Sir James Lighthill Lectures: The Public Lecture

Science and Society: 100 reasons for doing science

K.R. Sreenivasan
Abdus Salam Research Professor
Director, ICTP, Trieste

Michael James Lighthill 1924 - 1998

Provost Abele, Professor Hussaini, Colleagues, Ladies and Gentlemen:

I am honored to deliver the 2006 Sir James Lighthill Lectures organized by the Florida State University, and grateful to Professor Hussaini for providing me the opportunity. As a great admirer of Sir James, I am happy to celebrate his memory with you today.

Sir James Lighthill

Lighthill was a great applied mathematicians of his times, and his name properly belongs in the league of the best of them from the 19th and 20th centuries. Some of them are

Sir George Gabriel Stokes (1819-1903)
Lord Kelvin (1824-1907)
Lord Rayleigh (1842-1919)
Osborne Reynolds (1842-1912)
Ludwig Prandtl (1875-1953)
Theodore von Kàrmàn (1881-1963)
Sir Goeffrey Ingham Taylor (1886-1975)

Lighthill himself thought highly of his abilities. For instance, when he was appointed to the Lucasian Chair in Cambridge---the chair that was once held by Sir Isaac Newton---I have heard that Lighthill expressed his pleasure because it ensured that at least one occupant of the chair in the 20^{th} century would be a person of great distinction. This remark is curious because Lighthill's predecessor was none other than Paul Dirac. By the way, I need not mention that Dirac is a familiar name within FSU.

Nor did Lighthill think less of his swimming abilities. His own words follow:

"In the holidays I always do each year an adventure swim, … usually choosing swims where there are quite difficult currents to deal with … one of my famous swims is the one around Sark which I've done five times, and one of them was during a south-westerly gale, which was the one that actually caused the Fastnet disaster. So one needed quite a lot of nerve and stamina to complete the swim on that day … during this Fastnet swim I was constantly having to add up vectorially my swimming velocity and the current velocity, and the wave drift due to these very powerful waves. It was rather interesting. I was really having to swim at right angles to the direction I wanted to go in, which you often have to do, of course … And, of course, you meet seals and all sorts of interesting animals who have a fellow feeling with swimmers when you do these swims."

These remarks say something about the vivacity and confidence of the person.

A reporter notes as follows:

"He [i.e., Lighthill] spent two weeks studying the hazardous currents before setting off one sunny morning at 10 AM. Using a 'two-arm, two-leg backstroke thrusting with the arms and legs alternately' he reached Grande Greve after two and a half hours, and shared a picnic lunch there with lady Lighthill. He then continued the swim, completing it by 7 PM. He modestly called the nine mile swim 'a pleasant way to see the scenery'. He repeated the achievement half a dozen times before the accident that claimed his life."

Lighthill was 76 at the time of the accident. It was ironic that his knowledge of waves and currents, and his intellectual ability to profit from that knowledge, did not compensate for the fact that he was no longer a young man in body. His body was washed ashore part of the way through his intended swim.

I remember how shocked I was upon hearing the news. Yet, I could admire the man's spirit even in his death. This is perhaps a great way to meet one's maker---even as one's creativity, intellectual power and sense of adventure are still very much in tact.

I must now state my own debt to Lighthill. I learnt attractive scientific writing, to the extent that it is true at all, in good measure by reading his papers on shock boundary layer interactions and aerodynamic noise. Each of his papers is a stylistic masterpiece. His elegant mathematics was always accompanied by powerful intuition; he made everything look simple. The grace with which he acknowledged the contributions of past workers made an enormous impression on me. He was, however, given to no false modesty. His famous work on aerodynamic noise generation did not contain any references---clearly proclaiming that it was entirely original, which it indeed was.

The context of the lecture

I will now proceed with the subject of my talk, and shall keep to the spirit of a public lecture. As has been just said by the provost, I now serve as the Director of the International Centre for Theoretical Physics---or ICTP, as it is commonly known---in Trieste, Italy. I may say more about ICTP later, but it suffices to note here that its major goal is to support advanced studies and scientific research of deserving scientists from developing countries. I was concerned that science was losing its appeal for young students, and so took the occasion of our center's 40^{th}

anniversary, in 2004, to invite some 100 distinguished scientists with strong connection to the center to write a brief piece each, about two pages in length, describing what circumstances got them interested in science as youngsters and what advice they have for the new entrants. About 45 Nobel Laureates, 25 Fields Medalists and 25 Wolf Prize Winners wrote for the book. Other writers are equally distinguished. Here is the cover of the book. I shall use some of those brief essays to present a view of what scientists think are the major issues of science and society. Obviously, there is much more to those beautiful essays than I can discuss here.

