SCIENCE AND SOCIETY

YVES QUÉRÉ[1]

When an ordinary caveman, 100 000 years ago, set about chipping a flint to form a tool, he was already celebrating the wedding of Science and Technology: Science, because he was using knowledge learnt from his ancestors about nature (i.e. the hardness and brittlness of silicon dioxide); and Technology since this particular utilization of scientific notion was aimed at a precise and practical purpose (to cut wood or meat, or fight an enemy).

The long story of interaction between science and human societies is precociously contained in this tiny episode. Most evolution of societies is due to a mixture of science related technological progress (of course including agriculture, medicine, navigation...) and of ethics-related behaviours (linked to religion, philosophy...). In other words, Science and Technology have always progressed hand in hand, and societies have used both for better and for worse with regards to human dignity and happiness. However entangled Science and Technology may appear in this perspective, we can separately describe their possible influence upon societies, having in mind that our understanding of both depend strongly o the scientific education which we have received as children.

1. Science, a learning model for societies

The development of societies demands one absolute prerequisite: the intellectual and moral development of Man, and here science may play a def-

[1] Co-Chairman of IAP (*InterAcademy Panel for international issues*) and Foreign Secretary of *the Académie des sciences*, 23 quai de Conti, 75006 Paris (*international @academie-sciences.fr*).

inite role. Indeed, science is tirlessly educating us, decreasing our ignorance, and addressing not only our intelligence but also our personal and social behaviour, shaping our outlook on the world and even our character or our public spiritedness. From this viewpoint, a precocious education in science particularly along the lines of Hands-on or *La main à la pâte* approaches, should be of great help for developing this sense of civic responsibility which is highly requested in our times of hatred, racism and violence.

If we leaf through the large volume that this learning method represents for all of us and in particular for those who are not destined to practice Science, we might select some of the following chapter headings.

1.1. *The idea of freedom*

Science being par excellence a space for liberty, it constitutes a kind of humus for the spirit of freedom. How could societies develop, in the long term, with men held back by prohibitions or curbs on their thought, on their liberty to circulate, or publish? Science, its history and practice, teaches us liberty: that of a postgraduate who starts on his subject and soon frees himself from the orders of his supervisor; or that of an engineer who invents a new process, often well beyond, or in contradiction with, established ideas and his manager's directives.

Either lodged in the depths of human conscience, or expressed through visible institutions charged with preserving it (learned societies, academies, ethical committees, and so on), the spirit of freedom establishes these two virtues of mankind, *creativity* and *dignity*, two ingredients undoubtedly crucial for a development (or capacity building) of societies which will be sustainable and will escape to the deadly hold of dictatorships and various dependences, as well as to specious illusions of easy money and unbridled consumption.

1.2. *The virtue of humility*[2]

With Galileo, at the revolutionary time of Renaissance, Science becomes humble in that Man decides to seek the answers to his questions at the very heart of Mother Nature, by questioning her directly, via experi-

[2] Let us make it clear here that, while considering this virtue as consubstantial to Science, I do not pretend that scientists practice it all the time! In fact, some are arrogant, some are humble, and most lie in-between. I just claim that, whenever they flout humility, they put themselves in contradiction with their own discipline.

mentation rather than by extracting the fruits of his own thought. The law of falling bodies is no longer what Aristotle declared – however great a genius he might have been – but is rather based on what experimentation reveals: in fact, what Nature says about herself. Henceforth, the man of Science is no longer a god-like figure who decides on what is, or should be, but a simple decoder, a sort of interpreter with the job of transcribing for other men what nature unveils about herself, and in the language that she herself has chosen ("Geometry", as Galileo put it).[3]

This modesty, taken on by Science, is one of the hidden forces (generally we celebrate more its power than its humility) that should influence societies. It is this patient observation, often inglorious indeed, of nature, the renouncement by Science to explain everything and its capacity to draw the demarcation line between knowledge and ignorance which should teach us to respect the facts, to test permanently our thoughts against them, to mistrust preconceived ideas, to hate arrogance and to increase our tolerance towards fellow human beings, a necessary condition to put an end to conflicts.

1.3. *The spirit of research*

By unveiling some of the great fundamental laws that govern nature, Science teaches us the immensity of what we do not know, or do not yet know. It is these *not yets* which generate the spirit of research, and thus the endeavour for undertaking it and therefore the ability to progress. This is one of the major reasons for favouring a sound, open-minded (i.e. non dogmatic) scientific education for children.

Those for whom a scientific education has imbued both the sentiment that there is a "blank page" open in front of them and the necessity of rigorous thinking, should undoubtedly have more respect for facts than for ideas, more respect for ideas than for certainties. They should be inclined to think with honesty and resist the *more-or-less*, the *preconceived*, and also the *ready-to-wear* (including sectarian and superstitious) types of behaviour. Without a doubt, if this education has included elements of the multidisciplinary harmonics of our environment (physical and social), they will be attentive to the many different – possibly complementary – approaches we have to the world, and their minds will be tuned to sub-

[3] We would now rather say "Mathematics", the only language, together with music, being universal.

tlety. Here, Science is indubitably providing a space, a priviledged theatre, for imagination, creativity, open-mindedness, and thus for a harmonious development of our societies.

2. Technology, a debated path to progress of societies

As previously recalled, Science and Technology are consubstantial with each other each benefiting from the advances of the other. However, we generally consider Technology (in the broad meaning of the word) as the real visible link between Science and Society.

The unbelievable and astounding progress of recent decades in well being, health, life expectancy, agricultural output, comfort, travel, communication... due to Science and Technology is so obvious that it is useless to elaborate. It also looks so normal that we have to force ourselves never to forget, or to underestimate, it. Nonetheless, hunger, extreme poverty, infectious diseases... still exist in many parts of the world, while environmental degradation, global trends in climate change, growing economic disparities, dreadful injuries inflicted to nature, not to forget more and more sophisticated weapons, may be counted at the debit of Technology.[4]

A necessary (if obviously non-sufficient) condition to tackle these dramatic questions is to invite social and human disciplines (demography, sociology...) to enter the scene. In particular, it has become clear that if Science and Technology are imposed on societies without a minimum of respect for local customs and the social, religious and moral principles that these are founded on, there is a great danger that the graft will not take. Instead of anticipated smooth development, mass rejection may occur, and even social regression, generated by migrations of populations, chaotic urbanization, feelings of frustration... This is where the reference to Ethics has become, in the last decades, more and mor explicit, as a natural mediator between Technology and Societies.

2.1. *Ethics and the Golden Rule*

The purpose of Ethics is to set forth principles that can guarantee basic human right by repressing the priority instinctively given by each individual,

[4] See, in particular, the Proceedings of the IAP Conference on Transition to Sustainability (Tokyo, 2000) and the subsequent *Statement of the World's Academies*.

group, nation, to its own interests to the detriment of all others. In a word, Ethics is an attempt to establish as much equity as possible in a society. Although morality differs from one civilization to another or from one era to another, it has universal characteristics. One cannot deny that all men rally, around a few major prescriptions. One of them, the so-called Golden Rule, has the advantage of summing them all up in an expression known on all continents: “Do not do unto others a you would not like them do unto you”.

Regardless of whether the reference is secular or religious, we are seeing a widening of its applicability even as the men that it commnends to our sollicitude retreat from our field of vision, in space and in time. From the clan to the village, from the village to the nation, from the nation to the planet, but also from today to tomorrow, the duties given us become increasingly abstract because we are increasingly unfamiliar with the recipients of our grace. We can imagine the assistance given to the strangers in ancient societies: the foreigner, the traveller, who is protected even if he does not return the favour to his benefactor.[5] This succour given to all and sundry is doubtless more meritorious than services rendered to our close ones. It is the sign that we bring those who are distant into our midst, that we give them the substance, attributes and privileges of true brothers.

The first duty which the Golden Rule gives to Technology is of course not to harm men of today. This is the root of so many present debates on what should be done, or nor done, in an increasing number of Technology-related problems: genetically modified crops, chemical pollution, internet-favoured pedophilia, mad cow desease (and social struggle)... But aside from this rather classical duty, new types of problems arise concerning men of tomorrow. In this case Technology helps Ethics to open a new chapter of its history: this is the signification of the Golden Rule concerning a very far future.

2.2. *Problems and duties for a far tomorrow*

New problems appear like those raised by greenhouse gas production, by chemical or nuclear waste accumulation, or by frenzied consumption of natural resources, which are more detrimental for future than for present generations. If we consider nuclear waste, the potentiality of the danger which we create now may last tens of millennia. In the case of some chemical waste, the period of danger has no known limitation in time.

[5] This is well illustrated by the parabola of the Good Samaritan.

These long term harmful effects that we generate and leave as an inheritance for others prompt us to introduce not just the man from elsewhere but the man of the future in our ethical field of vision and to ensconce him there. How can one fail to recognize that this intrusion is profondly unprecedented? The obligation just described, to provide hospitality and fraternity was less abstract than it appeared. The meeting of contemporaries, one man to another, was still possible. In this new scenario, it becomes unthinkable. No cordiality will ever reign between beings hundreds of centuries apart. Henceforth, we find ourselves confronted with this new anxiety: expanding the Golden Rule to include men of the far future obliges us to consider hopelessly faceless human beings, whereas it previously applied to outsiders who, as different as they might be, were at least contemporary and capable of communicating with us.

Not that this ethical tie that links us to our remote descendants is a new idea: doubtlessly, the carpenter or stone cutter never existed who built a bridge without somewhat vaguely meditating on his responsibility to future rnen who will cross this bridge, with a confident step, for centuries to come. But this ethical duty takes on a unique dimension in our time due to our increased capacity to harm, sharpening our sense of responsibility for our descendants. We have learned to regard the intensive mining of the planet's riches as pillage to our descendants' detriment, and the accumulation of waste from our industrial activities as flagrant injustice in their regard. We would be guilty of gross negligence not to heed this widening of the Ethics. With the risks that we subject them to, come the special duties of elder brothers.

Before, time frames were quantified in terms of generations: "I want to leave my great nephews an Earth where they can live in peace and well being". Now, human beings who are totally unimaginable to us enter the scene, beings whose customs, knowledge and rapport with nature we cannot even imagine. Will they be supermen, through natural or artificial evolution? Or will dreadful cataclysms return them to the caveman state? Will they be able to decipher our messages? Will they have any awareness of their distant ancestors? Does it even make sense to try to penetrate the mists of time to ponder their situation?

Given the impossibility of finding answers, what purpose is served by asking ourselves questions about future humankind? Let us instead see in the production of greenhouse gas or in the disposal of long-lived radioactive or chemical waste, an ethical command of unforeseen magnitude. It is this injunction that we must consider: we have no right to leave behind a heritage of risks for generations in the distant future, and we cannot dodge the issue by postulating that scientific progress will protect them. At least, our contemporaries profit from the beneficial effects of our activities, which is not the case of future generations. These should not assume the responsibility for dealing with the harmful effects accompanying the benefits that we ourselves have gained. Among all the unknowns that torment us, at least one certainty remains: that our negligence will cause harm, and that our present behaviours have acquired the formidable power of exercising influence that is practically unending in time. The magnitude of the harm sets the tone for the breadth of the vigilance required and for the crucial importance of the research to be done in this field.[6]

As a conclusion

Let's be honest. Our generation would probably not have mapped out this "new ethical frontier" so unwavenngly had it not been driven by fear. Accidents such as those of Bhopal or Chernobyl have created a new mistrust of industrial operations that generate pollution and immediate or eventual fallout. Because of those accidents, ecologists have found added justification for their warnings, denouncing the wounding of nature, as much as the harmful effects to man. In this mistrust, let us salute the part that is well-founded, therefore spurring our research on safety and environmental protection, and also sort out the part that may be irrational and subjective.

In this regard, we may note that many other tangible risks – airplane crashes, smoking... – are more or less accepted because they are part of daily life and therefore commonplace. In front of the above-evoked long term and global dangers, the public's lack of familiarity with complex technical issues, the affected community's feeling of powerlessness, the quasi-infinite duration of potential harmful effects, and above all the original sin represented by Hiroshima and Nagasaki urge us to re-examine some of our asumptions about Science and Technology. We have also, in this broad field, to create a renovated dialogue between policy-makers and the

[6] Large scale programs of research have been launched in countries like Canada, France, Germany, Sweden, Switzerland, USA, to assess the long term reliability of various types of nuclear waste repositories. In France, customers participate, via a percentage of their electricity bill, to this effort.

public.[7] The latter must remain conscious of the immense benefits which we derive from Science, for the shaping of our minds, the intellectual stature of mankind, and the increased well being of many societies. But, at the same time, the former should be prepared to evaluate properly the dangers – those rooted in reality, not in obsessive fears – in which we live, be they natural or manmade.

To so do requires a minimum of education, understanding, judgment and solidarity.

[7] See for instance: Sir Robert May, "Bringing Science into Governance", *Science and Governance*, Brussels, October 10, 2000.

HANDS-ON SCIENCE

RICHARD L. GREGORY

Presenting science and technology, Hands-on to children and the general public, is not a new idea. It was clearly expressed nearly four hundred years ago by Francis Bacon, in his unfinished book *New Atlantis* (1626), which describes how the technology and science of his day could be made available to everyone. Francis Bacon describes his House of Saloman, as having:

> Perspective Houses, where we make demonstrations of all lights and radiations; and of all colours; and of things uncoloured and transparent, we can represent unto you all several colours; not in rain-bows, as it were in gems and prisms, but of themselves single. We represent all multiplications of light, which we carry to great distance, and make so sharp as to discern small points and lines; also all colourations of light... We procure means for seeing objects afar off, and things afar off as near; making feigned distances... We have also engine houses... We imitate also flights of birds; we have some degree of flying in the air; we have ships and boats for going under water, and brooking of seas; also swimming girdles and supporters. We have diverse curious clocks, and other like motions of return, and some perpetual motions. We imitate also motions of living creatures, by images of men, beast, birds, fishes and serpents....

We have also a mathematical house, where are represented all instruments, as well as geometry and astronomy, excuisitely made.

Bacon saw that science could, and should, be a social activity with all kinds of contributions according to individual abilities and personal interests. He emphasized *methods* of enquiry and discovery, and stressed the importance of useful inventions deriving from questioning and research. It could be claimed that he invented planned organized research and the use of science for practical ends. Bacon's *Novum Organum* of 1620 set up rules for scientific method, which inspired the foundation of the Royal Society in 1660; but nothing came of his *New Atlantis* dream – though then as now the future depends on children coming to appreciate how science works, and what it does and fails to do.

The principal modern pioneer of Hands-On science is Frank Oppenheimer (1912-1985), who founded the *Exploratorium* in San Francisco in 1969. Oppenheimer wrote (1976): 'I suspect that everybody – not just you and I – genuinely wants to share and feel at home with the cumulative and increasingly coherent awareness of nature that is the traditional harvest of scientists and artists'. He said of his exhibits (Murphy 1985), 'We do not want people to leave with the implied feeling: "Isn't somebody else clever"'. Our exhibits are honest and simple so that no one feels he or she must be on guard against being fooled or mislead'. Yet, though he was a physicist, Frank Oppenheimer loved the subjective phenomena of illusions of perception. He saw them as a way to introduce the observer – us – into science's account of the universe.

Three and a half centuries earlier, Bacon included in his *House of Salomon* – in which as we have been there were to be Houses of Mathematics, Engines, Instruments for measuring, and all the science and technology of the time – demonstrations of perception and illusion:

> We have also Houses of Deceits of the Senses; where we represent all manner of juggling, false apparitions, impostures, and illusions; and their fallacies. And surely you will easily believe that we have so many things truly natural which induce imagination, could in a world of particulars deceive the senses, if we could disguise those things and labour to make them seem more miraculous.

The recent popularity of Exploratory Science Centres, shows that a significant proportion of the public of all ages find direct experience of science entertaining and interesting (Pizzey 1987). For example, generally following the *Exploratorium* in San Francisco, there are the unusually well endowed Toronto Science Centre, and the astoundingly ambitious Parc La Villette in Paris. The first in Britain was the *Exploratory* in Bristol, which after twenty years was to be superceded by Lottery-funded *Explore*; then *Techniquest* in Wales, in Cardiff; and now some forty Centres and Galleries in Britain including Birmingham, Manchester, Sheffield, Liverpool and Glasgow. There are science and technology Centres in almost all European countries and around the world, including: Italy, Australia, India, Singapore, Switzerland, South America and so-far small Centres in Africa;

though not yet in Russia. The physicist Professor Paolo Budinich has been striving for many years to make his “Laboratory of the Imaginaton” a major Centre open to the public in Trieste, and is gradually succeeding. A large Science Centrte has openrd recently in Naples. This is now a widespread rapidly growing movement, with the coordinating organization ASTC (Association of Science and Technology Centers) in America, and the European ECSITE (Consortium of Science Industry and Technology Exhibitions) co-ordinating all European countries.

An important question is: Do interactive, hands-on Science Centres, really convey science? With their necessarily quick and easy demonstrations are they much more than Fun Fairs? Certainly there are similarities. But it is interesting that even when there is similar apparatus (such as almost zero-friction pucks on an air table, for a Fun Fair’s game and in Science Centres to demonstrate Newton’s First Law of motion) they are handled differently and apparently are seen differently, by children and adults.[1] The context and ‘atmosphere’ is very important for how things are seen. Possibly though, as suggested by Michael Shortland (1987), we have been too free with phrases such as “Science is Fun”, for much of science is tedious, difficult and sometimes dangerous. And science has social and moral implications which it is most unwise to ignore. This charge of triviality is important. It needs to be met with evidence of what people do get from Hands-On learning, but unfortunately hard data on this is not readily available and is difficult to obtain.

But it is hard to believe that learning can’t be fun. There are experiments with children showing that games, and active involvement of many kinds, aids learning (Hodgkin 1985). There is strong evidence that babies and children learn to see by hands-on (and mouth-on) experience, especially from the germinal work of Jean Piaget (Piaget 1929, 1952, 1955).

Perhaps most dramatically, the power of Hands-on experience as the basis of visual perception is shown by some rare cases of adults who were blind at birth, or at infancy, then recovered sight by eye operations when adult. Some of these people see, almost immediately, things that they had learned through their early touch experience; but are effectively blind for objects they knew nothing about before the operation (Gregory and Wallace 1963, Valvo 1971). For Gregory and Wallace’s patient ‘S.B’, upon first being shown an object (in the Science Museum in London) which for years he had wished he could use – a lathe – S.B. was frustrated. For

[1] This is rather like a frame affecting how a picture is seen.

although it was there in front of him, he could not *see* it. It was meaningless, until he shut his eyes and ran his hands over it. Then he stood back, and said: "*Now I've felt it, I can see*". He then described the lathe he saw for the first time, with considerable accuracy.

