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'MUCH MORE IS REQUIRED'[1] SCIENCE EDUCATION IN THE 21st CENTURY: A CHALLENGE

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Introduction

Observing the many themes of Workshops or Sessions held over the last decades by the Pontifical Academy of Sciences, it is striking that none of them had directly dealt with *education* as a main title. This preoccupation was nevertheless present, especially in recent years and at the 2000 Jubilee Plenary Session, as shown in the vigorous summary of the 2000 Budapest *World Conference on Science* given by Werner Arber or the plea for responsibility given by André Blanc-Lapierre. With great foresight Ahmed Zewail, writing on the '*New world dis-order*', and Paul Germain underlined the importance of *education in science* as a fundamental need of modern societies to achieve peace, justice and a sustainable development. In fact, the urgency to deal with this subject around the world has recently been demonstrated by an unprecedented number of Conferences,[2] which were called by

[1] John Paul II, *in* Letter to the Director of the Vatican Observatory, 1.6.1988.

[2] *World Conference on Science*, ICSU/UNESCO, Budapest 2000; *Transition of Sustainability in the 21st Century*, IAP, Tokyo 2000; *International Conference on Research Related to Science Education*, Monterrey, US-Mexico Foundation for Science, Monterrey 2001; ICSU/CCBS *Conference on Primary School Education on Mathematics and Natural Sciences*, Beijing 2001; ICSU/CCBS-IAP *Regional Conference on Science Education*, Kuala Lumpur 2001; *Science Education in the 21st Century: a Challenge*, Pontifical Academy of Sciences, Vatican City 2001; *Science Education*, Chilean Academy of Sciences, Santiago 2002; Regional ICSU (CCBS)/IAP *Conference on Science Education*, Rio de Janeiro 2002; *The Generation of Experimental Material & Learning Modules for Science Education*, IAP & Indian Academy of Sciences, New Delhi 2002.

Science Academies (*InterAcademy Panel* IAP or national Academies) or scientific bodies (mainly ICSU, through its *Committee for Capacity Building*). Education, not only of the future scientists but of all the children, has become a subject of intense attention from a number of prominent scientists and institutions: this is certainly a new development, where the creators and actors of science feel responsible to share it on a broad scale. Why is this concern emerging now? Is it only a lobby action of scientists, worried by the disinterest for science shown by students in developed countries? Or does it correspond to a deeper sense of urgency and justice?

It is quite obvious that the pace of development of the scientific and technological body of knowledge, its complexity, the *tour d'ivoire* in which many scientists live have left behind most of the inhabitants of the Earth, even those whose intellectual performances or cultural background would qualify for understanding what happens. To make things worse, the classical way by which the advances in knowledge used to percolate into the school, especially at primary and secondary levels, has become entirely unfit to the goal. For these two main reasons, sharing of scientific knowledge does no longer properly occur.

Was it appropriate of the Pontifical Academy of Sciences to move into this area, as its Statutes request this Academy ...*to contribute to the exploration of moral, social and spiritual problems*? The Council so decided, and a Workshop was held during three days in November 2000, gathering thirteen Academicians and thirteen experts, to discuss *Science Education in the 21st Century: a Challenge*. The developed world was well represented, as were Latin America and India. China, Africa and the Islamic world were practically absent, which is unfortunate since preserving the cultural diversity of the world is an essential part of any education issue. The conclusions were published in the form of a Statement[3] later approved by the PAS Council.

I shall try in this summary to convey the spirit of the Workshop, which was fully published in 2001.[4] It essentially focused on primary and secondary education, leaving somewhat aside specialized and university training. There was a broad agreement on the importance of the subject, a number of encouraging plans or projects were reported, several difficult issues were identified and, before writing the final Statement, an enlightening discussion brought signs of hope.

[3] This Statement is reproduced at the end of this communication.

[4] 'The Challenges for Science: Education for the Twenty-First Century', *Scripta Varia* 104, Pontifical Academy of Sciences (2002).

