and it is difficult for him to change. Gaston Bachelard describes this as the 'epistemological obstacle'.

What can we conclude from these brief remarks on the development of science? The historical study of science enables us to recognise the limits of scientific work. In particular it shows how science is simply one human activity among others: like all human activities, it is exposed to chances of every kind.

All this leads us to ask more fundamental questions about the nature of science itself. What makes something 'scientific'? What precisely do we mean by a rigorous 'scientific method'?

3. What is science?

Scientists sometimes give the impression that there is no difficulty about knowing whether or not a certain piece of research is really scientific. It might seem that everyone was agreed about what the relevant criteria are. After all, without some idea of these criteria, we wouln't be able to talk about science. Yet in fact our notion of science need to be rendered clear. As long as it remains ambiguous, it inevitably gives rise to misunderstandings and even to polemic, as happened recently with regard to 'water-memory', or during the Sokal affair.

Why does it sometimes prove difficult to agree on what counts as science? It is doubtless because science is made up of a variety of elements, and, as the history of science reveals, the importance accorded to these various elements has changed over the years. This also helps us to understand the difficulties which science is currently experiencing in certain countries: the very notion of 'science' is not understood in the same way in every culture.

A last point: the criteria which render something scientific vary according to the various branches of science.

3.1. *Science and pseudo-science*

Scientists today are sometimes confronted by what they consider to be *pseudo-science*. In France last year, this led to a very interesting argument at a certain university. A student who was known for her astrological publications submitted a doctoral thesis in sociology in which she described these publications as scientific. Scientists and other academics protested vigorously, considering astrology to be no more than a pseudo-science.

In fact, things like astrology have a complicated relationship with science. Sometimes they may be examples of a pre-scientific sort of knowledge which can in fact serve as a basis for science itself. It was in this way that alchemy was related to chemistry or ancient astrology to astronomy.

But they can also be the result of a hi-jacking of science, as is the case with certain religious sects which claim the title of science for what they practise in their healing-sessions or for their vision of the universe. The study of history enables us to make an impartial judgement of these matters and helps us to establish sure criteria of what counts as science.

3.2. *The basic criteria of science*

There are a certain number of criteria about what counts as a truly scientific approach to the world on which the whole scientific community is agreed.

1. *Objectivity*. All scientific work pre-supposes a separation between the scientist and his work. Objectivity is guaranteed by the fact that independent observers can obtain the same result; observations must be *repeatable*.

2. *Precision*. Observations must be precise, as must the words in which they are described, whether it is hypotheses, concepts, laws or theories which are in question.

3. *Attention to detail*. In his analysis of the facts, the scientist must endeavour not to overlook any aspect of what he observes.

4. *Universality*. Science does not seek just to ascertain individual facts, but also to draw from them generally-applicable laws. This requires an abstract language capable of expressing the 'models' which scientists use to explain their observations.

5. *Refusal of occult explanations*. The scientific mind does not explain its observations by recourse to occult causes, for example magic, or agents which lie outside the natural world, such as spirits, genies, or demons. This attitude implies a certain detachment from the world of religion, though it fits well with the acknowledgement of a unique, transcendent God who is not a part of the universe.

6. *Consistency*. A given explanation must be susceptible of incorporation into a more general theory. There can never be contradictions between the various parts of science. The scientific endeavour implies a desire to unify human knowledge.

7. *Regularity*. Science seeks to discover some regular pattern in what it observes, and it is this pattern which needs to be highlighted by the scientist.

8. *Open-mindedness*. The true scientist always has a critical attitude towards what he receives from the past, wishing to verify for himself the truth of traditional views. An argument from authority is not enough for him.

9. *Desire for constant improvement*. To be true to itself, science must always seek to be more and more closely shaped by the real world.

These criteria of genuine science are of course very general. They apply not only to the sciences of nature, but to all intellectual endeavour. We should also add that contemporary science is based on additional criteria, stricter than the ones just cited.

3.3. *Some more specific criteria*

In addition to the nine criteria given above, there are others which govern a more precise scientific method. It is in recent years that these stricter criteria have been clearly expounded. Thus:

1. Experiments are possible which modify nature to a significant degree.

2. All concepts used are subject to a full analysis, so that they may be 'operational concepts'.

3. Principles, ideas and theories must be capable of being measured against real facts. Thus Popper introduced the negative notion of falsifiability to explain what counts as genuine verification.

4. Knowledge is not to be understood as yielding certitude – this is a Cartesian ideal. Instead, it gives us greater or lesser degrees of probability.

5. The kind of measurement used has to be precise and clear.

6. Many notions hitherto the preserve of theology and metaphysics have to be considered objects of scientific thought. Examples include the formation of the universe, the formation of living species, the generation of living things. These facts which were previously explained theologically are now objects of scientific study. At the same time, it's important to recognise that such study is just one of the activities of man's intelligence, and that it doesn't exclude other approaches to these problems.

7. The notion of final causality is to be excluded from scientific discourse.

8. The process of mathematisation must be allowed to increase and become ever more refined. Mathematical objects, in fact, are no longer limited by the ideas and images implied by Euclidean geometry.

9. Experiments may be more various than was previously the case. There is a place, for example, for so-called 'thought-experiments'.

10. Statistical laws are to be accepted on the same footing as the strict laws of classical mechanics. It seems that theoretical physics, dominant as it is, leaves a place for the sciences of life.

This brief discussion of what counts as genuine science shows how useful the study of the history of science is. It enables us to see how scientific criteria have gradually become more precise, and how these criteria may be variously arranged and emphasised, thus giving rise to various ways of thinking. The distinction of science and pseudo-science is particularly important in the formation of the scientific mind.

4. Human formation

The remarks we have made about the scientific mind show how the study of the history of science can help promote a well-rounded human formation.

4.1. *Relations between various branches of knowledge*

What has been said about the training required by the scientist, in particular the distinction between science and pseudo-science, may serve as a general invitation for us all to consider what is the exact relation of our own discipline to other disciplines. It can be humbling for us to have to admit how very limited our own discipline inevitably is; yet in so doing we become more ready to learn from others, and to accept other points of view. We also become more cautious about demarcating the various parts of human knowledge too absolutely. History shows us the troubles that can be caused by inadequate definitions of different disciplines. One need only think in this connection of the arguments put forward in the name of religion on such questions as geocentrism, the history of the world, the gradual development of each human being, the evolution of living things and the origin of mankind. Unfortunately, as the influence of various fundamentalist movements demonstrates, the arguments in question are still to be found today.

Again, history helps us to avoid the mistake which is sometimes termed ‘scientism’, a philosophy according to which only scientific knowledge is truly worthy of the name of knowledge. History shows us how much the criteria of what counts as science have changed over the years. This should dissuade us from supposing that science holds a monopoly on the truth.

4.2. *The just appreciation of one’s own area of expertise*

The foregoing remarks about the history of science may not only prompt us to revise certain opinions about scientific work; they can also bring us to a better understanding of our own field of expertise, whatever that may be. The scientist, after all, is well aware that his knowledge is always in a somewhat precarious condition. He knows that he mustn't treat it as something absolute. This doesn't mean that he lessens its value, simply that he sees it as a part of a wider scientific effort. In this way, he is better able to appreciate the science which is still in the process of development, as well as the science which has already established definite results. The development of science is far from being a purely deductive affair – it calls for imagination and creativity, and even for that sort of 'contemplativeness' which is to be found wherever there is a genuine desire for knowledge.

History shows us that to judge of the truth of a given scientific proposition, we need to be able to place it in a broader context. In the life of the mind, there are certain fundamental options which govern everything else. An awareness of this allows us to see more clearly what intuitions and convictions have guided a particular piece of research.

4.3. *The foundations of science*

We can appreciate the greatness and the fruitfulness of science only when we truly understand its limits. The first of these limits comes from within science itself. For the exactitude and objectivity of science, and the clarity at which it aims, presuppose that the constitutive elements of a given scientific endeavour are properly defined. Yet when we seek rigorous definitions of all relevant terms, it becomes clear that science relies on certain notions which it is not able to define by itself – such things, namely, as force, space, time, matter, energy and so on. All these notions come to science from outside. They depend upon certain basic intuitions, upon that 'first philosophy' which is coaeval with thought itself and of which we are all the heirs.

In this way, science discovers its own foundations, and is thus also brought into contact with philosophy. Just as there was once a time when cetain great thinkers, men such as Descartes, Pascal and Leibniz, could be both scientists and philosophers, so even today every scientist has some philosophy upon which all his research is founded. The study of the history of science makes one aware of this link between science and philosophy. It is interesting in this respect to compare these earlier periods in the history of scientific thought with scientific education today, where the aim is generally to pass on those results which will help the student to gain a professional competence.

A scientific training which takes into account the various stages in the history of science thus enables the student to situate his discipline more successfully. He can learn to see what relation it has to the philosophy of nature, to the study of man himself, and to God.

4.4. *Science and reality*

The wish to come into contact with the real world is an important part of any scientific endeavour. As the criteria of what counts as genuine science show, particularly those which have to do with objectivity and experimental observation, the aim of the scientific method is to give us a more complete understanding of what exists independently of man. No doubt the object of science is something constructed by the mind: the scientist must not take the object with which he has to do, and which he represents by mathematical language or by general concepts, for reality itself. But his intention is always to come into contact with the real world, the existence of which he takes for granted.

Science thus aims at *truth*: and truth is defined by philosophical tradition as the agreement between knowledge and the world exterior to the one who is seeking to know. The scientific endeavour is therefore a movement towards a horizon which cannot be crossed.

Conclusion

In the context of this symposium of the Pontifical Academy of Science, which has education for its theme, it was important to stress that scientific training involves some intellectual elements and some practical ones. Nor should we forget the relations between the people who carry out the work of science, of which work education itself is one part.

Although teaching obviously includes the passing on of information, its aim is also broader than this. This fact is well-reflected by a change in official nomenclature that took place in France recently. What was formerly the 'Ministry of Public Instruction' has become the 'Ministry of National Education'. In other words, the formation given to children and teenagers is not simply to be reduced to a handing-on of items of knowledge; it must have a broader aim. Education has to foster all the various human qualities which will make for an adult life worthy of the name.

The study of science will obviously have an important rôle to play in this context. To complete what has already been said: a place must be found for the history of science within the teaching of the sciences themselves. This seems to me vital if the abstract and theoretical knowledge contained in the sciences is to be communicated in a way that takes into account the student's need for a well-rounded human formation. It is not during history lessons or philosophy lessons that this teaching should take place, but actually as a fundamental part of the scientific teaching itself.

Such an undertaking would seem to me to have a twofold value. In the first place, it would help students to gain a more accurate understanding of the true nature of scientific propositions. Secondly, it would give them a new relation to the scientific knowledge which they possess. One can add also that the study of history, whilst it may 'relativise' knowledge, nevertheless helps the student to develop a certain sympathy with what is unfamiliar. In this way he is better able to appreciate realities which encompass or transcend his own limited area of expertise.

Thus the remarks which I've made in this communication about the importance of the historical point of view are not limited solely to the history of the natural sciences. They also apply to the human sciences, and they have implications for the way that we relate to *any* branch of knowledge. This is particularly true for theology, for the progress which this has made in modern times is bound up with our understanding of history, as the case of biblical studies shows. It is the historical method which allows Christians to read the fundamental texts of their faith in a way that benefits not only their intelligences, but also their moral and spiritual lives.

A PHILOSOPHICAL PLATFORM FOR PROPORTION IN EDUCATION: THE "SCIENTIFIC SUBJECT" AND THE CREATIVE ACT OF THE HUMAN BEING

ANNA-TERESA TYMIENIECKA

Introduction

The Crisis of Science and Culture: The Danger of Overobjectifying and the Dissolution of a Harmonious Worldview

a) When Edmund Husserl in his *Die Krisis der Wissenchaften und des Europäischen Menschentums* called out his alarm signaling the crisis of Occidental science and culture, that work aroused intense intellectual excitement and provoked a discussion that has continued through the decades since. However, the focus of that discussion has changed with time. Husserl's focus was on a sclerosed, rigidly rational approach to scientific inquiry that put science in danger of losing all relation to the world in which it is rooted. True appreciation of the "lifeworld" from which scientific research into the manifestations of reality proceeds was at the heart to his appeal. the essence of his philosophical innovation. An overobjectifying rationalism was confining science to the strictly mathematical description of reality. The effect of this approach was the opening of a gulf between the so-called "hard sciences" and the humanities effecting an alienation of man from himself.

Today our situation has a different aspect. The crisis of Western – and, we can say, of all – culture has deepened, but there has meanwhile occurred a series of transformations in the nature of scientific inquiry such that its relation to the humanities has been revised. The issues involved concern ultimately the human being as an individual and the person in his/her role in life and place in the world.