The importance of hands-on experience for learning and discovery is of course very clear in the history of science. This is generally accepted for modern science; but it now seems that there was an infra-structure of surprisingly sophisticated technology behind Greek science and philosophy (Sarton 1952, Clagget 1957, Sambursky 1987).[2]

It seems that both the development of science, and individual perception and understanding, require interactive experience with objects (including working models that can be constructed and handled) to approach and appreciate abstract theoretical principles. But unfortunately much generally available hands-on experience is misleading. The genius of Galileo and Newton was to select appropriate experience – as in Galileo's apparatus in the Florence Science Museum – which is perfect for today's hands-on Science Centres.

The importance of active touch precedes humans. There are many studies on animals showing the importance of active touch exploration for learning to see, such as the ingenious experiment of Richard Held and Alan Hein (1963), on a pair of kittens in baskets which were free to move but linked together. One of the kittens was free to move as he wished; but the other, could only follow passively n his linked basket – so he had similar visual inputs, but lacked voluntary control of where he moved. It was found that the 'active' kitten learned normally; but the linked 'passive' kitten did not learn to see, remaining effectively blind.

It is sometimes claimed that young children do not start with a 'blank sheet', but rather from very early on have their own explanations – which

[2] This is shown most dramatically with the discovery of an elaborate Greek astronomical computer c. 80 BC, found by pearl fishermen in 1900, in an ancient ship that sank near Greece off the island of Kythera. The American historian of science Derek de Solla Price describes an elaborate geared calendar mechanism designed to represent with remarkable accuracy astronomical cycles, especially of the Sun and Moon. The existence of this mechanism (and there are references to such mechanisms of several hundred years earlier, on public display in Greece) shows an active technology of metallurgy and applied mathematics, with remarkable mechanical skill. This suggests that Ptolemy's system of epicycles for explaining planetary movements was almost certainly built, with working models used as thinking tools for explaining the science of their day. As shown by the remarkable work of Joseph Needham (1954-) much the same is true for China.

are remarkably Aristotelian, and they may be very hard to shift (Driver, Guesne and Tiberghien 1985; Matthews 1980). Presumably children's '*naive theories of science*' (as sometimes called), derive from their everyday hands-on experience from infancy. The conclusion is inescapable, that although hands-on experience is effective – indeed essential, for learning to see and understand – it can hardly be adequate for arriving at *scientific* understanding. More is needed, if only because many basic principles and phenomena are normally masked, by for example 'poluting' friction. The normal world is not a good hands-on Science Centre! So children are quite largely misled by their everyday experience. Designers of toys might do a lot to improve matters.

One might say that Aristotle's, rather than Galileo's physics, is suggested by everyday hands-on experience of pushing objects and so on. Specially designed Science Centres can, for example, (almost) remove friction from moving objects, to reveal Galileo's principles, for children's individual discovery.

Is it possible that children *need* to live for years with an Aristotelian view of physics? Is there perhaps some kind of innate structuring, and inborn development, that we may upset with risk of harm? Also, where facts are concerned, is it perhaps best to let children learn facts isolated from interpretation – so they can build up their own cognitive structures, in their own ways, appropriate to their generation? There is certainly a danger of teachers imposing out-moded unhelpful ways of seeing and thinking. The alternative, is to promote originality in children, and expect them to develop in their own, largely unpredictable ways.

If we are able to stimulate originality through individual experimenting, how do we know that children will be better off, than when given at least a basis of accepted knowledge and beliefs? Surely we should try to assess effects of Hands-On experience with controlled experiments, comparing effects of interactive experience with other ways of presenting phenomena and ideas to children. But, for such educational research on how understanding may be be gained – how can we measure understanding?

Perhaps the greatest danger for a Science Centre open to the public, is switching visitors off by appearing intimidating. For the habits of mind needed for entering the Magic Circle of science, are intimidating for many people – perhaps because Science Centres were not be available for them, when they were children! It is well known that mathematical formulations are generally incomprehensible and scary. Indeed, looking for logical structures in ordinary arguments can be seen as rudely challenging; so the problem goes beyond mathematics, and is very general. Research is needed on how to introduce effective rigorous science-thinking into Science Centres.

It is remarkable how little science there is in traditional Science Museums. It is generally impossible to find concepts of force, energy, Relativity, Quantum physics, or computing in museums. There are motor car museums that do not show how an engine works; computer museums which do not show how mechanisms can represent and handle numbers. Conventional museums should gain with Hands-On experience. For without it, visitors are blind to the most significant collections of fossils, engines, or even the apparatus of science, presented in glass cases.

Returning to perception itself, Frank Oppenheimer said (1983):

> The Exploratorium introduces people to science by examining how they see, hear and feel. Perception is the basis for what each of us finds out about the world, and how we interpret it – whether we do so with our eyes or develop tools such as microscopes or accelerators.

Paradoxically, perhaps the most effective way to see our own role and limitations as observers and 'understanders' is through the intriguing phenomena of *illusions*, of vision and the other senses. These are wild and wonderful deviations from the physical world: deviations which may seem closer to fantasies of art, than to verities of science; yet they illuminate *us* as observers and so as scientists.

However curious this may be, phenomena of illusions reveal the tenuous links of perception, by which we appreciate ourselves and our relation to the world. Apart from their own interest they serve to warn us that we must check our perceptions, and question even what may seem most clearly true. As Frank Oppenheimer found (and I helped him in this at the start of the Exploratorium), these 'subjective' though often explainable phenomena help the visitor to be aware of what it is to observe and understand – through recognising failures to observe and understand.

Then pendulums, locks and keys, clocks, pucks floating on air, elliptical billiard tables – almost *anything* – takes on richer meaning. But to see these as meaningful phenomena of science considerable help may be needed. It takes genius to read phenomena without help from the past. Indeed, the history of science can be most revealing and helpful.

Even without knowledge of the ways things work, it is wonderful to experience the surprising forces of gyroscopes, magnets, inertia, patterns of spectral lines in glowing gasses – to discover the same patterns in light in stars. To go on, for example to appreciate the Red Shift, and how this tells us the Universe is expanding and that we can see billions of years back in time, it is necessary to understand abstract principles such as the Doppler shift. Additional sources of information are needed. Then Science Centres can be useful resources for schools, and are symbiotic with schools.

Handling Explanations

Following initial *hands-on* experience, there are various kinds of understanding. There are what we might call '*Hand-Waving*' explanations, which though satisfying and useful are not strictly justified or proved. Then, there are mathematical accounts – generally preferred by scientists – that we might call, '*Handle-Turning*', They capture computing and mathematics, with the essentially mechanical processes of algorithms.

So, we have a handy terminology:

HANDS-ON	Interactive experience	Explorations
HAND-WAVING	Common sense	Explanations
HANDLE-TURNING	Mathematics	Computations

Commonly accepted Hand-Waving assumptions may be hopelessly wrong, and misleading. The assumption here, is that initial hand-waving explanations may be corrected by selected hands-on experience, and refined and quantified by Handle-Turning scientific methods of mathematics.

Hand-waving explanations (in spite of science) remain important. An interesting example is understanding the gyroscope's tendency to turn ('precess') at right angles to tilt, and vice versa. For some scientists, a mathematical account is essential. But with no mathematics one can see what is happening, directly from Newton's First Law of motion, (that moving bodies resist imposed changes of direction or velocity. This applies to each 'point mass' of the spinning wheel).[3]

[3] Consider the changes of direction of its point-masses, composing it. When the spinning wheel is tilted, say to incline to the right, the point-masses at the wheel's front and back are forced to change direction – which they resist by Newton's Law – though the point-masses at the top and bottom are shifted sideways but not changed in their direction of motion. So they hardly resist the wheel being tilted. The resistance to change of direction of the vertically moving point-masses produce a force at right angles – horizontal – which turns the wheel right or left, according to its direction of spin The opposite happens when the wheel is turned right or left – then it 'precesses' at right angles to tilt to one side. Once one 'sees' this one understands the essential principle of

Signs of Understanding

How can we measure effects of Hands-On experience for gaining understanding?

There are well-established ways of assessing knowledge in schools. These include the written questions of formal examinations. They may also be open-ended essays, or multiple-choice questions. The latter are easily run by computer; the former is more revealing but requires skilled assessment, so is expensive. If only to prevent Exploratories looking like schools, which they are not, we should develop different kinds of assessment – which may useful for research into effects of hands-on experience.

1) *Surprise*: A powerful technique is to set up situations for *predicting* – where correct prediction requires and so demonstrates understanding of what is going on. Clearly defined and usually simple situations should be set up. False predictions can be clear evidence of inappropriate mental models of the situation. A classical example is Aristotle's rejection of the notion that the stars appear to move because the earth spins round. He jumped up – and landed in the same place – so how could the Earth have been spinning under him? What Aristotle lacked was the concept of inertia. This shows how important concepts are, and how soon we depart from common sense in science.

2) *Analogies*: A further test of understanding at a more-or-less deep level is ability to see analogies. If one understands, for example resonance, then similarities and deep identities are seen between what on the surface are different-appearing things or phenomena, such as: musical

gyroscopes, and one can predict which way it will precess for any turn or tilt, with either direction of spin – with no mathematics. And having seen it in this way the mathematics takes on meaning. By experiencing these forces interactively, for building informal hand-waving intuitive conceptual models in one' mind, one is set up to understand the mathematics – which allows precise generalizations even to all situations and is essential for *designing* for example gyro-control systems. I suggest that the major aim of interactive Science Centres, after stimulating interest and curiosity should be setting up Hand-Waving explanations giving useful intuitive accounts. They are vital for meaningful seeing, and for going on to rigorous Handle-turning mathematics which is so important for much – though not all – science and technology. It is interesting that almost all scientists use Hand-Waving mental models, images, and analogies for their creative thinking. The greatest, Newton, was skilled at Hands-On model and toy making; thinking up rich working Hand-Waving accounts of light, gravity and much else before attempting to arrive at his wonderfully broad and powerful Handle Turning mathematical formulations of Laws of nature.

instruments; the divisions of Saturn's rings; tuned radio circuits; the positions of spectrum lines given by resonances within atoms. It is clearly important to have *many examples* of different-appearing phenomena to practice seeing analogies.

We may look at *increased power* to see analogies for assessing effects of hands-on experience Here again the importance of a rich variety of examples is clear, for this allows not only discovering basic principles common to many examples (which is surely the key to creative intelligence) but also is a means for setting up on-the-surface surprising predictions – which by succeeding or failing *surprisingly* can test understanding. (Sir Karl Popper emphasizes failures of prediction as necessary for gaining knowledge; but surprising positive predictions are, surely, just as effective though perhaps rarer).

3) *Inventing*: We may look for ability to fill in gaps, and invent novel solutions – where gap-filling or inventing requires more-or-less deep understanding. An example would be filling in or inventing hidden parts of mechanisms. One can only see into black boxes by understanding them.

4) *Jokes*: With increasing spread of understanding of science and technology we may look for more widely shared humour – which will surely enliven literature and life. Ability to see and to make jokes is clear evidence of relevant understanding. Science Centres should have humour and be run with a sense of humour. Here again the 'Explainers' or Guides or Pilots or very important.

5) *Small effects*. Appreciating significance of small effects or phenomena shows they are appreciated as *conceptually* important though they are not *perceptually* dramatic. (Thus the Photoelectric Effect heralded Quantum Mechanics, and the precession of the perihelion of the planet Mercury was a key to Relativity. Though conceptually dynamite they are physically tiny. There are many such examples.)

6) *Nothing: happening*. Perhaps the most dramatic evidence of understanding is seeing significance in *nothing*. This is the point of experimental controls. We should widen the notion of *experiencing* phenomena, for in science a great deal comes from significant small effects and *nothing* happening. But only when the situation is understood; for it is essential to appreciate what should (or should not) have happened on alternative hypotheses to appreciate nothing.

We have suggested, that to assess effects of hands-on experience we may look for: (1) Being surprised by predictions that turn out wrong; or against the odds, are right; (2) Ability to draw analogies, or see links between what on the surface look like different kinds of phenomena; (3)

To fill in gaps, of mechanisms or whatever, and invent what could be there but hidden; (4) to appreciate relevant jokes; (5) To appreciate *conceptually small* but *perceptually significant* effects; (6) To appreciate significance of *nothing happening*.

Beyond Hands-On Exploratories?

We have admitted a danger of exploratory Science Centres trivializing science, and unfortunately many do just this. Should we, indeed, speak of a '*Science* Centre' that lacks the rigour of science? For as we have said science is a slow, often tedious and sometimes dangerous business

Explanatories

As we have said: looking at the traditional museums of science, we find remarkably little science. There are very few explanations or examples of *methods* of science. It is hard to find Kepler's or Newton's Laws; or how spectral lines may be related to atomic structure; or concepts of Quantum Physics or Relativity. This general lack extends to technology. It is quite hard to find explanations of how motors, or radios, television or freezers work. Yet, technology can be exciting as *successful* experiments that reveal general principles.[4] Is it simply that science museums seldom attempt explanations because this is not their traditional aim or purpose? Or have they have found it almost impossible to present ideas in a museum context? Are the concepts and principles just too hard to present, without the kind of background knowledge instilled over years in courses in schools and universities? This is an important question. It may be answered by seeing how far Hands-On science can be pushed towards explanatory concepts. But can we interact with *abstractions*, hands-on? Perhaps we need to add to Exploratories, somewhat separate more thoughtful '*Explanatories*'.

Possibly existing schools and universities *are* the Explanatories we need. But in schools and universities explanations are built up gradually, on

[4] To give a recent example; it is a most imaginative concept to use a microscope *backwards* to shrink design drawings into working integrated circuits (and even minute motors and tiny geared mechanisms) with components as small as nerve cells of the brain. And now we can actually see electron charges moving through the logic gates of micro-chips, with a beam-switched scanning electron microscope, strobing repeated signals to slow things down to speeds we can see – which takes us right inside Alice's wonderland by technology.

a carefully planned slowly growing basis of knowledge. Can we speed this up? Can we introduce sometimes difficult and counter-intuitive concepts, of physics, chemistry, life, symbols or whatever – in *minutes* rather than years? This is the challenge. Possibly only a few people will wish to take the step from the familiar assumptions of every day life into the non-intuitive, even bizarre concepts of science. But surely many people, of all ages, will find it incredibly exciting; even to giving new meaning to their lives.

How can we explore *abstract* concepts hands-on? Some essential principles can be experienced directly by removing contaminating effects. Indeed, this is how many experiments have lead to discoveries. Less direct, but vital for moving from particular instances to principles, is providing a wide variety of examples – so that *general principles* emerge. Perhaps familiar technology can help to introduce unfamiliar, strange ideas of science.

New technologies of data search could be useful for Eplanatories. Interactive computer-video disc technology can provide explanations, and allow individual journeys through facts and abstract concepts. But even apart from the expense there are problems to solve. For example, it is important to approach the same facts or ideas from different starting points – when they may appear in a different light – or remain dark! For this and for reasons of economy, many of the same pictures and descriptions will appear in different 'journeys'.

"*Handle-Turning*" *mathematics*

Finally, should interactive Science Centres introduce what is for many people difficult and intimidating: *Handle-Turning* mathematics? Here, computers can come to the rescue. They remove so much of the sweat and tears of 'handle-turning', and their graphics reveal to the eye abstract principles and functions, with great beauty. Then, computers can be linked to actual experiments, to show mathematical functions and underlying principles operating beneath appearances in real time.[5]

It has even been suggested – by Philip Davis and Reuben Hersh in *The Mathematical Experience* (1980) – that computer interaction allows dimensions beyond the three of space and one of time, that we normally experi-

[5] This is the basis of Seymour Papert's work (Papert 1980) on Logo, in which the computer controls a mechanical tortoise which interfaces the object world with the symbolic world of mathematics.

ence, to be visualized. A Rotating, computer-generated hypercube looks meaningless; but upon taking up the controls:

> I tried turning the hypercube around, moving it away, bringing it close, turning it around another way. Suddenly I could *feel* it! The hypercube had leapt into palpable reality, as I learned how to manipulate it, feeling in my fingertips the power to change what I saw and change it back again. The active control at the computer console created a union of kinesthetic and visual thinking which brought the hypercube up to the level of intuitive understanding'.

This is truly turning minds on hands-on.

Conclusion

For some people making decisions by methods of science is alien, even dehumanizing. Perhaps they see scientific method (which objectifies judgements) as conferring a kind of *artificial* intelligence to human beings; even to turning us into machines. Although it may be admitted that science and technology transcend political and racial boundaries, and confer many undoubted benefits, this is not how many people want to see the world. Is this because science has been inadequately presented? Or is it because science is unable to answer questions that people see as important for their lives? Scientific method can be too slow to provide reliable answers in real-time, for individual and government decisions. These may all be true; but most people simply lack the understanding to have a comfortable, intuitive feel for science and their every day technology.

It may be that formal mathematics has too much prestige and over-dominates science education; as it intimidates so many people, to put them off science. Although "Hand-Waving" non-formal accounts generally have a rather low standing, it may be that they are very important for giving context to facts; for remembering and structuring experience into knowledge.

Discovering how to help children and adults explore phenomena, and appreciate principles effectively, must keep Exploratory Science Centres re-inventing themselves – to become viable mutations in futures they help to create. In our 'handy' terminology, surely they will succeed richly when they stimulate curiosity with *hands-on* experience, and give understanding through useful though informal *hand-waving* explanations – leading a few to *handle-turning* skills of mathematics.

This is introducing science, by shaking hands with the Universe.

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THE ROLE OF THE SCIENTIFIC COMMUNITY

THE RESPONSIBILITY OF SCIENTISTS IN THE EDUCATION OF YOUNG PEOPLE

RAFAEL VICUÑA[1]

We live in a world in which scientific discoveries follow one another with ever increasing momentum. Rarely have we the time required to reflect on the cultural, social and economic consequences of these findings, not to mention their ethical implications. It has become increasingly evident that science has ceased to be an exclusive bastion of the specialist, since it has entered the public arena and now relates to all sectors of society. In relation to this perspective, the scientific community has an inescapable obligation to both transfer this knowledge to the classroom in the teaching of the basic sciences and to participate in regulating the quality of this distribution. A good grounding in the basic sciences during the informative school years will not only produce better prepared candidates for higher education, but will also establish a society with more scientific understanding and thus enhance public participation in the ethical implications that may lie ahead.

