HAIM HARARI

Science education for the general public as a crucial ingredient for an advanced economy

Several of last night's speakers - the scientists, interestingly enough, not the industrialists nor the politicians - mentioned that education at the present time is of the highest priority. I would like to briefly describe what it means to live in a world increasingly dominated by science and technology, how it affects every one of us (by which I mean the general public, not the small circle of scientists) and in what way education, and especially science and technology education, can answer many of today's problems.

Practising science a hundred years ago could perhaps be compared to playing music by Shostakovich today. The circles of cognoscenti were limited - a few people practising it, a few people watching and following it, a few who actually understood it, a larger group which took some interest in it once or twice a year, and the majority of humanity totally ignorant of it. If you were to open a newspaper a hundred years ago, you would read about science just as often as you read today about Shostakovich's music, an article every few weeks or every few months, depending on your country of residence and on who happens to be playing at a given time.

Likewise, science was just as relevant as Shostakovich to the industry and economy of the time, in the sense that no big industry was interested in the latest scientific discoveries. This was the time that the electron and X-rays were discovered, it was the beginning of the revolution that eventually led to the understanding of the atom, to nuclear science, to electronics, to the theory of relativity, to the understanding of molecules; in brief, to almost all of 20th century science. It was all born at that time and it was as much in the news then as the music of Shostakovich is today.

Fifty years ago, the situation was already different. Partly because of World War II, which hastened certain technological innovations - from cryptography and code-cracking to radar, nuclear physics and many other fields - science and technology began playing a key role in politics, in war and peace, in life and death. It was at that time, about fifty years ago, give or take a decade, that the transistor, the laser and the role of DNA were discovered. Yet, fifty years ago, all this was still not the business of the general public. One began reading about science in newspapers; political leaders began to have a glimmer of its significance; large industries rose on the basis of its innovations, but it was definitely not something that the general public could feel, smell, or touch. The daily life of most people did not depend on the new scientific discoveries.

Today, we live in a completely different world. We are participating very actively, every single one of us, in two revolutions and in one crisis. One revolution is the electronic revolution, comprising all those things that have to do with the world of computers, electronics, telecommunications, informatics, internets and all their resultant technologies. Inescapably, it touches every area of our life; it is in our home, in our office, when we travel, everywhere.

The second revolution is the genetic revolution, of which most people are not yet fully aware. People are familiar with words such as "genes", "DNA" and "biotechnology", but have not yet absorbed the impact of the daily discoveries triggered by the genetic interpretation of diseases, but also of normal human, animal and plant physiologies, on our health. The ability to manipulate genes (and I'm not talking about cloning), the possibilities of gene therapy, of fixing things that went wrong, of doing experiments to see how certain genetic features relate to specific human problems - all this opens up an incredible panorama of possibilities that will increasingly influence our life, whether we like it or not.

Do you think that Watson and Crick, who discovered the structure of the DNA molecule in the fifties, could have imagined that forty-five years later the fate of the president of the United States would depend on the DNA analysis of his famous stain? When I was in Alpbach some years ago, I drew an example from an item that was then in the headlines - the role of DNA testing in the trial of O.J. Simpson. This is today no longer an extraordinary event; it is used in forensics frequently and in another decade it will be entirely routine.

It has been estimated that approximately 50% of the gross-product of the world is now based, in one way or another, on our understanding of the electron or of the atom: lasers, electronics, computers, new materials, biological aspects of molecular biology, and so on. These science-based products are no longer a little footnote in the annals of history or economics, they are no longer the business of a handful of scientists. Rather, they are in the life and home of every person.

I mentioned two revolutions and one crisis: the two revolutions are the electronic revolution and the genetic revolution. The crisis is of the planet - its environment, its energy and water sources. We are getting bigger in terms of population numbers and in terms of waste. For the first time in history, we are big enough to make a difference - a destructive difference - on the land that we inhabit. This leads to an enormous number of problems, some of which have not yet penetrated our understanding. In Austria, water is not a big problem, but it is absolutely clear that over the next twenty or thirty years, there will be quite a number of local wars in the world on the issue of water, as water becomes an unbelievably scarce resource. I will not get into the complex issue of environmental problems, except to say that the crisis is already here. And between two revolutions and one crisis, almost everything we touch has to do with science and technology.

