HAIM HARARI

Science -is it an art, a language or a natural resource?

It is a great pleasure for me to be here again in Alpbach, my second time here and, hopefully, not my last. I realise I am in a very difficult position - all of you have heard so many speeches in the last few days and I now have to follow them with yet another. You have had a very good lunch, with some wine, perhaps champagne, and I know that all you want to do is take a nap. Even the weather is beginning to look up. Realising the difficult task I face, I shall try to be controversial, entertaining and not too deep. I hope that this combination will keep you awake.

The topic that I selected was a question: Science - is it an art, a language or a natural resource? Clearly, science and art have many common features, for example, the creativity aspect, and we have heard quite a lot about these in the last two days. Science is definitely a language in which we describe the secrets of nature, the laws of the universe, new technologies which we develop. Science is obviously a natural resource in the sense that its economic value is already recognised - as was said repeatedly - as far greater than that of minerals, oil, or the like. So, yes, science is definitely a kind of art, a language and a natural resource.

Yet science, obviously, is not exactly an art - there is much more objectivity in science relative to art, and that's both good news and bad news. Science is, needless to say, not exactly a language, and even as a natural resource it is very difficult to measure its actual economic value. So, for those of you who have to leave now, the answer to the question is: science has many of the features of art, language and natural resource, it is all of those, yet it is not one of those precisely. What I thought I would do is share with you some thoughts along these lines and mostly raise questions rather than answers on many of the fascinating aspects in which science is slowly but surely penetrating every little corner of our life.

The Bible tells us that Moses took the children of Israel out of Egypt and then wandered about in the desert for 40 years, in the process of which he received the Ten Commandments and invented monotheism. After looking here and there for 40 years, he found the only place in the Middle East which does not have any oil and brought the Israelites to that place. This is a very old Jewish joke and we have always been telling it with a smile, but also with a tear. But today, and this is not a boast, the Gross National Product of Israel is larger than that of Saudi Arabia. This is not a statement about Israel or about Saudi Arabia, this is a statement about the value of a certain type of commodity versus others. In modern terminology, you could say that Moses brought with him some software from Mount Sinai and that software may exceed the value of natural resources.

Incidentally, there is a wonderful story about scientific advice. You know that when they were passing through the Sinai Desert, the Israelites were pursued by the Egyptians. The Red Sea was in front of them and Moses called his scientific and technological advisers and said: "The Egyptians are following us, the sea is in front of us. What can we do?" The advisers said: "Well, you can bring some heavy machinery and dry up the water, push some of it this way and some of it that way, and we pass through the middle; then you move the water back and the Egyptians cannot follow us." Moses asked them: "How long will this take?" They answered: "About six months." He said: "We do not have six months, they are catching up with us tomorrow." So he called his public relations adviser and asked him what to do. And the PR man said: "Well, you just stand by the sea and raise your arms. The water will part in the middle, the children of Israel will go through the dry part, then the water will come back and will close on the Egyptians." Moses thought a bit, looked at him, and said: "Do you really think this will work?" The man answered: "I am not sure, but if it does, I will get you a full page in the Bible."

We are witnessing today a fascinating historical process. For hundreds of years, and even just a hundred years ago, raw materials were crucial for the wealth of nations and this, after all, was the real reason behind the development of colonies by the European powers. Then the world moved through the industrial revolution to a stage where machinery (what we call today hardware), though still relying on raw materials, became more important than raw materials. This was the era that established the big industrial giants, ending with IBM, which is perhaps the last giant to rely on machinery. We are now in the next stage, which is development based on knowledge, know-how, software - not only in computer programs, but in a very broad sense - perhaps starting with the Ten Commandments and ending with Windows 95, and everything in between. It is very significant that IBM is slowly being replaced by Microsoft as a giant, and that Bill Gates is the richest man in the world. What is significant to us is not the person of Bill Gates, nor the fact that he has 5 or 10 billion dollars, but the fact that the richest man in the world made his money in this way. This is a symbol of the profound revolution that has taken place, of the incredible importance and power of this complicated collection of words: know-how, knowledge, science, technology, their applications and innovations. Strangely enough, scientifically speaking, Bill Gates did not really do anything. Sure, what he did derives in one way or another from science, but he did not really create new knowledge, and that is a very interesting thought.