In an brief discussion here we will show the great relevance of these issues to the matter of education. It is the human being who is meant to be educated, and thus what is fundamentally in question is the human condition in the world of life generally and as specifically human existence. This discussion is fundamental because it is one's worldview that gives one a foothold in existence, gives one's bearings in the world. The directions of one's striving in life are in the balance here.

b) At this stage of our scientific and cultural development, the crisis signaled by Husserl has taken the form of nothing less that the dissolution of the universal worldview that carried humanity over the last few centuries. That worldview, of course, was not static. It had its transitions and stages, which have followed developments in science and human knowledge in general.

But now the inherited, traditional worldview carrying human existence is disintegrating under the impact of an ongoing dissection of man so radical that worldview must be retrieved if the human being is to survive as human. The expansion of scientific knowledge has led to an imbalance view of man. The dazzling discoveries made there have diminished the significance of the reflective side of the human person, that is, his/her stream of emotions, sentiments, desires, expectations, hopes and ideals – a conundrum not entirely thematizable rationally – all of that which constitutes the inward, intimate dimension of the person within which she "dwells" in her very own being and within which she accomplishes her innermost striving for contentment, satisfaction, happiness.

While the hard sciences focus on the discovery of the physical world and its laws, the vast and ramified and ultimately imponderable side of the human being that is his own reflections has been left to the humanities to investigate. While the sciences deal with the objective sphere of reality, the humanities are concerned chiefly with the inner life of the person and with interpersonal relations. Although the sciences touch marginally on our human experience of beauty, solidarity, sympathy, beneficence, etc. (as well as on aggression, etc.), this experience is chiefly the focus of the humanities. Consequently, history, literature, the fine arts, etc. have an essential role to play in the education of the person and the foundation of his worldview, interpersonal life, and ultimate happiness. This side of life that appears at first to be strictly subjective is actually shared by people as sentiments and ideas so that there emerges what Nicolai Hartman called the "objective spirit", the culture of a society at a given time.

c) Plato, who distinguished in the Laws numerous matters indispensable in the education of an accomplished citizen, saw in the interrelations of the various disciplines of learning a harmonious order that he compared to a choral dance. In the Republic he calls for an equilibrium or proportionality to be established between them.

Today it has become urgent to devote some thought to how the effort devoted to education is to be apportioned among the disciplines. Do we focus early on education in a particular field in order to give the student a guarantee of professional success? Or do we make life enjoyment our aim and impart a broad education? For that matter, the question of how much versatility a person may need to be able to respond effectively to changing professional demands is rapidly forcing itself on us. These are the great practical issues underlying contemporary debates over education. The question of balance is of paramount significance for dealing with them adequately.

One postulate comes to the fore: In the formation of the human mind, we have to aim at such a proportionality that in the midst of the stream of unsettling transformations occurring in the world of science and societal life, a harmonious, flexible world view may be acquired so that students may find their bearings, their orientation in existence, their direction in and expectations of life. In order to find optimum equilibrium in all this, we have to spurn any one-sided over concentration on a particular field of study. In avoiding that pitfall the study of philosophy is of great significance for philosophy embraces all fields. In their investigations, therefore, philosophers are positioned to develop an estimation of the specific roles to be played by the various fields in the formation of the mind in their mutual interaction.

But what philosophy can be said to do so free from all presuppositions? Which may be said to be not only sufficiently informed but to have the impartiality to rightly estimate the shape of optimal education? As we have seen, in Husserl's estimation, the traditional accentuated opposition between the hard sciences and the humanities does not allow us to find in them a common denominator. But since his day the situation has changed. On one side, the sciences are transforming themselves from within sua sponte, and on the other side, a philosophy of life has emerged in which the sciences and the humanities may now converse on a common platform.

The proposal of this paper is that this platform is constituted by the coincidence of two developments. First, scientists are tending toward or have arrived at a new conception of the very nature of their pursuits and of the object of their pursuits as well. Second, in the philosophy of life, there has been a deepening recognition and appreciation that the human creative act is the source of all human pursuits, with scientific discovery and invention providing prime examples of that.

I will now review the general situation that has witnessed these developments that now may provide us a platform for balanced education.

Part One

TRANSFORMATIONS AND INNOVATIVE TENDENCIES IN CONTEMPORARY SCIENCE AND THE CONGRUENT INSIGHTS OF THE PHILOSOPHY OF LIFE

a. We are at a stage of transition in both science and our culture at large. Humanity finds itself in a sharply delineated transition period in all spheres: cultural, social, political, and scientific, which spheres usually coincide. Thus, when the Newtonian science of the seventeenth and eighteenth centuries – which had a deterministic, mechanical model of reality and which presented the world as originating from initial conditions in a strictly mechanical fashion so that all further developments were strictly determined, each being a step in a universal mechanical process, so much so that Laplace claimed that on the basis of it we could predict the future – reverberated through the scientific world and was almost universally accepted, that was because it accorded with the social outlook of the era of the Industrial Revolution, in which society too was viewed mechanistically.

Today we are witnessing the end of the Age of the Machine. This is Alvin Toffler's thesis in his foreword to Ilya Prigogine and Isabelle Stengers' work, Order out of Chaos. Man's New Dialogue with Nature.[1] As Toffler sees it, the deterministic model of the world was under attack already in the nineteenth century with the discoveries in thermodynamics, Darwinian biology, and quantum physics. It could then retain partial validity as a reference point for research and the formulation of issues. But in more recent times science has undergone a truly radical transformation such that the assumption of even a basic order and rationality in nature can no longer be persuasively upheld and is losing ground in a profound reassessment as new models of reality suggest themselves.

[1] Ilya Prigogine and Isabelle Stengers, Order out of Chaos, Man's New Dialogue with Nature (Boulder: New Science Library; New York: Random House, 1984).

As Prigogine, a prominent scientific researcher and interpreter, states, "Our physical world is no longer symbolized by the stable and periodic planetary notions that are at the heart of classical mechanics. It is a world of instabilities and fluctuations, which are ultimately responsible for the amazing variety and richness of forms and structures we see in nature around us".[2]

With Ilya Prigogine we may speak of a revolution in the scientific outlook, of the birth of a New Science.[3] The emphasis of classical science on the principles of stability, universality, regularity, symmetry, equilibrium recedes from the foreground and is replaced by the evidence of crucially significant states of disorder, arbitrariness, instability, irregularity, disequilibrium.

In all the sciences, not only the life sciences but those of physics, astronomy, mathematics as well, the essential role of change, transformation, evolution, event in the universe, the earth, human society has come to be appreciated. We have become aware of the birth and dispersion of elementary particles and of galaxies too, of changes in chemistry and geological upheavals that would be considered exceptional events in a mechanistic model. These are now considered to be part of a grand but hazy picture, as are the puzzling origins of living beings and the modalities of their differentiation and evolution, as are the unaccountable origins of and shifts in societal norms. The search for answers must correspondingly undogmatic.

This new outlook has proceeded from the "discovery" of time in physics, once almost ignored and now recognized as having crucial significance. The New Science, as presented by Prigogine in his numerous books, offers a "new dialogue" between the human being and nature. At its crux is precisely a reversal in the significance attributed to the temporal aspects of becoming.

b. With the introduction of the notion of "complexity",[4] encompassing all modes of order and disorder, we witness a bifurcation of hitherto one-sided concepts. For example, there are evident in dynamic systems contrasting processes that conserve energy and dissipate it. Similarly, we see mechanical and thermodynamic equilibria balanced by constraining non-equilibria. Moreover, Prigogine makes a sharp distinction between "closed

[2] Ibid., p. ix.

[3] Gregoire Nicolis and Ilya Prigogine, "Introduction", Exploring Complexity (New York: W.H. Freeman, 1989), p. ix.

[4] Ibid. pp. 71-141.

systems" in which things originate, change, deteriorate according to fixed patterns and "open systems" in which energy maintains itself.[5] It is the open systems of becoming that are primordial; these are open to exterior forces and exchange of energy, with the environment being susceptible to influences and exercising influence in turn.

The concept of open systems has emerged in response to the issues raised by Darwin's evolutionary theory and the dynamic systems observed by Prigogine. The common way of conceiving the temporality of becoming has been completely revised. When Ludwig Boltzmann set for himself the task of identifying evolutionary phenomena in the physical sciences analogous to those observed in the life sciences, he found them on the level of populations of molecules. He attempted to describe not only the equilibrium found in a population of molecules but how that equilibrium evolved. In doing so he discovered the irreversibility of the toward-equilibrium process, a time vector similar to that found in the evolution of species.[6]

Critically, Prigogine pursues the notion of irreversibility and attributes it to all open systems.[7] He shows that open systems, whether physical or biological or social, do not proceed in a reversible fashion, that the processes of constructive constitution do not go backwards. On the contrary, they follow a "vector of time". They are one-way constructions due to this irreversible vector of time.

It is precisely in such open systems having this constructive direction, interacting and exchanging energies with their environments in random, irregular, topsy-turvy fashion that Prigogine sees the initial conditions of becoming. Biological and societal systems present particularly striking open systems. Biology and genetics show us that below the recurrent scheme of life that we conventionally attribute to life's processes – what is merely an objectified, universalized surface – lie life's inner workings.[8] Under the surface innumerable sub-systems pulsate, bubble, criss-cross; instead of stability here is constant disorder and fluctuation.[9]

[5] Ibid., pp. 45-71.

[6] Ludwig Boltzmann, Populäre Schriften (1905), (Braunschweig-Wiesbaden: Vieweg, 1979).

[7] Prigogine and Stengers, op. cit., pp. 257-290.

[8] Nowhere do the inner workings of life appear more clearly than in the search for rules of articulation, the formation of models. See Rene Thom, Structural Stability and Morphogenesis: An Outline of General Theory of Models, trans. A.D. Fowler (Reading, MA: W.A. Benjamin, 1975).

[9] See Largeault, Systemes, op. cit. and Thom, "La creation de nouveau...", op. cit.

The very recognition by scientists of haziness, fleetingness, arbitrariness in physics and then in biology extends to all sectors of reality. In psychology too there is recognition of the turbulent life of the mind at the pre-conscious level. The pre-conscious turmoil of the psyche is also an open as well as closed system or cluster of systems, out of the interplay of which that which is irregular, crooked, fleeting, singular emerges. This is a game of chance factors, necessary dispositions, and the unforeseeable, the unpredictable.[10]

But what is most striking in all this is the rapprochement being achieved between the physical and the human, social, cultural sciences. The realization of the historicity of the human being and the course of society and culture is, following Dilthey, Unamuno, Ortega y Gasset, at the vibrant leading edge of contemporary thought. With Husserl and Heidegger's concept of the lifeworld and with Gadamer and Ricoeur's hermeneutics, this realization has entered literature, linguistics, sociology, political theory. We may safely say that it is transforming the human sciences. The goal in these disciplines is no longer the rigging of rigid, immutable models. The reality of "progress" has been discovered, the critical phases of turbulence, consolidation, and dissipation. With the recognition of the irreversible phenomena of physics and their constitutive propensities together with the vector of time, we are finding common denominators in physics and the human sciences.

The finishing touch of Prigogine's approach to becoming is his conviction that becoming is self-generative. Like Aristotle, Leibniz, Spinoza, Kant, and others, Prigogine believes that becoming emerges "from within", sua sponte.

Here is the gist of the phenomenology/philosophy of life: a coincidence between science and philosophy. Assuming that the varieties of becoming all proceed sua sponte from the interplay of the regular development of forms and irregular, unpredictable conditions, Prigogine suspends the sharp dilemma of determinism and freedom, necessity and chance. Both are at work in the processes of the universe. There is a vast intermediary realm, then, in which it is interrelations that are to be investigated.

Significant in its own way within the modern intrusion of unpredictability into the abstract, mechanical order reigning in classical science

[10] Creation et desordre, recherches et pensees contemporaine (Paris: L'Originel, 1987), (Interviews with Henri Atlan, Guitta Pessis-Pasternak, Gerard Ponthieu, and Michel Treguer).

is "chaos theory", that is, the study of turbulence. Altogether singular and unrepeatable is the flow of smoke out a chimney. From the same initial conditions, that flow can take innumerably different courses. Consideration of this invites a look into the chaotic disorder behind all ordering, the fleeting behind the fixed.

Furthermore, with recognition of an intrinsic mobility in all physical nature, the radical contrast between spontaneous movement in living beings and inertia in inanimate physical being vanishes. And so the mechanistic model yields to an overall organic model. The organization and finality of physics have thus come to approximate those of the life sciences.

The concept of science has undergone a radical transformation. Indeed, recognition of "chaotic systems"[11] and "catastrophe theory",[12] has removed the backdrop of a manifest objective order of the universe, world, and life by revealing a turbulence of bubbling energies and forces running at random.

There is a new approach to scientific validity as such. The classical postulates of precision, exactitude, certainty lose their hold on the imagination. We move to viewing a hazy, imprecise, fleeting reality. In this way the "hard" sciences seem to be becoming more like the sciences of life and society.