Some of the strategies that the scientist will apply in fulfilling these criteria will be universally applicable, whereas others will depend on the level of economic and educational development within each country. Either way, to approach the subject of the responsibility of the scientist in the scholastic education of sciences, it seems advisable to take an individual country as a model. I will concentrate specifically on Chile, a country that has a population of about 15 million inhabitants and a per capita income of US$ 5,000 dollars (US$ 8,400 corrected according to purchase power). In Chile the percentages of the population that undergo primary, secondary and higher education are 98.6%, 90.0% and 31.5%, respectively. In regard to sci-

[1] E-mail: rvicuna@genes.bio.puc.cl

ence, Chile possesses a small but effective community. Currently there are about 3,000 active investigators who annually publish close to 2,000 articles in mainstream scientific journals. This statistic of productivity is ranked fourth in Latin America, although it would be placed first if calculated on the number of publications per investigator.

It is just over a year (November of the 2000) – since the results from the Third International Mathematics and Science Study (TIMSS) were announced by the International Association for the Evaluation of Educational Achievement (IEA). The TIMSS, which was established in 1995, surveyed students of primary and secondary education from 41 countries. In the third version undertaken in 1999, Chile participated for the first time next to 37 nations, with a sample of 5,907 students of 14 years of age originating from 185 schools of differing socio-economic backgrounds. The selection of participating schools was made at random, as were the groups of students (all 14 years old, Chilean 8th grade of primary education) within each establishment.

Tests in Mathematics and Sciences both consisted of 30 questions and each student was given 90 minutes to respond to each section. The questions of the test, that were of multiple choice and written format, were processed by participant countries according to a pre-determined rigorous procedure designed to safeguard the universal validity of the test. Once the answers were obtained, the results were grouped in five categories, those including the top 10%, 25%, 50% and 75% population of students and a fifth category which included the lower 25%. It is hoped that those students who had been exposed to a curriculum content of basic Mathematics and Science would be grouped in the upper half, that is to say, in the first three categories.

The results obtained by Chilean students are dramatic, as much in Mathematics as in the Sciences. Chile occupied position 35 of the 38 participant countries, surpassing in both cases only the Philippines, Morocco and South Africa, and thus locating far below the general average (Table 1). In Mathematics, the three superior categories included only 15% of the Chilean students (1%, 3% and 15% in categories 1, 2 and 3, respectively). The fourth category included an additional 33% of students, those that according to the characteristics of the test possess a level of knowledge equivalent to that of an average 10 year old (Chilean 4th grade of primary education). The fifth category included 52% of the Chilean students. According to the definitions, this category includes students who do not even satisfy the requirements of the average 10-year-old. In simpler terms,

Table 1. INTERNATIONAL STUDENT ACHIEVEMENT IN TIMSS

Mathematics

01.	Singapore	604
02.	Republic of Korea	587
03.	Chinese Taipei	585
04.	Hong Kong	582
05.	Japan	579
06.	Belgium	558
07.	Netherlands	540
08.	Slovak Republic	534
09.	Hungary	532
10.	Canada	531
11.	Slovenia	530
12.	Russian Federation	526
13.	Australia	525
14.	Finland	520
15.	Czech Republic	520
16.	Malaysia	519
17.	Bulgaria	511
18.	Latvia	505
19.	United States	502
20.	England	496
21.	New Zealand	491
Average		**487**
22.	Lithuania	482
23.	Italy	479
24.	Cyprus	476
25.	Romania	472
26.	Moldova	469
27.	Thailand	467
28.	Israel	466
29.	Tunisia	448
30.	Macedonia	447
31.	Turkey	429
32.	Jordan	428
33.	Islamic Rep. Iran	422
34.	Indonesia	403
35.	**Chile**	**392**
36.	Philippines	345
37.	Morocco	337
38.	South Africa	275

Science

01.	Chinese Taipei	569
02.	Singapore	568
03.	Hungary	552
04.	Japan	550
05.	Republic of Korea	549
06.	Netherlands	545
07.	Austrialia	540
08.	Czech Republic	539
09.	England	538
10.	Finland	535
11.	Slovak Republic	535
12.	Belgium	535
13.	Slovenia	533
14.	Canada	533
15.	Hong Kong	530
16.	Russian Federation	529
17.	Bulgaria	518
18.	United States	515
19.	New Zealand	510
20.	Latvia	503
21.	Italy	493
22.	Malaysia	492
23.	Lithuania	488
Average		**488**
24.	Thailand	482
25.	Romania	472
26.	Israel	468
27.	Cyprus	460
28.	Moldova	459
29.	Macedonia	458
30.	Jordan	450
31.	Islamic Rep. Iran	448
32.	Indonesia	435
33.	Turkey	433
34.	Tunisia	430
35.	**Chile**	**420**
36.	Philippines	345
37.	Morocco	323
38.	South Africa	243

85% of 14-year-old Chilean students show an unsatisfactory proficiency in Mathematics.

In the Sciences, the results were somewhat better, as the average mark was closer to the international average. The three first categories included 22% of the student population, (1%, 5% and 22%, respectively). The fourth category included an additional 33%, which means that 44% of the Chilean students are located in the fifth category that could not not even answer the most elementary questions. In other words, 78% of the 14-year-old students have not reached a satisfactory level in the Sciences. Figure 1[2] (see page II) illustrates the performance of Chile in the TIMSS according to the designated categories.

Figures 2 and 3 (see pages II and III) enable better comparisons with other sample countries that are deemed representative of the five continents and different performances in the test. As it is evident, the countries with better education have the majority of their students in the upper three categories. In addition, these countries possess a high proportion of their students in the first category. In Mathematics, this is clearly the case of Singapore (46%), Taiwan (41%, not shown), Korea (37%) and Japan (33%).

Surprisingly, the TIMSS showed that diverse factors that commonly are associated with exam performance, such as the economic resources of the school, the number of students per class, the duration of the class, the style of management of the educational system, schooling of the parents, etc..., are not directly determining in the results obtained. The observation that only 1% of Chilean students are located in the highest classification category despite nearly 10% of the Chilean educational establishments being private schools is an eloquent representation of this phenomenon. Table 2 relates to the lack of correlation between the hours of education and productivity in the TIMSS. The socio-economic situation of the countries also failed to significantly influence the results, as demonstrated in the Mathematics test, where 14 countries that have a product to per capita ratio inferior to that of Chile, obtained better results.

What therefore, are the fundamental factors that affect education? The answer to this question is of vital importance for those teachers and scientists who wish to assume the responsibility of a collaborative role in the teaching of science. Possibly this is the variable that the TIMSS

[2] Figures 1 to 4 are adapted from the document entitled *The quality of Chilean education in numbers*, by B. Eyzaguirre and C. Le Foulon, Centro de Estudios Públicos, Saptiembre 2001, Santiago, Chile.

Table 2. YEARLY TEACHING HOURS AND PERFORMANCE

	Yearly teaching hours of Mathematics (a)	Average score in mathematics (b)	Productivity per hour (b)/(a)
Indonesia	222	403	1,81
Morocco	207	337	1,62
Chile	161	392	2,43
Czech Republic	139	520	3,74
Australia	138	525	3,80
Slovak Republic	137	534	3,89
Japan	127	579	4,55
Chinese Taipei	126	585	4,64
Singapore	126	604	4,79
Finland	93	520	5,59
Netherlands	94	540	5,74
Average	129	487	3,77

regrettably does not measure, that is to say, the quality of teaching. TIMSS only reflects the confidence that the teacher possesses in his or her preparation and ability to teach the subject. More than 40% of the mathematics and science teachers in Chile feel that they possess an insufficient level of preparation. Given this precedent, what can be asked of the students? Or, phrased in a more eloquent manner, what would be the outcome if the teachers in Chile took the test?

As anticipated, with this quality of primary science education, the level of knowledge in students who progress to higher education is insufficient. Several pieces of data serve to illustrate the magnitude of this problem. In Chile, since 1967, a system of national examinations has been used to gain entrance to university. The main exam is the Academic Aptitude test, which is obligatory and designed to evaluate verbal and mathematical ability. The mathematics section is composed of 60 questions that include direct operations, deductive logical reasoning, symbolic interpretation, data analyses, etc., with a degree of difficulty similar to that of the TIMSS for students of the same age. In the year 2000, more than half of the participating students (53%) failed to correctly answer 50% of the questions asked, with only one quarter of these students achieving a score of 60% or more which is representative of the ability to handle basic level mathematics.

Other important components of the national testing system are the Specialised Knowledge Examinations, which are based on the common curriculum and elective courses from the general education system. Close to 50% of university careers require these exams, at last half of which request Mathematics while only 5% request Chemistry. In the Specialised Knowledge Examinations the number of questions varies from 40 to 60 and the level of difficulty is regarded comparable to that of the TIMSS for students who have taken the advanced courses from the general curriculum education. Table 3 demonstrates these tests and the percentage of students undertaking them. In the sciences, the number of applicants ranges from 29% in Mathematics to 4% in Chemistry. As it is possible to observe, the results are clearly superior in the areas of History and Geography of Chile and in Social Sciences. The average number of correct answers per question in these last disciplines borders 45%, whereas in the sciences this figure varies between 34.2% in Chemistry and 18.3% in Mathematics. In the same vein, the percentage of students with a score equal or superior to 60% is extremely low, reaching only 1% in the case of Biology. Finally, a high number of students have negative scores in the tests, achieved by the cancellation of one correct answer by four incorrect answers. This statistical information paints a clear picture of the remedial work that must be undertaken once the students arrive to the university. Usually a large percentage of the curriculum during the first year of higher education is targeted at removing the deficiencies left by the Chilean primary and secondary schooling system.

Table 3. STUDENT ACHIEVEMENT
IN THE SPECIALIZED KNOWLEDGE EXAMINATIONS

	History and Geography	**Mathem.**	**Physics**	**Biology**	**Social Sciences**	**Chemistry**
% students taking SKE	63,0%	29,0%	6,0%	20,0%	17,0%	4,0%
Correct answers per question (average)	45,6%	18,3%	24,3%	23,8%	43,7%	34,2%
% students achieving at least 60% in the SKE	26,0%	6,0%	9,0%	1,0%	14,0%	13,0%
% students with negative achievement in the SKE	1,0%	33,0%	17,0%	6,0%	0,2%	9,0%

In Chile, this flaw is not unique to the education of science. Systematic studies also demonstrate deficiencies in respect to reading comprehension within the population. As illiteracy indicators no longer give sufficient information relating to the level of the education within a country, other techniques have been developed to achieve this aim. For example, the Organisation for Economic Co-operation and Development (OECD) has been conducting an international survey (IALS, International Adult Literacy Survey) for the last six years in an attempt to evaluate the reading comprehension of a country. A population age between 16 and 65 years was surveyed in a variety of countries with the aim of obtaining an accurate reflection on the literacy of the population and the country's education system. In 1998 this test was applied, for the third time, to a sample population composed of 18 member countries of the OECD, along with Chile and Slovenia. In Chile a sample population of 3,583 people was co-ordinated by the Faculty of Economy at the University of Chile. The test measured the ability to comprehend prose and written documents and to interpret quantitative data. Within each of these three areas the answers were grouped into five classifications. At the extremes, level 1 included people of low ability, incapable for example, to determine the dose of a medicine from the information printed on the package. In the highest group, level 5, the occupants demonstrated the capacity to integrate information from several sources and an enhanced capacity to process data. Level 3 is regarded the minimal grouping for those people who can participate successfully in the so called 'The Information Age'.

The results of this test were disappointing for Chile. More than 80% of the sample population was located in lower levels, 1 and 2. Level 3 included 13% of the sample with only 2% of Chilean population being classified in the upper levels 4 and 5. The statistical distribution was roughly the same in each of the three areas measured by the test (Figure 4, see page III). It is important to emphasise that extraordinary abilities are not required to reach levels 4 and 5, merely the ability to interpret what is being read. It is surprising that with close to 11% of the Chilean population possessing a completed university education, only 2% of Chileans are located in the higher levels of this test. Deplorably, Chile occupied the last place among the 20 countries evaluated.

Although every scientist must have a preoccupation in relation to basic science education in his or her respective country, in a country that possesses a diagnosis as I have just described, this preoccupation takes on an added ethical imperative. We could ask therefore, what can scientists contribute in this regard?. The answer to this question is not a simple one, as the demands of academic life do not leave much time for extracurricular activities. Further hindering this situation is that participation in this field generally does not yield economic reward, nor does it yield recognition in terms of academic merit. Despite these obstacles a varied range of alternatives are available, those that are of an institutional or individual nature. Without pretension of being exhaustive, I would like to elaborate on some of these alternatives.

Institutional activities include those that involve the establishments of higher education, private companies, scientific societies, scientific academies and other organizations, all of which – of course – requiring the active participation of scientists. As part of their dedication to teaching, the universities should be naturally inclined to contribute to improving the quality of science education. Perhaps the most obvious and available contribution in this respect are the university courses that are offered to school teachers during their vacations. For example, for several years the Pontifical Catholic University of Chile has been offering such courses. These courses rely on a professor in charge with the participation of several colleagues of the respective Faculty. It has been interesting to observe that it is the same schoolteachers that periodically return to the university to attend these courses and thus replenish their knowledge. Along similar lines, 'Project Seed' will be established this coming January at the University of Chile as an initiative of the Millennium Institute of Advanced Studies in Cellular Biology and Biotechnology, incorporating contributions from Fundacion Andes and the World Bank. This Institute will offer an 18 month course in Education and Tools in Modern Biological Sciences to 120 schoolteachers of secondary education from all over the country. In order to gain entrance to the course, each teacher must possess a personal computer and a network connection to their respective school. A fundamental part of the course will be the analysis of the scientific developments that are reported by the press, with the objective of learning the best methods to transfer this knowledge to the classroom.

Academic institutions may also offer stimuli to enhance teaching quality, such as the Father Molina and Michael Faraday Awards which the Pontifical Catholic University of Chile offers annually to teachers of Biology and Physics, respectively. Both awards recognise educational innovations, the search of quality in educational methods, creativity, personal contribution and commitment to enhancement of education, among other criteria. The awards are financial, with the purse divided between the teacher and as financial assistance in the purchase of educational equipment for the institution to which the recipient belongs. The press announces the call for candidates and the presentation takes the form of a formal ceremony performed in the presence of the University Rector and the Deans of the respective Faculties of Science, during which time a lecture is presented by a professor from either the Faculty of Biology or Physics.

Further institutional participation could consist of inviting teachers to do investigation in the university laboratories during the summer months. Although the level of university investigation is extremely different from the type of experimental demonstration used by the schoolteacher, the temporary exposure and experience of investigation may well increase the enthusiasm by which science is then taught in the classroom. In Hungary a program of this type, for students of 14 to 18 years of age began in 1995, with the participation of mentors of the highest scientific merit and with the support of both the government and private institutions.[3] Currently this program encompasses nearly 600 mentors, 68 of which belong to the Hungarian Academy of Sciences. Every year, a national student conference is organised and 20 to 30 student presentations are made. During this conference the mentors talk about their passion and approach to science. To date, the university laboratories and institutes of investigation have trained more than 1,400 talented young Hungarians from all the regions of the country. This same program has lead to the establishment of almost 100 science clubs in Hungarian schools, where more than 1,000 students are introduced to scientific research by established scientists who visit the clubs and speak about their own experience or summarise recent advances in their research fields. The operation of the program has also lead to the formation of a network for schoolteachers, who met for the first time in 1999 to exchange experiences and ideas. Further information about this program can be found at http://kutdiak.kee.hu .

Using somewhat different criteria, the Educational Program for Children with Academic Talents (PENTA UC), was offered by the Pontifical Catholic University of Chile for the first time this year. This program aims to deliver the opportunity of enhanced education to young people between 13 and 14 years of age who possess a talent which cannot be developed to its full potential in the student's current socioeconomic environment. The Program relies on a Directorial Committee incorporating professors from the Faculties of Chemistry, Physics, Biological Sciences, Social Sciences

[3] P. Csermely, G. Halász, G. Jeney, J. Máthé, L. Mikló, D. Solymary, A. Szekeres, G. Tamás. *Biochem. Educ., 28*, 132-133, 2000.

and the Humanities. During the semester classes are given on Fridays in the evening and on Saturdays during the morning, in conjunction with two-week summer courses. All courses are presented by professors who are of a recognised standing in each of the disciplines. The students, who at the moment number 80, also rely on the support of two psychologists, who act both as their tutors and serve as a link with the schools where they study. Further details on this program are available at http://puc.cl/pentauc/

There is another institutional participation that requires a special collaboration from scientists, which is to improve the basic formation of the future science teacher. It is traditional for teachers to be educated in schools of pedagogy in an environment removed from the world of science. The courses that the future teachers take typically include History of the Education, Philosophy of the Education, Sociology of the Education, Curricular Design, etc, and like an appendix, at the end of the university career, some courses of sciences are added. Normally, these courses are given by university professors who do not belong to the Faculties of Science. Fortunately, the main universities in Chile introduced a fundamental reform in this respect, allowing that students who have a degree in any discipline can obtain a teachers degree after taking some courses of pedagogy given by the Faculty of Education.

