Science Education and Our Future

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Introduction

ACCORDING TO CURRENT theory, matter was created from energy at the time of the Big Bang, at the beginning of cosmic history. As the hot, early universe expanded and cooled, it separated into pieces that later formed the hundreds of millions of galaxies we now see. One such galaxy was the Milky Way, which in turn spawned some 200 billion stars, of which the sun is one. Around the sun, a small planet was formed on which biological evolution has progressed during the last few billion years. You and I are part of the result and share this cosmic history.

Now here we are, atoms from the Big Bang, an intelligent and technological civilization of about 6 billion, fast multiplying, and largely unhappy human beings. This long evolution has now given us the wisdom to ask what is it that we want. We all want survival, of course, but survival on our own terms, for ourselves and generations to come. 1, and probably you, would want those terms to be comfortable, happy, and democratic.

If our most fundamental wish is a happy and democratic survival, this can be achieved only by an informed society. To be informed we must be educated, and in today's world no one ignorant of science and technology can be considered educated. Hence, science education appears fundamentally important to our happy future.

During the past decades people have been asking me what was the value of science when during the Apollo mission inspired by President John E Kennedy, we spent $24 billion to visit the moon. Now, finally, there seems to be an answer. Two years ago an auction of Russian space artifacts was held at Sotheby's in New York City. Among other treasures, there were three tiny pieces of the moon's surface weighing about 0.2 gram. The fragments were gathered by Luna 16. They arrived on Earth in September 1970 as part of a 100-gram payload returned from the Lunar Mare Fecunditatis by the automated soviet spacecraft. The samples were then presented to the widow of Sergei Korolev, who

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had directed the Soviet space effort from its inception until his untimely death in 1966.

The first ever public sale of lunar material brought its owner and Sotheby's the amazing sum of $442,500. On that basis, the 381 kilograms of rocks and soil brought back from the moon by the Apollo astronauts would be worth a whopping $850 billion!

Is this the kind of value of science that we should accept?

There are clearly other values of science, such as the creation of efficient technologies to provide a comfortable, peaceful, and happy human existence.

And again, the value of science can be assessed from the following U.S. Senate hearings discussing the value of the now abandoned supercollider or atom smasher. The dialogue is between Senator John Pastore and Cornell Emeritus Professor of Physics, Robert Wilson (Weinberg, 1992):

SENATOR JOHN PASTORE: Is there anything connected with the hopes of this accelerator that in any way involves the security of this country?

ROBERT R, WILSON: No sir. I don't believe so,

PASTORE: Nothing at all?

WILSON: Nothing at all.

PASTORE: It has no value in that respect?

WILSON: It has only to do with the respect with 'which we regard one another, the dignity of men, our love of culture. It has to do with, are we good painters, good sculptors, great poets? I mean all the things we really venerate and honor in our country and are patriotic about. It has nothing to do directly with defending our country except to make it worth defending.

I am often asked to comment on the values of scientific research, and I find that it is a challenge to explain to the public and the taxpayer the values of our discoveries. The challenge is even greater when our work on fundamental physics-such as particle physics, neutron stars, black holes, and galaxies---cannot have immediate benefits to the public.

I think that science has created a surprisingly broad and coherent understanding of the nature of the universe. We discuss in detail about happenings on extremely small sizes and during extremely short periods of time. We can also describe the history of the universe in billions of years and dimensions of billions of light years.

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This is the era of science and its resulting technology. The aim of science is to discover how nature works by searching for verifiable truths. Democracy does not work in science, because verifiable truths are indifferent to the opinions of a human majority; as Galileo Galilei said in 1632: "In questions of science the authority of a thousand is not worth the humble reasoning of a single individual." This human effort is blind to race or gender, and it is indifferent to political or religious doctrines.

That science does not have all the answers today does not mean that we are ignorant of the world. History has shown that, with time, our answers become better and better, and many of our scientific predictions are extremely precise.