This movement of the sciences toward each other is particularly obvious in the case of a mathematics that now treats sensitive and qualitative features as well as forms different from those of classical Euclidean geometry. This is the fractal geometry of Nature.[13] Although this geometry was discovered as far back as Leibniz, to whom its present inventor, Benoit Mandelbrot, refers,[14] and although it was somewhat developed at the end of the last century, it has just now gained proper acceptance and appreciation. It concerns the forms of nature, things etc. We are accustomed in life as well as in scientific inquiry to rely on forms, structures, on geometry in general as we deduce it in our constitution of reality. We seek in nature the geometrical relations so constructed. So-called "fractal geometry", however, looks past the preconceived forms usually seen in nature and the whole

[11] David Ruelle, Hasard et chaos (Paris: O. Jacob, 1991); Ivar Ekeland, Le calcul, l'imprevu (Paris: Seuil, 1984). For fascinating explanations geared to the layman of chaos theory as well as of the related theories making up the "New Science", James Gleick's Chaos, Making a New Science (New York: Penguin Books, 1988) is much to be recommended.

[12] Ekeland, op. cit., pp. 122-153.

[13] Benoit B. Mandelbrot, The Fractal Geometry of Nature (updated and augmented), (San Francisco: W.H. Freeman, 1977).

[14] Ibid.

of the reality which science encounters, seeing that there is there a completely different composition of things.

Liberation from Euclidean geometry's circles, squares, cones – into which we have been trying to squeeze reality – shows us the structure of nature's "dislocated" irregularity, all sorts of irregular objects torn, and fluid in their relations, constructs. Here is a new mathematical approach to nature, one freeing it from the absolute rigidity of forms and structures into which classical geometry pressed reality. Going against a growing tendency of formalism in mathematics that leaves behind human intuitive representation, Mandelbrot's fractal approach to reality is all intuitive. His device is, "to see is to believe".

From the side of mathematics, then, comes a revolutionary strong affirmation of the universal significance of the concrete, unrepeatable, unique.

The infinite range of the fractal forms proceeding from mathematical algorithms effects a crucial transition in mathematics from an abstract way of conceiving nature to one which passes into the visual. Mathematics is, as it were, given senses adequate to the riches of objective experience. We move away from the classical prejudice that mathematics involves "calculability" only, in a qualitative, aesthetic expansion of the discipline. The abstract science of mathematics "humanizes" itself!

At the end of this all too short survey of the revolutionary changes in science that have thrown our hitherto cultivated worldview into disarray, recognition is due Alexandre Kojeve for his having brought out the most significant factor of the "subject", the living concrete individual who as an inquirer envisages everything around him/herself, whose role is now universally accepted in physics and the rest of science. In describing the subject's central role in scientific investigation, Kojeve gave it this basic characterization: we should not identify the subject with a mathematical, abstract point, uniform and unchangeable, nor with its biological corporeity, nor as a psychological agent.[15] It remains to be seen how we must conceive of the subject according to its function in investigations.

At this point scientific investigation encounters the Archimedean point of the philosophy/phenomenology of life.[16]

[15] Alexandre Kojeve, L'Idee du determinisme dans la physique classique et dans la physique moderne (Paris: Librarie generale franeaise, 1990).

[16] For a full-fledged study of creative experience, cf. compare Anna-Teresa Tymieniecka, Logos and Life, Book I: Creative Experience and the Critique of Reason, Analecta Husserliana, Vol. XXIV (Dordrecht: Kluwer Academic Publishers, 1988).

c. To conclude our brief account, let us emphasize the striking innovative tendencies in science. 1) The physical and mathematical sciences seem to have abandoned sharp boundaries with biology as well as with the social sciences and cultural inquiries. The strict calculative nature of mathematics has taken on a qualitative aspect. These sciences seem to have become "humanized". 2) All of the disciplines have become sensitive to time and change. 3) Their theories of becoming and development seem to share some common features. 4) This sharing among the sciences without the breaching of their sharp boundaries does not allow placing them all on equal footing, nor reductively subsuming some under others, but indicates that a dynamic swing of generation, of ordering, of interactivity may well run through the entire gigantic game of existence. 5) With consideration of the transitory dimensions, transitory trajectories of the dynamic complexes of the world, with the shift in focus of thought away from seeking closed reversible systems to apprehending open self-projecting streaks in the cosmos as well as in nature-life and social life as well as appreciating the vast territories of their attunements, interferences, gulfs of mysteries are opened for science to explore.

These are the vast intermediary, unknown areas of interlinkages, generative propensities, and seminal endowments-in-process, ever expanding dynamic spheres of manifestation with their own turmoils advancing and regressing in complexity and quality, with phases of catastrophe and of regulative constructivism that have now become the fascinating areas of secretive reality. They draw our inquisitive mind wider and further. 6) But it is recognition of the central role of the subject in the process of science as such that will offer us a crucial point for the dialogue between philosophy/phenomenology of life and the New Science.

Today's science is, indeed, offering us elements for a new vision of the universe, nature, society. In fact, the chaotic and turbulent stream, the innumerable streamlets which make up cosmos, nature, life, society and culture, in which from arbitrariness, chaos, chance there emerge segments of ordered world, such that we may acknowledge through our own existence in relatively stable societal, natural, cosmic existential conditions, opens fascinating newly to be formulated issues, views, expectations.

This preeminence given to the turbulent, fluid, accidental, irregular, disorderly in the origination and progress of All does not mean, as I have hinted at a few times, a universal "disorder" or a forsaking of order and rationality. On the contrary, it opens vistas in which we have to ask after the kinds, rules, ways of interlinking, of intermingling, molding..... There are no sharp divides between matter and life, nature and the cosmos, nature and human culture, but vast intermediary spheres which fascinate our imagination.

This calls for the discovery of laws of transitional phases, of coincidence, encounter, and interlinkage, of systems of spontaneous emergence, of spontaneous designs or projects, developments. This also calls for the investigation of the nature of the center point of scientific inquiry, the human subject.

With this we enter into our sphere of the philosophy of life. To a superficial glance it could appear that this new vision of the world, life, cosmos, human social life in superseding classical visions makes philosophy's traditional queries and conceptual frameworks obsolete or that science has simply replaced them. Could philosophy become obsolete, indeed subject to the penetration of scientific inquiry?

Nothing could be more hasty and erroneous. But also nothing could be more preposterous than a philosopher who believes it possible to reach reality through primary experience and the power of speculation while ignoring scientific inquiry.

The striking fact of our present situation is that philosophy needs to consult scientific data, inquiry, methods in order to be able to grapple with reality. The natural and human sciences in turn need a philosophy that is appropriately informed by them for the more profound organization and interpretation of their findings and their own advance.

In short the situation of our culture with all its potentials and hazards calls for an alliance between philosophy and science.

Remarkably enough, the radical new perspectives which science opens fall in line with those being taken by the new philosophy. The phenomenology of life and of the Human Condition emerges like the phoenix from the ashes of traditional thinking.

The project of the philosophy/phenomenology of life and of the Human Condition springs forth from the idea of this alliance. The concept of the ëontopoiesis of life' is the crucial link and vehicle of the project.

In summary, let us emphasize the four pivotal new intuitions shared by the new scientific approach and philosophy/phenomenology of life.

There are indeed, four pivotal intuitions and proceeding from them four critical issues which are the meeting points for the phenomenology/philosophy of life and the sciences of life and the physical sciences in general. These issues also reverberate in our time's preoccupation with order and disorder, necessity, orchestration, etc.

First of all, new awareness of the temporality of events, processes, transformations in the organic as well as in the inorganic sphere has provoked great puzzlement over the nature of “developments”, that is, of the irreversible processes that carry life onwards. This is now the central issue of science. Addressing it is the grand idea of formation in which becoming may be grasped – the concept of ontopoietic unfolding, which constitutes the ontologico-metaphysical axis of becoming as such as well as of becoming in its lineaments. This is the fulcrum of the phenomenology-philosophy of life.

The second pivotal point of encounter between the sciences of life and philosophy of life is the whole question of the formation of “complexities” which confronts the sciences of life and of all reality “from physics to politics”.[17] Whether the complex reality we are facing be a living being, a society, a political state, a work of art, etc., we intuit that here is an ultimate manifestation of “self-organization”. On all levels phenomenology of life apprehends this ontopoietic process unfolding from within and directed by the guidelines intrinsic to the complexity-in-formation, beingness, entity.

Thirdly, philosophy of life and the sciences of life meet in the intuition of the guiding entelechial sequence of life’s unfolding, the linkage between individuation and speciation, the individual and the evolution of forms.

Fourthly, and most importantly, science and philosophy of life meet in the intuition of the Archimedean point that is the ground for inquiry into all existence, that is, the creative condition of the investigator, whether experimenting, or observing, or speculating.

This convergence in philosophy/phenomenology and the physical and life sciences of intuitions striking the same chords on the crucial issues of our culture has yielded an universal platform of the sntopoiesis of life upon which the great issues may be envisaged anew.

Therefore we will enter into our analysis of these essential correspondences by discussing the convergence between the “physical subject” of scientific experimentation and the creative human act and the more fundamental ontopoiesis of life.

[17] See Creation et desordre, op. cit., pp. 13-53.

Part Two

1. The Creative Act of the Human Being as the Archimedean Point of the Encounter between Science and Philosophy of Life

a. The "Physical Subject" in Scientific Inquiry and the Creative Mind

It is on the point of the inquirer as "subject", as the concrete center of any investigation, a point now recognized by the New Science, that science and philosophy of life and of the human creative condition arrive at a crucial understanding. Listening to an experimental scientist talk about his experience, we enter into the heart of the matter:

It is an experience like no other experience I can describe, the best thing that can happen to a scientist, realizing that something that's happened in his or her mind exactly corresponds to something that happens in nature. It's startling every time it occurs. One is surprised that a construct of one's own mind can actually be realized in the honest to goodness world out there. A great shock, and a great joy.[18]

The experiences of the scientific discoverer are not like any other. It is an experience of the creative mind. It is precisely the creative human mind immersed in the natural, physiological, psychic, intellectual circuits of an individual human person engaged in creative activity that calls up from its innermost core such powers as allow him or her to meet the powers of nature itself. The phenomenology of life and of the human condition proposes an evolutionary phase in which emerged the human creative condition accounting for this extraordinary synchronization of functions, energies for the constructive application of powers, for this extraordinary condensation of the entire spectrum of the universal conditions that the human creative mind emerged from, a mind that is not only capable of objectifying, differentiating, and charting the immensity of the real in which other beings are passively immersed in and participate in, but is – at the summit of its powers – capable of entering into the inner workings of that reality.

Hence it is from the point of investigation into the human creative genius that it is appropriate to enter into the exploration of reality. Here is our Archimedean fulcral point from which to probe all existence. Along these lines we pay close attention to Alexandre Kojeve as he describes his

[18] Leo Kadanoff, quoted in James Gleick, Chaos, Making a New Science (New York: Penguin Books, 1988), p. 189.

views as a physical scientist on the human subject as the reference point of scientific inquiry, of all inquiry. Kojeve – in his magisterial analysis of the basis upon which was founded the causal determinism of classical physics and of the principles by which it was undermined – elucidated the interpretation given by Niels Bohr to the arguments presented by Heisenberg on the essential and unavoidable imprecision of any attempt to examine the world physically, on the impossibility of speaking in physics of "exact causality in the structure of the world".[19] Bohr's interpretation is, according to Kojeve, a mathematical expression of an absolutely general principle according to which no physical observation is possible without the state of whatever is observed being modified "by the very fact that it is observed"[20]

It is not that physicists were not over time aware of this "gnoseological" state of affairs, but it was Heisenberg who drew all the conclusions together. These conclusions could have been drawn already within classical physics. According to Kojeve, "a necessary consequence of the classical principle of the equality of action and reaction is: if a physical entity is observed that means that it 'acts' upon the instrument of observation; this instrument has then necessarily from the outside 'acted' upon it and modified it in a certain fashion".[21] That is to say, with Heisenberg and Bohr it is the nature of experience and experimenting in physics that was brought into focus. With the theoretical assumption that physics deals with the real world and with the concepts which ultimately may be brought to experimental data, Bohr specified that physics does not deal with one world system as it is in itself but with two systems: the system of the observed and the system of the observer.

There is no way in physics to change the fact that it moves along the borderline between these two systems, which are both opposed and inseparable. Kojeve specifies: "In effect, the observed system is not accessible to experience unless insofar as it is in an interaction with the observing system, modifying it, and is in turn being modified by it".[22]

There are two consequences of this capital recognition. One of them leads Kojeve to affirm that it constitutes a principle rejecting classical causal determinism in physics, effecting the passage to modern physics which holds that physics does not study the world "in itself" as idealized

[19] Kojeve, L'Idee du determinisme, op. cit., p. 152.
[20] Ibid.
[21] Ibid., p. 154.
[22] Ibid., p. 157.

by the spirit but the world which is real and is given in experimentation and observation, in experience, that is, made by scientists with real, physical instruments, scientists who themselves are part of the real physical world that they study. The second conclusion that we may draw with Kojeve from Bohr's analysis is the clarification, elucidation of the situation of scientific experience as such. This clarification leads to the definitive acceptance of the physical subject at the center of physical inquiry, which subject belongs to the real world and simultaneously observes it and acts upon it, reaction to which in the world physics obtains in its data later.