It is also probable that industry may be interested in contributing to the improvement of scientific education. Perhaps in this case, its main contribution would be in the form of funds directed to the financing of the different programs. In this scheme, scientists must contribute not only to the design of the programs, but also will be required to obtain resources from the companies to finance them. On this theme, I wish to draw your attention to the ‘Program in Science Education’, a very interesting initiative that is being supported by GENER, an international electric power company with headquarters in Santiago, Chile. This Program is oriented to students between the ages of 6 and 14 from low-income schools. It is a ‘hands on’ educational scheme in which students are given the opportunity to gain knowledge through discovery, according to a carefully designed sequence of activities based on selected topics in the natural sciences and mathematics. The Program was developed by Chilean university professors who have extensive experience in scientific research and in both international undergraduate and graduate teaching. These professors train schoolteachers during the first two weeks of summer vacations. The training procedure involves confronting the schoolteachers with exactly the same research problems that will be presented to their students and thus advising the teachers on the problems and questions which may arise. Under supervision from these schoolteachers, the students have weekly 90 minutes workshops for around 35 weeks each year. The participating schools are provided with the same computer generated transparencies, lab instruments and other teaching aids used during the summer training sessions. To support the work of schoolteachers throughout the year, members of the university staff make weekly visits to each participating school and interact with teachers and students during the workshops. Staff members report weekly to the Program Director, who in turn reports monthly to GENER officials. Students participating in 'Program in Science Education' have demonstrated enhanced performance in both national and international proficiency tests. For example, a test consisting of three different problems taken from an earlier version of TIMSS was applied to six schools involved in the Program. Their scores were compared with those obtained by students from all countries that took this same test. Considering the schools as independent entities for each problem, they achieved places which would have ranked in the top thirteen countries which participated in TIMSS. Obviously, this is a considerable improvement, which is further enhanced by the observation that some of the students were two years younger than those from the other countries. The participating students also performed better than older students from the same schools who had not taken part in this Program. This Program started its operation in the summer of 1995 and since then over 200 teachers and 25,000 students from more than 40 different schools have participated. The Director of this Program is Dr. Sergio Hojman, a PhD in Physics from Princeton University and full professor at the University of Chile and at Andrés Bello University.

A summary of the participation of institutions in scientific education must also include those that form the scientific societies and the academies of sciences, a subject to which Dr. Jorge Allende has already referred to in this workshop.

Although all the previous institutional activities require the active participation of scientists, there are other possible approaches that can be performed based on their own initiative. An obvious participation would be to present classes in primary and secondary schools. In Chile such an action is currently not possible, since teacher's union regulations prevent those who do not possess a university title in pedagogy from presenting classes. Paradoxically then, scientists and academics who present lectures at both undergraduate and graduate levels in universities, cannot present a class within the school system.

Despite this obstacle, scientists can use other forms of participation in the classroom. For example, maintaining contact with teachers and acting as scientific mentors. They can advise on the form of presentation of theoretical concepts and in the design of experimental demonstrations. Scientists could provide support material such as experimental software, videos and kits that would be of great benefit to teachers. With respect to presentation design, classes could be organised based on questions that will stimulate the students to think, instead of the simple regurgitation of information. Simultaneously, the laboratory exercises should be more than mere demonstrations. They should encourage the active involvement of students, and as far as possible, be oriented towards data processing to enable an understanding of the scientific logic involved in the experimental process and not simply the reporting of results.

Scientists could also incorporate the schoolteacher into their environment, inviting them to their meetings and providing connections to the scientific community as a whole. Additionally, the access to journals, catalogues and instruments that are not commonly available in the school system could be of great help to teachers. Through the channel of the electronic mail and electronic networking the interaction between the schoolteacher and the scientist can be quick, continuos and effective.

The fore-mentioned examples do not exhaust the alternatives of interaction between scientists and schoolteachers. Far from it, these ideas provide the stepping stones and building blocks that will ultimately provide the framework of a fully integrated scientific community. What is important, is to find the manner in which to harmonise the demands of academic responsibility with the fulfilment of a true ethical obligation, which is to enhance scientific education – and with this – enhance the participation of society as a whole in the ethical dilemmas which science will present. In the long term, better scientific development of our youth will enable society to not only value science on the socioeconomic benefits that derive from its applications, but instead regard science as an integrative, stimulating and everyday part of our culture.

Acknowledgements

I am indebted to Barbara Eyzaguirre for supplying me with valuable data concerning science education in Chile, to Dr. Mario Quintanilla for his stimulating comments and to Dr. Gareth Owen for his help in the preparation of this manuscript.

THE SCIENTIFIC EDUCATION OF CITIZENS

PAUL GERMAIN

This paper attempts to show that the best answer to the challenges of science for the Twenty-first Century lies in the scientific education of the citizens. The education of future scientists and engineers to prepare them for their job is, of course, crucially important and has to be improved. The papers of this workshop were right to emphasize this point, to highlight the difficulties and to give some interesting suggestions. Such improvements are necessary. But I am not sure that they would be sufficient to meet the present challenges of science. I think that a scientific education for the citizens should not be just a diluted form of the education given to future scientists. In order to express the main theme of this paper, I will consider, first, the present challenges of sciences, then, the place and the character of science within a modern culture and, finally, the third and principal part of this contribution, how to achieve this scientific education for citizens and who would be involved in such a project.

The present challenges of science

It is not necessary to emphasize again what has been told clearly many times, the last few days: science has been one of the most important factors in the evolution of our world for at least three centuries. For people it has provided new knowledge and for societies, many new possibilities of action which have made the life of the people easier. The speed of this change and improvement of conditions has been steadily increasing, especially at the present time with the appearance of what is called today modern technology. That is the art of building new machines, systems or equipment with fantastic performances by application of many new scientific results of various fields, especially through communication and computing sciences and techniques. This explosion of new products is developed by the market and what is called the new economics. This process will probably continue.

For any nation, the first challenge is to survive and, consequently, to develop its own ability in science and technology through effective education of its future scientists and engineers. However, it is not an easy task for many reasons. One major problem is the 'brain drain' which incites bright young people to do their advanced studies and to work in a country which offers better conditions that those they might get in their native land. We must also confess that at the present time, science and technology appear less attractive than they were in the past. In particular a gifted boy or girl may generally find today a more gratifying job by becoming a good lawyer or a good manager. Another reason is that science and technology are becoming more complex. Even a scientist cannot have a very precise idea of the scientific fields which are not close to his own domain of competence. Moreover at this time, the ordinary citizen doesn't understand what the scientists and engineers are doing. A social fracture appears between the people involved in the progress of science and technology and the other citizens. In the past, it was clear for most of the people that science and technology were working for the benefit of mankind. Today, it is not so obvious. The citizens see the damage caused to the environment by some modern industries or by certain new methods of modern agriculture. The globalization of the economy which is generated by the worldwide application of scientific achievements sometimes has had very serious social or ethical consequences. Moreover, the advances made by miniaturization thanks to electronics open up to terrorists the possibility of using chemical and biological arms. The people are frightened and sometimes get made. Finally, recent progress gives humanity the possibility to influence or reorient or modify its future. But who will be able to make the choice of what to do? Science alone cannot do this. That is why it must be deep-rooted in the overall culture.

Science within culture

It is clear that science provides new knowledge by processes very different of those, which are involved in many other disciplines; in particular those which belong to what are called 'humanities'. It is the reason why it is often found convenient to admit the existence of 'two cultures'.

We will not follow this view. We will consider that any body of knowledge and inventions belongs to culture if it might help a human being understand himself and understand, enjoy and make beneficial his relations with his physical and social environment. With such a conception, science obviously belongs to culture. But it remains to analyze and to clarify its place and role within culture.

Let us first consider the statements emanating from the classical sciences mathematics, physics, chemistry, astrophysics, geophysics and biology. They will be called scientific statements. The proof of such a statement – a theorem in mathematics, a law in physics or in chemistry, the existence and the properties of the cell in biology – when given by a professor in a lecture in front of students or by a scientist in a paper published in a scientific journal – is completely independent of the political, philosophical or religious views of its author and of his nationality. That means that all the scientists, if they are in agreement on the starting assumptions of the reasoning or on the conditions of the experiment, will agree on the conclusion. That is why one may say that such a statement belongs to the 'world of complete agreement'.

It is then quite evident that it is impossible, strictly speaking, to derive any philosophical or ethical conclusion from statements which belong to the 'world of complete agreement'. Nevertheless, that has been done sometimes in the past, and, as that world is ever increasing, it was thought that, in the future at any rate, the other kinds of statement would lose their validity. Even now such a temptation has not completely disappeared. An ideology may claim to be the sole global conception compatible with the world of complete agreement and, then, on the strength of this claim, it might disable the validity of a traditional culture, any other conception of humanism or a philosophical or religious belief. That was the case with the communist ideology in the Soviet Union. Is it not the case today with some capitalist conception?

What is clear is the increasing interactions of sciences and technology with social, political and ethical situations and problems. Great efforts have been made in order to introduce scientific methods and reasoning into the treatment of such problems. As a result, one finds in a modern culture human sciences, social sciences, law sciences, historical sciences and political sciences. However the 'scientists' working in these fields reach conclusions which have not in general the same kind of validity as those obtained by the classical sciences because the personal view or opinion of their author affects them. Nevertheless, they are very useful for the decisionmakers and cultivated people who want to increase the information available to them and stimulate their thought.

When science and technology come into interaction with a culture, they induce changes in this culture, some of which may be profound, but the foundations of the culture are not necessarily affected. It is important that the culture offers the possibility in any situation of keeping a critical standpoint to discover what is scientifically valid and what depends on a personal opinion or belief.

MEANS OF PROVIDING SCIENTIFIC EDUCATION FOR THE CITIZEN

In the first section it was shown that, in order to face its challenges in the present century, science has to be deep-rooted in overall culture. In the second, that in any situation faced by the society, the culture of this society must offer it the possibility of deciding what is appropriate for scientific analysis and what is not. The best means of satisfying this requirement is to provide every citizen with a suitable scientific education. This last section aims to indicate some ways towards reaching this goal. Three points deserve to be considered: what the pupils and students have to gain; the contributions of teachers; the contributions of scientists.

Advantages for the pupils and students

The most important element out of all the instruction they must receive is training to recognize the specific character of a scientific statement. This training might favorably start in the primary school with simple experiments children can do themselves. If one asks them to write the properties they have found or the result they have obtained, they will immediately note that it is completely independent of their age, their nationality, whatever they live in a city or in the countryside. The initiatives of my colleagues of my Academy Georges Charpak, Yves Quéré and Pierre Léna who lead up the operation: 'la main à la pâte' show that it works very well. When they are in junior high school – a secondary school – they will see, with some very simple examples, what is a proof in mathematics and what is a physical law. For those who want to enter a professional career which does not require an extensive education in science or engineering it is not necessary to give them too many statements of theorems or laws they will soon forget But it would be good for them to get an idea of what science is and of is its place and role in the culture, in a Western culture and in other cultures, in China for instance. That implies they may receive some elements of the history of science. There is some chance they will recall that science has a history, that it is a conquest of humanity, that it was developed for the benefit of mankind. It would be good also if, during their schooling, they could see examples of some contemporary places devoted to sciences and technologies by visiting laboratories, factories and science-museums. It is essential that all these activities be led by the science teachers, under their responsibility and with their comments.

The teachers' contribution

Teachers in sciences in high school receive a special education to obtain the necessary knowledge in the field they will have to teach and also a training to develop their teaching ability. They are selected by some process which check that they have the required capacities. That is good. That is necessary. Is it sufficient? In many countries the answer is affirmative. But, if one agrees with what was said in previous sections, it is not. Future teachers must receive in addition some elements of the history of sciences, even elementary ones, and must be prepared to increase their knowledge when necessary. Their attention must also be drown to the importance of the interactions of scientific and technical developments with many modern problems of society. These complementary additions to the program of the purely scientific disciplines are useful to provide future teachers with the sound resources needed to fulfil their job. Of course, it is a controversial point which deserves to be discussed. The position taken in this paper is that the scientific education has to be given by a teacher of science who must receive everything that might help him to convey to any of his students a correct conception of science so that he or she might be an enlightened citizen. It is highly desirable that this teacher makes the teachers of the other disciplines aware of what he is trying to do in order to obtain their agreement and perhaps their support.

The scientists' contribution

Scientists must, of course, firstly feel concerned by all that might be done towards providing citizens with a good education and be ready to contribute to the operations undertaken for this goal. They may contribute to the education of the teachers of science, be aware of the problems and difficulties they encounted, and give them help and support. They can make suggestions which may be useful.

But they must also understand that if science today does not attract enough young and bright people, it is because public opinion has lost the confidence it have in the past. The arguments for science which worked a few decades ago do not now have the same impact. It is up to the present scientists to discover the new formulation of the scientific ideal, one which will be more appealing and fit present expectations. It seems to me that it would be necessary to assert and to prove the relevance of fundamental research to modern society, as did the report of ALLEA – the association bringing together the European Academies of sciences and humanities – in 1996. Scientific statements are universal. The interpretation which can be given to them depends on the culture of the society where they are received, in particular on its ability to take on board new results without losing its basic values. Consequently, scientists are encouraged to participate actively in the cultural life of society. That will make education of the citizens easier and more successful. As it was noted by some of you, Academies have a special duty in this respect. As it is written in the statutes of the French Academy of sciences, the Academy must work in order that the cultural values of sciences may be integrated in every human culture. Let us note also that such a scientific ideal is necessary if one wants to avoid domination of scientific activity by industrial and commercial forces.

FROM A STATIC TO A DYNAMIC SYSTEM OF EDUCATION IN SCIENCE

ANTONIS V. VERGANELAKIS

Introduction

Four years ago I was invited by the teachers of an elementary school in Athens to speak about microcosmos to its pupils who had already been exposed to interactions and changes, as well as conservation principles from their activities at school.

While I was speaking about atoms, a little boy, not more than nine years old, asked me: "But why the electron in the atom does not stick to the proton?"

What a profound question!

I had to give an answer, caring to use the appropriate language for a child of that age.

My answer, as I can recall, was:

"The electron does not stick to the proton because it resists to the confinement, it resists to being shut in, it does not like the confinement as yourselves do not, therefore it reacts".

From the expression of his face it was clear to me that the boy was happy with my answer.

Later on I started to tell the story of Big-Bang Theory concerning the creation of matter.[1] After having said a few things about the creation of the existing matter in the Universe, according to the theory, another pupil of the same age, asked me: "It means that my body comes from a recycling process?"

[1] You see I have confidence to the capability of children to assimilate new findings. I always remember the famous physicist Cecil Powell, many years ago saying that when you try to teach new things to a child it is as cultivating a plane. When you do the same with an adult it is as cultivating a desert.

I was surprised to hear that comment from a child nine years old.

Considering the number of questions the pupils of that school asked me that day, it was apparent that they were receptive, curious and imaginative. Furthermore, if they were exposed to some of the major conceptual schemes in science as they were at that school, they could be able to shape patterns of thinking and reasoning, which could help them attain a level of understanding and appreciation of new knowledge in science. This would serve them through their adult lives. This has been for me a very useful lesson.

Having said that, let us now go to the main part of my presentation.

Dealing with new scientific knowledge

The title of this paper could also be: “There is a need for continuous incorporation of the new scientific knowledge to the body of primary and secondary education”.

But in what sense is there such a need?

We know that one of the basic principles which the various physical phenomena seem to follow is:

“No change occurs without interaction and interaction implies change”.

When man interacts with *Nature* it is implied that *Nature* acts upon him and he, in turn, acts upon *Nature* resulting in mutual change.

All interactions of man with *Nature* have their limits, boundaries, rules and laws dictated by it, and this is something we should remember.

In the last decades man has started to interact with *Nature*, in most cases through the products of the application of sciences, in a novel *unnatural* way. The earth is forced by man to “live experiences” that have nothing to do with those in the past during the entire course of the human evolution and history. In that way man has modified his environment to such an extent that he has lost touch with his biological and ecological base.

Due to these novel interactions with *Nature, mankind now lives in phase of unprecedented and continuous changes of his environment* and nobody can foresee the consequences of these changes.

Among the consequences of the new interactions, there is one connected with the question: how far the new physical environment formed little by little on the Earth’s surface will continue to be consistent with life processes, and, in particular, with human life?

There is great danger that at a certain moment this environment will no longer be consistent with life processes as long as, man continuously violates the boundaries, the rules and the laws that he should be followed when interacting with nature, *and this is something that Nature does not tolerate; one either respects the principles of Nature and he survives, or violates them and is rejected as a foreign body*.

This problem, due to the tremendous and continuous accumulation of new scientific knowledge, becomes every day more and more complicated. The new scientific knowledge brings new applications and one has to be continuously aware of their cost. Of course, many times the cost of the application of new knowledge, is usually deeply hidden and, even with the best of all prior assessments, not predictable.

Nevertheless, predictable or not one should fight hard for the survival of mankind, complying with the limits and laws of *Nature* in his everyday interactions with it. Towards this goal we need continuous incorporation of new scientific knowledge to the body of primary and secondary education, since at that level the foundations of society's knowledge are built.

Regarding the problem we are discussing, the incorporation of new scientific knowledge described above is not enough. Science by itself has not helped to bring a balance between man and nature. Apart from knowledge of science we need *wisdom* as well.

Now let me mention some of several other reasons that continuous incorporation of new scientific knowledge to the body of primary and secondary education, is required.

– Delayed dissemination to general public or, worse, its total missing of new knowledge would perpetuate the society's ignorance and blindness to science and technology.

– Science is the major force shaping the world today. The new knowledge in science and its applications support and determine the economy of a country, creating new products, a new human ecosystem, new concepts of the surrounding world, new modes of thought, and even new societies.

– The new scientific knowledge renders existing professions marginal (reason of unemployment) but at the same time it creates new professions.

The society continues to act, knowingly or not, according to the old concepts of previous centuries, although the new scientific knowledge has established new concepts that should have led to a new system of values governing our everyday life.

Examples of such new concepts are:

– The world is that of universal interconnection
– The world is that of universal interrelationship
– The world is that of universal interdependence
– Globalization

– Complementarity
– Fragmenation of knowledge – Unification of knowledge

The public should know the foundations and the meaning of them and act accordingly, however nothing of the sort has happened.

The education system is at fault

Whatever the reason for all the above problems is, it is evident that our education system is at fault.

For many years the system has remained unchanged. Although last century an unprecedented conceptual revolution took place, which logically should have led to a completely new education system, nothing has really changed. It has remained and still remains in many countries static and closed.

The newly acquired knowledge has not provoked a revision and re-evaluation of older ideas and thoughts that are part of the existing teaching material. The teaching methodology of the physical sciences has missed the experience of research procedures and the acquisition of new knowledge.

As we see schematically in Fig. 1, the higher, secondary and elementary schools have no interaction with sources of new knowledge. Furthermore the knowledge offered is codified and static. The teaching material, with unrelated facts and details, is always the same, sometimes recycled. The classification also is the same for all levels.

Thus with time, while the frontiers of knowledge were being continuously pushed higher thanks to international scientific contributions, the level of schools has remained the same.

The result of that was, and in many cases still is, the continuous increase of the gap between the various levels of education and the frontiers of knowledge. In the last thirty years it has become apparent that if this gap continues to grow it could be disastrous for education.

In some school programmes there has been an attempt to include some of the new findings but to no avail. There are scientists that still believe that the whole can be described and understood as the sum of its parts, but that is a great mistake. *Science is more than a collection of isolated facts*.

