The Challenges for Science. Education for the Twenty-First Century
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SCIENCE EDUCATION AND CAPACITY BUILDING IN THE TWENTY-FIRST CENTURY

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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

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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.