Here comes the fascinating question of just how we should understand this subject in scientific experience. Philosophers have long since discussed these things and various of their formulations have thrown up distorting grids between the real world and the perceiving, experimenting subject. The main requirement of the new science is that the subject be seen as belonging to the same ontological region as the world and as interacting with it. In any case, I claim that given all this we cannot continue to consider cognition to be the main factor in scientific experience.

True, Heisenberg in discussing his "idealized" experiences emphasizes that he is discussing the cognition of the real but not the real itself. (This is also the view of Stanley Salthe, who throughout his book Development and Evolution, Complexity and Change in Evolution, to which we will return later, emphasizes that physics is talk about the 'discourse' concerning reality and not about reality itself.[23] But in a 'discourse' approach the subject is of the same significance discussed above, since he is the author of the discourse).

However, I propose that we ask ourselves what we must understand in speaking of the subject in the experience of scientific inquiry; we have to turn our attention to the collection of scientific data, their "verification" through technology. In the perspective of this collection we find a direct interference of the subject in the real, physical nature of the world. It is not discourse about this nature that makes it possible for the inventor to apply physical principles, to put material, physical materials to use. I submit that we must keep this point in mind as we seek a more adequate description of the subject in experimental experience and that we should seek it elsewhere

[23] Stanley Salthe, Development and Evolution, Complexity and Change in Biology (Cambridge, MA: MIT Press, 1993), p. 44: "Once more I remind the reader that what I am talking about is not the world but discourse".

than solely in the cognitive faculties of the human being. These faculties have to be acknowledged to belong essentially to processes deeper than our experimenting and law formulating. We reach the workings of nature under a yet deeper jurisdiction.

To state our problem in its fullness let us call it after Bohr the problem of the relationship between the system of the observer and the system being observed.[24]

A. If we attempt to analyze these systems, we find that the subject in the experience has to be a real physical, physiological being in order to belong to the real world. But physics, and science generally, is not interested in the variables that account for the singular features of a phenomenon. On the contrary, science is concerned with the constants. Consequently, we cannot conceive of the subject as being a singular individual with varying tastes, capacities, tendencies, etc. Inasmuch as the subject has to be concrete living being, we have to make an abstraction of its singularities and focus on its universal/concrete individuality. According to Kojeve, the "physical subject" is a physical entity insofar as it is represented by a system of physical entities".[25]

B. To its system must belong the entire schema of a specifically human personality embodied within a physical, biological framework. Here is a specific type of personality which is inclined toward and endowed with the capacities for scientific inquiry and it assumes various constant forms in accord with the special scientific interests of scholars.

C. How could we conceive of the scientific subject otherwise than as one endowed not only with all the elementary sensory, emotional, and valuating faculties making it an integral participant in nature/world, but with a mature human mind with its focusing, deliberating, calculating, and speculative powers? How could any observer not endowed with these three modes of operating even approach reality?

And yet, this is not enough. In order to complete the picture we have to acknowledge the great lights that throw it in relief. This entire system would not fulfill the expectations we commonly have of it if it did not rotate in all its aspects around the Archimedean point that is its specific but constant axis: the creative virtualities subtending the mind – the creative imagination inspiring it and the creative act bringing that imagination to its unique fruition.

[24] Niels Bohr, Die Naturwissenschaften (quoted by Kojeve, op. cit.).
[25] Kojeve, op, cit., p. 167.

If we unfold the "creative system" of the human being as the scientific subject, we will understand it in the light of what is accomplished in this extraordinary interaction between the technical application of science and the workings of nature. We will also unroll and circumscribe the creative compass of all the spheres of reality/life in which the living creative subject has to participate in order to assume the role of the observer or experimenter, or discoverer, inventor, creator.

In short, I submit that only the creative mind of the human being can fulfill all the conditions set by Kojeve, first, and most significantly, by legitimating its extraordinary vantage point and second by introducing us into the hidden spheres of reality itself.

b. The Circuits of Reality Revealed through the Creative Act of the Human Being

The thesis of the argument we will present may be summarized as follows. Within the mental, cultural, and vital expanse of the living human being there are present peculiar vestiges of all the molds in which living beingness has progressively unfolded from the womb of the biosphere, of all the degrees of life's inward/outward directed system of unfolding. As the study of phylogeny and ontogeny shows us, none of these constructive steps can be omitted in the progression to the next level. This means that the human individual stretches vitally throughout space within the Human Condition.

But let us now begin our argument within our own context, showing that it is in the creative act that the human being retrieves the fruits of its unfolding.[26] Where physics begins with the most fundamental elements of the real, in following the creative act of the human being, we have to distinguish first the sphere of the spirit and intellect of the human being – what is most directly engaged in the intuitive, exploratory, inventive, and creatively imaginative processes. But following this thread we are led to the vast turmoil of the individual psychic life of the human person. Here, first of all, a person gathers a conundrum of habits, predilections, scales and categories of evaluation which permeate his or her functional system. All this, however, is to some or other degree conducted or inclined by the per-

[26] For this context, see Anna-Teresa Tymieniecka, Logos and Life, Book 1: Creative Experience and the Critique of Reason, Analecta Husserliana, Vol. XXIV (Dordrecht: Kluwer Academic Publishers, 1988).

sons's will, aspirations, curiosities. We must recognize that personal factors in our psychic functional system command our feelings, emotions, wishes, aspirations, and the like and have an overall combinatorial tendency to bring the turmoil of disparate acts into some cohesive constructive composition whether merely to serve the demands of survival or at higher levels personal satisfaction, a sense of accomplishment.

We will see this psychic openness to constitutive modes much more clearly still if we will consider that it is immersed in a quite different preconscious turmoil, a turmoil involving the arbitrary and deformed.

And the intuition of Heraclitus comes to mind who, as interpreted by William Capelle, says: "Die Natur der Welte enthuelle sich ihm als er in die Tiefen seiner eigenen Natur hinabsteig".[27]

The idea of the human being as a cosmos in filigree is as old as Western Philosophy. Already with the Pre-Socratics Anaximander speaks of the cosmos as mirroring the human social order insofar as it indicates that its composite elements are to be kept within the confines of "justice" and "retribution".[28] Pythagoras draws a parallel between the "harmony" he conceives to be central to the order of the cosmic spheres and the human being in whom body and soul have to work together in harmony on a miniature scale.

This idea of the human being as presenting in miniature the whole of cosmos is reflected in Plato – in the Timaeus 35 A – when he draws a figure of the human soul and its combining opposite strivings toward the "pure" world of ideas and the "lower" world of the body as a charioteer driving two horses with great difficulty, for reason and irrational desires do not easily carry on together. The soul by partaking in both worlds plays a median role between them.

But it is in Leibniz's concept of the monad that we find the most striking picture of all living beings – each is animated, alive, and reflects the entire universe. It does so according to its own expansion and in its own perspective. Each living being is an embodiment of the universe, its living

[27] William Capelle, Die Vorsokratiker, die Fragmente und Quellenberichte übersetzt und eingeleitet (Leipzig: A. Kroner, 1935), p. 148. In my monograph "The Great Plan of Life" in Anna-Teresa Tymieniecka (ed.), Phenomenology of Life and the Human Creative Condition. Book 1: Laying Down the Cornerstones of the Field, Analecta Husserliana, Vol. LII (Dordrecht: Kluwer Academic Publishers, 1997), I quote and discuss this fragment.

[28] Rudolf Allers, "Microcosmos from Anaximander to Paracelsus", Traditio 2 (1944), pp. 319-409.

transposition in filigree, pulsating with the universe's life on its very own. Leibniz saw infinite gradations in the complexity and modes of nature, each of them reflecting the universe in its making.[29]

In his conceiving of the individual living being as a monad, Leibniz emphasized the reasons why "each created monad represents the whole universe".[30] He brings out first his general metaphysical concept that all there is interconnected. We read earlier,

For everything is a plenum, so that all matter is bound together, and every motion in this plenum has some effect upon distant bodies in proportion to their distance, in such a way that every body not only is affected by those which touch it and somehow feels whatever happens to them but is also, by means of them, sensitive to others which adjoin those by which it is immediately touched. It follows that this communication extends to any distance whatever. As a result, every body responds to everything which happens in the universe, so that he who sees all could read in each everything that happens anywhere, and, indeed, even what has happened and will happen, observing in the present all that is removed from it, whether in space or in time "All things are conspirant", as Hippocrates said.[31]

And then, to come back to the passage previously quoted explaining how the monad may mirror the entire universe, he writes:

Thus, although each created monad represents the whole universe, it represents more distinctly the body which is particularly affected by it and of which it is an entelechy. And, as this body represents the whole universe by the connection between all matter in the plenum, the soul also represents the whole universe in representing the body which belongs to it in a particular way.[32]

The great question is what is the "position" of the human mind such that we may attribute to it the power to descend into the inner workings of becoming and to then lift them up from their particular irregular/regular, chaotic/leading mix to an ordering, seemingly separated from that mix and in fact involving intermediary territories. What "sight" sees into this

[29] Gottfried Wilhelm Leibniz, Monadology, ed. and trans. Leroy E. Loemker, in Gottfried Wilhelm Leibniz, Philosophical Papers and Letters (Chicago: University of Chicago Press, 1956), 2 vols.

[30] Ibid., p. 1055.

[31] Ibid., pp. 1054-1055.

[32] Ibid., p. 1055.

immeasurable turmoil in which no order, no reason is visible and then distills sense from its fragments, truncated pieces, segments of ordering-in-process and by innumerable nudges provokes recognition of the wealth of rationalities which are projected by the conjunction of hazard and necessity in their constructive game?

We submit that it is precisely in the transitory phase of the Human Condition that we have within the topsy-turvy flux of constructive/destructive, advancing/receding progress within the distorted and yet constant "unity-of-everything-there-is-alive" an effervescence of the vast intermediary phase stretching from the life process getting ready for its constructive swing to the radical transition in which self-enclosed inner direction shifts toward an ever widening opening for interaction with the environment, interaction in which the soul in its "highest" swing enters into the entire spread of the "lower" bodily, organic and inorganic functioning of nature-life as well as the cosmic dynamism.

The imaginary intuitions of the Greeks, the metaphysical speculations of the moderns find an echo in the contemporary approach with its reformulations and adumbrations – its opening horizons. First, the human microcosmic realm at every moment gathers into its composition the functioning of the various preceding phases of the evolutionary process; nothing is lost; all is revaluated with respect to the new virtualities currently being activized.

We have confirmation of this in science. Paleolontologists in reconstructing the intermediary stages of the brain's development from anthropoid to full human being have found an incremental enlargement of the brain. At the same time neuropsychologists have demonstrated that the human brain is composed of three spheres of functioning that are all the time actively adjusting to each other. That is to say, homo sapiens has three brain centers, the reptilian brain, the mammalian brain, and the human brain. The reptilian brain evolved first and is still maintained in the human brain. Reptiles are characterized by lack of care for their offspring. When the mammalian brain evolved millions of years later as an extension of the reptilian brain, the reptilian brain did not vanish. It remained to provide the instinctive responses needed for individual survival, while the mammalian brain extended the individual's concern to the care and survival of its offspring and its group as well, but not beyond that. We see this at work in present-day animals. Some of them, like birds, display a solidarity with their whole flock. The brain specific to humans sustains what I call "creative" activity. It allows the expansion of the social, cultural world, while relying on the instinctive and caring responses of the reptilian and mammalian brains.[33]

This "third phase" in the human brain's development was marked by the growth of the neocortex. Its development made the median position of the human being possible. Self-individualizing beingness unfolded its latent powers, virtualities, valuating capacity at this stage allowing an outburst of personal freedom by which the individual may take in hand, at least partly, its own course, forging its own identity and destiny. This is the grand transitory phase in which all that was tending precisely toward such a liberation of the latent faculties of living beings saw the dawn of the Human Condition. A measure of freedom was realized within individualizing existence. All the preceding threads of the self-individualization of life have been gathered up and reworked in the accomplishment of this transition. The individual may now employ for itself all of life's streaks of energy, forces, segmented integrations, disintegrations, powers to mold its own functioning in novel significant fashions. This is what the creative virtualities of the Human Condition offer.

Thus the human condition becomes a relatively stable station in the process of life's game, a station processing all the material coming from the "lower" circuits of existence for the establishment of a "higher" region, that of the creative mind. The novum which the human condition as a phase in the progress of life presents is precisely creative virtualities attuned to the unique conglomerate of functions gathered up in this constructive passage.