So if not by addition how could an educational system incorporate the fundamental results embodied in the new scientific knowledge and develop the educational methodology continuously, so that the system is dynamically developed? *How can we make the most general ideas of modern science part of our culture?*

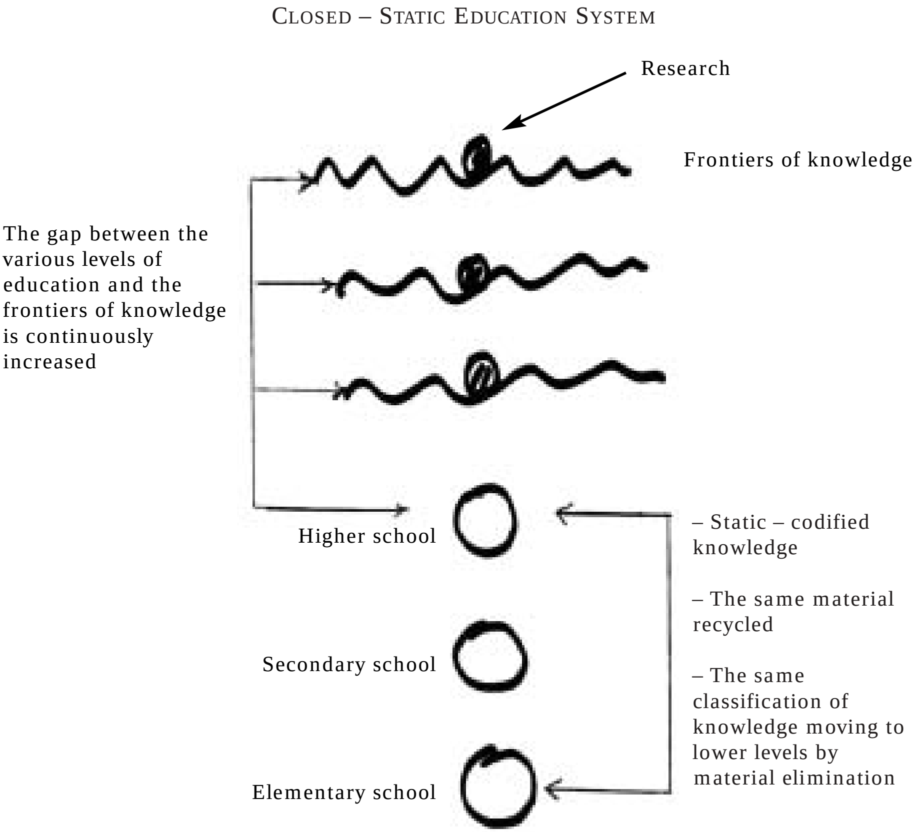


Fig. 1. The Higher, Secondary and Elementary Schools have no interaction with sources of new knowledge.

Presupposition for the dynamical development is that the system allowes, an immediate and continuous flow of new knowledge from the producing sources (research institutions) to the various grades of education.

The path of the flow of new knowledge in a dynamic system

Fig. 2 shows the path of this flow. It forms an expanding triangle. At the top there is the source (research institutions) of new knowledge, which moves on the frontiers of knowledge. At base there is the elementary education and at its sides the higher and secondary education.

By using the appropriate language and mechanisms and if the existing conditions allow it, the knowledge is going from the top to the higher and from the higher to the secondary and from the secondary finally to the elementary level.

As the new knowledge is passing through the various grades it is absorbed and in that way the system is refed.

This way, the foundations of the base (elementary school) are strengthened and they contribute to the elevation of all other levels on the right side of the triangle. The result is the top of the triangle goes higher, raising the frontier of knowledge as well. From its new position the source of knowledge gives new findings etc.

OPEN DYNAMIC EDUCATION SYSTEM CONTINUOUSLY REFEEDED

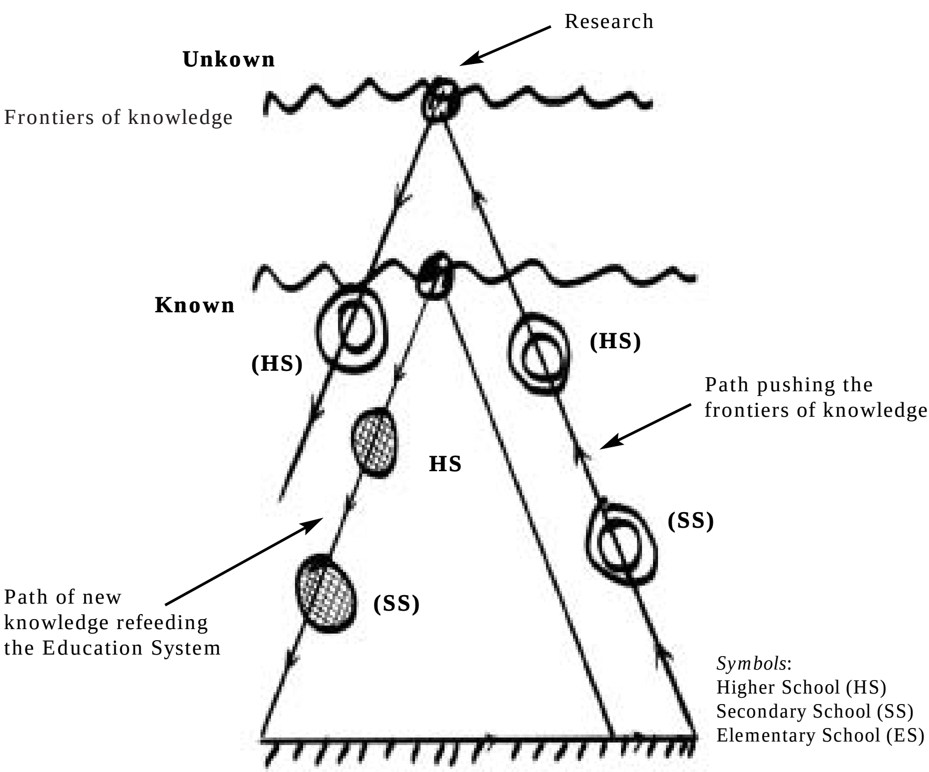


Fig. 2. The path of the flow of new knowledge.

The above flow procedure presents two serious difficulties:

1. How to insure the prerequisites for passing the new findings through the system and have them absorbed by it, or in other words how to keep the system in dynamical conditions.

2. How to find the mechanism to fulfil the above prerequisites and transmit effectively and quickly to the students of all grades the new findings.

Prerequisites for dynamical development

As it is known, every education system creates patterns of thinking and reasoning. These patterns constitute a kind of filter for the minds of the students. From that filter the general ideas of new knowledge may pass through and be absorbed by their minds.

In Fig. 3 this filter is presented schematically. Its characteristics are shaped by the patterns from which have been created.

FILTER FROM THE PAST

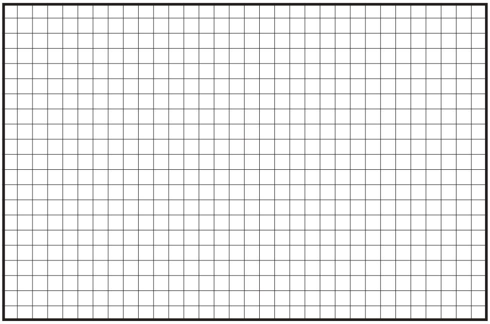


Fig. 3. A Schematic filter through which the new knowledge has to pass.

As is also well known physics taught in schools still today is based on nineteenth century science. At that time the only sources of information were the human senses.

In Fig. 4 you see an example. The observed phenomena were classified according to the way they were sensed. Thus sciences have been developed with the names: Acoustics, Mechanics, Optics, Thermodynamics, Electromagnetism, with little or no connection between them. This fragmentation of Physics, is so deeply ingrained in the minds of teachers of

Physical sciences that is difficult for them to adapt to different ideas of how to teach Physics.

In general man is not always prepared to have the foundations of his knowledge changed by new experience.

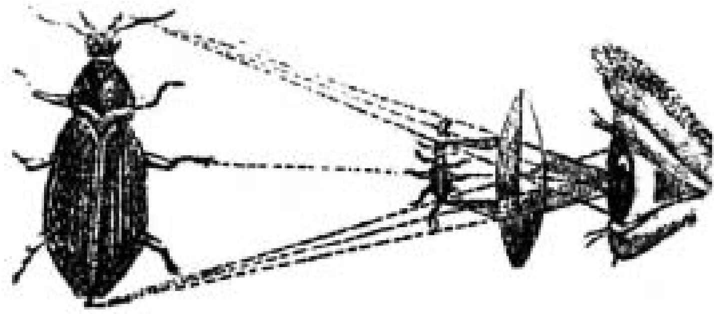


Fig. 4. Simple microscope.

The teachers of physical sciences usually transfer to their students the above “classical” model of physics and based on that they create to them patterns of thinking and reasoning for the physical world. With that “classical” pattern the students shape in their minds the filter through which they absorb or reject new scientific knowledge.

Today, in order to push the frontiers of knowledge further, our senses cannot play any more the role that used to play in the past. Nowadays in research we use instruments that go well beyond the capabilities of the human senses. In Fig. 5 you see a detector which is used in research of microcosmos. The comparison of the past and the present is given by Figs 4 and 5.

This detector reveals a new world in physics. Can we teach these revelations to the students? Will the filter that students have in their minds allow these revelations to pass through and be absorbed? The answer is negative. For pupils with the “classical” filter the new knowledge will be a “foreign body” and it will be rejected. Their basic concepts, their language, and their whole way of thinking are inadequate to understand atomic phenomena.

What should we do?

Obviously we have to take into account the revelations of the new detectors. The analysis of these revelations has led us to a conclusion: The new

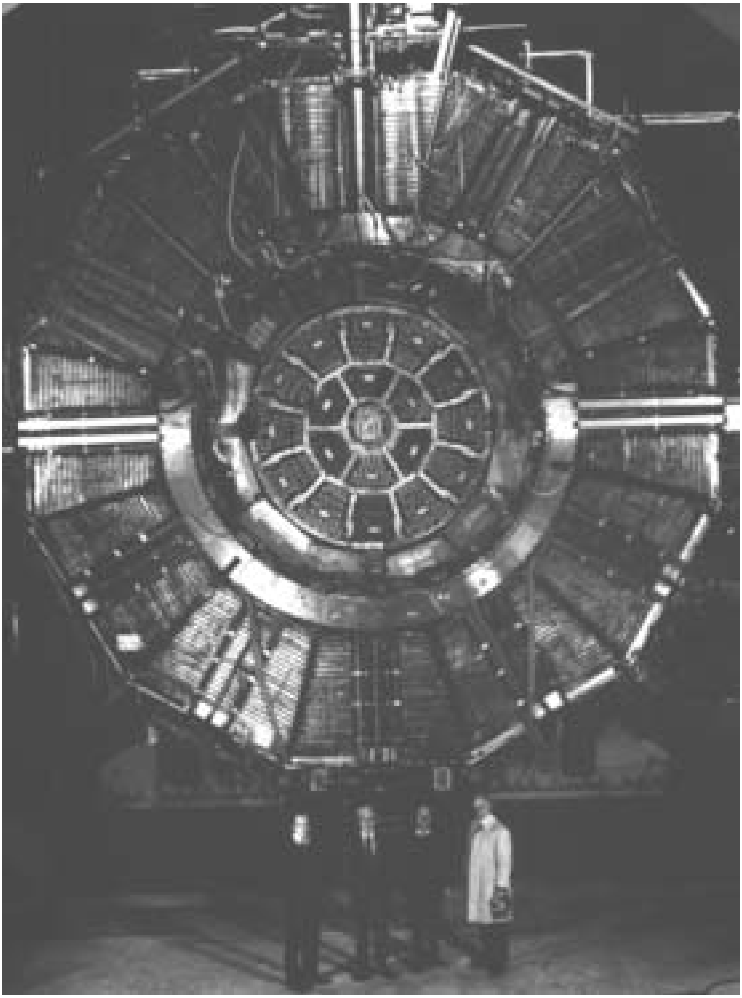


Fig. 5. A detector revealing the secrets of microcosmos.

phenomena that have been discovered follow some fundamental concepts which are valid in both macro and micro levels of the description of nature. If these concepts can be made meaningful to elementary and secondary school children, then with that equipment the children long after leaving school may retain some understanding of new findings.

From the same analysis we have learned that nature is not made up of a multimedia of objects, is not fragmented, but has to be pictured as one dynamic *whole*.

From Fragmentation to Unification

Nature forms a unity, which means that from fragmentation we have to pass to unification.

It is interesting to notice that this result turns us back to some centuries ago when our ancestors tried to understand the world as a whole, reveal the secrets of the Universe, and establish a relationship with their fellow men and their gods.

But after finding themselves unable to answer some questions convincingly, they discarded the attempt of discovering all the mysteries of the Universe and concentrated on certain isolated phenomena.

The success of this isolation rendered marginal the original problem of the relation of man with “nature” and his gods, and favored a false separation of man from nature. At the same time it influenced all aspects of human cultures, led to a fragmentation of their content, and gave a new direction to human thought and to the growth of knowledge.

This situation may have contributed to a certain progress, but at the same time it created boundaries and impasses. The separation of particular knowledge and concepts from others proved more and more dangerous.

Now in the light of accumulated experience we see that we are forced to review our course and change some aspects and the direction of our culture going back to its roots. A very nice result!!

Today the new knowledge is not in most cases a product of analysis but of synthesis of different phenomena. In order to have the necessary background to understand them we have to pass again from the fragmentation to the unification of the teaching of physical sciences.

If we want to prepare our pupils for this unification we should have the new science curricula focus on fundamental concepts that as we showed before, are valid in both macro and micro levels of the description of Nature.

If an educational system, since the primary school years, helps pupils assimulate the meaning of those fundamental scientific concepts, then it can provide them with patterns of thinking and reasoning which allow the incorporation of every piece of new knowledge into it. It helps to transform the education system from static to dynamic.

This solution is an answer also to the following five problems:

– The research is never ending, what we know today is inevitably just a small piece of what we are going to know in the next century. In our times it seems that the store of human knowledge doubles every five years, so there is a question how we would be able to teach all this material since the teaching hours at schools are always limited. One presupposes that the new knowledge should not remain "foreign body" for the next generations.

– The school has to provide the bases and the foundations for a "life-long education". What do we have to do to achieve that?

– How to provide teachers and students clearly defined goals, as well as a cohesive picture of science?

– How to ensure that schools produce competent students?

– Since science is more than a collection of isolated facts, how to unify broad ranges of experience?

From all the above we may conclude that prerequisite for an educational system to function dynamically is that the schools, instead of filling the minds of pupils with unrelated facts and details, must focus their attention on certain fundamental concepts of science that form the bases for all explanations of physical phenomena.

In the next two tables a set of such fundamental concepts is presented for elementary and secondary schools respectively:

Fundamental concepts for Elementary School

1. *The Universe is composed of Distinct Units*

2. *Interaction and Change*

3. *The Conservation of Energy*

4. *The Degradation of Energy*

5. *The statistical view of Nature*
   (Nature is predictable only by the play of large numbers)

Fundamental concepts for Secondary School

1. *The Universe is composed of Distinct Units*
   Particles, Properties

2. *Interaction and Change*
   There are only a few distinct fundamental interactions
   In all interactions certain quantities are conserved

3. *The Conservation of Energy*
   The conservation principles are related to certain symmetries observed in the Universe

4. *The Degradation of Energy*
   The laws of thermodynamics
   Direction of energy changes
   Entropy, The spontaneous evolution of a system

5. *The statistical view of Nature*
   (Nature is predictable only by the play of large numbers)
   Uncertainty, Probabilities, Distribution Laws

6. *The Quantum behavior of matter*
   Uncertainty principle, complementarity

These schemes[2] were selected years ago by the COPES (Conceptually Oriented Program in Elementary Science) of the New York University, "because they include most of what is fundamental in science and because they provide the basis for a logical, sequential development of skills and concepts through the elementary grades".

As you see, in booth elementary and secondary school, the same fundamental concepts are used. With the appropriate language they can be meaningful for both. As one goes to higher grades the topics under each concept, progressively expand.

[2] See also M. Alonso, E.J.Finn, Physics Today 50, 140 (1997).

Mechanism to fulfill prerequisite

Let us go now to the problem of how to find the mechanism to fulfill the prerequisites for keeping the system in dynamical conditions and to transmit new findings effectively and quickly to students of all grades.

There are some facts relative to this problem.

– Equipped and suited to teach fundamentals are the scientists.

– The sources of new knowledge are the research institutions. These institutions are the central transmitters of the new “message”. In particular the specific producers of new knowledge are the best for transferring the substance of their findings in a simplified way. They have that substance in their “blood”.

If so desired the new scientific findings to be disseminated quickly and precisely to students of different grades of education and to the public, the research units have to play a new role in education, complementary to that of Universities.

With these facts in mind, one has to adjust the hole education activity.

The scientists that produce new knowledge have to transfer, their findings to the teachers and then the teachers to their students in the appropriate way and language.

In order to have a good communication during these steps the “transmitter” and the “receiver” must function well and be “in tune”. The first “transmitters” (the researchers) have to show “receivers” (teachers) how and what to transfer to their students. It means that the teachers should be scientifically trained in the spirit of fundamental concepts.

The whole problem is the education of teachers, in particular of teachers of elementary schools.

MODERN COSMOLOGY, A RESOURCE FOR ELEMENTARY SCHOOL EDUCATION

GEORGE V. COYNE

Introduction

The wisdom which has already come to light in this symposium has reinforced for me the following ideas which I would like to collect, if possible, into a single argument which I will try to establish by providing an example of teaching an actual class to elementary school students. You assembled Academicians and invited scholars are to be my class.

The ideas which I have garnered are the following: (1) we should start teaching children from where they are at present, their current knowledge, interests, fears, and so on; (2) all of us humans, those who teach and those who are taught, "have been made in heaven", it has been said. This refers to the well known need for stellar nucleosynthesis to provide the chemical abundances required for life in the universe. It has been indicated that one of principal goals of teaching children should be an awareness of this birth of ours from star dust, if only at an elementary level. I would suggest that the didactic order be reversed and that this awareness should be the beginning point of elementary school education; (3) the aim to develop "scientific literacy" has been a recurrent theme but I have not heard it defined. I propose an elementary definition which suits the purposes of my presentation: To be scientifically literate means to have an understanding of ourselves in the *physical* universe (the emphasis being on *physical,* but with the implication that I am speaking of all of the natural sciences: biology, physics chemistry and their derivatives); (4) Much has been made of the distinction between the methodology and the content of teaching. I would like to suggest that these two aspects of elementary school teaching find a unity in an ideology, a guiding theme, a single dominant perspective on ourselves in the physical universe.