Let's begin at the beginning and ask:

Why do young people go into science in the first place?

Gerardus `t Hooft, the Physics Nobel Laureate of 1999, says that he became attentive to science as a child by observing how the laws of physics, once understood, could be used broadly and with insight. He adds: "The nice thing about Nature’s Laws is that they are fair. They are the same for everybody, and nobody has the power to change them, unlike the Laws that humans have invented themselves: you should speak politely, use your knife and fork when you eat, go to school and brush your teeth. Those rules could be changed by someone overnight without advance warning, but they can’t do that with Nature's Laws. Also, these Laws do not contain contradictions. They can’t.”

Paul Nurse, the 2001 Nobel Laureate in Physiology or Medicine, adds: “What first stimulated my interest in science was an over-whelming curiosity about how the world worked. I first remember being aware of this whilst walking to school, maybe at 9-10 years of age, and noticing that leaves on the same plant seemed bigger when they were growing in the shade compared with when they were growing in sunlight. This got me thinking .., I thought it might be something to do with the fact that leaves in the shade got less sunlight and so needed to be bigger. … I am still asking questions in science although they are more complex now, or at least the language I use the ask the questions is more complex. Which raises the question of what I think is the key for keeping an interest in science. … Two points are important. The first is keeping a real curiosity about the world and the second is a determination to find explanations for what we see. Without that curiosity and a wish to know answers, the passion for science is soon lost."

Similar sentiments were expressed by Leo Kadanoff, a remarkable physicist from the University of Chicago. He says: "When I was a young man, I was first drawn to mathematics and then physics by its possibility for finding out and describing true things. In contrast to the confusion and complexity of my adolescent world, statements like "for a right triangle, c squared equals a squared plus b squared" are verifiably true. In addition, one can determine whether this statement is also true for other kinds of triangles. I found this certainty attractive, and in some sense amazing.

"…The possibility of finding something indisputably real… attracted my imagination. I dreamed of saying things which were both true and new." As Sir Michael Berry says, "The excitement of scientific discovery is the inner knowledge it gives us, the quiet satisfaction at something understood. In science, when you discover something new, even a small thing, you're floating on a cloud for days."

David Mumford, the Fields Medallist of 1974, has this to offer: "When I was quite young, I interrupted once a painter who was an old family friend, at work on his canvas. I asked him whom he was working for—something I had just been told about—and he said 'myself'. Then it hit me. Why would anyone work for someone else if they could get paid for doing what they loved? … if you're working for someone else, there is always a deadline, a time when they want to see 'results'. If you work for yourself, a project can take 10 years—or a lifetime. It leads you in different directions if you think in those time scales. Andrew Wiles, who proved Fermat's conjecture, holed up in his attic for 10 years without publishing very much. This kind of freedom is rare in life and should be treasured."

The nature of a scientific life

But, what is a scientific life like? I have learnt over time that one reason why young students do not take to science is their view that science is very competitive and lonely. This is a common mistake, so I should like to cite Michael Berry again. "[The life of a scientist is good], and suits me personally because I'm not a very competitive person. This might seem strange, because again the popular image, encouraged by the media, is of scientists at each other's throats, fighting to get their discoveries published before other people, competing for research money. As with any human activity, that does happen sometimes. But in all my years as a scientist I've almost always encountered the opposite: not competition but friendly cooperation, sharing results. This isn't because scientists are better than other people: in our private lives we're no different from anyone else. We cooperate simply because the ways that nature works are so well hidden that no individual can discover them by himself or herself. We're much cleverer together than separately, so it makes sense to cooperate. And the cooperation works across all cultures, nations, races, religions."

The 1991 Nobel Laureate in Physics, Nicolaas Bloembergen, says: "In retrospect my choice to become a physicist more than sixty-five years ago has been very rewarding… New technologies have a profound influence on society in all countries, and they are all based on scientific principles. Every country will need further leaders with some familiarity of the scientific method." Daniel Joseph of the University of Minnesota says "I have had many wonderful students in my 40 years of research life. I love these students [and] I think that they love me also, … we form an academic family tied together by mutual respect and the joys of discovery. It is a great life".