Nothing rivals the predictive power of science today. One of the social values of science is its naked honesty. You cannot fool nature. You cannot deceive it. We cannot continue to believe in imaginary, mythological ideas-unless scientific methods prove their validity. Science inspires good judgment and it can be a good guide for the future. To be literate means to know what science says about the history of the earth and about the history of the universe. Our theories are not perfect, but science progresses by correcting our mistakes. Sure, our ideas are crazy, but the crazier they are the better chance they have of being right.

Nevertheless, science is under attack by society because some people feel that the misfortunes of our present civilization are primarily due to the progress of science, such as the development of destructive weapons including nuclear bombs, global overpopulation due in part to the advancement of medicine and agriculture, the greenhouse effect, the ozone hole, and acid rain. The British journalist Bryan Appleyard, in his book Understanding the Present (1993), preaches that the problem with our world is that scientists have destroyed morality, and that scientific knowledge destroys spiritual values, hence science is immoral and therefore so are scientists. Scientists are the bad guys of society.

And again many editorials in the news media suggest that since we may not be able to have a "Theory of Everything," then the scientific enterprise is doomed and we should abandon it. It has also been suggested by respected academics that society would be "enriched" when we give science up. The antiscience groups claim that by their

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nature the sciences are subject to eventual decay-the bankruptcy of science has been predicted primarily by nonscientists and those who are not very familiar with the scientific methods. Intellectuals who are scientifically illiterate, mystics, and radicals are the strongest critics of science. It is very clear that we need better science education for people to understand the issues.

In ancient times, people would sit on the seashore and stare at the heavens, watch the sun trace its arching path across the sky, and even speculate about Gods in deep space. Today, inductive sciences and experimentation have substituted pure speculation. Science now stands on the firm ground of experimentation and verification but has lost its serene wisdom and leisurely contemplation. We can regret this loss of purity, but we cannot change it.

Sometimes the legacy of science has been deadly and dangerous, but at the same time science has populated the earth with machines, has been able to feed the world of almost 6 billion people, has produced vast amounts of energy, has cured and prevented diseases, and has taken us to the moon. There is no going back to pure speculation.

Yes there is, no doubt, a certain arrogance that scientists exhibit most physicists believe that their understanding of the truths of nature are more valid and certainly more verifiable than those in other fields. Our scientific discoveries don't stand alone. Each new understanding is connected with previously understood principles. The explanations of diverse subjects show a converging pattern, and that the universe can be understood by these interconnections is one of the most important realizations of science.

The aim of physics is not just to describe the world, but to explain why it is the way it is. Our aim is to understand existence the way it is, not the way we wish it to be.

Science Education

The most important virtue that people in this world desperately need today is education, because it is clear that actions without knowledge are often misguided and sometimes disastrous. Education offers the only safe pathway for society to a happy, peaceful, and comfortable existence; however, education around the world is experiencing a rapid decline in almost all areas of study. The U.S.

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population's lack of knowledge in history, geography, and foreign languages is well documented, and the lack of scientific knowledge has reached alarming proportions.

During this century, science and technology have become central to the development of world society. The challenges of life in today's world demand a dependence by our civilization on science and technology. The achievement of peace between nations, the production of adequate food and machines, as well as health care, a clean environment, and a generally comfortable life, require continuous progress in all fields of science and technology. With a better education, people will develop higher levels of social responsibility and ethical awareness. The rise in illiteracy may then be reversed, poverty may decline, and the standard of living can be improved.

Science is practiced by scientists who are carefully prepared to carry on the scientific knowledge. It looks like we have an obligation to prepare more and better scientists. It is also clear that not everyone needs to be a scientist, but it seems appropriate that in today's world all people should have some knowledge about the basic sciences. Yet, there is a wide perception that the sciences are becoming more complex and more detailed, and most people are becoming more and more scientifically illiterate. History books tell us that culture is recognized mostly as the arts, music, literature, and religion; and science is given only a secondary role. Educated people today know about Shakespeare and Beethoven and Michelangelo, but most do not know about Newton and Faraday and Darwin and Bohr and Einstein.

Part of the reason that the sciences play a minor role in our society is due to the scientists themselves, who do not devote sufficient time and resources to science education. We are not doing enough to show that the sciences are part of everyday life. Physics, chemistry, and biology are everywhere around us; in our homes and cars, trains, airplanes, kitchens, television sets, remote controls, microwave ovens, and so on. Most people have no clue why these things work.