"Being" versus "Doing"

My aim in this presentation is to show by a living example that the unifying theme of our birth from star dust can serve as an effective and entertaining way of introducing children to the elements of science. So let me begin, but first I must share with you an important but hidden conviction of mine which may not become apparent to you as I teach. For many years I have taught a general astronomy course to college freshman. In an evaluation of the course after about one month I received a recurrent refrain: "This course is fascinating and full of very interesting and new ideas, but it is useless". After many attempts at trying to refute that remark, I finally realized that it is correct. The course is "useless", if that expression is understood correctly. Philosophers distinguish, I am led to understand, between "being" and "doing". A knowledge of astronomy helps us to "be", not to "do". It shares, in that regard, with the visual arts, with music, with sports. Astronomy will not help me repair my car or make better toothpaste, but it will help me be a more interesting person, to myself and to others. It will help me to participate in a richer way in our adventure as beings in the physical universe. Many of the other sciences, of course, share in this "useless" nature of knowledge, but astronomy, I hesitatingly assert, does so in a preeminent way. So that is why I have chosen to teach it to children. I would never, of course, admit to my class of elementary school students that this year's course is useless. Children are already convinced of that without realizing it. They are quite content to grow in "being" and surrender the doing to "adults". Let us begin. Remember I am teaching you a year-long course in fifteen minutes. This is an introductory class to elementary school students in which many themes are only introduced and will be elaborated on during the year. These children are somewhere between the ages of 8 and 14. I am afraid my inadequate understanding of this age group will cause me to wander a bit in the range of difficulty of the ideas to be comprehended. I repeat, you are my class, at least for the next fifteen minutes.

A Class Taught to Children

Welcome, children. This year we are going to study about the world in which we live, mostly about the world way out there. But we will also be studying about ourselves, because, as you will see, we are part of the world and, although they are a long way out there, the stars are in some ways very close to us. It is going to be fun to see how close we are to the stars, even more fun than taking a picnic to the seaside or to the mountains. At least, I am going to have fun and I think you will too. And as we have fun, we will also see how important science is because science is one of the ways in which we can bring all of those objects way out in the universe close to ourselves.

You know how much fun it is at night to look up at the stars and try to see how, when we tie them together with lines between them, we can imagine various faces and animals and soldiers and our heroes. Take Orion, for example. Our ancestors, thousands of years ago linked up those stars and saw one of their great heroes, the hunter Orion, up there in the sky. And in front of him they saw the bear he was hunting and behind him his little hunting dog. These are what we call constellations and we will study about them this year.

But let's begin to think like astronomers think. Are all of those stars at the same distance from us? The answer is NO, but it took many years to find that out and it will take us this year some time to understand that NO. But let us begin by doing a simple experiment. Hold a pencil up a little bit in front of your nose, close your left eye and with your right eye look at my head. Now close your right eye and look with your left eye. Now blink your eyes like that many times. What is happening? Yep, the pencil is sliding to the right and to the left of my head. Now hold the pencil at arms length. What happens? Yep, the shift of the pencil with respect to my head still occurs but it is smaller. Now let us go out to the playground. Hold up the pencil again but now look at that tree down the street and then look at the top of that mountain out there? What is happening? Yep, we have noticed two things. When I look at a distant object the closer I hold the pencil to my nose the larger the shift and, if I keep the pencil at the same distance from my nose, then the shift is less for more distant objects. We have just discovered what astronomers call "parallax" and we will study this year how we can use it to measure the distances of the sun, the moon, the stars and even galaxies. We will soon talk about all of those objects.

Now we are becoming scientists so we have to ask more questions. Why is there the shift we have observed and why is the shift different for different distances of the pencil and the distant objects I am looking at: my head, the tree, the mountains. What would happen if your two eyes were together in the middle of your head, like those big giants in fairy tales? You guessed it! There would be no shift. It is because our eyes are separated that we see the shift. But the stars are so far away that the small distance between our eyes will not allow us to see them shift. What if we could separate our eyes by very large distances? Well, astronomers have found a way to do that. Can anyone guess how? We will find out later in the year.

When we study “parallax” later on in more detail, we will really become astronomers and will know that the stars we see in Orion are at various distances from us, some of them thousands of times further away than others. They only appear to be at the same distance because our eyes are too close together. In fact, we see everything beyond the Earth, even spaceships, as if they were at the same distance, on what astronomers call the “plane of the sky”. Now that we have discovered this, let us look back at the stars in Orion.

With big telescopes – and we still study about telescopes later on – let us look at the belly of Orion. What we see is boiling gas and dust and, if we look very carefully, we see that some of the gas is red and some is blue and that the red and the blue are separated. Remember as scientists, when we see something like that, we have to find out why. Actually the red gas is the result of energy being transferred from stars to the gas, where that energy is swallowed up and then sent on to us. We will study about this later on. The blue gas is the result of starlight being reflected towards us, not swallowed up, just like light is reflected from a mirror; but the mirror in this case is the cloud made up of millions of gas and dust particles. Do you know why the sky is blue? It is for the same reason: sunlight is reflected from the particles in the Earth’s atmosphere. But let us return to the discussion of the red gas.

Deep inside that gas new stars have been born. Yes, that is one of the marvels of the universe. Stars are born. They have a very long lifetime and it takes them a long time to be born. But we will learn later on that a star like the sun – yes, the sun is a star like all of those we see in the sky – was born more than twice as fast as we are, if we consider how long it lives. (I would introduce here the concept of the relative measures of time and distance, to be discussed in more detail later on. The sun was born in about 2×10^7 years and will have a total lifetime of about 10^{10} years; we are born in about 1/100th of our lifetime). The stars are very far away, so we do not see them being born, but we will see how astronomers can know about their birth. In fact, the red light that we receive gives us a clue to the birth of stars.

But what is light and what do we mean by swallowing up energy? Light is energy and, in this case, it comes from the stars. We will study about different kinds of energy. Light is one kind. It is called radiant energy and it travel in waves. Let us now do an experiment to show how light travels in waves. (See Appendix I for an experiment which I would now do with the children to introduce the wave nature of electromagnetic radiation. I would do this experiment in this introductory lecture so that the children could have fun and realize that the course will have many other experiments and not consist only in lectures). In order to understand what we mean by energy from the stars being swallowed up by the gas, let us do another experiment. (See Appendix II for a second experiment that I would do with the children on the absorption and reradiation of electromagnetic energy).

Stars are born in the following way. A big cloud of gas and dust in the universe begins to break up and the pieces begin to collapse. As a gas collapses it heats up and as it expands it cools down. We will study about why this occurs later on this year. The piece of the cloud that collapses weighs many times more than the sun and so it heats up to millions of degrees in its center so that it creates a kind of atomic bomb by turning hydrogen into the heavier elements. (Here I would introduce the difference between weight and mass with the promise to study it in more detail later on). This is a kind of nuclear energy. Later on this year we will study what we mean by nuclear energy and by light and heavy elements, but I can tell you right now that the gas in the star that was hydrogen will eventually become carbon and then finally iron. So a star is born when it turns on a nuclear furnace and it lives by making heavier elements.

Eventually, however, a star dies, just as happens to everything else in the universe, even to you and me. It is not very nice to think about dying, but in the universe, if stars did not die, you and I would not be here. In order to have the chemicals necessary to make our toe nails and ears and everything that lives in the universe, stars had to make up the heavier elements and spew them out to the universe as they die. Why does a star die? Because it finally has no more fuel for the nuclear furnace and it collapses and then explodes to spew out to the universe many of the heavier elements that it has formed during its life time. We are born of those elements; we are made of star dust.

As we study astronomy this year we will come back time and time again to understand what it means to say that we are born from the stars. We will see that the sun is one of a hundred billion stars in our galaxy, that we call the Milky Way and that there are billions of galaxies like the Milky Way. But one star is very special to us and that is the sun, because planets formed around the sun and one of those planets is our Earth. The planets formed because some of the matter from the piece of a cloud that collapsed to form the sun was left over and, after the sun was born, this material had to collapse into a disk. Why do I say “had to?” The laws of physics, which we will study this year, are the same for the stars as they are for us and for any other object in the universe. The material around the star had to obey a certain law of physics. (I would introduce here with examples the conservation of angular momentum). Do you think planets formed about other stars in the universe? Why do you answer “yes” or “no”.

A marvellous thing has happened on our Earth. We can put the universe in our heads and that is what we are going to do during this year of studying astronomy. Some hundreds of years ago people like us discovered physics and mathematics and the other sciences and now we can use those sciences to find out how the universe works. Let me give you an example. When you go home I want you to weigh yourself and measure how tall you are. Tomorrow I want you to tell me what your weight is and what weight means. And then, without measuring your father’s height, I will want you to tell me how much taller than you he is: two times; 1.3 times? Then we are going to talk about weighing a star and a galaxy and also measuring its size, even though we cannot touch a star or a galaxy. That is the marvel of being able to put the universe in our heads. We can measure the mass and size of stars and galaxies by knowing physics and the other sciences. We are going to have fun doing that this year.

Conclusions

Thank you all for being my elementary school class. What I have tried to establish is that, by using the central idea of our origins in an evolving universe, the principles of physics can be taught in an interesting way by introducing them at a time when the curiosity of the student has been aroused by the search for an answer to a real problem concerning his or her place in the universe. Here is a summary list of some of those real problems and the principles of physics to which they direct the attention of the student, as I have discussed them above:

1. Problem: What are constellations? Principles: distances, parallax, geometry, trigonometry.

2. Problem: how to see further in the universe than our eyes can see? Principles: optics, telescopes.

3. Problem: increasing the distance between our eyes. Principles: think like a scientist.

4. Problem: What is the difference between red and blue gas? Between emission and reflection nebulae? Principles: nature of light, reradiation of energy, reflection of energy, black body radiation and absorption.

5. Problem: How long does it take for a star to be born? Principles: numbers are relative, use of mathematics in science, powers of ten for large and small numbers.

6. Problem: How is a star formed? Principles: difference between weight and mass, gas laws.

7. Problem: How does a star shine? Principles: thermonuclear energy, atomic and molecular nature of matter.

8. Problem: Why does a star die? Principles: hydrostatic equilibrium, metal enrichment of the universe.

9. How do planets form? Principles: rotation, conservation of angular momentum.

I surmise that other sciences might also be able to find a central fundamental thesis which would allow a course development such as the one I propose for astronomy and physics. I leave it to the reader to judge as to whether the four ideas listed in the *Introduction* have been successfully incorporated, in a preliminary way, into the class I have taught.

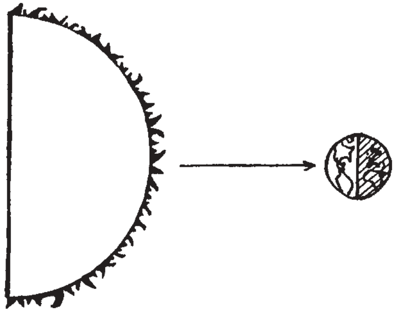
The Vatican Observatory has prepared two booklets of hands-on experiments which would be a key instrument for such a course as the one I envision. They are respectively for grades first to third and fourth to sixth (*Long Eyes on Space: Astronomy and You*, Designed and Developed by the Kino Learning Center [Tucson, Arizona: Vatican Observatory Foundation, 1991]). Samples of two experiments from those booklets are given in the appendices.

Appendices

APPENDIX I. *Long Eyes on Space: Astronomy and You*, II, p. 1.

DOES LIGHT TRAVEL?

People, animals and cars travel through space. Does light travel too?



Light travels from a ***source***, such as the Sun, through space and arrives at Earth in the form of sunlight. Light from ***stars***, other suns in the galaxy, also travels through space and eventually arrives at Earth as starlight. Some starlight comes from so far away that the light arriving at Earth has actually been traveling for millions of miles aver many years.

Light travels in ***waves***, much like those found on the ocean. To discover how light travels, use a simulation, or a model, to see how it works.

Make your own wave simulator to demonstrate how light travels.

Materials needed:

- large tub or pan
- marble
- water
- stop watch
- meter or yard stick

Procedure:

1. Fill the large tub with water, bringing the water level to within one inch of the top of the tub.
2. Drop the marble into the tub from approximately one meter (or one yard) above the water's surface.
3. Observe and record the movement of the water.

Draw and describe your findings

Light waves going through space move much like water waves in the tub. Energy from the Sun is released in the form of radiation, some of which is heat, so sunlight is warm. Starlight does not feel warm because stars afe so far away that the amount of energy that actually reaches Earth is very slight.

APPENDIX II. *Long Eyes on Space: Astronomy and You*, I, p. 11.

LIGHT MEANS ENERGY

Visible light is energy that you can see with the naked eye. The Sun, at the center of our solar system, ***radiates*** or shines this energy in all directions through space. Some of this light energy comes to Earth where it affects everything it touches.

Which is hotter in sunlight, a black object or a white object? To find out, conduct this experiment.

Materials needed:

- 3 large jars of the same size
- 3 thermometers
- black and white construction paper
- sunlight
- water
- clear tape
- aluminum foil
- 3 paper towels

Procedure:

1. Place one crumpled paper towel in the bottom of each jar.
2. Cover the outside of one jar with black paper, one with white paper, and one with aluminum foil. Tape the paper and foil in place.
3. Add equal amounts of water to the jars.
4. Place a thermometer in each jar. Make sure the thermometer rests on the paper towel so it does not touch the jar bottom.
5. Place the jars in direct sunlight.
6. Record the temperature of the water in each jar at the beginning of the experiment and every 15 minutes far an hour.

Record your observations on the chart below.

	Temperature				
Jar type	Beginning	15 minutes	30 minutes	45 minutes	60 minutes
White paper					
Black paper					
Foil					

Which jar had the warmest temperature?______________________________

Which jar had the coolest temperature?______________________________

Why do you think there were differences in temperature?____________________

____

If you lived in a desert, what color would you want your house to be in the hot summer?______________________________________

In the cold winter? ______________________________________

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THE IMPORTANCE OF THE HISTORY OF SCIENCE IN INTELLECTUAL FORMATION

JEAN-MICHEL MALDAMÉ

What we call ‘scientific knowledge’ has two distinct facets. In the first place, the term ‘science’ refers to a collection of known facts which taken together give mankind a great power over nature. This is the side of science which is at once most visible and best-known. It allows us to carry out a vast range of projects, and it is thus part of the foundation of the modern global economy. Science in this sense has a place at the heart of our civilisation, a place which it will without doubt retain in the century which is before us.

The second aspect of science is something less well-known to politicians and to the public at large, but of great importance in the formation of scientists, namely, the scientific method. The scientific method is what allows science to develop successfully and to be put to practical use. Thus it is not enough for trainee scientists to gain a knowledge of what has already been scientifically established; they have above all to gain an understanding of the methods which will permit them to establish new truths and to envisage new technological applications of what they already know. This means developing a certain mentality, which we can call the scientific mind. A person with a scientific mind will know how to make the most of his rational gifts, yet at the same time be able to evaluate critically the use which he does in fact make of them.

This is the background to the remarks I shall be making about intellectual formation. There is one point in particular which needs to be stressed, namely the place which history must have in the teaching of science. The history of science is a branch of history which should not be neglected.

1. What is the 'History of Science'?[1]

1. The study of the history of science developed very significantly during the 20th Century. The work that has been done in this area allows us to determine more precisely what we mean by the history of science, and what ground this discipline covers. It is in practice the history of the natural sciences plus the history of mathematics. It is only rarely that the human sciences come into consideration in this connection. Some people would give the term 'history of science' a stricter sense, and mean by it just the history of the natural sciences. Nevertheless, the human sciences and mathematics share a common method with the natural sciences inasmuch as they are also rational acticivities.

The history of science as it has developed in the 20th century has two principal concerns. The first is to understand the way in which scientific knowledge progresses. The second is to understand the notion of science itself, which involves the questions of what methods are truly scientific and what kind of knowledge science actually offers us.

The studies that have been carried out in this field show how hard it is to separate the history of science from other branches of history. For example, medicine is at once a science, a technique and an art, and its history is bound up with the development of many different sciences.

2. The history of science obviously includes many different facts about things which happened at various times in the past. Yet simply compiling a list of such facts does not suffice for genuine history. For this, it is necessary to bring out the relationships between facts, indicating where there is continuity and where there is a break with the past. The history of science has thus to take into consideration the process by which science comes into being, that's to say, the various stages of its development. It's sometimes necessary in this connection to take into account the personalities of scientists themselves, in order to understand how they came to their various conclusions.

Not only must the history of science talk about 'facts', it must also talk about 'results', or about the diffusion within the wider scientific community of a particular piece of research. What happens here is that something which was the property of one individual becomes a sort of 'common good', and in the process gains a certain 'objectivity'. As soon as a result is published, it no longer belongs exclusively to the man who discovered it: it is now in the public domain.

[1] Cfr. François Russo, *Nature et méthode de l'histoire des sciences*, Paris, 1983.

What does this imply? It implies that other people may now find a significance of their own in what was discovered. They can adopt a given result for their own purposes and put it to uses which were not those of the original researchers.

3. This gives rise to a third consideration, namely the way in which the very notion of science changes as its methods evolve. What precisely is the sort of knowledge at which scientists are aiming?

Studying the history of science makes us see a dimension of intellectual work which is sometimes neglected, namely the cultural and spiritual context in which work is done. What appears to be insignificant at one moment can be of great importance later on. Thus Darwin would certainly have known about the work done by Mendel, but he didn't take it into account. Mendel's work didn't answer the questions which Darwin was actually asking, as their approaches to their subject were so different.

2. The Development of Science

One of the benefits of studying the history of science is that it helps to free us from a naïvely 'progressive' understanding of science. According to this view, science is supposed slowly but surely to have gained possession of the whole field of human knowledge; everything solid or well-founded in human knowledge is supposed to have come about thanks to the scientific method. In fact, history shows us that the development or progress of science is far from being a peaceful or uninterrupted affair. It is on the contrary an *adventure*, a human enterprise which is subject to the same vicissitudes as any other human endeavour.