One fascinating aspect, which I will just mention, is the growing number of points of interaction between the two revolutions, between the world of electronics, computers, informatics on the one hand and the world of genetics, medicine, agriculture on the other. I can give several examples.

When you go to a hospital, you see today a fantastic collection of technology - from magnetic-resonance imaging, to tomography, to laser operations, to radioactive scans - all demonstrating what the world of physics and computers can do for human health.

When you think about the correlation between the understanding of the human brain - a biological problem - on the one hand, and the design of modern computers - an aspect of the world of informatics - on the other, you see a growing connection between the two. And still nobody has succeeded in producing a computer strong enough, fast enough, to compete with the human brain.

Understanding the complex structure of biological molecules for the purpose of designing new drugs and creating cures for various diseases is an endeavour of biology, yet it is entirely played in the field of chemistry, physics and computers.

And finally, there is the international effort, known as the Human Genome Project, to decipher the code of the entire human genome, which will apparently be completed by the year 2003, just five years from now. This vast undertaking, whereby sophisticated mathematical methods must be used to digest huge amounts of biological information, is a prime example of the commingling of two disciplines - the world of genetics and the world of informatics.

My point is that the two revolutions may end in ten years by becoming one revolution, and all this will be just a little more confusing than it already is. The reason is that this revolution touches everything: health, agriculture, environment, energy, industry, communication, transportation, defence, education, politics and even religion.

For example, every person daily faces a certain risk-analysis. The individual doesn't think of it in those terms, but when we walk out on the street, we know that there is a certain risk of being killed in a car accident, yet we do not let this awareness take over our lives, we don't stop walking in the street or driving a car because of it. We calculate the risk and we try to minimise it. And yet there are many other risks - health risks, environmental risks - which nobody bothers to calculate. The issue of statistics - calculating risks, forecasting eventualities - is becoming increasingly dominant in our lives, and will become much more so over the next decade or two. It is fundamental to national policy.

Speaking of statistics, I am reminded of the story about three statisticians who went duck-hunting. The first one who saw a duck, took a shot at it and the bullet passed twenty centimetres above the duck; the second one took a shot, and his bullet passed twenty centimetres below the duck; the third one said: "We got it!" Statistics, clearly, has its dangers, but it has become a very serious business in national policy-making and requires a lot of common-sense.

The world of politics is influenced by the emerging technologies of communication. It's already a very different world than it was just a generation ago, when today every politician depends on television and mass-media, but it is going to be a far more different world when everybody will be able to sit at home and, at the end of the evening news, press a button to express his or her opinion. The screen will instantly show the results of this public opinion poll, or rather this national plebiscite. This technology already exists; it's still a little too expensive, but in ten years it will be commonplace. This will certainly change politics. So much will depend on who is asking the question and how the question is formulated. This too is a very serious business and, incidentally, a potentially great danger to democracy.

To prove my point that science is everywhere, I can even turn to religion and ethics. There are issues that nobody ever thought about, all the issues that emerge from how life is created. This reminds me of the story about the Catholic priest, the Protestant minister and the Jewish rabbi, who were debating the great biological, ethical, religious problem of when life begins. The Catholic priest said: "At the moment of conception"; the Protestant minister said: "At the moment of birth." And the rabbi said: "Life begins when the children leave home and the dog dies."

Two short remarks about how science is generated and what it can do, before we move to education; specifically, to science education. All of science emerges from basic science. Basic science alone may not be useful, but science without basic science simply cannot exist. The best analogy is to think about basic science as raising children: you don't know how they will turn out and what will become of them, but you cannot get them ready-made, fully grown and successful adults. To argue that we should put all our efforts into applied science and industrial research is exactly like saying: "Children are useless, let us therefore start producing them at the useful age of eighteen." Just as you cannot create an adult person out of nothing, without investing eighteen years in raising and educating it, and sometimes also losing your investment, so it is with science. Its outcome is unpredictable and its benefits may only become apparent after fifty or even eighty years. And just as you don't want to raise too many children, you don't want to invest too much in basic science. But you have to invest enough, and you have to let it flourish as freely as possible.

