HAIM HARARI

Scientific research and its dual interaction with industry and with the general public*

It is a great privilege for me to address this distinguished gathering. I would like to take this opportunity to share with you some thoughts on the subject of interaction between science and practically everything else in our lives, be it politics, public policy, industry, or economic interests, to name but a few.

Whether you are today an architect, and you have to design an energy-efficient building which will be environmentally sound; or you are a lawyer, negotiating the establishment of a new high-tech, start-up company or dealing with matters of technological patents; or you are a farmer, who has to decide which particular kind of crop to grow next year; or the principal of an elementary school who must decide what kind of computers to buy for the children in your school; whether you are a construction worker, a simple labourer, who has to adjust to new machinery in your industrial plant; or a diplomat participating in international negotiations on disarmament or arms limitations; an army general who has to make a decision about a new weapons system; an ordinary citizen who wants to join an environmental organisation, or who has to vote in general elections or a municipal election or on a referendum on some issue having to do with a nuclear power station or the environment or a medical system or laws governing genetic engineering or anything else that is happening around you; or your are just a normal person, who becomes sick and the doctor explains to you exactly what is wrong with you and what tests you must have and what medication you need to take; in all these situations, although you are not a scientist, or an engineer, or a technical person, you have to participate and sometimes to make decisions which involve science and technology, and you must at least understand, and sometimes speak, the language of science.

* This speech was transcribed from a taped version, with minor editing.

It doesn't mean that you are able to perform scientific research, nor does it mean that you are a member of the community of scientists and technologists. Rather, you are just a simple citizen, perhaps a Prime Minister and perhaps a simple labourer who has no formal scientific education, but who actively participates in making decisions, both daily decisions and historic decisions which have a scientific and technological nature. This is the sort of world in which we live. And it is only going to become more scientific and more technological in the future.

But this situation is very new. It didn't exist thirty years ago, fifty years ago, sixty years ago. Our world of today is a changing world, and what I would like to do, with your permission, is to spend some time reflecting on some of the issues that this world presents to us, some of the trends and developments and how to cope with them, as well as some of the paradoxes with which I will conclude my discussion.

The main message I would like to transmit is that we live in a period of crumbling boundaries. All kinds of walls, all kinds of partitions that existed between various areas are disappearing, and they are disappearing very fast.

Let me illustrate this situation with a few examples, because in my opinion, this dissolution of boundaries is the central phenomenon that we face today. First of all, the partitions between the different areas of science are rapidly falling. This is not a completely new development, but its pace has been accelerated in the last few years. It is not true any more that you have physics separate from chemistry and chemistry separate from biology and biology separate from computer science. All of these areas are now interconnected in a very intricate and complex manner.

Take the field of environmental science and energy research, which is so important for the future of this planet, for the future of mankind, for the future of every little village or city or factory. What sort of science is this? The ecological aspects and the saving of the species obviously involve biology. Dealing with pollution, preventing it, and monitoring it is, of course, chemistry. The atmospheric and oceanographic problems are, of course, physics. The integration of all of these studies involves very sophisticated computer models. And all of these areas which are scientific are also related to engineering and many different types of technology. So here you have a scientific-technological area which is so important, so critical, that cannot be categorised and cannot be classified and cannot be discussed without a coalition of experts from numerous fields.

A very different example is the research into the human brain, undoubtedly the most fascinating of objects and a subject of great intellectual curiosity. The brain is certainly, obviously a biological object, but understanding the influence that chemicals have on the brain - drugs, legal drugs, illegal drugs, tranquillisers, psychiatric drugs - involves a deep understanding of the chemistry of the brain. The brain is a bunch of electric wires and electric signals, clearly a problem of physics. The brain is also the best computer ever designed - even the brain of a child can perform tasks which the most sophisticated computers cannot perform. Here is another fascinating scientific problem which involves all the different areas of science, and the secret of success in this field today involves the integration of all these different areas.

A final example which is self-evident, but which must nevertheless be mentioned, is the study of complex biological molecules. The structure of these complicated biological molecules utilises very sophisticated methods from the world of physics and chemistry - in order to understand biological processes ranging from diseases to genetic manipulation to anything you can think of. And all of these studies employ extensive computer modelling and computer calculations. Here again is an example of a field which involves, in a very profound way, a multitude of areas.

I could go on for hours, giving such examples, and everyone of you is well aware of them. The point is that, although boundaries among scientific fields have been re-drawn in the past, today this process has accelerated to such an extent that it is now difficult even to see where the boundaries are anymore.