How do others feel, especially women? In particular, many scientists bemoan the image of science as a masculine activity. Myriam Sarachick, former President of the American Physical Society, says: “My life as a physicist has been enormously satisfying and great fun. That doesn’t mean that every moment has been fun. There have been problems and challenges along the way, and there have been setbacks, small and large. One of the most exhilarating aspects of being a scientist is that one continues to learn, stretch and expand. It’s a wonderful challenge.” Maxine Singer, a distinguished scientist at the Carnegie Institution, adds: “Doing scientific research is demanding, hard work. The sometimes frustrating experiences are more than made up for by the curiosity to understand nature and those extraordinary moments when an experiment reveals something new and unexpected. It is sixty years since I entered high school and I don’t remember ever being bored.”

Let me give add a sombre note here. In science, one cannot be equally productive throughout one’s life. Some scientists compensate for this diminished vigor by engaging in other constructive endeavors; some others do not deal well with loss of creativity. I mention below the thoughts of my former colleagues, Serge Lang, who was a mathematician of no mean accomplishment: He recalled asking his thesis advisor the following question: “OK, I got the thesis, it worked out, I had an idea, but later in life, what happens when I don’t get ideas and I’m stuck?” The answer he received was: “That’s the price you have to pay to be a mathematician.” Despite his apprehension, Lang was indeed highly productive well into his seventies. Alas, when he discovered that his mathematics abilities had diminished to levels he regarded as unacceptable, he simply killed himself. This, however, is a very rare solution to the dilemma of diminished creativity.

The role of parents, teachers and society at large

Who nudges young people towards science? Most said that their parents played a key role in instilling the love of science and free inquiry. Claude Cohen-Tannoudji, the 1997 Nobel Laureate in Physics, remarks that “it is very important for a young child to feel that his parents pay attention to his education”, while John Fenn, the 2002 Nobelist in Chemistry, said that “They moulded the raw material”. The importance of parents was especially crucial for women. Helen Grant, former President of the American Physical Society, drew inspiration as follows: “My parents valued imagination and curiosity. They treated me no differently from my brothers in the way they encouraged these skills...”

Next to parents, the inspiration came from teachers. This was echoed by statements such as “My interest in physics was really stimulated by an extraordinary teacher,” by James Cronin, the 1980 Nobel Prize winner in Physics, to “I deeply believe in the influence that an outstanding teacher can have for arousing a scientific vocation,” by Cohen-Tannoudji. Elsewhere, Hans Krebs sums it up as follows: “If I ask myself how it came about that one day I found myself in Stockholm, I have not the slightest doubt that I owe this good fortune to the circumstance that I had an outstanding teacher at the critical stage of my career … without him, I am sure I would never have reached those standards which are prerequisites for being considered by the Nobel committees."

The support of teachers was critical for women scientists, particularly when confronted by the ambiguity in the thinking of the parents. Sometimes, the parents of yesteryears had conflicted thinking about their daughters: strong encouragement mixed with concerns about the exclusive pursuit of careers by their daughters. Mildred Dresselhouse, one of the most decorated of American physicists, remarks that she got into physics essentially because of the encouragement by her teachers.

Chance encounters

I will now comment on an aspect that is more common in developing countries than in industrialized countries where there is better control on how one leads one's life. That is the role of chance encounter. Scientists from poor countries have repeatedly stressed that they were directed towards science essentially by chance interactions, by an uncle, by a causal encounter with a famous scientist, by the availability of certain text books at home, and so forth.

In particular, accomplished scientists of a certain ethnicity had a large impact on others of that same ethnicity. The inspiration that C.N. Yang and T.D. Lee had on young Chinese students such as Daniel Tsui, a Physics Nobelist of 1998, was immeasurable, though the students had not met these distinguished scientists; similarly the influence of Sir C.V. Raman on young Indians such as C.N.R. Rao and M.G.K. Menon, who have later distinguished themselves in many different ways, was extraordinary. An outstanding book, especially if recommended by an elder who mentored the young person, could often serve as adequate inspiration. Occasionally the supportive role played by classmates could provide the needed momentum, as in the case of Steven Adler of the Institute for Advanced Study at Princeton, who says "My actual career path began in sixth grade of elementary school, when a classmate started to talk to me about his interest in radio; I visited him at home and saw his equipment and tools."

Ahmad Zewail, the 1999 Nobelist in Chemistry, remarks as follows. His achievements are clearly out of the ordinary but the setting is quite common.