Science, as Professor Lehn said, is a wonderful way of bringing together people and nationalities. And there is no place where this was better demonstrated than at the beginning of rapprochement after world War II between Israel and Germany, which was initiated by scientists of the Max Planck-Institute and the Weizmann Institute only fourteen years after the Holocaust. Scientists from Israel and Germany got together and planted the seed that grew into a new friendship between the two countries. And there is no greater friendship between Israeli and European scientists than the one that exists today between Israeli and German scientists, and there is no more beautiful example of how science can create bridges between people and countries.

If science and technology touch on every aspect of the life of each of us, what are we expected to do about it? We cannot make everybody a scientist - that would make no sense at all. But we certainly need science education as an integral part of general education. At the end of this century, no high school boy or girl, no university student, can consider themselves well educated if they do not have some scientific education.

It may also be a cultural need, as I believe it is, but it is first and foremost a crucial economic need. Because the only sector of the economy in advanced countries which creates wealth is the high-tech sector. And the only kind of people that the high-tech sector needs are people with some level of scientific training. This involves an entire pyramid of skills: there are scientific stars at the top, there are scientists who do routine scientific work, engineers, technicians, laboratory workers, and a host of others with some level of scientific or technical ability. A labourer in a plant, a reception clerk in a hotel, an airline reservation clerk - everyone today must have more technology and more science know-how than before. Think about the business of job creation: a parking-garage twenty or thirty years ago and a parking garage today. A parking garage thirty years ago meant a person sitting with a little book, collecting money, handing out little pieces of paper - a job that required only the ability to count, not even to read - and employed too many people for no good reason. A parking garage today requires no people. The jobs are elsewhere: they are in the company which produces the automatic money machines for the parking garage; they are the jobs for technicians who maintain and repair these machines; they are the jobs in supervising the whole system. There may be less jobs than before, but each of them is much more sophisticated.

Let me try another analogy. Everybody who watches football at least once a year, even someone who is not a great fan, knows a few rules of the game. You know you have to kick the ball and not use your hands, but you also know that there is one guy at the edge of the field who is allowed to use his hands. Having figured that one out, you also realise that sometimes other players also use their hands, but only when the ball goes out of the field. If you are really sophisticated, you note that the one guy who is allowed to use his hands all the time is sometimes *not* allowed to use them. Thus, even a non-expert in football is probably a little more sophisticated in his understanding than he may realise.

My point is that for an advanced economic structure we need people to understand science at the level that they understand football. Not more. You really don't have to understand the thermodynamic principles of a refrigerator in order to open it and take out the milk. But you do have to know that this is a box connected to electricity, in which everything is cold, that if you remove the electricity it will no longer be cold - and a few other principles.

I use these two rather simplistic examples to illustrate the message that there is a certain minimal scientific literacy that is a must, and I claim it does not exist today. You meet very educated and intelligent people, including one of Israel's past ministers of education, who proudly announced: "I failed in mathematics in high school and I wasn't the worse off in life on account of it." Maybe he wasn't, but if a kid fails high school mathematics today, it will surely damage his or her career, because we live in a different world. And in ten or twenty years, I guarantee that it is going to be much more crucial for a lawyer, an entrepreneur, or a business person to have a strong scientific background. My conclusion is that the only solution is a strong national and international effort that will make science education available to everybody, adults and children alike.

What does this mean, science education? If we want the whole population to understand science as it understands football, what do we have to teach? That is not an easy question. But before I address it, I want to add one more argument why it is absolutely crucial - and this time it is not an economic necessity, but a cultural one - to educate the public to a certain level of scientific thinking and literacy.

There is too much anti-science in the world. As we approach the end of a century (the same thing happened a hundred years ago) we see anti-science flourishing in various forms - in superstitions, the coming of the Messiah, the end of the world, but also through ostensibly good magicians, who pretend to have supernatural forces and a variety of "alternative" techniques for the healing of body and soul. When this irrationalism goes beyond a certain point, it becomes dangerous. It threatens democracy, leads to religious fanaticism and other forms of fundamentalism. This is a very compelling reason for ensuring a certain level of science literacy for the general population. Somebody was saying that the best way to fight superstition is to convince superstitious people that superstition brings bad luck.

The issue of what we can believe or can't believe is a difficult one, as the following example may illustrate. In my home country Israel, it was reported that an unidentified flying object had been observed. Lights were seen flashing in the middle of the night, the thing was hovering in the sky, and many people swore they saw it.