Education in Science

At this point, it may be useful to clarify what is meant by *education in science* (science understood as the ensemble of disciplines dealing with nature, phenomena, and artifacts). During the last two decades, a strong emphasis was placed on scientific information of the general public through the mass media (press, television) and on informal science learning media (museums). But *information* is not *education*. Over these years, little attention was paid to the role and content of science education in the school systems, especially during the years of compulsory education, which in most countries extend over 8 to 9 years (primary and junior high school). No thorough reforms were undertaken. The subjects taught, the way they are taught, the teachers, training are more or less divorced from the living body of science in progress, of technology in action. To make things worse, the scientific community has remained outside this part of the education system, since it was often considered that the teaching at such elementary levels does neither require the sophisticated knowledge, which we develop and apply in our laboratories, nor the involvement of outstanding and respected scientists. It is only in the recent years that innovative initiatives have been taken.

The overall result is quite worrisome, as was repeatedly mentioned at the Workshop. In many countries, not necessarily developing ones, science is absent from primary schools (a 'good' example is France, where in 1995 science was taught in only 5% of the 350 000 classes). Too often, science lessons are made of accumulation of information, facts, results, formulae, lessons to be repeated by heart which make little sense for the child: Jonathan Osborne suggested that '*current practice is rather like introducing a young child to jigsaws by giving him bits of a one thousand piece puzzle and hoping he has enough to get the whole picture, rather than providing the simplified hundred pieces version*'. As an echo on the aim of the schools, Einstein quoted by Giuseppe Tognon: '*...the general ability to think and judge independently should ... take the first priority*'. Accumulation of mere facts, admiration of technological black boxes do not suffice to build up a critical mind, possessing the basic roots of scientific attitude towards the natural world, able to properly use rationality, to express himself with adequate words and arguments in order to deal with more abstract concepts, with causality, probability – a notion on which André Blanc-Lapierre used to insist – to discriminate between true, false, uncertain. It may seem odd but it is a fact, in many countries whether they are developed or not, that

public policies or privately owned schools tend to undermine the importance and the role of science in education: this social trend probably reflects the increasing gap between science and the public and sometimes a suspicion, reflected by the politicians.

Going beyond this and quoting Erwin Schrödinger asserting that '*life is not merely made of science*', Stanley Jaki proposed a much deeper view on the goals that education in science should pursue, beyond the commonly accepted view that it is the art of imparting skills in computation or experimentation, a leisure to play with '*something that is technically sweet*' (Robert Oppenheimer).

At the beginning of the Workshop, a consensus was quickly established on the absolute need to develop these basic abilities for every child in the world, firstly to establish the technological and scientific basis of development, as strongly postulated and pointed out by Chintamani Rao. Quoting the latter, speaking on capacity building: '*I make this presentation with the fundamental faith that the mechanism to reduce global imbalance of development and to increase the stability of the world has to be based on knowledge*'. But the way is long, from the knowledge accumulated in laboratories or industries to sharing it through a school system, in order to achieve capacity building. Rafael Vicuña made an extensive and quantitative description of the poor capacities measured in the Chilean population, answering simple tests in reading comprehension.

Yves Quéré went further and pointed out, as M. Menon also did, that education is carrying values, not only knowledge: science is continuously educating us, decreasing our ignorance, addressing not only our intelligence but also our personal and social behavior, shaping our outlook of the world and even our character. Science teaches us values, which are fundamental for the intellectual and moral development of Man and of the societies: the idea of freedom, the virtue of humility and modesty, the spirit of research against the *more-or-less*, the *preconceived*, the *ready-to-wear* types of behavior, the ethical concern to deal with the applications of science. He recalled this universal Golden Rule '*Do not do unto others what you would not like them to do to you*', to be remembered in order to protect from technological harm the men of today and tomorrow. Again, this stresses the point that teaching science, even at an elementary level, goes far beyond learning the density of substances or the atomic weight of various elements.