All of this brings up a fascinating subject that was raised here by several people, which we could perhaps discuss in detail at some future Alpbach conference. This is the subject of intellectual property, its value, how to measure it, how to compensate for it, how to guard it, everything from cryptology for preserving your property to patenting - what can be patented, what patents can be protected. A small change in your patent, and it becomes unprotectable - and this product may go on to become the biggest seller! Patenting, of course, has always been important, but it was never such a crucial issue - knowledge was just one small commodity. Now, when knowledge has suddenly become the number one commodity, it has become the number one legal economic issue. And it coolly pervades so many other issues in science: Can you still publish freely without losing the ownership of your knowledge? If you cannot, then the way scientific work is being carried out is destroyed, and science without free information is not good science. How do we cope with this? How do we measure knowledge in a company's balance-sheet? A company may have fantastically important knowledge, of vast economic significance for its future, but this does not appear on the bottom line of the balance-sheet. We heard some comment on this matter earlier this morning, but the truth is that we do not know yet how to cope with this. There is also much conflict of interest in these complicated interactions between industry and the research world. We are only beginning to scratch the surface of this extremely important topic, which, incidentally, requires a new type of person to deal with it. It requires an economist, financier or lawyer with a deep understanding of the scientific and technological issues, and it is my prediction that we will see more and more people getting a degree in science or engineering and then going to law school for this specialisation. This is going to become very important, perhaps the big business of the future.

How do you protect your property when it is so easy to steal it? We mentioned Moses who invented monotheism - he did not issue a patent and you know the end of the story: he only has about 10 million customers. Two others who took the product and changed it somewhat now have a billion customers each, and they have not paid him any royalties!

The profound basis of the knowledge industry is basic science. Without good basic science, there can be no scientific infrastructure. Basic science does not only answer questions; no less importantly, it asks questions. This was clearly demonstrated to us during the pleasant evening we had two nights ago listening to the Nobel laureates telling us their stories. Very often, asking the right question will lead you to the right place, but in basic science, it is not good to try from the very beginning to arrive at a useful outcome.

Two years from now, we will mark the 100th anniversary of the electron, discovered by J.J. Thompson in Cambridge in 1897. I propose that the Alpbach meeting of 1997 be devoted to this discovery, because this fundamental particle really changed our life dramatically. There is a story, which I could never verify, but which I have heard from several sources, that after the electron was discovered, a toast was proposed in Cambridge which said: "Gentlemen, let us drink to the electron, and may it forever remain useless." It is estimated by one of the best physicists of our time, Nobel laureate Leon Ledermann, who made a careful calculation, that approximately 40% of world's gross product is now based on our understanding of the electron. Less than a hundred years separate that toast in Cambridge from this sobering fact. This gives much food for thought, because the next discovery that will dominate our life will probably take less than a hundred years to exercise its full impact, given the much more rapid pace of development today.

The business of managing basic science is very difficult. On one hand, you must let the good people, who engage in it, do it freely. You must give them, as John Kendrew said two nights ago, the opportunity to work five or ten years without achieving results, provided they really know what they are doing. On the other hand, how do you decide if they know what they are doing? And can you allow everybody to do this? Obviously, you cannot let everyone run completely loose. These issues are so complex, so crucial, that it is all too easy for a government or a ministry to destroy basic science.

I find a very useful analogy between basic scientific projects and raising children. When we raise children, we give them our all - our time, attention, love, resources, everything. We do not know what will come of them, we hope something very good, perhaps only good, perhaps useful, perhaps good and useful. Sometimes we know that something terrible will come out of a child, or perhaps nothing will come of it at all, and in any case it takes at least two decades before we really know the result of our huge investment. We do know, however, that a family which produces ten or twelve children, may not have enough to feed them all. This is very similar to many projects in basic science. If you have too many scientists doing research, too many people who are allowed to sit on too many projects for ten years without discovering anything, the result is that there are not enough resources for any of them. This is bad basic science. On the other hand, if you try to regulate it, as the Chinese regulate birth control by limiting every family to no more than one child, when you become invasive and try to control every little thing, this too is destructive to basic science. There is a very delicate balance that needs to be preserved. You have to let science run freely, you have to let it find its own way to bloom, you must also allow some waste, but you obviously cannot allow thousands of people to sit for years and discover nothing. Clearly, not all of them are going to become John Kendrew. We must invest a great deal of energy in cultivating this fine balance, because what you destroy in one year, will take 15 years to correct. This is a message to ministers of science, to ministers of finance, to governments in general.