In spite of the amazing understanding of nature, most people are not friendly with the sciences.

When two years ago the twenty-three broken pieces of the comet Shoemaker-Levy (which we had labeled a,b,c ...) bombarded the planet Jupiter, a respected citizen from a Western country wrote to the editor

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of a science magazine and said, "I understood everything except how come the pieces bombarded Jupiter alphabetically?"

When a philosopher was asked what was more important the sun or the moon, he replied, "The moon of course, since at night when it is dark the moon gives us some light; but during the daytime, when it is bright, who needs the sun?"

When a student was asked who was Isaac Newton, he replied, "He was a famous British scientist who verified Albert Einstein's theories of relativity!"

These real stories bring to mind the following anecdote. A group of people fascinated with space travel were discussing that it was about time for us to also visit the sun. When someone mentioned that it would be difficult due to the sun's high temperature, someone quickly suggested that we should go at night.

Science follows a pattern of reasoning dictated by nature. Humans, being vastly weaker than nature, have tried to understand it by putting the pieces of knowledge together and by making models, much like the old parable from India that says: "There were six men of India in learning much inclined. They want to see the elephant though all of them were blind."

This scientific method has resulted in amazing understandings of the nature of the universe, resulting in technological achievements that even a century ago would have been regarded by many as "miracles." Here I summarize the "seven miracles" that I consider superior:

- **Nuclear Energy**
  Powering a city as large as Los Angeles from the energy of a few grams of matter.
- **Computers**
  A small computer now performs one billion multiplications per second-it is humiliating playing chess with a computer.
- **Instant Communications**
  Electronics, radar, satellites, televisions, and so on have connected the globe almost instantly.
- **Jet and Rocket Travel**
  At the beginning of this century we only dreamed that we could fly. Today a jumbo jet carries hundreds of people and cargo from one continent to another in a few hours, our spaceships travel the solar system, and we have walked on the moon.

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- **Antibiotics and Genetic Engineering**
  A person living with a plastic heart could not have been imagined a century ago, and genetic engineering is exploding into controlled living systems.
- **Fertilizers**
  The Green Revolution in the 1960s made possible the production of vast amounts of foods and maintained the population explosion.
- **Nuclear Catastrophe**
  The capabilities that we have acquired to destroy the entire human civilization and all its beautiful creations in only ten minutes.

All these milestone developments, and many others, are based on science. The future promise of science is expected to create yet unimagined realizations. The more science discovers, the more the daily lives of individuals will be transformed and the economic lives of nations will change.

The physicist Robert M. May (1995) gives the following example: "Life in developed countries today differs strikingly from life 10 years ago, and scientific advances are the cause. In the first few decades of this century, more than 25% of the U.S. work force was employed in agriculture. Today, the fraction is around 2916. Yet this smaller fraction produces more food than ever before because of higher-yielding crops. Underlying these extraordinary developments are fundamental scientific advances in areas such as genetics, soil chemistry and cell biology."

The modern world has provided democracy and individual freedom, and it also has provided science and its resulting technology. Surely these are desirable triumphs for all around the globe. At the same time, there have been distinct negative byproducts of our successes, such as the large economic spread in many societies, and the damaging environmental byproducts of science and technology.

For some, science is no longer seen as an automatic force for progress and technology, and is instead being blamed for damaging health, society, and the environment. These are some of the findings in UNESCO's World Science Report 1996, a global survey of efforts to connect research with economical and social goals (Chapman, 1996). Nuclear power and biotechnology are singled out as particularly controversial areas. As the British cosmologist Hermann Bondi has remarked, "The public tend to think of science as something rigid,

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soulless and generally dull, which is generated in an objective and often solitary manner by cold, passionless people" (Bondi, 1996).

We have developed a society based on science and technology, but now we find very few people understand science and technology-this situation presents serious dangers for the happy and democratic future of our civilization. Normally, very few people in politics and governments have any significant background in the sciences. When I find myself conversing with nonscientists, they always ask me about astrology, UFOs, and ESP. Sometimes these are bright and gifted people, but our educational system has allowed them to fall through the cracks of scientific literacy.