There is an important issue, which the Workshop did not specifically address and which can not be decoupled from school education: lost in a world, urban and technological, which most people hardly decipher, all

kinds of beliefs propose simple-minded explanations, leading sometimes to dramatic issues in the most radical sectarian movements. On its Internet front page, with the same seriousness and on equal footage, the French public-owned Telecom Company offers weather forecast, stock exchange access and... astrological predictions! It seems essential to constantly urge religious thinkers and leaders to educate properly on the nature of science, on the use of reason; to explore and properly integrate, no matter how difficult, the new areas of freedom opened by science (e.g. therapeutic use of stem cells, information technologies); to constantly re-think their message in terms which account for the progress of knowledge and are understandable within the new representations provided by science; to make sure the training of the clerical persons includes such preoccupations. Let me quote John Paul II: '*Il est illusoire de penser que la foi, face à une raison faible, puisse avoir une force plus grande: au contraire, elle tombe dans le grand danger d'être réduite à un mythe ou à une superstition*'.[5] During the last Plenary Session of this Academy, Ahmed Zewail made a similar plea, to avoid '*fanatical mix-ups of state laws and religious beliefs*' and to note the importance of knowledge, science and learning in the Quran as it is addressed to the Muslims, who are close to one billion in the world population. Placing truth, a virtue essential in science, at its right place becomes an essential objective in a world torn by simple-minded, oversimplified and dangerous views on truth: Jean-Michel Maldamé insisted to refute the idea that '...*science holds a monopoly on the truth*'.

I shall conclude this section by a warning, formulated by Giuseppe Tognon: '*If ...public opinion continues to consider scientific research as a means to an end, the scientist will continue to be viewed only as an economic entity...*'. Quoting Jorge Allende: '*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 in Santiago*'. One more reason to restore in schools a deep understanding of what is a free mind doing free science.

Hard points & Great hopes

The Workshop documented a picture of science education in the world which was rather grim: aside from the formation of an elite of exceptional quality, carrying out research mostly in developed countries (even with lim-

[5] *Fides et ratio,* Encyclical of Pope John Paul II, IV, 48 (1998).

itations of efficiency, as pointed out by Rudolf Mössbauer for Germany) and often through brain-drain (in 1999, 36% of Science & Engineering Ph.D.s in United States were given to non-citizens, while the foreign-born Ph.D.s represent 30% of the total academic employment of doctoral scientist and engineers in this country[6]), the percolation of modern science into the cultures through schools is poor or often absent. On the other hand, a number of remarkable and recent initiatives were reported, which seem to indicate a potential for deep transformations, where the science community is called to play a novel and major role.

Two main related factors were identified: the first dealing with the goals assigned to science education and the pedagogy implemented to reach these goals, the second with the quality of teachers, considered as an absolute requirement for any sustainable transformation.

It would be too long to summarize here the deep analysis carried by Jorge Allende, Richard Gregory, Stanley Jaki or Jonathan Osborne on the entirely outdated and inefficient pedagogy used today to convey the nature of science and scientific knowledge to children and teenagers. Characterized by an accumulation of unrelated facts, a lack of historical context and of experimental approaches, a dogmatic teaching without the exercise of the proof or the virtue of error analysis, a knowledge broken into disciplines and hiding the unity of science, the fundamentals of scientific method and the beauty or power of its results, this teaching has little meaning to children and teenagers: '*La science, cela n'a rien à voir avec la vie*!' (a French pupil) or '*It does not mean anything to me. I am never going to use that. It's never going to come to anything, it's just boring*!' (Quoted by J. Osborne).

Fighting this, and referring to many analyses carried out on *How people learn*?,[7] a novel conception of basic education in science has emerged in recent years, and was beautifully demonstrated at the Workshop, including a practical laboratory working session proposed by Douglas Lapp. Under various names (*Hands-on* or better *Inquiry* science in United States, *La main à la pâte* in France, *Mao na massa* in Brazil, *Zuò zhong xue* in China) the same concept is proposed and implemented, in some cases in a limited number of schools (Mexico, China, Brazil), or inspiring broader reforms in

[6] National Science Foundation, *Science & Engineering Indicators 2002*, http://www.nsf.gov/sbe/srs/seind02.