Here we have a great similarity to art. It is often very difficult to know what is good art, and the artist, like the creative basic scientist, goes through long spells which are dry, or dull, during which he may learn a technique, or in which he or she produces nothing, until finally the breakthrough comes, or maybe never comes. Perhaps you know the famous story about the efficiency expert who went to inspect the philharmonic orchestra. He reported that the timpani player is inefficient because he plays only when the conductor looks at him - this is sometimes the kind of report you get about basic science. You have to be very careful about it.

But basic science is only the foundation. The next step, of course, is the interaction between basic and applied science, which is rapidly becoming one and the same thing. Industry has to have a finger in the academic world, and the academic world must keep a finger in industry. I believe it is not good to give the academic world full 100% government funding, it is better to leave it with a little hunger for industry money. Conversely, it is good to encourage industry, even by government subsidies, to spend money in the academic world, because commercial companies will spend money on something they find useful. In Israel, we have very good experience with this kind of combination, and this interaction may be worth discussing on some other occasion.

We have an old saying that most great scientific discoveries happen accidentally, and the bigger the funding, the longer it takes the accident to happen. That is not always true. Sometimes, if the funding is inadequate, the accident will never happen. And incidentally, it is absolutely true that you have to be lucky in science, but it is absolutely false that luck alone can get you somewhere. Every scientist is lucky at one point or at several points in his or her life, but only the ones who are persistent, ambitious, clever, catch this lucky opportunity and push it to great achievements. Those who failed to achieve were no less lucky, but they did not recognise their luck. This is a very important lesson about science.

There is another aspect which, to me, is the number one issue today in our society vis-à-vis science and technology, and this is education. Science penetrates every sphere of life. A minister of communications will deal with science and technology; the same is true for a minister of agriculture, or health, or defence, or, obviously, science, or industry, environment, or energy. One can go on and on, in every government of the world, more than 50% of the ministers deal almost exclusively with science- and technology-related problems. But not only the ministers, also their assistants and advisors, the leaders of industry, military leaders, in fact, everybody - simple workers who must use sophisticated tools, hotel clerks who have to use the computer, and so on. Does this mean that all of those people, from the minister of agriculture to the hotel clerk, all have to be scientists or engineers? Definitely not. A world of only scientists and engineers would be a disaster. But everybody has to be able to speak this language of science, they all have to understand what is explained to them, what the issues are, how to think in a quantitative way. All kinds of concepts which are part of the language of science we get automatically, if we have scientific training. Yet such scientific training is very visibly absent among people at very high positions, all over the world. In the modern world, scientific and technological education, in the sense of understanding the language - not in the sense of remembering the equation for the solution of quadratic equation - has become a very crucial part of general basic education. Only 50 years ago you could be a great man without any scientific knowledge, you could even boast "I failed in mathematics, whenever I tried". Today, not any more, and less so in the next generation, the generation of our children.

I seriously believe that as scientific knowledge becomes increasingly important in our society, the most important issue for the future is to give a certain level of science and technology education to the general public and to every child, no matter what profession they pursue. Some level of science and technology has to be taught as a language, as a tool that we are able to use, because there is no point in learning the science of yesterday. The basics will remain - mathematics, physics, the laws of nature, but the latest electronic technology is likely to change five times before a student will have obtained his first job. This, I honestly believe, is a most crucial issue in a world that is moving in the direction I have described.

This is a good point to spend two minutes on science as a language. What do I mean by this? When you learn a language, you have, for instance, to read a text. If I wished to learn German, which I do not speak, and if I lived in Austria, perhaps I would read the writings of Franz Werfel, or maybe Freud, or I would read "Der Standard" or even "Täglich Alles". One may learn a language from all these sources, including badly written texts. It does not really matter whether the text you learn from comes from literature, history or science, the important thing is to learn to speak, to write, to understand.