“The family’s dream was to see me receive a high degree abroad and to return to become a university professor—on the door to my study room, a sign was placed reading, “Dr. Ahmed”… My father did live to see that day, but a dear uncle did not. Uncle Rizk was special in my boyhood years and I learned much from him—an appreciation for critical analyses, an enjoyment of music, and of intermingling with the masses and intellectuals alike…

“As a boy it was clear that my inclinations were toward the physical sciences. Mathematics, mechanics, and chemistry were among the fields that gave me a special satisfaction. … In my teens, I recall feeling a thrill when I solved a difficult problem in mechanics. It is not clear why I developed this attraction to science at such an early stage.

But with passion and sincerity, *It Is Possible,* as human achievements [are] limited neither by race nor by origin."

One should also not forget that science was also a way to escape the limitations of colonialism when it was the norm, a way to transcend the inequities of the oppressed societies, a way of joining the masters despite the limitations imposed by color and race. To a smaller degree, this experience is shared by the children of the immigrant families in the US: the knowledge that science could pull them out of poverty, and that strong learning tradition existed in the country of their origin, sufficed to nudge them into scholarship and in science.

The understanding public

While the greatest impact on young children is the input from parents and teachers, that kind of encouragement ultimately comes only when there is a better public understanding of the value of science, and a good resonance exists between science and society. Peter Lax, the Abel Laureate and one of the past Lighthill lecturers, says: "I was born in Hungary where mathematics had a long and respected tradition. I was encouraged and tutored by distinguished mathematicians and pedagogues." If one takes the long-term perspective, nothing pays off better than the investment on improving the public understanding of science.

Thus, Jean-Marie Lehn, the 1987 Nobel Prize winner in Chemistry, regards not only science education in our schools, colleges and universities as important but also regards the education of the general public as a major priority. In a non-democratic system, the support for science can be large or small depending on the policies of a few. Old Soviet System or the modern China are examples of how science and technology can flourish, while Saudi Arabia is an example of where the scientific activity is not particularly strong. In democratic societies, on the other hand, the people's elected representatives are entrusted with decisions about resource allocation, including science funding. It is squarely the fault of scientists if too few people in power understand science.

What smothers this understanding is partly the gap between the public and the elitist sentiment of the scientist, which is best expressed by the statement attributed to Luis Alveraz, a Nobel Laureate in Physics: “There is no democracy in physics. We can’t say that some second-rate guy has as much right to an opinion as Fermi.” How is the ethos of science, with its subject matter confined to the elite few, to be woven into the fabric of a nation that is interested in achieving the good of the many? This vexing dilemma seems to have only grown with time. This uneasy tension with democracy from which science has derived its vitality, sustenance and purpose is an important feature of our times.

How do these scientists view the present scene of science?

First, they are optimistic about the potential of science. Jean-Marie Lehn remarks as follows: “Science offers most exciting perspectives for the future generations. It promises a much more complete understanding of the universe, an always greater creative power of chemical sciences over the structure and transformations of the inanimate as well as of the living world, an increasing ability to take control over disease, aging, and even over the evolution of the human species, a deeper penetration into the working of the brain, the nature of consciousness and the origin of thought.”

T’ Hooft remarks as follows: “Future generations of smart kids should be able to figure these things out. Perhaps we are all dinosaurs compared to the generations of the distant future, if today’s children decide to exploit the tremendous opportunities science is likely to offer, by making their own new discoveries… Only a few decades ago, people from poor countries, or, countries separated from the West by the Iron Curtain, were in a severely disadvantaged position to make any discovery at all. Today, the situation is much better: all you need is an Internet connection, and you will have access to the most up-to-date knowledge of the most reputable centers of science in the world."

The reality of internet access is, alas, quite sad, as shown in this figure.

Even though the scientists are optimistic about science per se, they have become pessimistic about the rising hostility within the society at large. Harold Varmus, the 1987 Nobel Laureate in Physiology or Medicine, has recently wondered [see, Bulletin of the American Academy of Arts and Sciences, vol. LIX, no. 4, p. 6, 2006] if American science is under siege, especially from the religious faith. Similarly, Elias Zerhouni, the Director of the National Institute of Health, has noted that the anxiety is palpable among the US scientists through out the country [Science, 314, p. 1086, 2006]. Tullio Regge, a distinguished Italian Physicist, puts it more bluntly as follows:

"The image of science is tarnished, a sizable and growing fraction of the public distrusts scientists and thinks that we are all Frankensteins: we must seek a remedy for this lamented state of affairs. Even worse, some of our most bitter critics are scientists themselves; if old fellow Freud could come back he would have something interesting to say about them...