[7] *How people learn?* National Research Council, National Academy of Sciences, Washington, D.C. (1999).

other countries (United States, France) and rapidly spreading. As pointed out by R. Gregory, *Hands-on* science is not a new idea, since Francis Bacon described it in his unfinished bool *New Atlantis* (1626).[8]

The central idea 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 directly through observation and experimentation, to stimulate their imagination, to broaden their mind and to improve in this process their command of language. On a subject proposed by the teacher, a child asks a question and immediately, instead of giving the answer, the teacher throws the question back to the class: through observation, hypothesis, arguments, experiments, writing and drawing, children practice the dialectic of reasoning and experiment which is at the heart of research and science. The questions, instead of the answers, become the focus of a learning process which indeed must ultimately lead to answers. Through this process, three fundamental points are to be progressively carried to the pupils, along the way of their progression in the curriculum: the marvels of the world, sensible or hidden, are understandable by the human intelligence seeking answers to the questions, as these are not the product of magic or remote characters; this understanding, which we call science, gives us an incredible power to act on the world, to build machines, and we call this technology; science and technology are the products of a long and endless human history, made of errors and flashes of genius, of patience and team efforts.

Although no large-scale assessment of these innovative programs could be presented at the Workshop, they at least produce happy and lively classes, encounter broad support wherever they are put in practice, and it is already proven that their impact is especially impressive on children with difficulties ('street children' in Mexico City with Guillermo Fernandez, *Réseaux d'éducation prioritaire* in France with Georges Charpak, Chicago slums with Leon Lederman). They seem to achieve the goal Rudolf Mössbauer was assigning to education: '*...Help children and youth to preserve their joy of life, their curiosity and their concern for one another*'.

Two important questions place this old method into new perspectives. The first is the role and use of the computer: should it take a significant place in science education? When? How? *Hands-on* approaches insist on the contact of the child with the real world, since he should first perceive it with his own senses rather than through artifacts or scientific instruments. Antonio Battro made a strong point in dismissing the classical (and too

[8] Bacon, Francis (1620) *New Atlantis*. Oxford: O.U.P. (1915).

easy?) opposition between real and virtual: '*Many human activities can be projected in two dimensions, real and virtual*'. For him, '*...the neural plasticity is expanded by the help of a computer ... new digital tasks require new digital skills and the exercise of new patterns of brain activation. This opens a new field in education which may be called neuroeducation*'. To comfort this thesis, a fascinating experiment carried by R. Pawar in the streets of Indian cities was recently reported at the TWAS General Assembly:[9] children are given computers without any instructions, and seem to learn quickly their use teaching it to adults. M. Menon underlined also the potential impact of information technologies, stressing the need to conceive and produce on large scales a one hundred dollar PC, with a simple operating system, battery driven, for operation in Brazil, India, Africa.

Related to this issue is the whole understanding of the learning process, as explored today by cognitive sciences. In particular, Stanley Jaki stressed the underestimated role of memory training. The development of cognitive sciences was barely addressed at the Workshop, and would deserve further confrontation of ideas. The importance of emotion in the learning process of children has too often been underestimated, and may become a fundamental factor in societies where children and families are submitted to drastic social changes, as in China with the current policy of the single child.[10] The concept of a child with a 'virgin brain', to be filled by knowledge, had already been contradicted by the studies of Piaget and Wittowski. More recently, cognitive studies carried on babies[11] have shown the incredible plasticity of newborns to put in action a number of cognitive schemes, which are typical of scientists at work: the scientist, as the music composer or the painter, is a person who by good fortune has not lost his childhood abilities, as many of us know!

Finally, another very interesting point was raised by Mambillikalathil Menon: his plea for the diversity of cultures was expressed as a wish to maintain the diversity of languages, hence to explore possibilities for a 'universal networking language' (UNL), which may become possible with proper machine translation and may have a strong impact in spreading innovative pedagogical tools.