Science is the same. It does not really matter whether you learned in school a lot of biology, or chemistry, as long as you learned something that gave you the method of science, a way to understand science. Ask any of our Nobel laureates here how much they know about scientific fields outside their expertise - probably very little, but they can master those fields quickly, because they speak the language of science superbly. Needless to say, not everybody can reach their level, but we need to develop a population which has a certain ability to cope with science; to recognise, for example, that if you read in the newspaper that somewhere radioactivity was discovered which is five times the normal, that is not the same thing as saying that it is five times the minimum danger quantity. As you know, in radioactivity there are certain levels above which it becomes dangerous. The background radiation of normal radioactivity is many times below this level. So if you have five times the normal, you are still below any danger. It might, no doubt, be useful to check what is happening, but there is no danger. We recently had such an incident in Israel, where a newspaper headline of this type created panic about an institution that had higher than the normal background radiation, something really minor, which I would be ready to bring into my house and sit near for at least a week without the slightest hazard. Citizens have to make decisions about new power stations, they have to worry about health issues, about military issues - these are all issues which are related to technology and one has to learn the language.

I want to devote the last part of my remarks to two or three specific examples which, in one way, are familiar to all of you and, in another way, totally unfamiliar, just to show you the strange ways in which all of these ingredients work together. The first one is MRI - Magnetic Resonance Imaging. You go to a hospital when you have a problem or, God forbid, a tumour or a suspected tumour, and you let them take a MRI-test. You will get a beautiful picture of the inside of your body - without radiation hazards, because you have been put inside a magnet, not inside an x-ray machine. How does this work? Physicists discovered that everything is made of atoms, therefore you too are made of atoms. Then it was discovered that in an atom there is a nucleus, and therefore each of us is full of nuclei. Now, you do not go to sleep in the evening saying: "I have some atoms and nuclei inside me." You certainly do not care about the fact that this little nucleus has electric charge and that it also spins, namely it rotates around its own axis. Now, everything that is both electrical and rotates is like a magnet, and therefore many of these little nuclei inside your body are little magnets. I am telling you, therefore, that every one of you has a magnetic personality. Every one of you is full of atoms and in the atoms there are nuclei, the nuclei are magnets and you are full of an enormous number of tiny magnets. This was in you since you were born and you did not know it. Does this change your life? Yes, it does. Because the big magnet into which you enter in the hospital recognises - just as a radar catches a plane in the sky - your little magnets in the body, finds out where they are and what is happening to them. This is how an MRI picture is obtained. Have you ever stopped to think about the fact that the discovery of the atomic nucleus by Rutherford and some totally basic work - nobody knew why it could be useful to know that this nucleus has a spin, rotates around itself and has magnetic properties - might one day save human life? Almost certainly there are people in this room whose life was saved by this machine.

This is a very strange business. For all of this would not have happened, had it not been possible for computerised techniques to read the map the magnet provides. It also would not have been possible if other scientists had not tried to discover some fundamental particles and needed accelerators in order to find the particles, and needed to develop bigger and bigger magnets in order to improve their accelerators. This resulted in an incredible array of theories and machines which have nothing to do with your personal health. Finally, at the end of the day, they are the ones who save you in the hospital, yet originally they were not related to medicine at all.

What does this mean? It means that if, 25 years ago, somebody had asked: "Where should I put my money to save the largest number of lives from cancer?", everybody would have answered: "In medical research, biological research." In retrospect, the answer is: "Put it in good magnets and good computerised techniques!" Does this mean that today you should invest in good magnets to save the lives of the next generation from cancer? Nonsense! The next stage will be very different, and we have no idea how it will go. We have to move on a very broad front, and try to come up with new solutions that will probably be no less surprising than the one provided by the magnet.

What, then, is the next step in this MRI business? The next step is not only to find where the problem is, but what it is. In the not too distant future, I believe, we will be able to perform a good chemical analysis without penetrating the body at all. You will stick your finger into the magnet and your blood test will come out without taking one drop of blood. That may take another 25 years and it is not such a great achievement, because, after all, taking blood is not such a big deal, but it gives you an idea of how tumours could be detected without doing a biopsy, simply by knowing their chemical composition. It may sound like science-fiction, but it is definitely going to happen, subject to further development of this technique.

This reminds me of the latest story I heard from an American friend just a few days ago. The lawyer of O.J. Simpson came to him and said: "We have the results of the blood test, and there is some good news and some bad news." O.J. asked: "What is it?" The answer: "The bad news is that the blood in the crime-scene is yours." "What is the good news?" "Your cholesterol is very low!"