“Science is under attack either directly or through spin off of research. A direct approach with our critics with the aim of reaching some minimal agreement is “mission impossible”. They are a strange mixture of zealots and political demagogues who reject any solutions to the problem for the fear of losing votes. All this reminds me of a Robert Mencken's quotation: ‘Puritanism is the haunting fear that someone, somewhere, may be happy.’

“I’ve never met a puritan from the time of Mencken but I’ve met many in recent days. We must improve our image.”

It is, in fact, a commonplace belief now that science is under attack, that religion and faith have been interfering with governmental decisions and matters of scientific research, and so forth. One hears, as well, that the diminished role of scientists in policy making translates to diminished concern for global change and its consequences.

Why this pessimism?

Some are concerned about the diminishing role of scientists in industrialized societies.

The aftermath of the Second World War witnessed a great surge in the influence that scientists wielded in the decision making of the government, especially physicists from the atom-bomb generation. Their power was not subject to public scrutiny, an aspect that was, in fact, much discussed even at that time. With time, as the abuses of technology have increased, it has become clear that the special place that science once held in the minds and hearts of the people of industrialized countries began eroding in importance. On top of it, the expense of doing big science just kept increasing: the most popular example is the superconducting supercollider which was priced at $4.4 billion in 1987 but was tagged at 12 billion by 1993.

There is also the connection between science and military technology that makes the society ill at ease. The interest of scientists as consultants for the military is not new. Examples abound from Archimedes to Leonardo da Vinci to Robert Oppenheimer. Such scientists were driven by the desire to preserve liberty as they understood it. While the decision on the use of weaponry is often based on ethical and moral values of the society at large, it is clear that the distinction is often lost on a sizeable part of the public, which feels that a number of the ills that affect human society are due to the rapid developments in science and technology. Aside from the nuclear war which could wipe out very large parts of humanity, problems such as the depletion of ozone, environmental degradation, climate change, wide ranging degradation of natural resources, unknown risks associated with advances in biology, have all caused certain weariness about science.

It is important to discuss these issues openly. This does not, however, mean putting limits on scientific inquiry, but instituting steps to ensure that the applications of science benefit human society as a whole. Such a perspective has to be taken by society on the basis of commonly shared moral and ethical values.

There is also some concern that scientists come across as arrogant to the public. There is, of course, no room for arrogance. Indeed, our knowledge of the material world, however profound, is not applicable to the many aspects of human life, such as love and hate, compassion and violence, rationality and irrationality. In any case, recent developments in cosmology suggest that the overwhelming majority of our knowledge has been confined to about 5% of the Universe related to ordinary matter. We know very little about the nature of the missing 95% of the Universe.

Perhaps what comes across as arrogance is the tendency of physical scientists to apply the objectivity of the natural world to the society around them. This perception creates imperfect relations with the public whose support is so important to science in democratic societies. While the guilt of arrogance extends to other successful professions such as medicine and law, it is particularly insidious in scientists because it is easily justified in terms of objectivity.

The perception of arrogance creates a chasm between scientists and the public, and alienates students; it is a barrier also to the inclusion of underrepresented groups in science. It dulls the willingness to reach out to such groups even before they achieve something, spot their talent and encourage them. For diversity and excellence to coexist, one needs to invest a great deal of work.

Science of sustainable development

Several scientists point out that, while our knowledge of the physical world is profound, the knowledge related to the functioning of Earth as a system—the interaction between the environment, ecosystems, and the behavioral patterns of living things is poor. Those areas of inquiry require integrated thinking, which is equally deep and valuable.

Keilis-Borok, a well-known seismologist, says that “the very survival of our civilisation is threatened by natural and man-made disasters. Among them are earthquakes, self-inflicted destruction of megacities, environmental catastrophes, economic and social crises. Today, a massive release of radioactivity from a nuclear waste disposal, an earthquake in the middle of a megalopolis, an outburst of mass violence, or any other global disaster, can cause up to a million of casualties, render large part of our world inhabitable, trigger global economic depression, or a war in a “hot” region. Such dangers keep growing, although trillions dollars a year are spent to contain them by all known techniques. The hope and the responsibility for breaking the stalemate rest not on the money but on intellectual resources.”

His remarks can be rephrased as follows. Today’s world population is about 6 billion and is still increasing. The projection calls for its stabilization around 8 or 9 billion in 30 or 50 years' time. At the least, we will have to feed 20-30% more people in the steady state. Today's food production globally is adequate for the present population---though, I should note in parentheses, that enormous inequities in its distribution exist, leading to unfathomable tragedies. Feeding the next two or three billion people, given that no more significant arable land is available, is a challenge that requires advances in biotechnology and genetic engineering.