Of course, there were two theories: One said that it was a falling meteorite, the other said that these were little green men coming from outer space.

As a scientist, I cannot be sure that it was a meteorite, and I can be pretty sure that there were no little green men from space. But if you think about it for a moment, there is no concrete proof in favour of either of the theories and there is no absolute proof against either of them. So why am I, as an allegedly open-minded scientist, taking sides in such a debate? Why would I prefer to believe that it's a meteorite and not little green men? This entails a very complicated thought process, the gist of which is that we know that meteorites exist and that sometimes they fall, and that when they fall, they create such phenomena, though I cannot be sure it was so in this case; whereas we do *not* know that little green men from outer space exist, and I must wait for clear evidence before I can believe in them.

One can elaborate on this example, which I will not do here, but it demonstrates that this is not a legal issue, nor a mathematical one. A lot of experience, intuition and common-sense are involved. People who do not understand science think that science is always very precise. But this example shows that science is not necessarily precise. The whole point of science is to know when you need to be precise and when it is enough to be approximate.

For all these reasons, we need to undertake an educational revolution in the next decades that places a high priority on science education. The trouble is that every big change in education takes at least a decade or two, or a generation, because first teachers have to be trained. What should we be doing, what should we be teaching, in order to make the general public science literate? The beauty is that it doesn't really matter, since you cannot teach people *all* of science, but as long as you teach certain parts of science, and teach it well, the goal can be reached. It doesn't matter if you teach more biology than physics, or more physics than biology; the essential point is to teach how to *think* in science. To endow people with the tools for rational thinking, you have to teach them how to weigh things, how to think quantitatively, how to evaluate when an algorithmic way of thinking is necessary or when more lateral, intuitive thinking is best.

Children do not think algorithmically, yet they can do fantastic things. When you write a computer program today, you use algorithms, but maybe the computer programs of the future will be different. It has been said that a computer can simulate a professor of classical botany more easily than it can simulate a five-year-old child. And that's probably true, because there are certain fields of science which are very well structured, like classical botany, whereas a five-year-old child is usually very creative - and this cannot be simulated.

There are also the languages of science, which you have to teach. Science is, as I said before, not always precise, as my final example will show: How much is 5000 plus 2? Well, you say 5000+2=5002. Let me give you my answer in the form of a story about the tour guide at the Egyptian pyramids. He was showing the big pyramid to the tourists, and said: "This pyramid is 5002 years old." The tourists asked him how he could know this so precisely. The tour guide said that when he started working there two years earlier, he was told that this pyramid was 5000 years old. This example demonstrates to you that 5000+2 most of the time is 5000, but there are situations where it is 5000+2. When you win a 5000 meter race in the Olympic games by two meters, those two meters are very important. Clearly, to understand these differences, scientific thinking is necessary.

Now you're in a panic because you say: science moves so fast, how can we move it into the educational system? We develop new programs, we introduce them into the school, and by the time they reach the child, science has changed. That is not true. First of all, the basics of science do not change so fast. What changes very fast is technology, and the last thing you need to teach in school is last week's technology, because this indeed will be different next week. The internet doubles itself every year. Teaching the specific technology used to carry the information is totally useless in the school. But to teach the basics of mathematics, of physics, of logic, of algorithmic, quantitative and scientific thinking - this is absolutely crucial. And, paradoxical as it may sound, the faster science moves, the more important it is to concentrate on the basics.

There is also a whole new dimension to teaching. A science teacher today cannot be expected to master everything there is to know about science. Teachers, children, and parents must all understand that a teacher nowadays is like a traffic policeman. He or she has to guide the pupils to the resources - - to the books, the internet, the libraries, the science sources - and find the answers together with them, in a joint effort to think together and reach the truth. A teacher has to know how to *think* about the facts, not to *know* all the facts. Of course, there is a danger of superficiality, and this too should not be ignored. I make no claim to have a ready formula for transmitting scientific literacy to the general public. All I know is that scientific literacy is absolutely imperative in a world so overwhelmingly dependent on science and technology, and that every single country will need to make a big change in its approach to education. If you agree with the ample evidence that scientific knowledge and technology are the most important economic resource of modern nations, then you will also agree that education, and especially science education, is their best investment.