A second boundary which is falling is that which used to divide pure, fundamental scientific research and applied, practical scientific research. Again, there has always been an interaction. But now the boundaries between the two have virtually disappeared. Needless to say, it is almost unthinkable to tackle any fundamental problem in biology without there being far-reaching implications in many directions - from nutrition and agriculture to curing disease.

Similarly, if you tackle the field of condensed-matter physics, you find an area which is fascinating intellectually - but in addition, these are exactly the issues that will make it possible for us to create the next generation of microchips for the electronics industry. Again, a fundamental problem of great intellectual curiosity has direct commercial and practical implications.

There is a general trend in science towards measuring and monitoring and sensing - in the sense of sensors - smaller and smaller quantities with greater and greater accuracy. Quantities of anything. Smaller electric currents, smaller amounts of chemicals, smaller amounts of this and that and the other. This is pure science, the development of instrumentation that allows you to measure and to detect smaller and smaller quantities of things.

But immediately, there are other implications. Medical diagnostics become much, much better if you can measure smaller and smaller things, as does, to choose examples from a very different world, police detective work or espionage. In the case of arms limitations, verification has to do with the ability to measure smaller and smaller and smaller things. Ethical issues, moral issues, invasion of privacy issues all follow from our ability to measure smaller, smaller and smaller things. Here again, a very intimate interconnection between pure and applied science.

I come from a research institute, the Weizmann Institute, which has always been, and is, and will be, dedicated to pure research. And yet - and once again, this is just a personal example - we have found ourselves in the last few years dealing with enormous numbers of projects which are or immediate commercial relevance, not because we wanted to move in the direction of applied research, but because we are trying to do good basic research. It is very clear that science today should be classified as "good science" and "bad science", with "good science" being good "pure science" which also has immediate practical applications.

Ten years ago, when I was asked: "Is there any field of science which has no practical application at all?", I would reply with what was then the standard answer: "Well, the only thing I can think of is the theory of numbers which is such a beautiful topic in pure mathematics. It is very beautiful, it is very entertaining, it is very challenging, but obviously it has no application". And yet in the last few years, thanks to the work of several people, including some of our own Weizmann scientists, number theory is being applied - with tremendous success - to the field of cryptography. This is clearly a field with great practical implications, from banking secrecy to encoding satellite TV signals, not to speak of military applications. And to those of you who get the signal from the Sky movie channel on satellites, and this signal has to be decoded, you decode it with a little gadget, and when you buy this little gadget, the Weizmann Institute gets a few cents royalties, and this is due to the same scientist who last year received the Pius XI Gold Medal, in recognition of his contribution to basic science. And of course, he research into numbers theory, and its relationship to computer science, was not undertaken with the aim of enabling the Sky movie channel to protect its signal en route to your home. And only ten years ago; number theory was foremost scientific disciplines thought never to be useful.

Another falling boundary is that between pure and applied research in different fields of science. I will give you just one range of examples. Take, for instance, the medical applications of fundamental physics - the CT (computer tomography) scanners and magnetic resonance imaging. The two most powerful diagnostic tools of modern medicine emerged from the field of particle physics, which happens to be my own field of research (except that I had absolutely nothing to do with this developments). Both of them were born from applications of technologies and techniques developed in order to understand the most fundamental particles of nature. The purely intellectual quest to understand the most basic building blocks of the world led to this important by-product.

Another falling boundary is that between science and technology. It is simply no longer true that there is science without technology or technology without science. A hundred years ago, there was a lot of technology that was totally unrelated to any science, especially to contemporary science. Today the two are inextricably combined. At a technical university today, the computer science department, which is science, and the electronic engineering department, which is technology, have almost the same curriculum. The distinguishing features between biotechnology and biology are very nearly non-existent. Energy research, is it science, or technology? It is obviously a mixture of the two.

Another falling boundary is that between academia, the world of research in universities and research institutions, and the world of industry. When I graduated from university, my generation had to make a choice, whether to go to university and do intellectually challenging fundamental research, leading an interesting life, albeit on a relatively small salary, or to go to industry, to be part of modern technology, and make more money, produce something, but perhaps with less intellectual gratification.

That was the picture of 25 or 30 years ago. But the picture has changed. Today the question is very different. First of all, the world of research cannot exist without industry, and industry can no longer exist without the world of research. It is no longer true that universities and research institutions have the best equipment and instrumentation. Very often sophisticated industry has them. Both for special instrumentation and for financing, research depends on industry.