A further problem with increasing population is that it enhances the tendency to concentrate: more and more people will live along the coasts and in megacities, thus making them vulnerable to disasters---whether or not the reasons for their occurrence are natural or human. A tsunami or an earthquake that might have killed only a 100 people a century ago now has the potential to kill 100,000 of us. Other problems that arise from population concentration are increased pollution, receding levels of the ground water, problems with sanitation and healthcare, and so forth. While the prospects of nuclear proliferation and war have not yet disappeared, other serious problems have arisen. Some examples concern the economic development without depleting Earth's resources irretrievably, containing dangerous epidemics such as the avian flu, meeting the costs of healthcare for the aging population in the world at large, especially in industrialized nations.

There is thus no doubt that more science and more scientists are needed in the world. The number of scientists in many developing countries is pitifully small. Without high-level scientists who can offer good advice to their governments, all the problems just discussed assume high levels of urgency. We cannot ignore the situation in Africa as being remote from us: bad decisions made in one part of the world affect all others because of the finiteness of the Earth's resources and our global interconnectedness. It is clear that, if we have to survive as humanity, we need scientific solutions for an increasing range of problems.

Within the US, the number of Ph.D. level scientists is about 1000 times larger than that in sub-Saharan Africa. Even so, you may have seen periodic debates on whether there are enough Ph.D. level scientists in the country. The new element in the discussion is the drop in U.S. visas issued after September 2001, and the efforts that other countries are making to lure their countrymen back to their fold.

Essentially everyone agrees that Science and Technology will continue to advance rapidly as we move into the next millennium. What is important is to ensure that these advances benefit humanity as a whole. Parochial considerations of narrow commercial interests, nationalism, fundamentalist religious aspects and inflexible ideological divides have to give way to the basic ethics of human dignity and human rights, and harmony with nature---value systems that are outside the realm of science but have to guide its applications. As Susan Solomon, an accomplished atmospheric scientist, says: “Science has a very important role to play in serving society, helping to understand what is happening and why. But in my opinion, that is where my job as a scientist stops and those of others—the economists and the politicians—begins. Science is an important input to many societal choices, but it is only one input." There is a growing realization that physical scientists have to work in cooperation with social scientists to address many of our societies' ailments.

An important issue concerns the attitude of the scientist with respect to ethics and society. As Leo Kadanoff remarks, "… [scientists] are better at finding true things than knowing the nature of love, justice, humanity or indeed Truth. So I have become more modest in my hopes for what portion of the world can be encompassed by science. But I remain steadfastly tied to my original view that the value of science is in its possibility to discover and state things which have a considerable content of verifiable correctness.

"In doing that, science might perhaps serve as an example to other parts of life. Our world suffers from an abundance of falsehoods, as in classifying a whole group of people as evil, or in listing a played out oil-field as productive, or in treating a parochial political view as universal, or in describing management theft as "protecting the interests of stockholders". One major benefit that might be provided by science and scientists is to serve as an example of an area in which such falsehoods are neither prevalent nor rewarded.

"Alas, it is not so. Our scandals are comparable to those in other walks of life. When we get wildly optimistic about cold fusion, or about hot fusion, or find a need for developing a technology for shooting down asteroids, or argue for practical benefits from huge investments in impractical parts of science, then we are behaving in the same self-serving fashion as the community around us. … So long as we minimize the management failures which put the names of Batlogg, Bell Laboratories, and Lucent on the fraudulent work of Schon, we cannot claim that our world is managed better than, say, the world of corporate accounting. And if we scientists don't represent the truth, who will?"

The problem is probably the belief of scientists that the ethical values need not emphasized in relation to the universal values of science. As a result, honest physicists are perhaps gullible victims of those who do not feel restricted by ethics. Open discussion about the importance and challenges of ethical behavior is desirable, and it is healthier to openly recognize that ethical weakness is as common in scientists as in others.

In particular, environmental ethics demands different considerations: equity within this generation is perhaps no more important than inter-generational equity. Issues of bio-ethics call for sensitive considerations. What is the meaning of ‘consent’ in the case of genetic testing and screening of an illiterate woman whose blood will be used to look for rare genes? To whom does this knowledge belong? What will they be used for? Will they eventually serve the purposes of some multinational company?

What advice do these scientists have for young students?