The creative act of the human being in its meanders yields insight into the "creative forge", the sphere in which our specific, singular objective oriented creative process encounters its source. The source is the human being who carries out the creative quest. In this quest the human being descends not only into the originary moment of the singular creative process but most significantly into the networks of its existential/vital functions, which carry the creative quest as such. He discovers that the specific creative search after a shape, a form, or a substance for an object in view is carried on by a shifting schema of functions in which all of the individual's powers – the intellectual, imaginative, sentient, volitional, physiological – are involved in specific ways, employed from a center, this center being the fulcrum of force, the agency in which all the powers are gathered and from which they flow with roles being assigned them. In short, there is an "agency" in the performance of the creative act who plays all the strings that radiate in all direc-

[33] Stephen Jay Gould, Ontogeny and Phylogeny (Cambridge, MA: Belknap Press, 1977).

tions, a "power" that gathers and distributes, directs and controls every move, a central distributor of forces and roles, a full-fledged conscious being who is obviously self-governing and self-initiating in its acts. This so ramified, versatile, imaginative, and powerful constitutive act fulgurates from its innermost. It is a simultaneous orchestration of all the faculties under the aegis of a creative imagination that projects possibilities, of an intelligence that scrutinizes, compares, differentiates, etc., and of an effective will which prompts the search and the progress. All of these faculties represent the dynamic complex of the living individual carrying the process and determining its self-promoted constructive/interpretive route. Here we gain access to the inner virtualities, freely projected from within in consistent albeit fluctuating and changeable directions as trial and error dictate – directions whose sequence itself knows interchangeability and mutability, is uncertain in its steps, and yet, as fragile as it may be and as unpredictable as its outcome may be, being subject to disruption and periods of stagnation, still advances with a discrete continuity/discontinuity of purpose. In all its potentialities, virtualities, advantageous situations for their actualization as well as hindrances, through progressive steps, this is a self-projecting, self-organizing system of meaning by which an entity, an object, a creation is produced by human acumen and power as it were crystallized.[34] These poietic threads reveal the lines human functional powers follow and the poietic selfhood of the human being as a projecting and effectuating agent.

Drawing a conclusion from the above, we may recapitulate by stating that it is due to the creative virtualities of the human condition – as a station in the evolving progress of types with all their ties to the cosmos and its laws and to the biosphere – that the human creative act may progressively penetrate into all the spheres of existence, of life, the reality in which this station is not always openly rooted but out of which it has developed in stages maintaining permanent ties.[35] Since these developmental stages represent the becoming of the universe of life, we find here a new version of the Leibnizean monad that "reflects" the entire universe. But as we will see in our further analysis, this is a different type of monad.

[34] For a fuller treatment of cultural creation, see Anna-Teresa Tymieniecka, Logos and Life, Book 3: The Passions of the Soul and the Elements in the Ontopoiesis of Culture. The Life Significance of Literature (Dordrecht: Kluwer Academic Publishers, 1990).

[35] See my elaboration of the Human Condition in Anna-Teresa Tymieniecka, "The First Principles of Phenomenology of Life", Analecta Husserliana, Vol. XVII (Dordrecht: D. Reidel, 1978).

The significance lies in the elucidation of in virtue of what the creative act of the human being may penetrate into the innermost workings of nature, existentially partaking of the interaction which the living being maintains with them. For this is what makes the creative human individual unique and what must be taken into account in appreciating him or her as the “subject” in scientific experimentation and experience.

c. Having reached with the human creative act not only the point of the encounter with the discovery endeavor of the scientist but also with that of the writer, artist, choreographer, poet and of every undertaking of the human being aiming at the grasp, ciphering and formulation of reflective experience, we may indeed, establish a platform for the investigation of all human endeavor in respect to the functions of the mind and of their life significance. A vast field upon which education may seek to project the ordering of its “choral dance”.

THE PONTIFICAL ACADEMY OF SCIENCES: A HISTORICAL PROFILE

MARCELO SÁNCHEZ SORONDO

Pio XI, 'Motu proprio De Pontificia Academia Scientiarum, 28.10.1936', in *AAS 28* (1936), pp. 421-452; Giovanni Paolo II, 'Discorso alla Pontificia Accademia delle Scienze in occasione del 1000 anniversario della nascita di A. Einstein, 10.11.1979', in *Insegnamenti II*, 2 (1979), pp. 1115-1120; 'Discorso in occasione del 500 della Rifondazione', in *Insegnamenti IX*, 2 (1986), pp. 1274-1285; 'Discorso in occasione della presentazione dei risultati della Commissione di studio sul caso Galileo, 31.10.1992', in *Insegnamenti XV*, 2 (1992), pp. 456-465; 'Messaggio in occasione del 600 della Rifondazione, 22.10.1996', in *EV 15*, pp. 1346-1354.

I. The nature and goals of the Academy. II. A historical survey: from the Accademia dei Lincei to today's Pontifical Academy of Sciences. III. The role of the Academy in the dialogue between scientific thought and Christian faith.

I. The Nature and Goals of the Academy

The Pontifical Academy of Sciences has its origins in the Accademia dei Lincei ('the Academy of Lynxes') which was established in Rome in 1603, under the patronage of Pope Clement VIII, by the learned Roman Prince, Federico Cesi. The leader of this Academy was the famous scientist, Galileo Galilei. It was dissolved after the death of its founder but then recreated by Pope Pius IX in 1847 and given the name 'Accademia Pontificia dei Nuovi Lincei' ('the Pontifical Academy of the New Lynxes'). Pope Pius XI then refounded the Academy in 1936 and gave it its present name, bestowing upon it statutes which were subsequently updated by Paul VI in 1976 and by John Paul II in 1986. Since 1936 the Pontifical Academy of Sciences has been concerned both with investigating specific scientific subjects belonging to individual disciplines and with the promotion of interdisciplinary co-operation. It has progressively increased the number of its Academicians and the international character of its membership.

The Academy is an independent body within the Holy See and enjoys freedom of research. Although its rebirth was the result of an initiative promoted by the Roman Pontiff and it is under the direct protection of the ruling Pope, it organises its own activities in an autonomous way in line with the goals which are set out in its statutes: 'The Pontifical Academy of Sciences has as its goal the promotion of the progress of the mathematical, physical and natural sciences, and the study of related epistemological questions and issues' (Statutes of 1976, art. 2, § 1). Its deliberations and the studies it engages in, like the membership of its Academicians, are not influenced by factors of a national, political or religious character. For this reason, the Academy is a valuable source of objective scientific information which is made available to the Holy See and to the international scientific community.

Today, the work of the Academy covers six main areas: a) fundamental science; b) the science and technology of global questions and issues; c) science in favour of the problems of the Third World; d) the ethics and politics of science; e) bioethics; and f) epistemology. The disciplines involved are sub-divided into nine fields: the disciplines of physics and related disciplines; astronomy; chemistry; the earth and environment sciences; the life sciences (botany, agronomy, zoology, genetics, molecular biology, biochemistry, the neurosciences, surgery); mathematics; the applied sciences; and the philosophy and history of sciences.

The new members of the Academy are elected by the body of Academicians and are chosen from men and women of every race and religion on the basis of the high scientific value of their activities and their high moral profile. They are then officially appointed by the Roman Pontiff. The Academy is governed by a President, appointed from its members by the Pope, who is helped by a scientific Council and by the Chancellor. Initially made up of eighty Academicians, of whom seventy were appointed for life, in 1986 John Paul II raised the number of members for life to eighty, side by side with a limited number of Honorary Academicians chosen because they are highly qualified figures, and others who are Academicians because of the posts they hold, amongst whom: the Chancellor of the Academy, the Director of the Vatican Observatory, the Prefect of the Vatican Apostolic Library, and the Prefect of the Vatican Secret Archive.

In conformity with the goals set out in its statutes, the Pontifical Academy of Sciences 'a) holds plenary sessions of the Academicians; b) organises meetings directed towards the progress of science and the solution of technical-scientific problems which are thought to be especially important for the development of the peoples of the world; c) promotes scientific inquiries and research which can contribute, in the relevant places and organisations, to the investigation of moral, social and spiritual questions; d) organises conferences and celebrations; e) is responsible for the publication of the deliberations of its own meetings, of the results of the scientific research and the studies of Academicians and other scientists' (Statutes of 1976, art. 3, § 1). To this end, traditional 'study-weeks' are organised and specific 'working-groups' are established. The headquarters of the Academy is the 'Casina Pio IV', a small villa built by the famous architect Piero Ligorio in 1561 as the summer residence of the Pope of the time. Surrounded by the lawns, shrubbery and trees of the Vatican Gardens, frescoes, stuccoes, mosaics, and fountains from the sixteenth century can be admired within its precincts.

Every two years the Academy awards its 'Pius XI Medal', a prize which was established in 1961 by John XXIII. This medal is given to a young scientist who has distinguished himself or herself at an international level because of his or her scientific achievements. Amongst the publications of the Academy reference should be made to three series: *Scripta Varia*, *Documenta*, and *Commentarii*. The most important works, such as for example the papers produced by the study-weeks and the conferences, are published in the *Scripta Varia*. In a smaller format, the *Documenta* series publishes the short texts produced by various activities, as well as the speeches by the Popes or the declarations of the Academicians on subjects of special contemporary relevance. The *Commentarii* series contains articles, observations and comments of a largely monographic character on specific scientific subjects. The expenses incurred by the activities of the Academy are met by the Holy See.

During its various decades of activity, the Academy has had a number of Nobel Prize winners amongst its members, many of whom were appointed Academicians before they received this prestigious international award. Amongst these should be listed: Lord Ernest Rutherford (Nobel Prize for Physics, 1908), Guglielmo Marconi (Physics, 1909), Alexis Carrel (Physiology, 1912), Max von Laue (Physics, 1914), Max Planck (Physics, 1918), Niels Bohr (Physics, 1922), Werner Heisenberg (Physics, 1932), Paul Dirac (Physics, 1933), Erwin Schroedinger (Physics, 1933), Sir Alexander

Fleming (Physiology, 1945), Chen Ning Yang (Physics, 1957), Rudolf L. Mössbauer (Physics, 1961), Max F. Perutz (Chemistry, 1962), John Eccles (Physiology, 1963), Charles H.Townes (Physics, 1964), Manfred Eigen and George Porter (Chemistry, 1967), Har Gobind Khorana and Marshall W. Nirenberg (Physiology, 1968). Recent Nobel Prize winners who have also been or are presently Academicians may also be listed: Christian de Duve (Physiology, 1974), Werner Arber e Geroge E. Palade (Physiology, 1974), David Baltimore (Physiology, 1975), Aage Bohr (Physics, 1975), Abdus Salam (Physics, 1979), Paul Berg (Chemistry, 1980), Kai Siegbahn (Physics, 1981), Sune Bergström (Physiology, 1982), Carlo Rubbia (Physics, 1984), Rita Levi-Montalcini (Physiology, 1986), John C. Polanyi (Chemistry, 1986), Jean-Marie Lehn (Chemistry, 1987), Joseph E. Murray (Physiology, 1990), Gary S. Becker (Economics, 1992), Paul J. Crutzen (Chemistry, 1995), Claude Cohen-Tannoudji (Physics, 1997) and Ahmed H. Zewail (Chemistry, 1999). Padre Agostino Gemelli (1878-1959), the founder of the Catholic University of the Sacred Heart and President of the Academy after its refoundation until 1959, and Mons. Georges Lemaître (1894-1966), one of the fathers of contemporary cosmology who held the office of President from 1960 to 1966, were eminent Academicians of the past. Under the Presidency of the Brazilian biophysicist Carlos Chagas and of his successor Giovanni Battista Marini-Bettòlo, the Academy linked its activity of scientific research to the promotion of peace and the progress of the peoples of the world, and dedicated increasing attention to the scientific and health care problems of the Third World. The Presidency of the Academy is presently entrusted to the Italian physicist, Nicola Cabibbo.

The goals and the hopes of the Academy, within the context of the dialogue between science and faith, were expressed by Pius XI (1922-1939) in the following way in the *Motu Proprio* which brought about its refoundation: 'Amongst the many consolations with which divine Goodness has wished to make happy the years of our Pontificate, I am happy to place that of our having being able to see not a few of those who dedicate themselves to the studies of the sciences mature their attitude and their intellectual approach towards religion. Science, when it is real cognition, is never in contrast with the truth of the Christian faith. Indeed, as is well known to those who study the history of science, it must be recognised on the one hand that the Roman Pontiffs and the Catholic Church have always fostered the research of the learned in the experimental field as well, and on the other hand that such research has opened up the way to the defence of the deposit of supernatural truths entrusted to the Church...We promise again, and it is our strongly-held intention, that the ‘Pontifical Academicians’, through their work and our Institution, work ever more and ever more effectively for the progress of the sciences. Of them we do not ask anything else, since in this praiseworthy intent and this noble work is that service in favour of the truth that we expect of them’ (*AAS* 28, 1936, p. 427; Italian translation, *OR*, 31.10.1936).