The values of our society today are severely misplaced when astrology columns populate more than 90 percent of our nation's newspapers because, apparently, "the public shows great interest in astrology" and because "astrology columns sell newspapers." The values of our society are surely misplaced when a person carrying a football a few yards gets paid $1 million and a schoolteacher has a $20,000 annual salary.

To a large degree, the popular press and television decide what the public should know. However, the press and television have not taken an active role to alert the public on pseudoscientific claims. They have mostly ignored their educational responsibilities and have concentrated on what they view as newsworthy information, entertainment, and advertising. The freedom of the press is essential for a democratic society, but with freedom comes responsibility and the power of the media should be used to educate the public.

The first scientific journals began late in the 1600s, and by 1700 there were a few dozen medical and scientific periodicals, mostly in Western Europe. By the end of the nineteenth century there were some two thousand scientific journals worldwide, and today the number is about seventy-five thousand. The rate of growth of scientific knowledge during the last fifty years has been immense, and the average individual's knowledge of science today is minute compared with what we have learned in science and technology. A century ago, a person was considered literate if he could sign his name, but by the middle of this century you had to have completed elementary school. In today's high-tech world, even university graduates are illiterate in many fields.

Even though understanding science and technology is more important than before, the public thinks that it knows much more about

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science than it really does. The historian Daniel Boorstein has put it this way: "The great obstacle to progress is not ignorance, but the illusion of knowledge," and Morris Shamos (1995) relates the "89 percent story" where a recent Danish survey tried to determine how well informed the public was on biotechnology by asking them to check a box indicating "I do understand" or "I do not understand." Eighty-nine percent claimed they were well informed. In Ireland the same question asked the respondents to state in their own words what they understood biotechnology to be. Eighty-nine percent professed ignorance.

Most people find science difficult because of its mathematical nature and its necessary vertical structure. Morris Shamos in his recent book The Myth of Scientific Literacy concludes that, "By now it should be apparent that the notion of developing a significant scientific literacy in the general public ... is little more than a romantic idea, a dream that has little bearing on reality." Shamos suggests that we have tried very hard to educate the public and that we have decisively failed; therefore, he suggests we should give up this noble idea. Instead he suggests the public should learn to ask the advice of the expert scientists on scientific matters, and treat scientists much like medical doctors or lawyers.

Shamos argues that the only practical solution to scientific illiteracy is to provide the public with easy access to responsible expert opinions. In this model an individual does not have to know and understand complex scientific ideas and theories, but should be able to seek out and judge expert scientific opinion.

Maybe Shamos has gone too far by washing his hands of teaching science to the public. At least students should learn to appreciate science as a social enterprise. They should know what science is about and how scientists arrive at their conclusions. The public accepts the useful products of science and the public shows some admiration for the spectacular scientific discoveries, even when they do not understand how an airplane flies.

Problems and Possible Approaches

The Directors of the Pew Charitable Trusts' clusters of colleges and universities across the United States working to improve science education have discussed the following issues as significant problems:

1. General Science Literacy

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Educating the broad population about science so that citizens of the future understand scientific issues and appreciate the potential of science. It is important for people to understand the unity and connectedness of science-there is only one universe, which is governed by the same natural laws. In addition people should understand that science stands on the pillar of verifiability. Understanding nature must be verifiable and repeatable.

2. Science Education of the Very Young

We continue to underestimate the potential for learning of young students, even in kindergarten. These young people do not receive the science education to excite them about the future and prepare them for future study of science. Teachers are mostly averse to science and math, and the curriculum lacks the important science component.

3. Equality in Science

Members of some minority groups and women continue to be underrepresented among science students and professionals, particularly in some disciplines.

4. The Science job Market

The current job market may discourage bright students from studying the sciences in some fields.

5. Ethical Issues and Values of Science

Ethics and values are important considerations when we teach and practice the sciences, and these issues must be taught and discussed.