[9] R. Pawar, *Digital divide: problems and opportunities*, at Third World Academy of Sciences 8th General Conference, New Delhi, 19-23 Oct. 2002.

[10] Wei Yu, *Cultivate the emotion competency of our children*, OECD, 2002.

[11] Alison Gopnik et al., *The Scientist in the Crib: What Early Learning Tells Us About the Mind*, Harper, 2001.

Implementing new teaching methods depends on curricula and standards, which may quite easily be modified (such a global change just occurred in France in 2002 for the primary school, following the *La main à la pâte* effort). But this is nothing without the teachers, a point that has been the focus of many exchanges at the Workshop. Restoring their social status, improving their salaries is one aspect. Providing equipment is another: 70% of Indian schools do not have libraries or laboratory facilities; in Brazil, only 26% of secondary rural schools do have a science laboratory, and 7% of the primary urban schools. One should not overstate this problem: an excellent science lesson can be done with very little and cheap equipment, or even only with the natural phenomena available in the school surroundings, as long as the teacher is prepared to exploit the opportunities. The Workshop did not consider extensively, as it probably should have, the economics of school development and the competition between private and public sector in what becomes in some countries a profitable market. An analysis of the World Bank education policies, as often suggested in recent Conferences on science education, may at some stage become useful.

But the central point is teacher training, in order for the teacher to understand what the science is, how it evolves and how it ought to be taught. In many countries, teacher training is too often full of elaborate considerations on theoretical pedagogy without application to real cases: Jorge Allende mentioned the case of Chile where '*...this training is done in Education Faculties or Teacher's Colleges ... which do not have groups doing scientific research*'. The same is true in France, where primary school teacher training in science, already slim, has been cut by a factor of two in 2001 and is practiced with little or no contact with active scientists. To reverse this, there is one simple and powerful idea: to put the teacher in the same questioning and inquiry process that will be later proposed to children. This makes them realize and understand the mental process at work, and is better than feeding them with a formal knowledge, to be later reinjected to children. Stanley Jaki went even further, saying that '*the science of education* [which organizes teacher training] *resembles ever more closely a machine devised to produce illiterates in ever larger numbers*'.

Modifying the teacher's views and tools to transform education in science is such a radical revolution that it may only occur if the scientific community gets involved and supports the transformation. In fact, every new program mentioned above and detailed at the Workshop has been conceived, supported in front of governments and implemented, including teacher training, by scientists, often prominent ones, and with the support

of the Academies (Brazil, China, France, Mexico, United States). In countries with weak Academies, or without, implementation could only succeed with external help (Morocco, Vietnam). Along with their prestige, which is useful to convince governments, and their numerous ties with the grassroot scientific community in their home country and across the world, the permanence of the Academies offers a significant, even decisive advantage when dealing with educational issues, where the time constant of changes has to be measured in decades rather in the usual 'political' time constants of a few years. A remarkable example was presented by Celso Pinto de Melo, who in Brazil is devising a national program devoted to the creation of *Centers of reference in science education*, initially focused on secondary education, providing a regional space of continuous re-training of science (and mathematics) teachers. Another example was developed by Rafael Vicuña for Chile, pleading for an integrated community between science teachers and scientists, a very ambitious goal given today's fractures. It is significant to observe that many Academies, as well as their common body the *InterAcademy Panel* (IAP), are putting education in science as one of their forefront programs for the years to come.

The production of pedagogical resources at the appropriate scale is a challenge, for which no one yet has provided convincing solutions. But our times are granted a formidable tool, if properly used: *the Internet*. Although many schools, areas or even countries do not yet have an easy access to the Web for their teachers at decent transmission rates, this situation is rapidly changing (in 2001, 23% of rural Brazilian primary schools have a computer laboratory, 20% of French primary school teachers are connected to the Web and use it). Regarding science education, the Internet has several virtues: *a/* it allows teachers to exchange their experiences, and problems; *b/* it allows a broad dissemination of successful class protocols, lists of equipment; *c/* it allows a direct link between teachers and scientists, for questions and answers bridging the ever increasing gap between the ones who create the knowledge and the ones who teach it; *d/* it allows to connect schools across the whole planet to undertake cooperative work, contributing to forge the idea of science universality.[12] A convincing demonstration