After more than forty years, John Paul II once again emphasised the role and the goals of the Academy at the time of his first speech to the Academicians which was given on 10 November 1979 to commemorate the centenary of the birth of Albert Einstein: ‘the existence of this Pontifical Academy of Sciences, of which in its ancient ancestry Galileo was a member and of which today eminent scientists are members, without any form of ethnic or religious discrimination, is a visible sign, raised amongst the peoples of the world, of the profound harmony that can exist between the truths of science and the truths of faith...The Church of Rome together with all the Churches spread throughout the world, attributes a great importance to the function of the Pontifical Academy of Sciences. The title of ‘Pontifical’ given to the Academy means, as you know, the interest and the commitment of the Church, in different forms from the ancient patronage, but no less profound and effective in character. As the lamented and distinguished President of the Academy, Monsignor Lemaître, observed: ‘Does the Church need science? But for the Christian nothing that is human is foreign to him. How could the Church have lacked interest in the most noble of the occupations which are most strictly human – the search for truth?...Both believing scientists and non-believing scientists are involved in deciphering the palimpsest of nature which has been built in a rather complex way, where the traces of the different stages of the long evolution of the world have been covered over and mixed up. The believer, perhaps, has the advantage of knowing that the puzzle has a solution, that the underlying writing is in the final analysis the work of an intelligent being, and that thus the problem posed by nature has been posed to be solved and that its difficulty is without doubt proportionate to the present or future capacity of humanity. This, perhaps, will not give him new resources for the investigation engaged in. But it will contribute to maintaining him in that healthy optimism without which a sustained effort cannot be engaged in for long’ (‘Discorso alla Pontificia Accademia delle Scienze, 10.11.1979’, in *Insegnamenti*, II, 2 (1979), pp. 1119-1120).

It was precisely in that speech that John Paul II formally called on historians, theologians and scientists to examine again in detail the Galileo case.

And he asked them to do this 'in the faithful recognition of errors, by whomsoever committed', in order to 'remove the distrust that this case still generates, in the minds of many people, placing obstacles thereby in the way of fruitful concord between science and faith' (*ibidem*, pp. 1117-1118).

II. A historical survey: from the Accademia dei Lincei to today's Pontifical Academy of Sciences

The historical itinerary of the Academy is summarised in the articles written by Marini-Bettòlo (1986) and by Marchesi (1988), and in broader fashion in the monograph by Régis Ladous (1994). As was observed at the beginning of this paper, the roots of the Pontifical Academy of Sciences are to be traced back to the post-Renaissance epoch. Its origins go back to the ancient Accademia dei Lincei, established in 1603 by Prince Federico Cesi (1585-1630) when he had just reached the age of eighteen. Cesi was a botanist and naturalist, the son of the Duke of Acquasparta, and the member of a noble Roman family. Three other young men took part in this initiative: Giovanni Heck, a Dutch physician aged twenty-seven; Francesco Stelluti di Fabriano; and Anastasio de Filiis de Terni. Thus it was that the first Academy dedicated to the sciences came into being, and it took its place at the side of the other Academies – of literature, history, philosophy and art – which had arisen in the humanistic climate of the Renaissance. The example of Cesi and of the group of scholars led by him was followed some years later in other countries – the Royal Society was created in London in 1662 and the Académie des Sciences was established in France in 1666.

Although he looked back to the model of the Aristotelian-Platonic Academy, his aim was altogether special and innovative. Cesi wanted with his Academicians to create a method of research based upon observation, experiment, and the inductive method. He thus called this Academy 'dei Lincei' because the scientists which adhered to it had to have eyes as sharp as lynxes in order to penetrate the secrets of nature, observing it at both microscopic and macroscopic levels. Seeking to observe the universe in all its dimensions, the 'Lincei' made use of the microscope (*tubulus opticus*) and the telescope (*perspicillus-occhialino*) in their scientific research, and extended the horizon of knowledge from the extremely small to the extremely large. Federico bestowed his own motto on the 'Lincei' – '*minima cura si maxima vis*' ('take care of small things if you want to obtain the greatest results').

The Cesi group was also interested in the new scientific and naturalistic discoveries then coming from the New World, as is demonstrated by the most significant works of the college of the first 'Lincei' – the *Rerum medicarum thesaurus novae Hispaniae*, later known as the *Tesoro Messicano*, which was printed in Rome in 1628. This was a very extensive collection of new geographical and naturalistic knowledge, and contained in addition accounts of explorations carried out in the Americas.

From the outset the Academy had its ups and downs. A few years after its foundation it was strongly obstructed by Cesi's father because he believed that within it activity was being engaged in which was not very transparent in character – for example, studies in alchemy. But after the death of Federico's father, the abundant economic resources which were now obtained thanks to Federico's inheritance, as well as the fact that renowned scholars such as Galileo Galilei, Giovan Battista della Porta, Fabio Colonna, and Cassiano dal Pozzo joined its ranks, enabled the Academy to progress and advance.

The religious character of the Academy cannot be overlooked. It was placed under the protection of St. John the Evangelist who was often portrayed in the miniatures of its publications with an eagle and a lynx, both of which were symbols of sight and reason. It was therefore conceived as an assembly of scholars whose goal – as one can read in its Rules, described as the 'Linceografo' – was 'knowledge and wisdom of things to be obtained not only through living together with honesty and piety, but with the further goal of communicating them peacefully to men without causing any harm'. Nature was seen not only as a subject of study but also of contemplation. Amongst the suggestions of the 'Linceografo' there is also that of preceding study and work with prayer – 'for this reason the Lynxes, near to doing anything at all, must first raise their minds to God, and humbly pray to him and invoke the intercession of the saints' (cf. di Rovasenda and Marini-Bettòlo, 1986, p. 18). Amongst the practices of the spiritual piety of the members there was the reciting of the liturgical office of the Blessed Virgin Mary and the Davidic Psalter. For this reason, as Enrico di Rovesanda observes, 'the religious inspiration of the Lincei cannot be overlooked, as is done in many quarters, nor can it be reduced to an 'almost mystical glow of the school of Pythagoras', as has also been suggested. The high moral figure of Cesi acts to guarantee the sincere and loyal profession of its religious faith' (*ibidem*, p. 19). One of the mottoes of the Academy – *Sapientiae cupidi* – indicated the striving for constant research into truth through scientific speculation, based upon the mathematical and natural sciences but always located within a sapiential horizon.

Like Galileo, whose great supporter he was, Cesi admired Aristotle but not the Aristotelians of the University of Padua who had refused to look at things through the telescope of the Pisan scientist. He was in addition rather critical of the university culture of his day. Federico Cesi also engaged in important activity of mediation between the Roman theological world and Galileo, reaching the point of advising the latter to not insist in his polemics about the interpretation of Holy Scripture so that he could dedicate himself in a more effective way to scientific research. Death struck Cesi down in 1630 when Galileo was about to finish his *Dialogo sui Massimi Sistemi*, the manuscript of which Galileo wanted to send to Cesi himself so that the latter could organise its publication. After Cesi's death the activities of the Academy diminished to such an extent as to bring about its closure.

The first attempts to bring the 'Lincei' back into existence took place in 1745 in Rimini as a result of the efforts of a group of scientists belonging to the circle made up of Giovanni Paolo Siomne Bianchi (known as Janus Plancus), Stefano Galli and Giuseppe Garampi. But the new Academy had a very short life. The attempt at refoundation made by Padre Feliciano Scarpellini (1762-1840) in Rome at the beginning of the nineteenth century met with greater success. He gave the name of 'Lincei' to a private academy that he had established in 1795. Despite a lack of funds and a whole series of difficulties, Scarpellini managed to keep the name of 'Lincei' alive and to bring together in a single academic body the various scientists working in the Papal States such as the mathematician Domenico Chelini, the naturalist Carlo Bonaparte, the anatomist Alessandro Flajani, the chemists Domenico Morichini and Pietro Peretti, Prince Baldassarre Odescalchi, the physicists Gioacchino Pessuti and Paolo Volpicelli, and the physician Benedetto Viale (cf. Marini-Bettòlo, 1986, p. 10).

The authorities of the Papal States took new practical initiatives to refound the Academy during the first half of the nineteenth century in response to the wishes of Pope Pius VII (1800-1823) and Leo XII (1823-1829), with the allocation of the second floor of Palazzo Senatorio in Capidoglio to the Academy as its headquarters. But in 1847 it was Pius IX who officially renewed the Academy with the name (which had already been suggested by Gregory XVI in 1838) of 'Accademia Pontificia dei Nuovi Lincei' ('the Pontifical Academy of the New Lynxes'), ensuring the drawing up of new statutes which envisaged, amongst other things, the presence of thirty resident members and forty correspondent members. During this period of activity famous astronomers and priests were present within its ranks, such as Francesco de Vico and Angelo Secchi. During the revolutionary upheavals of 1848 the Roman Republic sought to expel the Academy from the Campidoglio. However, the institution managed to keep its headquarters by using various bureaucratic manoeuvres. In 1870, following the fall of the independent Papal States and the unification of the Kingdom of Italy, the Academy divided into two different institutions: the 'Reale Accademia dei Lincei', which later became the present Accademia Nazionale dei Lincei with its headquarters in Palazzo Corsini alla Lungara, and the 'Accademia Pontificia dei Nuovi Lincei', which was transferred from the Capidoglio to the Casina Pio IV villa in the Vatican Gardens.

One had to wait, as has already been observed, until 28 October 1936 for a further renewal of the institution, which took place in response to the insistent requests of the Jesuit Giuseppe Gianfranceschi. This scientist was Professor of Physics at the Gregorian University and had been the President of the Accademia Pontificia dei Nuovi Lincei since 1921. A new Pontifical Academy of Sciences was thus created by Pope XI by the Motu Proprio *In Multis Solaciis* (for an Italian translation see Marini-Bettòlo, 1987, pp. 199-203. This work has an accurate summary of the life of the Academy for the years 1936-1986). The Presidency was entrusted to the Rector of the Catholic University Padre, Agostino Gemelli, who was flanked by the Chancellor, Pietro Salviucci, and by a Council composed of four Academicians. Annual (and later two-yearly) plenary sessions were proposed for all the Academicians. The accounts of the activities and the contributions of the members were published in the *Acta Pontificiae Academiae Scientiarum* and later on in the *Commentationes*. The first assembly was inaugurated on 1 June 1937 by the then Cardinal Secretary of State, Eugenio Pacelli, the future Pope Pius XII. In discussing this period of the Academy reference should be made to the presence of such distinguished members as Ugo Armaldi, Giuseppe Armellini, Niels Bohr, Lucien Cuenot, Georges Lemaître, Tullio Levi-Civita, Guglielmo Marconi, Robert Millikan, Umberto Nobile, Max Planck, Ernest Rutherford, Erwin Shrödinger, Francesco Severi, Edmund Whittaker, and Pieter Zeeman.

During the years 1937-1946 the publications of the Academy had a largely Italian character, presenting, for example, the work of the Italian Academicians Pistolesi, Crocco, and Nobile on aerodynamics. But there were also papers by foreign Academicians such those as by E. Schrödinger in 1937 on quantum physics and by M. Tibor in 1937-1939 of an astronomical character. During the Second World War the Academy greatly reduced its activity but nonetheless found space for the publications of Jewish Italian scientists who had been marginalised by the race laws of 1938, amongst whom should be mentioned a group of mathematicians of Jewish descent including Tullio Levi-Civita and Vito Volterra, and others such as Giuseppe Levi, Rita Levi-Montalcini, E. Foà and G.S. Coen. Pius XII (1939-1958), who succeeded Pius X, did not fail to make addresses to the Academicians, even during the war years, such as the address of 30 November 1941 on the occasion of the inauguration of the fourth academic year. This address was dedicated to a long and profound reflection on the position of man in relation to the Creation and God (cf. *Discorsi e Radiomessaggi*, III, pp. 271-281).

In the post-war period, at a time of sensitive reconstruction and the rebuilding of international relations, in the face of the great difficulties encountered at the level of scientific contacts and exchange, the Academy undertook the publication of the research results of greatest interest of the various fields of science which had been achieved during the war in its work *Relationes de Auctis Scientiis tempore belli* (aa. 1939-1945). This publication was of marked importance in fostering the renewal of scientific contacts between the nations which had previously been at war. In 1946 Alexander Fleming (1881-1955) was appointed an Academician in recognition of his discovery of penicillin – a discovery which opened the way to the pharmacological production of antibiotics.

During the 1950s, in parallel with the problems of reconstruction and the development of under-developed regions, the activity of the Pontifical Academy of Sciences centred around the questions and issues of applied science. In 1955 the study-week on trace elements was held, when for the first time the problem of agrarian production and food sources was addressed. After the election to the papacy of John XXIII (1958), Padre Gemelli died in 1959. The Presidency of the Academy was then held by G. Lemaître.