The advice varies in range. Basically, they echo Maxine Singer's sentiment that "Each scientist discovers a passion for science in a unique way." Marcos Moshinsky of Mexico says as follows: "My advice to a young physicist and, also to a young scientist in any field, is not the example of Einstein to work in a light-house far from the pressures and distractions of the main institutions of learning, but rather choose a university or research group that is just beginning to be able to contribute to its transformation into a first-rate establishment." This echoes the sentiment expressed elsewhere by Jim Watson of the DNA fame: "I think it is extraordinarily important that you have a scientific patron because there'll be times when you are bound to strike it bad and you'll need somebody to convince people that you are not irresponsible." That of Peter Lax is: "… be open to problems, wherever they arise, and especially to be on the lookout for new … phenomena that cry out for an explanation."

I should now quote Christian de Duve, the 1974 Nobelist in Physiology or Medicine: “Scientists are often described as persons who know a lot. This is not entirely wrong. To do good science, you must be trained in some discipline, like mathematics, physics, chemistry, or biology, sometimes in more than one. In addition, you must know what others have been doing in your field. But that is not enough. A “know-it-all” is no more a scientist than a collector of paintings is an artist. What counts is the generation of new knowledge or, better said, understanding. *The true aim of science is to understand the world.*

“Not everyone can be a Newton, Darwin, or Einstein. Most of us do not grapple with cosmic issues and have to be content with adding a little brick to the edifice. On a day-to-day basis, scientific research deals mostly with small problems. You are faced with some intriguing fact or observation that tickles your curiosity. Thinking about it, you let your imagination run, using all the available clues, all the bits of relevant knowledge you happen to have in store, trying to come up with some plausible explanation.

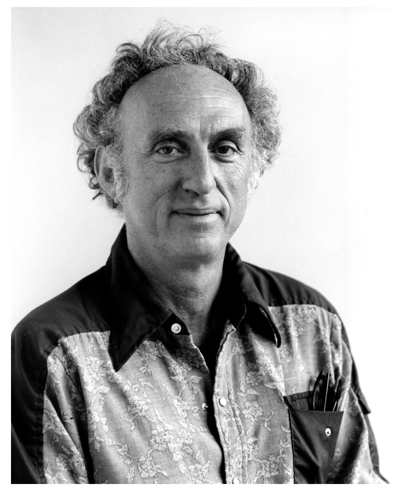
This is the truly creative part of scientific activity, what it has in common with the arts. But it is only the first step. Then comes the hard job of confronting the hypothesis with facts. Does it fit with all observations? And, especially in the experimental sciences, how can you best test its validity? Not by trying to prove it right, incidentally, but by doing your best to prove it wrong—and failing."

The advice of Martin Perl, the 1995 Nobel Laureate in Physics, has some valuable advice, which I shall describe in totto.

DOING EXPERIMENTAL SCIENCE

Martin M. Perl

Stanford Linear Accelerator Centre, USA



The popular image of a scientist and how one does science is very distorted and that is what drives many young people away from careers in science. And so I want to tell you what I have learned in the course of fifty years of doing experiments in physics. I will summarize in 14 maxims what I have learned and it is these maxims that make doing experimental science enjoyable and exciting. I will use examples from my own life.

You must take account of your personality and temperament in choosing your science and your interests in that field.

I have a mechanical view of the universe, I am competent in mathematics but I don't excel in mathematics and so I have been an experimenter. I speculate about experiments that might be interesting but I don't work in physics theory. I like to work on equipment because I am mechanically handy. But don't try to fit yourself into any particular image of what a scientist should be. You don't have to be a mathematical genius, you don't have to be mechanically handy. You just have to want to find out new things about nature and you just have to have the strength to keep working on an experiment when no one knows the answer. The great joy will then occur when you are the first one to know the answer.

It is best to use your own ideas for experiments.

You can't always use your own ideas because you may be part of a larger science group with defined goals, but it is always more fun to work on your own ideas.

You don't have to be a fast thinker or a fast talker. In fact, it is best to avoid such people.

When you begin to get a new idea it may be badly formulated or even wrong. Beware of fast thinkers and fast talkers who delight in showing that your idea is wrong. This is because by working on a somewhat wrong idea you often can get a good idea. But this takes time and you need sympathetic and helpful colleagues, not fast-talking critics.

You don't have to know everything. You can learn a subject or a technology when you need it.

Science moves very fast these days and if you try to get into a new area you may think you will have to first spend all your time studying the subject before you get into it. It is best to jump fairly fast and then learn what you need from colleagues or books or courses or from experience.

For every good idea, expect to have ten or twenty bad ideas.

But expect that most of your own ideas will not work out, but when you get a good idea that works it is marvelous.