[12] An interesting example of this is the Eratosthenes network of schools, built for measuring the radius of the Earth with the old method of Eratosthenes: it simply requires to measure simultaneoulsy in two schools the length of a pole shadow at local noon, and to know their kilometric distance in latitude. Results are spectacular (http://www.inrp.fr/lamap/eratosthenes). *Hands-on astronomy* could be practiced the same way.

is offered by the French *La main à la pâte* site open in 1998, which I presented at the Workshop (50 000 connections a month), or its counterpart in Chinese at Nanjing, open in 2001 (similar audience), or in Portuguese for Brazil.[13] Again, none of this could have occurred, been funded and accepted by the official public school systems without the support and the explicit responsibility of prominent scientific authorities.

Of special importance is the difficult task to select then convey the essentials of the new knowledge to teachers, in order to make it percolate in the schools. It is a pity to observe the formidable accumulation of facts, often irrelevant or impossible to understand, that are present in textbooks for secondary schools. Only active scientists, working closely with teachers, can discriminate in this flood of information, which is finally dis-informing the pupils. Georges Coyne, for instance, made the point that modern cosmology is a remarkable resource for elementary school education, leading children to understand that '*we have all been made in heaven*' and broadening their view point, in order for them to become acutely aware of mankind's interdependence with the environment and the Universe.

Conclusion

The Workshop Statement, which in February 2002 was approved by the PAS Council, summarized the thorough concern of the participants in front of a problem of immense magnitude and a formidable task: these cannot be brushed aside by the scientific community and entirely left to the 'classical' actors of education policies, although the scale of solutions does require Government actions. The scientists, who are often privileged in the resources they are granted, encounter here a moral obligation of justice, as said Yves Quéré quoting *The good Samaritan*.

As teachers are at the heart of the required changes, every effort should be made to help them change their view of science and their pedagogy: partnership or rather companionship (as extensively implemented by *La main à la pâte* in France); personal encounters with scientists and science activities at a simple level, far from the spectacular but often too remote 'shows of science' given by television; restoration of their trust in themselves to teach science; research activities to tie progress in cognitive sciences to actual teaching of science.

[13] In France: http://www.inrp.fr/lamap. In China: http://www.handsbrain.com. In Brazil: (http://ciencia.eciencia.pe.gov.br/).

I have always been impressed by the impact the *International Center for Theoretical Physics*, founded by Abdus Salam in Trieste, had and still has on the scientific development of many countries, by systematically organizing the contacts between prominent scientists and post-doctoral students. I wonder if this model could not be adapted to the needs of science education. We have repetitively observed how teachers, initially feeling incompetent to teach science in primary schools, have been transformed, have gained self-confidence and later achieved beautiful lessons, once they were exposed to convincing classes, given proper resources and scientists' companionship. On the model of ICTP, could *Regional Centers* be implemented where education leaders or teachers visiting for short periods (a few weeks) would meet high reputation scientists involved in education, practice *Hands-on* science, discover resources and get moral support to become later advocates of change?

At the Workshop, several participants supported the idea to have a well documented website to circulate information, country by country, on these issues. ICSU and IAP have agreed on this goal, have funded it and an International Website on science education,[14] in primary schools to begin with, will open in January 2003.

If I may conclude with a personal touch, it strikes me that education in science has to achieve a delicate balance between the universality of science, which is one of its fundamental characteristics and values, and the character of education, which must be deeply rooted in a particular culture, especially through language. Modern globalization, linked to technology, tends to a uniformity, which many resent as negative. By placing science in historical and cultural perspective, by inspiring education in local contexts, scientists have a great role to play.

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[14] The temporary address of this site, built for ICSU and IAP under a contract with the Académie des sciences in France, is: http://www.icsu.org/ccbs/teaching-science. For information contact: jasmin@inrp.fr .