The 1960s witnessed an exponential growth and development of science connected with electronics and the conquest of space. This gave new impetus to industry and technological advance but also to nuclear armaments. In astrophysics the discovery of new sensors and the development of radio-astronomy opened up the universe to new interpretations. Biology became directed towards the molecular study of genetics. In 1961 the Pontifical Academy of Sciences organised a study-week on the macromolecules of interest to biology, and in particular on the nucleoproteins, a subject which was then of major importance for international research. On that occasion, when meeting the Academicians, John XXIII reaffirmed the educational and cultural mission of the Church and the function of scientific progress in relation to the positive appreciation of the human person. The Pope recalled in addition that science is directed above all else towards the development and growth of the personality of man and the glorification of God the Creator: 'indeed, far from fearing the most audacious discoveries of men, the Church instead believes that every advance in the possession of the truth involves a development of the human person and constitutes a road towards the first truth, and the glorification of the creative work of God' ('Discorso in occasione del XXV dell'Accademia, 30.10.1961', in *Discorsi, Messaggi e Colloqui del Santo Padre Giovanni XXIII*, vol. III, p. 493). In 1962, at the time of the plenary session of that year, a study-week dedicated to astronomy which addressed the subject of cosmic radiation in space was held, guided in first person by the President of the Academy, Monsignor Lemaître.

In 1964, at the time of the pontificate of Paul VI (1963-1978), there appeared amongst the publications of the Pontifical Academy of Sciences the *Miscellanea Galileiana* of Monsignor Pio Paschini, who was Professor of History at the Lateran University. The Galileo case was slowly reopened, a development favoured by the reference made to it by Vatican Council II in n. 36 of *Gaudium et Spes*. This led to the address by John Paul II of 1979 to which reference has already been made. After the death of Georges Lemaître, in 1966 Padre Daniel O'Connell was made President of the Academy. A Jesuit and Irish astronomer, he had previously been Director of the Vatican Observatory and had been an Academician for life since 1964. He was also the author together with other astronomers of an important general atlas of the stars. The year 1967 was marked by the publication of the encyclical *Popularum Progressio*, in which Paul VI brought to worldwide attention all the major problems inherent in the development of the Third World. This document also contained an appeal to engage in international scientific co-operation so that this could in all forms favour developing countries. It introduced the idea that scientific progress and advance must be guided by a 'new humanism': 'every advance of ours, each one of our syntheses reveals something about the design which presides over the universal order of beings, the effort of man and humanity to progress. We are searching for a new humanism, which will allow modern man to refind himself, taking on the higher values of love, friendship, prayer and contemplation' (n. 20). In harmony with the themes of the encyclical, the Academy thought it was necessary to open itself to collaboration with the scientists of the Third World and by 1968 it was already holding a study-week on the subject of 'organic matter and soil fertility', a subject which dealt with the applications of science to agricultural production and the solution of the problems of hunger in the world.

In 1972 for the first time a secular President was elected – the Brazilian Carlos Chagas, who had already been a member of the United Nations and the General Secretary of the first conference of the United Nations on Science and Technologies for Development. The new President imparted a new direction to the activities of the Academy which were now more centred around solving the great problems of post-industrial society (cf. di Rovesanda, 2000). The scientific activity of the Academy was thus directed not only towards the subjects of science which were more specific to Western culture but also began to be concerned, with the co-operation of Giovanni Battista Marini-Bettòlo (who succeeded Chagas in 1988), with the scientific and health care problems connected with the growth and development of the Third World ('development ethics').

The 1980s witnessed the development of new directions in scientific research which moved in the direction of the life sciences, the earth sciences, and ecology. Mankind had to face up to new problems, such as pollution, changes in the biosphere, energy reserves, and genetic manipulation. In 1982 the Academy committed itself at an international level to the promotion of peace with the drawing up of a document on nuclear armaments (cf. 'Dichiarazione sul disarmo nucleare' ('Declaration on Nuclear Disarmament'), *EV*, 7, pp. 1811-1825) and devoted the next plenary session (of 1983) to the subject of 'science for peace'. In connection with that event, John Paul II appealed to members of governments to work in an effective fashion in order to remove the danger of a new war and invited States to engage in nuclear disarmament (cf. 'Il sapere scientifico edifichi la pace, 12.11.1983' ('Scientific Knowledge should Build Peace, 12.11.1983'), in *Insegnamenti*, VI, 2 (1983), pp. 1054-1060). This document and appeal achieved a strong resonance in the United States of America and the Soviet Union. During the 1990s meetings and study-weeks were held which were dedicated to analysing the question of the prolonging of life; the question of determining the moment of death; the question of transplants and xenografts; and the question of sustainable growth and development. The issues of artificial fertilisation, cloning, and genetic manipulation were also considered. These were subjects which increasingly involved issues of an ethical character (bioethics) and which drew scientists, philosophers and theologians into dialogue. Although the usual practice of involving various disciplines was maintained, the research and the debates of the

Academicians were directed in a special way towards reflection on the anthropological and humanistic dimensions of science. In November 1999 a working-group was held on the subject of 'science for man and man for science', and the Jubilee session of November 2000 was dedicated to the subject 'science and the future of mankind'.

III. The Role of the Academy in the Dialogue between Scientific Thought and Christian Faith

In the relations which exist between Academies and the States in which they carry out their activities, the case of the Pontifical Academy of Sciences can be seen as a singular case, as indeed in basic terms the role of the small State which hosts it is also singular. During these long years this relationship has become very fertile. The Church has paid careful attention to the Academy. She has respected its work and fostered the autonomy of its scientific and organisational dynamics. Through the Academy, the Magisterium of the Church has sought to make the scientific world understand her teaching and her orientations in relation to subjects which concern the good of man and society, the complete human development of all the peoples of the world, and the scientific and cultural co-operation which should animate the relations between States. On the occasion of numerous addresses and messages directed towards the Academy by five pontiffs, the Church has been able to repropose the meaning of the relationship between faith and reason, between science and wisdom, and between love for truth and the search for God. But through the Academy the Church has also been able to understand from nearer to hand, with speed and in depth, the contents and the importance of numerous questions and issues which have been the object of the reflection of the scientific world, whose consequences for society, the environment and the lives of individuals could not but interest her directly, 'given that there is nothing which is genuinely human which does not find echo in her heart' (cf. *Gaudium et Spes*, 1). The Pontifical Academy of Sciences has thus become one of the favoured *forums* for the dialogue between the Gospel and scientific culture, gathering together all the stimulating provocations but also the inspiring possibilities that such dialogue brings with it, almost thereby symbolising a shared growth – of both the scientific community and the Magisterium of the Church – of their respective responsibilities towards truth and good.

The above survey, although general in character, dealing with the activity carried out over the sixty years since the foundation of the Pontifical Academy of Science, the subjects of the numerous meetings and study-weeks, and the publications which the Academy has produced, brings out all the contemporary relevance and the importance of the subjects which have been addressed. Scientists from all over the world, often co-operating closely with a group of philosophers and theologians, have examined questions and issues which have ranged from genetics to cosmology, from agriculture to the distribution of resources, from the surgery of transplants to the history of science, and from ecology to telecommunications. The speeches addressed by the Pontiffs to the Academicians, from Pius XI to John Paul II, have offered important elements of reflection not only in relation to the ethical and moral responsibility of their activities but also on the very meaning of scientific research, and on its striving for truth and an increasingly profound knowledge of reality. The subject of the relationship between science and faith, both at an epistemological and an anthropological level, has been the usual framework of almost all these papal addresses. The forms of language employed have been different as these decades have passed, and different emphases have been placed on the various questions and issues, but the attention paid to scientific work has been unchanging, as has been the case in relation to the philosophical and cultural dimensions which that work involves.

Side by side with such dialogue, which we could call 'ordinary', international public opinion has been witness to certain 'out of the ordinary' events. From the mass media it has learnt about speeches of special importance for the relationship between science and faith, speeches given at the Academy in particular during the pontificate of John Paul II. Of these reference should be made to the address with which, as has already been observed (see above section I), John Paul II spoke to the plenary session of the Pontifical Academy of Sciences in November 1979 to express his wish for, and then formally request, the establishment of a committee of historians, scientists, and theologians which would re-examine the Galileo case and present public opinion with a serene analysis of the facts as they occurred (Galileo, IV). The aim of this was not in a historical sense to recognise the inadvisability of the condemnation of the heliocentrism carried out four centuries beforehand by the Sant'Uffizio (something which had already been effected in 1757 with the removal of the works in question from the list of prohibited books), but rather to ensure that the historical-philosophical context of the episode, as well as its implications at a cultural level, were more illuminated, thereby clarifying in a public way which would be comprehensible to everybody what had already been made clear in a narrower circle of intellectuals and experts. During a new assembly of the Academy which was held on 31 October 1992, Cardinal Paul Poupard, in the presence of the Holy Father, presented the results of the committee and commented on the work which it had carried out.

Four years later, on 22 October 1996, this time in the form of a message on the occasion of the sixtieth anniversary of its refoundation, John Paul II once again chose the Pontifical Academy of Sciences as a qualified interlocutor to expound certain important reflections on the theory of evolution (*Magistero,* V.2; *Uomo, Identità Biologica e Culturale,* V.3). Returning to and developing certain observations made by his predecessor Pius XII in the encyclical *Humani Generis* (cf. *DH* 3896-3899), he now added that 'new knowledge leads the theory of evolution to be no longer considered as a mere hypothesis', thereby recognising 'that this theory has progressively imposed itself on the attention of researchers following a series of discoveries made in the various disciplines of knowledge', imposing itself also therefore on the attention of theologians and bible experts (*Scienze Naturali, Utilizzo in Teologia*).

It would not however be exact to confine only to recent years the climate of mutual listening and serene encounter on subjects of great relevance. History has also been a witness to other episodes of intense dialogue with the Roman Pontiffs of which the Academy or some of its members were the protagonists. This is the case, for example, of Max Planck, who wanted to make himself the interpreter in a direct way with Pius XII in 1943 of the risks of war connected with the use of armaments based upon nuclear fission (cf. Ladous, 1994, p. 144), or the close relationship between Pius XII and Georges Lemaître, who enabled the Pontiff to understand from closer to hand at the beginning of the 1950s the meaning of the new cosmological models which were by then beginning to become established in the scientific world, and the philosophical, or even theological, questions which at first sight appeared to be involved (Lemaître, IV). In more recent years, Carlos Chagas was especially concerned in 1981 to take on board the worries of John Paul II, who was still convalescing after the attack on his life, about the consequences for the planet of a possible nuclear war. He decided to himself present the studies carried out on the subject to the principal Heads of State in his capacity as President of the Academy (cf. di Rovesanda, 2000).

In the letter sent to Padre George Coyne, the Director of the Vatican Observatory and a member of the Council of the Academy, a document which is certainly one of the most profound there is on the subject of the dialogue between science and faith, John Paul II observed that science has acted to purify faith and that faith has acted to generate scientific research, a truth demonstrated by the fact that Galilean modern science was born in a Christian climate with the increasing assimilation of the message of freedom placed in the heart of man. Thus, in the same letter, referring to the wider context of universities, the Pope declared that: 'The Church and academic institutions, because they represent two institutions which are very different but very important, are mutually involved in the domain of human civilisation and world culture. We carry forward, before God, enormous responsibilities towards the human condition because historically we have had and we continue to have a determining influence in the development of ideas and values and the course of human actions' ('Lettera al Direttore della Specola Vaticana, 1.6.1988' ('Letter to the Director of the Vatican Observatory, 1.6.1988, *OR* 26.10.1988, p. 7) For this to come about, the Pope stressed the importance of there being experts and places especially dedicated to such a dialogue: 'the Church for a long time has recognised the importance of this by founding the Pontifical Academy of Sciences, in which scientists of world renown regularly meet each other to discuss their research and to communicate to the wider community the directions research is taking. But much more is required' (*ibidem*).

And in this 'more' John Paul II saw the need, in their irreplaceable dialogue, for scientific institutions and the Catholic Church not to think in a reductive way about the settling of ancient conflicts, and also saw the more important need for mutual help in the investigation of truth and a shared growth in their responsibility for the good of the peoples of the world and their future. And it in this logic, with this new readiness to engage in service, that the present President of the Academy, Professor Cabibbo, in his address to John Paul II on the occasion of the Jubilee plenary session on the subject of 'science and the future of mankind' (*OR* 13-14.11.2000, p. 6) was able to speak about the 'renewed commitment' of the Pontifical Academy of Sciences together with the Holy See to the good of the whole Church, of the scientific community, and of those men and women who search and believe.

BIBLIOGRAPHY

For studies and works of a historical character see:

E. di Rovasenda and G.B. Marini-Bettòlo, *Federico Cesi nel quarto centenario della nascita* (Pontificiae Academiae Scientiarum Scripta Varia, 63, 1986).
G.B. Marini-Bettòlo, *Historical Aspects of the Pontifical Academy of Sciences* (Pontificae Academiae Scientiarum Documenta, 21, 1986).
G.B. Marini-Bettòlo, *L'attività della Pontificia Accademia delle Scienze 1936-1986* (Pontificiae Academiae Scientiarum Scripta Varia, 71, 1987).
G. Marchesi, 'La Pontificia Accademia delle Scienze, luogo d'incontro tra ragione e fede', *Civiltà Cattolica* 139 (1988), III, pp. 235-246; R. Ladous, *Des Nobel au Vatican. La fondation de l'academie pontificale des sciences* (Cerf, Paris, 1994).
P. Poupard (ed.), *La nuova immagine del mondo. Il dialogo fra scienza e fede dopo Galileo* (Piemme, Casale Monferrato, 1996).
E. di Rovasenda, 'In ricordo dell'antico Presidente della Pontifica Accademia delle Scienze, C. Chagas', *OR* 21-22.2.2000.