2.1. *The Development of science: a fitful affair*

If the development of science were perfectly regular and harmonious, it would be a continual advance in which every result allowed one to proceed still further in the same direction. In reality, we find on closer inspection that science necessarily implies breaks with the past. This is what gives rise to the expression 'scientific revolutions', though the phrase is perhaps overly strong. Furthermore there is sometimes a long gap between the moment when a new discovery is made public and the moment when it is actually taken into serious consideration. For example, Saccheri published his work on non-Euclidean geometry at the beginning of the 18th century, but it wasn't looked at seriously for another hundred years. His work was easily available and yet it simply failed to generate any interest.

Another aspect of the fitfulness of scientific progress is that some periods seem much *richer* than others. During certain periods there is a great creativity about scientifc research; at other times science seems as it were to be in hiding. For example, in the first few years of the 20th century, we find Planck's work on quanta in 1900, and in 1905 the three principal theses of Einstein, namely those on Brownian motion, special relativity and photons. Likewise, between 1925 and 1930 we find the development of quantum mechanics, whilst in 1932 some very successful investigations are made into the nature of matter, with the discoveries of the disintegration of matter and of the neutron. What is is that makes one short space of time so extraordinarily rich? It is hard to say. Sometimes, of course, it can be the opposite which happens. In the Middle Ages, for example, there was not a great deal of scientific discovery: that was to come in with the 17th century, during which the foundations of modern science were laid.

Again, not all disciplines advance at the same rate. Biology, for example, developed much more slowly than physics, and even within a given discipline, the various parts do not always progress at the same pace.

A final point: the progress of science is also fitful in a geographical sense. We find that certain great centres of science – Athens, Alexandria, Bagdad, Seville, Oxford, Paris, Padua etc – flourish for a while and then decline.

2.2. *The search for greater precision*

Scientific discoveries, when they are first made, are not always so clear-cut and precise as they may appear to be later when they have found their place in a well-defined system. This causes problems for the historian of science. In the initial stages, ideas are often vague and ill-defined, and perhaps ambiguous, both in the mind of the scientist and in the experimental application which he makes of them. Yet it is precisely these ideas which turn out in the end to have been fruitful. Even when they are made more precise later on, we shouldn't forget what a rich significance they had originally, as it was precisely this that led scientists to interest themselves in them and to benefit greatly as a result.

Now scientific precision is acheived only gradually and often clumsily. The history of science shows us many a strange mixture of truth and error. True and false ideas are found together not only in the same science and in the investigation of a given question, but even sometimes in one and the same scientist. The founders of modern science themselves, men such as Kepler, Galileo, Descartes, Newton and Leibniz, were not immune from this law. The erroneous views which they all held on various matters didn't stop them from greatly furthering scientific knowledge: but their erroneous views had eventually to be criticised. Thus Newton, for example, sought to give a scientific account of the stability of the solar system, but at the same time put forward a whole host of speculations about divine activity at particular points in the world. It was not until the end of the 18th century that Laplace was able to give a fully satisfactory account of the planetary movements. Obsolete ideas can sometimes get in the way of scientific progress – witness Galileo's attachment to the idea of circular motion or Sadi Carnot's belief that calories were a certain kind of liquid.

2.3. *Conflicts of approach*

The history of science also shows us that one and the same question can be approached in quite different ways by different scientists, though this doesn't necessarily stop them arriving at the same conclusions. The best example of this is perhaps that of quantum mechanics. The formalism worked out by Louis de Broglie was quite different from the one worked out by Werner Heisenberg, but both of them give the same results. Planck and Einstein, likewise, approached the question of the quantum from very different perspectives.

Sometimes this varierty of approach causes conflict. One thinks of the battles between geocentrism and heliocentrism, or again between the followers of Descartes and the followers of Newton. Later on there were the battles between evolutionists and those who maintained the stability of species, and later still between the realist view of science and the conventionalist view. This raises the question of how a theory is to be proved.

We find in the development of science two opposing forces. On the one hand there is the urge to gain a fuller understaning of one's subject. On the other hand there is always a certain resistance to what is new. This resistance to change no doubt arises from the scientist's own attachment to certain opinions. He is used to thinking in a given way, and it is difficult for him to change. Gaston Bachelard describes this as the 'epistemological obstacle'.

What can we conclude from these brief remarks on the development of science? The historical study of science enables us to recognise the limits of scientific work. In particular it shows how science is simply one human activity among others: like all human activities, it is exposed to chances of every kind.

All this leads us to ask more fundamental questions about the nature of science itself. What makes something 'scientific'? What precisely do we mean by a rigorous 'scientific method'?

3. What is science?

Scientists sometimes give the impression that there is no difficulty about knowing whether or not a certain piece of research is really scientific. It might seem that everyone was agreed about what the relevant criteria are. After all, without some idea of these criteria, we wouln't be able to talk about science. Yet in fact our notion of science need to be rendered clear. As long as it remains ambiguous, it inevitably gives rise to misunderstandings and even to polemic, as happened recently with regard to 'water-memory', or during the Sokal affair.

Why does it sometimes prove difficult to agree on what counts as science? It is doubtless because science is made up of a variety of elements, and, as the history of science reveals, the importance accorded to these various elements has changed over the years. This also helps us to understand the difficulties which science is currently experiencing in certain countries: the very notion of 'science' is not understood in the same way in every culture.

A last point: the criteria which render something scientific vary according to the various branches of science.

3.1. *Science and pseudo-science*

Scientists today are sometimes confronted by what they consider to be *pseudo-science*. In France last year, this led to a very interesting argument at a certain university. A student who was known for her astrological publications submitted a doctoral thesis in sociology in which she described these publications as scientific. Scientists and other academics protested vigorously, considering astrology to be no more than a pseudo-science.

In fact, things like astrology have a complicated relationship with science. Sometimes they may be examples of a pre-scientific sort of knowledge which can in fact serve as a basis for science itself. It was in this way that alchemy was related to chemistry or ancient astrology to astronomy.

But they can also be the result of a hi-jacking of science, as is the case with certain religious sects which claim the title of science for what they practise in their healing-sessions or for their vision of the universe. The study of history enables us to make an impartial judgement of these matters and helps us to establish sure criteria of what counts as science.

3.2. *The basic criteria of science*

There are a certain number of criteria about what counts as a truly scientific approach to the world on which the whole scientific community is agreed.

1. *Objectivity*. All scientific work pre-supposes a separation between the scientist and his work. Objectivity is guaranteed by the fact that independent observers can obtain the same result; observations must be *repeatable*.

2. *Precision*. Observations must be precise, as must the words in which they are described, whether it is hypotheses, concepts, laws or theories which are in question.

3. *Attention to detail*. In his analysis of the facts, the scientist must endeavour not to overlook any aspect of what he observes.

4. *Universality*. Science does not seek just to ascertain individual facts, but also to draw from them generally-applicable laws. This requires an abstract language capable of expressing the 'models' which scientists use to explain their observations.

5. *Refusal of occult explanations*. The scientific mind does not explain its observations by recourse to occult causes, for example magic, or agents which lie outside the natural world, such as spirits, genies, or demons. This attitude implies a certain detachment from the world of religion, though it fits well with the acknowledgement of a unique, transcendent God who is not a part of the universe.

6. *Consistency*. A given explanation must be susceptible of incorporation into a more general theory. There can never be contradictions between the various parts of science. The scientific endeavour implies a desire to unify human knowledge.

7. *Regularity*. Science seeks to discover some regular pattern in what it observes, and it is this pattern which needs to be highlighted by the scientist.

8. *Open-mindedness*. The true scientist always has a critical attitude towards what he receives from the past, wishing to verify for himself the truth of traditional views. An argument from authority is not enough for him.

9. *Desire for constant improvement*. To be true to itself, science must always seek to be more and more closely shaped by the real world.

These criteria of genuine science are of course very general. They apply not only to the sciences of nature, but to all intellectual endeavour. We should also add that contemporary science is based on additional criteria, stricter than the ones just cited.

3.3. *Some more specific criteria*

In addition to the nine criteria given above, there are others which govern a more precise scientific method. It is in recent years that these stricter criteria have been clearly expounded. Thus:

1. Experiments are possible which modify nature to a significant degree.

2. All concepts used are subject to a full analysis, so that they may be 'operational concepts'.

3. Principles, ideas and theories must be capable of being measured against real facts. Thus Popper introduced the negative notion of falsifiability to explain what counts as genuine verification.

4. Knowledge is not to be understood as yielding certitude – this is a Cartesian ideal. Instead, it gives us greater or lesser degrees of probability.

5. The kind of measurement used has to be precise and clear.

6. Many notions hitherto the preserve of theology and metaphysics have to be considered objects of scientific thought. Examples include the formation of the universe, the formation of living species, the generation of living things. These facts which were previously explained theologically are now objects of scientific study. At the same time, it's important to recognise that such study is just one of the activities of man's intelligence, and that it doesn't exclude other approaches to these problems.

7. The notion of final causality is to be excluded from scientific discourse.

8. The process of mathematisation must be allowed to increase and become ever more refined. Mathematical objects, in fact, are no longer limited by the ideas and images implied by Euclidean geometry.

9. Experiments may be more various than was previously the case. There is a place, for example, for so-called 'thought-experiments'.

10. Statistical laws are to be accepted on the same footing as the strict laws of classical mechanics. It seems that theoretical physics, dominant as it is, leaves a place for the sciences of life.

This brief discussion of what counts as genuine science shows how useful the study of the history of science is. It enables us to see how scientific criteria have gradually become more precise, and how these criteria may be variously arranged and emphasised, thus giving rise to various ways of thinking. The distinction of science and pseudo-science is particularly important in the formation of the scientific mind.

4. Human formation

The remarks we have made about the scientific mind show how the study of the history of science can help promote a well-rounded human formation.

4.1. *Relations between various branches of knowledge*

What has been said about the training required by the scientist, in particular the distinction between science and pseudo-science, may serve as a general invitation for us all to consider what is the exact relation of our own discipline to other disciplines. It can be humbling for us to have to admit how very limited our own discipline inevitably is; yet in so doing we become more ready to learn from others, and to accept other points of view. We also become more cautious about demarcating the various parts of human knowledge too absolutely. History shows us the troubles that can be caused by inadequate definitions of different disciplines. One need only think in this connection of the arguments put forward in the name of religion on such questions as geocentrism, the history of the world, the gradual development of each human being, the evolution of living things and the origin of mankind. Unfortunately, as the influence of various fundamentalist movements demonstrates, the arguments in question are still to be found today.

Again, history helps us to avoid the mistake which is sometimes termed ‘scientism’, a philosophy according to which only scientific knowledge is truly worthy of the name of knowledge. History shows us how much the criteria of what counts as science have changed over the years. This should dissuade us from supposing that science holds a monopoly on the truth.

4.2. *The just appreciation of one’s own area of expertise*

The foregoing remarks about the history of science may not only prompt us to revise certain opinions about scientific work; they can also bring us to a better understanding of our own field of expertise, whatever that may be. The scientist, after all, is well aware that his knowledge is always in a somewhat precarious condition. He knows that he mustn't treat it as something absolute. This doesn't mean that he lessens its value, simply that he sees it as a part of a wider scientific effort. In this way, he is better able to appreciate the science which is still in the process of development, as well as the science which has already established definite results. The development of science is far from being a purely deductive affair – it calls for imagination and creativity, and even for that sort of 'contemplativeness' which is to be found wherever there is a genuine desire for knowledge.

History shows us that to judge of the truth of a given scientific proposition, we need to be able to place it in a broader context. In the life of the mind, there are certain fundamental options which govern everything else. An awareness of this allows us to see more clearly what intuitions and convictions have guided a particular piece of research.

4.3. *The foundations of science*

We can appreciate the greatness and the fruitfulness of science only when we truly understand its limits. The first of these limits comes from within science itself. For the exactitude and objectivity of science, and the clarity at which it aims, presuppose that the constitutive elements of a given scientific endeavour are properly defined. Yet when we seek rigorous definitions of all relevant terms, it becomes clear that science relies on certain notions which it is not able to define by itself – such things, namely, as force, space, time, matter, energy and so on. All these notions come to science from outside. They depend upon certain basic intuitions, upon that 'first philosophy' which is coaeval with thought itself and of which we are all the heirs.

In this way, science discovers its own foundations, and is thus also brought into contact with philosophy. Just as there was once a time when cetain great thinkers, men such as Descartes, Pascal and Leibniz, could be both scientists and philosophers, so even today every scientist has some philosophy upon which all his research is founded. The study of the history of science makes one aware of this link between science and philosophy. It is interesting in this respect to compare these earlier periods in the history of scientific thought with scientific education today, where the aim is generally to pass on those results which will help the student to gain a professional competence.

A scientific training which takes into account the various stages in the history of science thus enables the student to situate his discipline more successfully. He can learn to see what relation it has to the philosophy of nature, to the study of man himself, and to God.

4.4. *Science and reality*

The wish to come into contact with the real world is an important part of any scientific endeavour. As the criteria of what counts as genuine science show, particularly those which have to do with objectivity and experimental observation, the aim of the scientific method is to give us a more complete understanding of what exists independently of man. No doubt the object of science is something constructed by the mind: the scientist must not take the object with which he has to do, and which he represents by mathematical language or by general concepts, for reality itself. But his intention is always to come into contact with the real world, the existence of which he takes for granted.

Science thus aims at *truth*: and truth is defined by philosophical tradition as the agreement between knowledge and the world exterior to the one who is seeking to know. The scientific endeavour is therefore a movement towards a horizon which cannot be crossed.

Conclusion

In the context of this symposium of the Pontifical Academy of Science, which has education for its theme, it was important to stress that scientific training involves some intellectual elements and some practical ones. Nor should we forget the relations between the people who carry out the work of science, of which work education itself is one part.

Although teaching obviously includes the passing on of information, its aim is also broader than this. This fact is well-reflected by a change in official nomenclature that took place in France recently. What was formerly the 'Ministry of Public Instruction' has become the 'Ministry of National Education'. In other words, the formation given to children and teenagers is not simply to be reduced to a handing-on of items of knowledge; it must have a broader aim. Education has to foster all the various human qualities which will make for an adult life worthy of the name.

The study of science will obviously have an important rôle to play in this context. To complete what has already been said: a place must be found for the history of science within the teaching of the sciences themselves. This seems to me vital if the abstract and theoretical knowledge contained in the sciences is to be communicated in a way that takes into account the student's need for a well-rounded human formation. It is not during history lessons or philosophy lessons that this teaching should take place, but actually as a fundamental part of the scientific teaching itself.

Such an undertaking would seem to me to have a twofold value. In the first place, it would help students to gain a more accurate understanding of the true nature of scientific propositions. Secondly, it would give them a new relation to the scientific knowledge which they possess. One can add also that the study of history, whilst it may 'relativise' knowledge, nevertheless helps the student to develop a certain sympathy with what is unfamiliar. In this way he is better able to appreciate realities which encompass or transcend his own limited area of expertise.

Thus the remarks which I've made in this communication about the importance of the historical point of view are not limited solely to the history of the natural sciences. They also apply to the human sciences, and they have implications for the way that we relate to *any* branch of knowledge. This is particularly true for theology, for the progress which this has made in modern times is bound up with our understanding of history, as the case of biblical studies shows. It is the historical method which allows Christians to read the fundamental texts of their faith in a way that benefits not only their intelligences, but also their moral and spiritual lives.

A PHILOSOPHICAL PLATFORM FOR PROPORTION IN EDUCATION: THE "SCIENTIFIC SUBJECT" AND THE CREATIVE ACT OF THE HUMAN BEING

ANNA-TERESA TYMIENIECKA

Introduction

The Crisis of Science and Culture: The Danger of Overobjectifying and the Dissolution of a Harmonious Worldview

a) When Edmund Husserl in his *Die Krisis der Wissenchaften und des Europäischen Menschentums* called out his alarm signaling the crisis of Occidental science and culture, that work aroused intense intellectual excitement and provoked a discussion that has continued through the decades since. However, the focus of that discussion has changed with time. Husserl's focus was on a sclerosed, rigidly rational approach to scientific inquiry that put science in danger of losing all relation to the world in which it is rooted. True appreciation of the "lifeworld" from which scientific research into the manifestations of reality proceeds was at the heart to his appeal. the essence of his philosophical innovation. An overobjectifying rationalism was confining science to the strictly mathematical description of reality. The effect of this approach was the opening of a gulf between the so-called "hard sciences" and the humanities effecting an alienation of man from himself.

Today our situation has a different aspect. The crisis of Western – and, we can say, of all – culture has deepened, but there has meanwhile occurred a series of transformations in the nature of scientific inquiry such that its relation to the humanities has been revised. The issues involved concern ultimately the human being as an individual and the person in his/her role in life and place in the world.

In an brief discussion here we will show the great relevance of these issues to the matter of education. It is the human being who is meant to be educated, and thus what is fundamentally in question is the human condition in the world of life generally and as specifically human existence. This discussion is fundamental because it is one's worldview that gives one a foothold in existence, gives one's bearings in the world. The directions of one's striving in life are in the balance here.

b) At this stage of our scientific and cultural development, the crisis signaled by Husserl has taken the form of nothing less that the dissolution of the universal worldview that carried humanity over the last few centuries. That worldview, of course, was not static. It had its transitions and stages, which have followed developments in science and human knowledge in general.

But now the inherited, traditional worldview carrying human existence is disintegrating under the impact of an ongoing dissection of man so radical that worldview must be retrieved if the human being is to survive as human. The expansion of scientific knowledge has led to an imbalance view of man. The dazzling discoveries made there have diminished the significance of the reflective side of the human person, that is, his/her stream of emotions, sentiments, desires, expectations, hopes and ideals – a conundrum not entirely thematizable rationally – all of that which constitutes the inward, intimate dimension of the person within which she "dwells" in her very own being and within which she accomplishes her innermost striving for contentment, satisfaction, happiness.

While the hard sciences focus on the discovery of the physical world and its laws, the vast and ramified and ultimately imponderable side of the human being that is his own reflections has been left to the humanities to investigate. While the sciences deal with the objective sphere of reality, the humanities are concerned chiefly with the inner life of the person and with interpersonal relations. Although the sciences touch marginally on our human experience of beauty, solidarity, sympathy, beneficence, etc. (as well as on aggression, etc.), this experience is chiefly the focus of the humanities. Consequently, history, literature, the fine arts, etc. have an essential role to play in the education of the person and the foundation of his worldview, interpersonal life, and ultimate happiness. This side of life that appears at first to be strictly subjective is actually shared by people as sentiments and ideas so that there emerges what Nicolai Hartman called the "objective spirit", the culture of a society at a given time.

c) Plato, who distinguished in the Laws numerous matters indispensable in the education of an accomplished citizen, saw in the interrelations of the various disciplines of learning a harmonious order that he compared to a choral dance. In the Republic he calls for an equilibrium or proportionality to be established between them.