On the other hand, no industry - no matter how large a conglomerate or multinational company - can encompass the full infrastructure of all the areas of science necessary to its workings, now or in the future. Even those two industrial giants, IBM Research and Bell Labs, the only companies that succeeded in building fantastic laboratories for fundamental research, are dismantling their wonderful scientific laboratories, and losing their influence.

The new situation is a growing, intimate relationship between the world of scientific research and the world of industry. At the moment, the scientific world provides a very broad and very thin infrastructure. When industry looks around and finds a specific item - sometimes initiated by industry and sometimes initiated by the academic world - it is up to industry to expand on it, putting increased effort and a very major emphasis on that specific area, which then has to be picked up by a coalition of the industry and academia.

We see this principle in operation in many different areas. Today, for instance, an institute devoted to pure research such as the Weizmann Institute, with an annual budget of a hundred and twenty million dollars, receives twelve million dollars a year from royalties and industrial contracts, especially aimed at developing specific commercial projects. And I repeat, this is not an institute which is aiming at industrial research. This is an institute whose goal is to perform first-class, basic fundamental science. Yet already, we receive ten percent of our financial volume from industry, as opposed to only three percent merely five years ago. And this figure is guaranteed to grow, regardless of what we do. So this is a growing trend that we have to recognise, promote and understand.

The boundary between the scientific world and the world of business is also falling very quickly. I already mentioned the patent lawyer, who has to educate himself on scientific matters. Now there is a whole new madness in the financial world. Investment managers are using very advanced techniques from modern mathematics and the theory of chaos to give investors a high turn. In the United States and also now in the UK, you have companies who specialise in these techniques; investment portfolio managers who hire more PhD mathematicians and theoretical physicists than economists. It is a crazy new world which is going in some as yet unclear directions, but these interactions are developing.

Another change is that it is no longer only high-tech industry which needs technology; today, it is any industry that wants to survive and be successful. Today, for instance, if you are in the business of producing underwear, you have to be a high-tech underwear producer. The only way to survive in the global market economy is by using the most modern technology, the most modern management methods, the most modern computer controls, the most modern scientific methods, no matter what it is that you are producing. And the penetration of the business world into the scientific world is very clear in those research institutes which are advanced. And if you do not see this happening in a research institution, then it is a warning sign that perhaps the research is not up to standard.

Science is penetrating in a very strange way into major national and international political decisions as well. The world of politics is becoming intertwined with the world of science in a very peculiar manner. And that leads to something else which is very disturbing. The more science is involved in political decision-making, the more this political decision-making requires a certain depth of understanding, especially an understanding that life is not simple, that events are not defined in terms of black and white, yes and no, good and bad. On the other hand, the modern world of communication, of global television, is a world which emphasises superficiality. It gives messages in one minute, in thirty seconds, in fifteen seconds. Certainly the video clip, rather than the two-hour film, is the pervasive unit. Suddenly, the one-minute news item is the unit, rather than an article in the newspaper spanning three columns.

And that speed goes against the trend of the invasion of science and complicated technological matters into our political life. When you have to cope with such complex matters, you have to spend a little more time and more thought weighing the various aspects of the problem. You cannot make do by looking at an issue for just thirty seconds, even if you are introduced to the problem by a thirty second message.

And finally, science, which always was a truly international activity, is today done by multinationals, but not in the sense of multinational companies. Today, almost every little scientific project, with five scientists working on it, is multinational. It is very often that you will find an Italian, a German, a Russian and a Belgian sitting in Paris and working on a little problem, communicating by computer with somebody in California and somebody in Tokyo and discovering that somebody at the other end of the world has been doing exactly the same thing at the same time, or perhaps five days earlier, or maybe even five days later.

So all these boundaries are falling. We are losing the boundaries between the areas of science, between pure and applied science, between science and technology, between academia and industry, between science and the business world, between science and the political world. We are losing the boundaries between the different nations in matters of science and technology.

Where is all of this taking us? It is taking us into a world which is very, very complex, yet it is a development which we cannot stop, so we had better join it and run with it in the most intelligent way that we can. And the answer, in my opinion, to all of this, is primarily education. Education from the cradle or the kindergarten to the last days of our lives. And a different sort of education than the traditional one. The tradition was that scientists and the engineers received a scientific education. And if you were not a scientist, you could say: "I am a well-educated person, I am an intellectual, I know about history and art and music and literature and I hate mathematics and I don't understand science and none of this is of any interest to me". And if you said this, it was considered a sort of 'bon ton'.