A second very interesting example is cryptology. Here again, fascinating developments have emerged from scientific fields like number theory, surely the most useless field ever invented. As you know, mathematicians always tell us that infinity is larger than any number, it is larger than a million, larger than a billion, and, of course, this is mathematically true. If you take a number like, for example, 10 to the power 100, a number with 100 zeros, and ask "Is that infinity?" - well, I have shocking news for you - that is practically infinity, because there is no 10 to the power 100 anything in the universe. The number of particles in the universe is much less than that; the age of the universe measured in seconds is much less than that. And even if you do not measure it in seconds, measure it in microseconds, measure it by the fastest process known to man (which is the fastest decay of the fastest decaying particle), the age of the universe from creation until now measured in this very tiny unit is still less than 10 to the 100. So, in practical terms, there is nothing in the universe that is 10 to 100 and, therefore, if you have something that will happen once in 10 to the power 100 times, it will never happen. So, suddenly you have this wrong statement that infinity equals 10 to 100, and there are several fascinating scientific results that emerge from it, with a crucial role in cryptology, but this is a long topic by itself.

My concluding example is something that has not happened yet and may never happen, but it is intriguing to speculate about it. The two leading scientific fields which are making the big news today are electronics, microelectronics, computers on one side, and biotechnology, genetics on the other side. These are the fast-moving fields in science, technology and industry. Yet the meeting point between them has only now begun to emerge, and there are countless fascinating meeting points that may develop in the future. One direction has to do with the human genome project, the mapping of genes, and the processing of this vast amount of information. This is certainly a coming problem - information processing, a heavy usage of computers, and eventually a personal computerised signature of every person, which would provide a full picture of that person's genetic makeup. Such results can only come from a marriage between the world of computers and electronics and the world of genetics.

But there is another new area which is only beginning to develop - sensory discoveries - all kinds of phenomena which must be measured and monitored in tiny amounts. Imagine what one could do for agriculture, if we could give plants just enough water, just enough sunshine, just enough minerals, just at the right time, without wasting 95% of it, as so often happens now, in a world which is starving for energy and water and does not like to use too many fertilisers. Imagine what one could do for a human being, if we could continuously monitor by an electronic gadget everything that occurs in the body - how much insulin, how much haemoglobin - and correct it by electronically designed combinations of drugs. A vast field of possibilities presents itself. There was an item in the Herald Tribune two days ago, about success in trying to achieve direct connection between a neuron and a micro-chip, namely, to transmit information between the electric signals of the nerve system and the electric signals of the micro-chip. Just stop thinking about anything else for 3 minutes and try to develop the possibilities of this - it boggles the mind!

Finally, I'll throw in one last example, we may see molecules serving as the next generation of chips. These will be micro-chips much smaller than anything that we are able to produce today by the various electronic methods with which we are familiar. This may be pure science-fiction, but the possibility is fascinating.

I once met an Israeli general, the former head of the Mossad, the Israeli intelligence agency, who told me excitedly about a science-fiction book he was reading. I told him, I never read science-fiction, because I find real scientific work so much more fascinating, wild and crazy, surprising and imaginative than any sci-fi. He looked at me and said: "You know, that's very interesting, that's precisely why I never read spy novels."

So, we can take off with our imagination, but the moral of this example is that nothing will happen without basic science, nothing will happen without interaction, innovative interaction, with industry and with the economy, nothing will happen without educating the general public in the language of science. All of these things have to work together like a very clever orchestra without a conductor, because there is no one who is good enough to be a conductor of such an orchestra. This is the kind of world in which we live today. Science indeed is an art which has to be encouraged, basic scientists have to be encouraged like artists, but, in the same way, we also want to bring up the general public. We also have to force the scientists who do basic science to bring themselves to the public, to explain what they do, why it is important, even if its usefulness may only become evident in 25 years.

We have to encourage the learning of science as a language, this is the challenge of educational systems - to teach science as a vehicle for changes that will happen in the lifetime of the child that is under the care of such systems. Last but not least, I return to what I said at the very beginning, science is the most expensive, the most important, the most economically valuable resource. Countries which have a pool of talent and are not using it properly are exactly like countries which, fifty years ago, were sitting on an enormous amount of oil and did not know how to drill for it and how to sell it. This is the natural resource of the present and the future. What remains to be done is to learn how to use it best, how to measure it, how to value it economically, how to compensate for it, how to protect it against crime, how to deal with all this new complexity of valuable things which cannot be physically touched and sometimes cannot be seen.