A few possible approaches to these issues are as follows:

1. Learning through inquiry

A revolution in the classroom is essential to make students participate, inquire, discover, and report the subject matter of study.

2. Learning through collaboration

Effective problem solving needs collaboration. Students must learn to work effectively with one another. Teamwork between students, between departments, and between institutions is essential in educating scientists.

3. Use of modern technology in education

The use of electronic communications should be used worldwide effectively and constructively. Computers and televisions represent our best hope for increased efficiency in the educational process.

4. Science and society

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Linking science to societal issues is very important to motivate student interest and to create an appreciation in the public for the role of science and technology.

In summary, we need a workforce with basic understanding of science and mathematics; with problem-solving skills; with communication skills; with critical thinking skills; with skills to understand statistics and probabilities. In general, science education will improve when students realize that in order to get better jobs they need to understand science, mathematics, and technology. The following presents my ten pragmatic suggestions for the improvement of science education in general.

What Should We Do To Improve Science Education?

- We must devote more time to science education.
- We must devote more funds to science education.
- We scientists should be actively involved in improving the scientific literacy of the public.
- We must promote the importance, usefulness, and benevolence of science.
- We need qualified, enthusiastic, and well-paid science teachers. We must promote and recognize excellence in science teaching.
- We must seek ways for colleges and universities to work more closely with elementary and secondary schools.
- We must encourage high schools to introduce the teaching of astronomy (my personal bias).
- We must ensure that we do not divorce the sciences from the humanities.

The Director of the U.S. National Science Foundation, Neal Lane (1996), in one of his recent talks said:

> *The American dream is about opportunities, aspirations, and a better quality of life. In the past, science has provided an important pathway to that dream. Whether or not this will continue to be true is a question of great concern to me.*

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> *In this new environment, leadership from you, the science community, requires much more public and civicPersona. You are needed more than ever to be visible and vocal in your communities. This requires a presence, as scientists, outside the walls of your laboratories and the gates of your universities to a much greater extent than in the past.*
>
> *Now, however, science can only he funded if the electorate and their representatives remain convinced of its value and contribution, Without this understanding among citizens and policy makers "Science and the American Dream" may only be a memory from our past and not a part of our future.*
>
> *There is a very limited public understanding of science and, more important, how science and technology contribute to our lives, our aspirations, and our national goals, Perhaps the public's lack of understanding says more about us (scientists) than about them.*
>
> *The public likes science, hut do scientist like the public? I think we need to ask this question of ourselves as a community. We may then better comprehend the discrepancy between the public interest and public understanding.*

Clearly Neal Lane's statements apply equally well around the world.

And again from a different corner of the globe, in his novel Sugar Street, Naguib Mahfouz, the Egyptian Nobel laureate in literature, clearly assesses modern society. He states that:

> *Science is the foundation of modern life. A person who doesn't know science is not a citizen of the twentieth century, even if he is a genius. Artists, too, must learn their share of science. Yes, the responsibility for comprehensive and profound knowledge of the field, as well as for research and discovery in it, belongs to the scientist, but every cultured person must illuminate himself with its light, embrace its principles and procedures, and use its style. (Lederman, 1996).*

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The world seems to be walking on thin ice. As the twentieth century comes to a close, academic institutions are plunging into a depressed mood. The public trust of higher education continues to erode, the economic outlook for education in general is dismal, and the level of literacy of the public is not improving. The twenty-first century appears to be a decisive period that will determine the long range future state (happy or not so happy) of the whole human population.

In education lies a realistic gleam of hope. If what we want is a peaceful and comfortable survival for ourselves and the future generations, the public must learn to understand and assess the relevant issues.

How can we improve the current state of education? How can we foster an effective collaboration with the public and the politicians to address the importance of education? Are we willing to make drastic sacrifices for the happy, long-term survival of humanity?

People around the world will encounter extremely difficult times unless we apply our knowledge wisely to improve the living standards of the poor population. Knowledge by itself sometimes can be inhuman; we need knowledge, compassion and love for a comfortable and happy human existence.

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Note: A similar presentation was made by the author in the Greek language at the University of Thessaloniki.

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