The new world is not like that. Science has become an integral part of general education. And every single person and every single child in every single school, whether he or she does or does not wish to become a scientist, has to learn a certain level of it in order to participate in the new world in which we already live. This will be even more true in future generations.

It is the responsibility of governments, political leaders, industrial leaders - especially industrial leaders, because they are the main beneficiaries of this - to see to it that a different kind of scientific and technological education is offered to the public. And it is very important to emphasise that we are not talking here about traditional scientific education. The Prime Minister of a country, and the army general, and the industrial leader, do not have to remember the formula for solving a quadratic equation. In order to enjoy a bottle of wine, they don't have to know the chemical formula of alcohol. But they have to be able to listen to a scientific-technological issue presented in simple terms, and to weigh it and to know who is making sense and who is not making sense, and to know which argument is reasonable and which is not reasonable to a certain extent. It is impossible to demand absolute understanding in the same way that it is impossible to demand that everybody know every other subject. But a certain literacy in science is absolutely necessary, a certain way of thinking about science, a certain quantitative way of thinking, a certain logical way of thinking which is so clearly manifested in scientific issues.

Take the example of a government discussing issues of energy or the environment, two of the most common issues today, which touch on technology, the problem of water resources in those countries which are lacking water, etc. You can see very clearly the lack of ability to address these issues among much of our leadership.

But even at the level of the hotel clerk and the industrial worker and anybody else who has to manipulate and employ modern technology, it is crucial that we correct this situation for the sake of our future. It is also the obligation of scientists and industrialists to transmit this message to the public, to explain what they are doing, to explain the importance of their work. This is a very crucial issue. Traditionally, scientists just don't care about communicating with the layman. Ninety-eight percent of the scientists of the world don't feel that they owe anybody an explanation of what they are doing. This is wrong, and simply cannot continue in a world which depends on these interrelationships.

But all of these issues lead to paradoxes, and I would like to conclude with these paradoxes and to propose solutions to them. The first paradox is that we live in a world of specialisation. Everybody is getting more and more specialised, with a narrow domain of expertise. Yet I am convinced that we are living in a world of falling boundaries, in which legal matters mix with technological matters which mix with science, and the different scientific disciplines mix. How are these two things consistent? How can you be multidisciplinary and very broad and at the same time be a skilled specialist? The only answer - and this is precisely what is happening - is to develop more and more specialities which themselves are interdisciplinary.

To use the example I have already mentioned, there will be, for instance, lawyers with a good scientific education. Although they are not scientists, not professors of science, they will have enough scientific education to deal properly with the matters of high-tech companies. And there will be brain researchers who know enough physics, enough chemistry and enough biology to solve the problems of the brain, without knowing all of physics, all of chemistry and all of biology. Already there are more and more new niches, new specialities, being developed which never existed before. And it is only by coalitions of people of different specialities, each of which is interdisciplinary, that progress can be made.

The second paradox is that even though I feel that education is the answer to the quickening pace of change, how can we bring such change quickly into educational system? If in 1993 we have a certain electronic technology, can you bring it into the high schools of 1993? Obviously not, it costs too much money. If you are very rich, you can perhaps bring the technology of 1988 into the high school of 1993, but by the time a child finishes high school, he or she will already be three generations of technology behind, because every four years there is a new generation of electronics technology. And by the time he or she becomes a technician or a labourer working in some industry, he or she will be five generations behind in technology. So how do you cope with it?

The answer is very simple. The more changes you have to make in your life, the more important it is not to learn the latest fashion, but to learn how to cope with change, how to cope with innovation, how to learn a new technology. And what is common to all the new technologies are certain basics. For instance, what is common to all the new technologies in electronics are the same basic rules of mathematics, logics and physics. The faster things move, the more you have to return to the basics. And this is the principle that should be emphasised.

I don't know how to solve the paradox I already mentioned, that of an ever-more-complicated world whose messages are being communicated in scant minutes or even seconds. This may be the most difficult paradox of all. This may be the reason why, in such an advanced technological world, we see the development of astrologists, fortune tellers and religious fundamentalists - three different kinds of people, all of them going against what we were talking about. This development represents a very major danger. Again, the only solution is education and strong leadership, but unfortunately, I don't see a great movement world-wide in that direction.

To conclude, we are in a very challenging, exciting, complicated, interrelated world, in which science and technology have found their way into our lives in an irreversible way. And only societies and countries and communities and people who know how to find the correct mixture and how to merge all of these things properly are going to succeed in getting the best out of science and technology and in avoiding the dangers which indeed lurk behind all these wonderful innovations.