Some publications of the Academy on subjects referred to in this paper:

P. Paschini (ed.), *Miscellanea galileana*, 3 vols., (Pontificiae Academiae Scientiarum Scripta Varia, 1964).
Science and Technology for Developing Countries (Pontificiae Academiae Scientiarum Scripta Varia, 44, 1979).
S.M. Pagano and A.G. Luciani, *I documenti del processo di Galileo Galilei* (Pontificiae Academiae Scientiarum Scripta Varia, 53, 1984).
The Artificial Prolongation of Life and the Determination of the Exact Moment of Death (Pontificiae Academiae Scientiarum Scripta Varia, 60, 1985).
Discorsi indirizzati dai Sommi Pontefici Pio XI, Pio XII, Giovanni XXIII, Paolo VI, Giovanni Paolo II alla Pontificia Accademia delle Scienze dal 1936 al 1986 (Pontificiae Academiae Scientiarum Scripta Varia, 64, 1986).
The Responsibility of Science (Pontificiae Academiae Scientiarum Scripta Varia, 80, 1988).
Science for Development in a Solidarity Framework (Pontificiae Academiae Scientiarum Documenta, 25, 1989).

The Determination of Brain Death and its Relationship to Human Death (Pontificiae Academiae Scientiarum Scripta Varia, 83, 1989).

Science in the Context of Human Culture, I-II (Pontificiae Academiae Scientiarum Scripta Varia, 85-86, 1990-1991).

Resources and Population (Pontificiae Academiae Scientiarum Scripta Varia, 87, 1991).

The Legal and Ethical Aspects Related to the Project of the Human Genome (Pontificiae Academiae Scientiarum Scripta Varia, 91, 1993).

Discorsi dei Papi alla Pontificia Accademia delle Scienze (1936-1993) (Pontificia Academia Scientiarum, Vatican City, 1994).

For all the publications of the Pontifical Academy of Sciences see *Publications of the Pontifical Academy of Sciences (1936-1999)* (Vatican City, 1999).

STATEMENT ISSUED AFTER THE WORKSHOP HELD AT THE PONTIFICAL ACADEMY OF SCIENCES ON 19-20-21 NOVEMBER 2001, AND APPROVED BY THE COUNCIL OF THE ACADEMY ON 17 FEBRUARY 2002

The challenges for science: education for the twenty-first century

We, members of the *Pontifical Academy of Sciences* and experts, after meeting in the Vatican on 19-20-21 Nov. 2001, declare as follows.

The immense and increasingly rapid development of science as an important element in culture bestows a new responsibility on the scientific community, beyond its traditional role of creating new knowledge and new technology. Ensuring proper education in science for every child in the world and, consequently, a better public understanding of science and what science stands for, has become both a necessity and a challenge.

As a belief in the constant capacity of humanity to progress, education requires caring for the children of today and preparing the citizens of tomorrow. Access to knowledge, therefore, is a human right, even more so in the knowledge-based society of the future.

The extremely uneven access to education in today's world generates profound inequalities. Let us not tolerate the existence of a knowledge divide, in addition to an unacceptable economic divide which also includes a 'digital divide'. For, unlike the possession of goods, knowledge, when shared, grows and develops.

Education in science for all girls and boys is essential for several reasons. In particular, this education helps:

– to discover the beauty of the world through emotion, imagination, observation, experimentation, reflection and understanding;

– to develop the creativity and rationality which enable humans to understand and communicate;

– to contribute to moral development and sense of values: the search for truth, integrity, humility, and man's responsibility towards his neighbours and future generations;

– to share the accumulated wealth of knowledge amongst all people, as required by justice and equity;

– to be aware of mankind's interdependence with the environment and the Universe;

– to enable contributions to the solution of the acute problems facing humanity (poverty, food, energy, the environment).

From the perspective of these objectives, it is our conviction that the present state of education in science is of great concern throughout the world, regardless of the local stage of development. In the case of developing countries, in particular, the magnitude of the problem is immense.

After consideration of a number of encouraging experiences in various countries, and the actions of several Academies, we conclude that the following initiatives should be taken without delay, both at a national and an international level. Moreover, they should be shared and integrated within the diversity of cultures found in contemporary societies.

1. The highest level of attention has to be given to science education in primary and secondary schools, including children with special needs.

2. Education in science must be seen and implemented as an integral part of the whole of a person's total education (language, history, art, etc.).

3. The most important contribution to improving education in science in elementary and secondary education lies in helping teachers and parents to cope with this difficult task. This will involve increased resources, partnership, professional development, social recognition and support for teachers.

4. Such a challenge cannot be met without the deepest commitment on the part of the various members of the world's scientific and technological community. Meeting this challenge must be viewed as a new moral obligation.

5. Every means should be used to convey the urgency of the situation to governments. They alone have the capacity to deal with the magnitude of the problem, to provide the necessary resources, and to implement suitable policies. Non-governmental organisations and financial institutions should also participate in such an initiative.

6. Relevant research on science education should be stimulated and encouraged, and should consider the potential of communication technologies.

What is being called for is a global commitment to revitalize science education at school level with support not only from the teachers, parents and scientists, but entire communities, organisations and Governments, for a better and more peaceful world to live in.

Success along these lines, pursued with perseverance and dedication, will constitute a decisive contribution to the socio-economic and cultural development of humanity, the achievement of social justice, and the promotion of human dignity.

TABLES

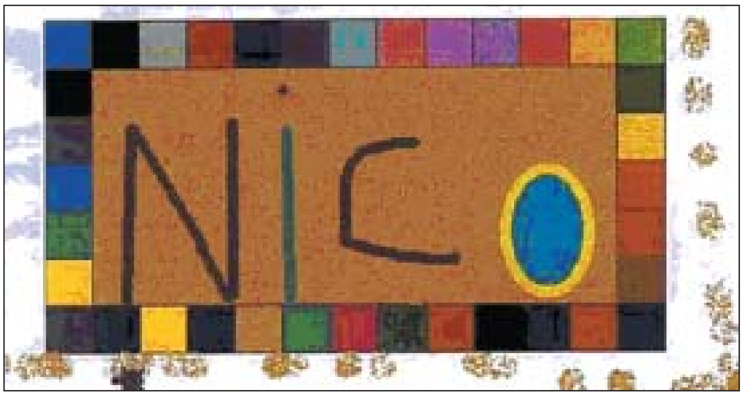


Figure 2. Two different ways of drawing. Analog task: The name Nico was hand-written with the mouse as a pencil. Digital task: The colored framework was generated by a computer procedure (Logo). Different cortical areas are involved in these tasks. In this case, because of the right hemispherectomy both tasks take place in the left hemisphere.

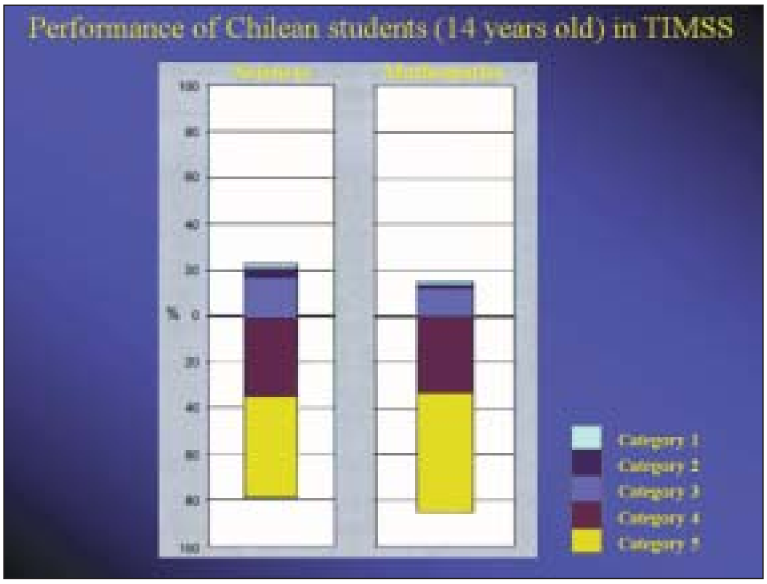


Figure 1.

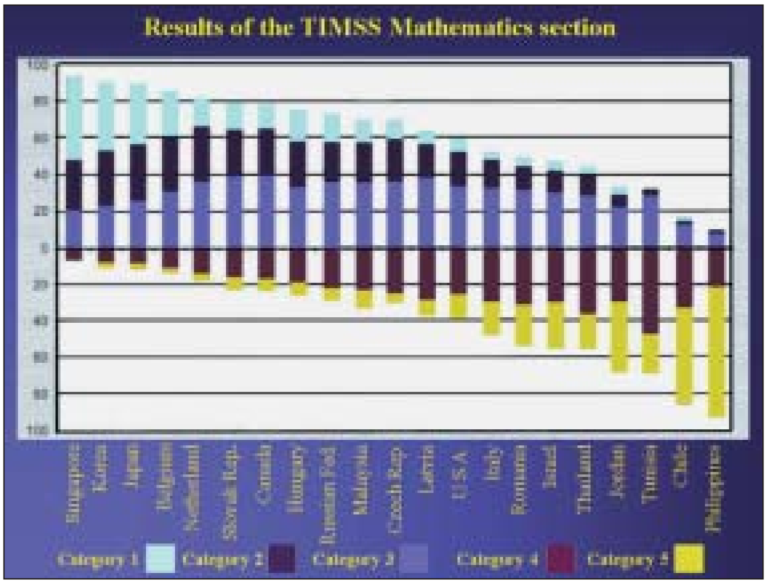


Figure 2.

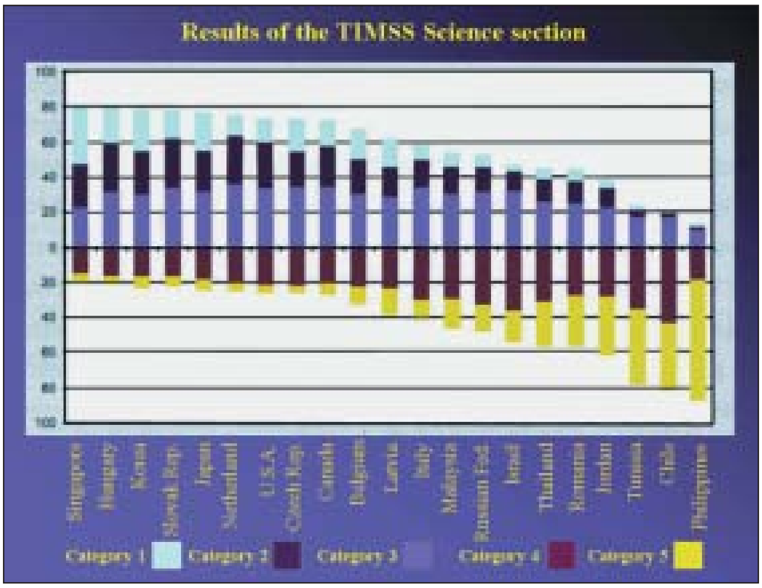


Figure 3.

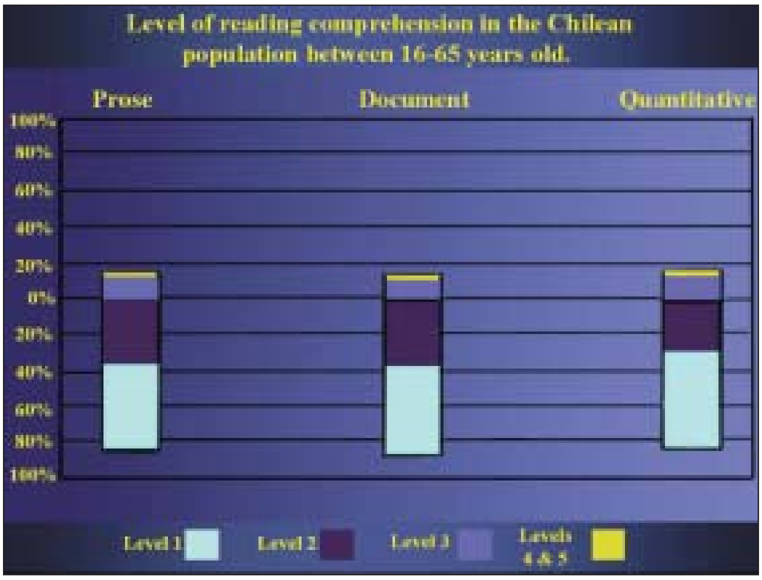


Figure 4.