It is often impossible to predict the future of a technology used in engineering or science.

I was a chemical engineer before I was a physicist and in late 1940's I worked for the General Electric Company. I worked on an R&D project to make very small electron vacuum tubes so that radios could be made smaller and use less power. Meanwhile the transistor was invented at Bell Laboratories.

You must be interested in, even enchanted by, some of the technology or mathematics you use. Then the bad days are not so bad.

There will always be bad days when you do experimental science when nothing works or you discover that designs have to be changed. It is crucial that you be enchanted with some parts of the experiment so that you can get through these bad times.

Another advantage of being enchanted by the technology or the mathematics is that you will be more likely to think of improvements and variations.

This is obvious.

You may dislike, even dread, some of the technology or mathematics used in a large experimental or engineering projects, and you may be happy to leave these areas to colleagues. But don't be surprised if you have to get into one of these areas yourself.

Although I started my career as a chemical engineer these are many areas of chemistry that I don't like. But our present searches for fractional electric charge particles in meteoritic material uses much colloidal chemistry. I have had to learn it.

You should be fond of the technology or mathematics that you use, but not too much in love with the technology or mathematics. There may be a better way.

This is obvious.

You must learn the art of obsession in science and technology.

When working on an experiment it is important to be obsessed with it. When you wake up in the middle of the night you should be thinking about the experiment. But with all experiments there will come a time when you cannot improve it substantially or when someone else has devised a more fruitful experiment in the same area. Then you should end the present experiment and move on. This is the art of obsession in science.

In many areas of science it is getting harder and harder to have the time to do both experimental work and original theory. In some areas, such as particle physics and astrophysics it is usually impossible.

I believe that in many parts of science the design and building of modern experimental apparatus has become a full time job, as has doing original theoretical work. It is sad, but there is usually not enough time in the day and the night to do both.

Theory should be a good companion to the experimenter, inventor and engineer. sometimes leading, sometimes following. The experimenter or engineer should not let theory set the fashion or dictate what is important.

Theory, even very speculative theory has come to dominate the thinking and presentation of science inside and outside the science community. These days, experimenters do experiments because a theory, often a very speculative theory, suggests the experiment. If you are doing the experiment anyway you will not waste much time in also testing the speculation, but you will be happier and find out more about nature if you do the experiments in which you believe. In the end the validity of science depends upon experimental results and measurements.

Developing countries

Abdus Salam, the founding director of my center and a 1979 Physics Nobel Laureate, drew attention to another dimension of difficulty facing scientists from poor countries. Support for science in developing countries is small, and the scientific communities are sub-critical. You may be appalled to know that the country Chad has perhaps only two mathematicians of any depth. The facilities are downright abysmal. In a certain African country, the entire science library consisted of 40 books some three years ago:

when the civil war broke out, the first dastardly act was to burn down the library. This situation is not unfamiliar in the annals of history.

Salam decried that developing countries do not realize that scientists are a precious asset, and that they are not given opportunities and responsibilities for the development of their countries. The few scientists that exist are often underutilized, creating the familiar problem of brain drain. He argued that this can be redressed by allowing for scientists to circulate freely for certain periods of time. He often framed these issues in terms of moral responsibilities of the developed countries to offer solutions, but the plain fact is that self-interest alone must dictate developed nations to pay attention to the happenings in the poorer parts of the world. If we leave some part of the world too far behind, it is bound to bite us back in unforeseen ways.

Behind every action of our center lies the desire to keep scientists engaged in creative work where they are badly needed, by allowing them to be connected to their peers and by providing intellectual support. Let me take a few minutes to describe what it does, very briefly. EXPLAIN MORE.

People often say that one cannot do much in countries where there is no tradition of science. The argument is specious as we know by experience. Lennart Carleson, the 2006 Abel Laureate and a distinguished mathematician, puts it metaphorically: “Sweden has no tradition in downhill skiing—we have the snow but no mountains that can compare to the Alps. … Nevertheless, in the 1970’s Ingmar Stenmark from the little village Tärnaby in Sweden became the leading skier in Europe. A few years later Sweden had 3 skiers among the 15 best and they all came from the same village! This is now history. However ---and this may be sign in the sky also for mathematics---this year (2004) the leading skier in the women’s competition is again Swedish and she also comes from Tärnaby!

The story illustrates that many of us can obtain amazing results if we are willing to concentrate our efforts on one goal for a long period and if we believe in ourselves. The young people in Tärnaby knew Ingmar Stenmark as one of them and thought if he could do it, they can also.”

Thank you for your attention.