THE WORKSHOP STATEMENT

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 economical 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 their 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.

DISCUSSION ON THE PAPER BY LÉNA

BATTRO: I want to share with you that we are doing a nice experiment now with our students of education at Harvard. I proposed to them, graduate students and doctoral candidates, to design an exhibit at the Museum of Science in Boston about the classes I'm giving to them. Instead of writing a paper, an assignment, I invited them to produce an exhibit of one of the main themes, and they've chosen to design an exhibit on chronobiology, and the way our brain sleeps or is awake. I can tell you that they are very excited to do that instead of writing an assignment.

ARBER: When I was a child we were taught at the level which we could identify with our senses, the eye, smelling and so on. We were stimulated to go into the field and to look at plants ourselves and make discoveries, and it worked beautifully. I do realise that in the last fifty or more years research has gone through micro- into nanoscales both in life sciences and in physics. At these scales it is very difficult for non-initiated people to understand and to accomplish an experimental approach. So, this was missing in your report. I think we have there a major natural barrier of scale. Children still like to look through the optical microscope, that's fine, but if it goes lower down, we just lose them, and I have a hard time telling them how at the level of filamentous DNA molecules the things proceed. One should really give serious thoughts on how to teach at that level and incorporate it with the macroscale views in order to get the message through.

LÉNA: I cannot agree more with what you say and should have insisted more on those first steps where perception and the use of their senses by children is absolutely essential to bring them in contact with reality. One can then build upon this to reach the next steps, which are more remote, deal with very small or very large scales, and with more abstract concepts.

IACCARINO: Many years ago children had to study much less in all fields of knowledge compared to now, and today one of the things that has

changed is the number of hours that children are required to stay at school or study at home, and we perhaps do not appreciate enough this change. For example, the hyperactive children syndrome, which is a problem today, was non-existent one hundred years ago. Have you discussed these types of problems?

LÉNA: Not specifically, but your remark reminds me of the comment made again and again on the need for revolution, because science teaching is in many circumstances made up of an accumulation, a superposition of layers of successive science which ultimately hide the substance of science. It's more an accumulation of facts than an attitude toward the world and conveying the fact that it's possible to understand it, and therefore the revolution is probably to rethink the whole process and avoid this accumulation which leads to confusion in the children's minds.

JAKI: Dr. Goldwin, the Director of the NASA programme in the United States, gave a speech, a nationally publicised speech about the problem of recruiting engineers to further the cause of space exploration, and he gave the following data: between 1965 and 1970 or 1969, that is the time of the moon landing, NASA had to recruit a total of sixty thousand electrical engineers. At that time twenty-four thousand Americans graduated with a BS in electrical engineering. In 1989, according to his data, the number was down to fourteen thousand. In 1994 the number was down to ten thousand, and I am sure that today the number is not more than eight thousand per year. At the same time, in 1965 the number of those who graduated from American Colleges with a BS, a Bachelor of Science degree in park and recreational services was zero. In 1989 their number was five thousand, in 1994 their number was equal to the number of those who graduated in electrical engineering, that is ten thousand, and today, in 2000, the number of those who graduated in park and recreational services and get a Bachelor of Science degree exceeds by a few thousands the number of those who graduate in electrical engineering. I merely hope that the shock of September 11, 2001 will be very effective, and I think that similar reversals in the numbers could be quoted from other western nations as well.

PAVAN: I would like to inform you that at the University of Campinas in Brazil a group under the leadership of Prof. Octavio Henrique Pavan developed a new system of teaching at high school level through a kind of game in which not only the student would learn but the professors must be updated in relation to the subject matter of their area.

LÉNA: Thank you for this comment, Professor Pavan. One thing which is repeatedly said at those conferences and that we observe in classes in France is the fear that teachers have of questions when dealing with science. They feel they have to give answers, and answers in science are too complicated, so they avoid the complete theme rather than moving into a field so uncomfortable for them that entering the question without being sure of the answer becomes dangerous. So, I would say that one of our goals should be to restore the culture of questions.