Today it has become urgent to devote some thought to how the effort devoted to education is to be apportioned among the disciplines. Do we focus early on education in a particular field in order to give the student a guarantee of professional success? Or do we make life enjoyment our aim and impart a broad education? For that matter, the question of how much versatility a person may need to be able to respond effectively to changing professional demands is rapidly forcing itself on us. These are the great practical issues underlying contemporary debates over education. The question of balance is of paramount significance for dealing with them adequately.

One postulate comes to the fore: In the formation of the human mind, we have to aim at such a proportionality that in the midst of the stream of unsettling transformations occurring in the world of science and societal life, a harmonious, flexible world view may be acquired so that students may find their bearings, their orientation in existence, their direction in and expectations of life. In order to find optimum equilibrium in all this, we have to spurn any one-sided over concentration on a particular field of study. In avoiding that pitfall the study of philosophy is of great significance for philosophy embraces all fields. In their investigations, therefore, philosophers are positioned to develop an estimation of the specific roles to be played by the various fields in the formation of the mind in their mutual interaction.

But what philosophy can be said to do so free from all presuppositions? Which may be said to be not only sufficiently informed but to have the impartiality to rightly estimate the shape of optimal education? As we have seen, in Husserl's estimation, the traditional accentuated opposition between the hard sciences and the humanities does not allow us to find in them a common denominator. But since his day the situation has changed. On one side, the sciences are transforming themselves from within sua sponte, and on the other side, a philosophy of life has emerged in which the sciences and the humanities may now converse on a common platform.

The proposal of this paper is that this platform is constituted by the coincidence of two developments. First, scientists are tending toward or have arrived at a new conception of the very nature of their pursuits and of the object of their pursuits as well. Second, in the philosophy of life, there has been a deepening recognition and appreciation that the human creative act is the source of all human pursuits, with scientific discovery and invention providing prime examples of that.

I will now review the general situation that has witnessed these developments that now may provide us a platform for balanced education.

Part One

Transformations and Innovative Tendencies in Contemporary Science and the Congruent Insights of the Philosophy of Life

a. We are at a stage of transition in both science and our culture at large. Humanity finds itself in a sharply delineated transition period in all spheres: cultural, social, political, and scientific, which spheres usually coincide. Thus, when the Newtonian science of the seventeenth and eighteenth centuries – which had a deterministic, mechanical model of reality and which presented the world as originating from initial conditions in a strictly mechanical fashion so that all further developments were strictly determined, each being a step in a universal mechanical process, so much so that Laplace claimed that on the basis of it we could predict the future – reverberated through the scientific world and was almost universally accepted, that was because it accorded with the social outlook of the era of the Industrial Revolution, in which society too was viewed mechanistically.

Today we are witnessing the end of the Age of the Machine. This is Alvin Toffler's thesis in his foreword to Ilya Prigogine and Isabelle Stengers' work, Order out of Chaos. Man's New Dialogue with Nature.[1] As Toffler sees it, the deterministic model of the world was under attack already in the nineteenth century with the discoveries in thermodynamics, Darwinian biology, and quantum physics. It could then retain partial validity as a reference point for research and the formulation of issues. But in more recent times science has undergone a truly radical transformation such that the assumption of even a basic order and rationality in nature can no longer be persuasively upheld and is losing ground in a profound reassessment as new models of reality suggest themselves.

[1] Ilya Prigogine and Isabelle Stengers, Order out of Chaos, Man's New Dialogue with Nature (Boulder: New Science Library; New York: Random House, 1984).

As Prigogine, a prominent scientific researcher and interpreter, states, “Our physical world is no longer symbolized by the stable and periodic planetary notions that are at the heart of classical mechanics. It is a world of instabilities and fluctuations, which are ultimately responsible for the amazing variety and richness of forms and structures we see in nature around us”.[2]

With Ilya Prigogine we may speak of a revolution in the scientific outlook, of the birth of a New Science.[3] The emphasis of classical science on the principles of stability, universality, regularity, symmetry, equilibrium recedes from the foreground and is replaced by the evidence of crucially significant states of disorder, arbitrariness, instability, irregularity, disequilibrium.

In all the sciences, not only the life sciences but those of physics, astronomy, mathematics as well, the essential role of change, transformation, evolution, event in the universe, the earth, human society has come to be appreciated. We have become aware of the birth and dispersion of elementary particles and of galaxies too, of changes in chemistry and geological upheavals that would be considered exceptional events in a mechanistic model. These are now considered to be part of a grand but hazy picture, as are the puzzling origins of living beings and the modalities of their differentiation and evolution, as are the unaccountable origins of and shifts in societal norms. The search for answers must correspondingly undogmatic.

This new outlook has proceeded from the “discovery” of time in physics, once almost ignored and now recognized as having crucial significance. The New Science, as presented by Prigogine in his numerous books, offers a “new dialogue” between the human being and nature. At its crux is precisely a reversal in the significance attributed to the temporal aspects of becoming.

b. With the introduction of the notion of “complexity”,[4] encompassing all modes of order and disorder, we witness a bifurcation of hitherto one-sided concepts. For example, there are evident in dynamic systems contrasting processes that conserve energy and dissipate it. Similarly, we see mechanical and thermodynamic equilibria balanced by constraining non-equilibria. Moreover, Prigogine makes a sharp distinction between “closed

[2] Ibid., p. ix.

[3] Gregoire Nicolis and Ilya Prigogine, “Introduction”, Exploring Complexity (New York: W.H. Freeman, 1989), p. ix.

[4] Ibid. pp. 71-141.

systems” in which things originate, change, deteriorate according to fixed patterns and “open systems” in which energy maintains itself.[5] It is the open systems of becoming that are primordial; these are open to exterior forces and exchange of energy, with the environment being susceptible to influences and exercising influence in turn.

The concept of open systems has emerged in response to the issues raised by Darwin’s evolutionary theory and the dynamic systems observed by Prigogine. The common way of conceiving the temporality of becoming has been completely revised. When Ludwig Boltzmann set for himself the task of identifying evolutionary phenomena in the physical sciences analogous to those observed in the life sciences, he found them on the level of populations of molecules. He attempted to describe not only the equilibrium found in a population of molecules but how that equilibrium evolved. In doing so he discovered the irreversibility of the toward-equilibrium process, a time vector similar to that found in the evolution of species.[6]

Critically, Prigogine pursues the notion of irreversibility and attributes it to all open systems.[7] He shows that open systems, whether physical or biological or social, do not proceed in a reversible fashion, that the processes of constructive constitution do not go backwards. On the contrary, they follow a “vector of time”. They are one-way constructions due to this irreversible vector of time.

It is precisely in such open systems having this constructive direction, interacting and exchanging energies with their environments in random, irregular, topsy-turvy fashion that Prigogine sees the initial conditions of becoming. Biological and societal systems present particularly striking open systems. Biology and genetics show us that below the recurrent scheme of life that we conventionally attribute to life’s processes – what is merely an objectified, universalized surface – lie life’s inner workings.[8] Under the surface innumerable sub-systems pulsate, bubble, criss-cross; instead of stability here is constant disorder and fluctuation.[9]

[5] Ibid., pp. 45-71.

[6] Ludwig Boltzmann, Populäre Schriften (1905), (Braunschweig-Wiesbaden: Vieweg, 1979).

[7] Prigogine and Stengers, op. cit., pp. 257-290.

[8] Nowhere do the inner workings of life appear more clearly than in the search for rules of articulation, the formation of models. See Rene Thom, Structural Stability and Morphogenesis: An Outline of General Theory of Models, trans. A.D. Fowler (Reading, MA: W.A. Benjamin, 1975).

[9] See Largeault, Systemes, op. cit. and Thom, “La creation de nouveau...”, op. cit.

The very recognition by scientists of haziness, fleetingness, arbitrariness in physics and then in biology extends to all sectors of reality. In psychology too there is recognition of the turbulent life of the mind at the pre-conscious level. The pre-conscious turmoil of the psyche is also an open as well as closed system or cluster of systems, out of the interplay of which that which is irregular, crooked, fleeting, singular emerges. This is a game of chance factors, necessary dispositions, and the unforeseeable, the unpredictable.[10]

But what is most striking in all this is the rapprochement being achieved between the physical and the human, social, cultural sciences. The realization of the historicity of the human being and the course of society and culture is, following Dilthey, Unamuno, Ortega y Gasset, at the vibrant leading edge of contemporary thought. With Husserl and Heidegger's concept of the lifeworld and with Gadamer and Ricoeur's hermeneutics, this realization has entered literature, linguistics, sociology, political theory. We may safely say that it is transforming the human sciences. The goal in these disciplines is no longer the rigging of rigid, immutable models. The reality of "progress" has been discovered, the critical phases of turbulence, consolidation, and dissipation. With the recognition of the irreversible phenomena of physics and their constitutive propensities together with the vector of time, we are finding common denominators in physics and the human sciences.

The finishing touch of Prigogine's approach to becoming is his conviction that becoming is self-generative. Like Aristotle, Leibniz, Spinoza, Kant, and others, Prigogine believes that becoming emerges "from within", sua sponte.

Here is the gist of the phenomenology/philosophy of life: a coincidence between science and philosophy. Assuming that the varieties of becoming all proceed sua sponte from the interplay of the regular development of forms and irregular, unpredictable conditions, Prigogine suspends the sharp dilemma of determinism and freedom, necessity and chance. Both are at work in the processes of the universe. There is a vast intermediary realm, then, in which it is interrelations that are to be investigated.

Significant in its own way within the modern intrusion of unpredictability into the abstract, mechanical order reigning in classical science

[10] Creation et desordre, recherches et pensees contemporaine (Paris: L'Originel, 1987), (Interviews with Henri Atlan, Guitta Pessis-Pasternak, Gerard Ponthieu, and Michel Treguer).

is “chaos theory”, that is, the study of turbulence. Altogether singular and unrepeatable is the flow of smoke out a chimney. From the same initial conditions, that flow can take innumerably different courses. Consideration of this invites a look into the chaotic disorder behind all ordering, the fleeting behind the fixed.

Furthermore, with recognition of an intrinsic mobility in all physical nature, the radical contrast between spontaneous movement in living beings and inertia in inanimate physical being vanishes. And so the mechanistic model yields to an overall organic model. The organization and finality of physics have thus come to approximate those of the life sciences.

The concept of science has undergone a radical transformation. Indeed, recognition of “chaotic systems”[11] and “catastrophe theory”,[12] has removed the backdrop of a manifest objective order of the universe, world, and life by revealing a turbulence of bubbling energies and forces running at random.

There is a new approach to scientific validity as such. The classical postulates of precision, exactitude, certainty lose their hold on the imagination. We move to viewing a hazy, imprecise, fleeting reality. In this way the “hard” sciences seem to be becoming more like the sciences of life and society.

This movement of the sciences toward each other is particularly obvious in the case of a mathematics that now treats sensitive and qualitative features as well as forms different from those of classical Euclidean geometry. This is the fractal geometry of Nature.[13] Although this geometry was discovered as far back as Leibniz, to whom its present inventor, Benoit Mandelbrot, refers,[14] and although it was somewhat developed at the end of the last century, it has just now gained proper acceptance and appreciation. It concerns the forms of nature, things etc. We are accustomed in life as well as in scientific inquiry to rely on forms, structures, on geometry in general as we deduce it in our constitution of reality. We seek in nature the geometrical relations so constructed. So-called “fractal geometry”, however, looks past the preconceived forms usually seen in nature and the whole

[11] David Ruelle, Hasard et chaos (Paris: O. Jacob, 1991); Ivar Ekeland, Le calcul, l’imprevu (Paris: Seuil, 1984). For fascinating explanations geared to the layman of chaos theory as well as of the related theories making up the “New Science”, James Gleick’s Chaos, Making a New Science (New York: Penguin Books, 1988) is much to be recommended.

[12] Ekeland, op. cit., pp. 122-153.

[13] Benoit B. Mandelbrot, The Fractal Geometry of Nature (updated and augmented), (San Francisco: W.H. Freeman, 1977).

[14] Ibid.

of the reality which science encounters, seeing that there is there a completely different composition of things.

Liberation from Euclidean geometry's circles, squares, cones – into which we have been trying to squeeze reality – shows us the structure of nature's "dislocated" irregularity, all sorts of irregular objects torn, and fluid in their relations, constructs. Here is a new mathematical approach to nature, one freeing it from the absolute rigidity of forms and structures into which classical geometry pressed reality. Going against a growing tendency of formalism in mathematics that leaves behind human intuitive representation, Mandelbrot's fractal approach to reality is all intuitive. His device is, "to see is to believe".

From the side of mathematics, then, comes a revolutionary strong affirmation of the universal significance of the concrete, unrepeatable, unique.

The infinite range of the fractal forms proceeding from mathematical algorithms effects a crucial transition in mathematics from an abstract way of conceiving nature to one which passes into the visual. Mathematics is, as it were, given senses adequate to the riches of objective experience. We move away from the classical prejudice that mathematics involves "calculability" only, in a qualitative, aesthetic expansion of the discipline. The abstract science of mathematics "humanizes" itself!

At the end of this all too short survey of the revolutionary changes in science that have thrown our hitherto cultivated worldview into disarray, recognition is due Alexandre Kojeve for his having brought out the most significant factor of the "subject", the living concrete individual who as an inquirer envisages everything around him/herself, whose role is now universally accepted in physics and the rest of science. In describing the subject's central role in scientific investigation, Kojeve gave it this basic characterization: we should not identify the subject with a mathematical, abstract point, uniform and unchangeable, nor with its biological corporeity, nor as a psychological agent.[15] It remains to be seen how we must conceive of the subject according to its function in investigations.

At this point scientific investigation encounters the Archimedean point of the philosophy/phenomenology of life.[16]

[15] Alexandre Kojeve, L'Idee du determinisme dans la physique classique et dans la physique moderne (Paris: Librarie generale franeaise, 1990).

[16] For a full-fledged study of creative experience, cf. compare Anna-Teresa Tymieniecka, Logos and Life, Book I: Creative Experience and the Critique of Reason, Analecta Husserliana, Vol. XXIV (Dordrecht: Kluwer Academic Publishers, 1988).

c. To conclude our brief account, let us emphasize the striking innovative tendencies in science. 1) The physical and mathematical sciences seem to have abandoned sharp boundaries with biology as well as with the social sciences and cultural inquiries. The strict calculative nature of mathematics has taken on a qualitative aspect. These sciences seem to have become “humanized”. 2) All of the disciplines have become sensitive to time and change. 3) Their theories of becoming and development seem to share some common features. 4) This sharing among the sciences without the breaching of their sharp boundaries does not allow placing them all on equal footing, nor reductively subsuming some under others, but indicates that a dynamic swing of generation, of ordering, of interactivity may well run through the entire gigantic game of existence. 5) With consideration of the transitory dimensions, transitory trajectories of the dynamic complexes of the world, with the shift in focus of thought away from seeking closed reversible systems to apprehending open self-projecting streaks in the cosmos as well as in nature-life and social life as well as appreciating the vast territories of their attunements, interferences, gulfs of mysteries are opened for science to explore.

These are the vast intermediary, unknown areas of interlinkages, generative propensities, and seminal endowments-in-process, ever expanding dynamic spheres of manifestation with their own turmoils advancing and regressing in complexity and quality, with phases of catastrophe and of regulative constructivism that have now become the fascinating areas of secretive reality. They draw our inquisitive mind wider and further. 6) But it is recognition of the central role of the subject in the process of science as such that will offer us a crucial point for the dialogue between philosophy/phenomenology of life and the New Science.

Today’s science is, indeed, offering us elements for a new vision of the universe, nature, society. In fact, the chaotic and turbulent stream, the innumerable streamlets which make up cosmos, nature, life, society and culture, in which from arbitrariness, chaos, chance there emerge segments of ordered world, such that we may acknowledge through our own existence in relatively stable societal, natural, cosmic existential conditions, opens fascinating newly to be formulated issues, views, expectations.

This preeminence given to the turbulent, fluid, accidental, irregular, disorderly in the origination and progress of All does not mean, as I have hinted at a few times, a universal “disorder” or a forsaking of order and rationality. On the contrary, it opens vistas in which we have to ask after the kinds, rules, ways of interlinking, of intermingling, molding..... There are no sharp divides between matter and life, nature and the cosmos, nature and human culture, but vast intermediary spheres which fascinate our imagination.

This calls for the discovery of laws of transitional phases, of coincidence, encounter, and interlinkage, of systems of spontaneous emergence, of spontaneous designs or projects, developments. This also calls for the investigation of the nature of the center point of scientific inquiry, the human subject.

With this we enter into our sphere of the philosophy of life. To a superficial glance it could appear that this new vision of the world, life, cosmos, human social life in superseding classical visions makes philosophy's traditional queries and conceptual frameworks obsolete or that science has simply replaced them. Could philosophy become obsolete, indeed subject to the penetration of scientific inquiry?

Nothing could be more hasty and erroneous. But also nothing could be more preposterous than a philosopher who believes it possible to reach reality through primary experience and the power of speculation while ignoring scientific inquiry.

The striking fact of our present situation is that philosophy needs to consult scientific data, inquiry, methods in order to be able to grapple with reality. The natural and human sciences in turn need a philosophy that is appropriately informed by them for the more profound organization and interpretation of their findings and their own advance.

In short the situation of our culture with all its potentials and hazards calls for an alliance between philosophy and science.

Remarkably enough, the radical new perspectives which science opens fall in line with those being taken by the new philosophy. The phenomenology of life and of the Human Condition emerges like the phoenix from the ashes of traditional thinking.

The project of the philosophy/phenomenology of life and of the Human Condition springs forth from the idea of this alliance. The concept of the ëontopoiesis of life' is the crucial link and vehicle of the project.

In summary, let us emphasize the four pivotal new intuitions shared by the new scientific approach and philosophy/phenomenology of life.

There are indeed, four pivotal intuitions and proceeding from them four critical issues which are the meeting points for the phenomenology/philosophy of life and the sciences of life and the physical sciences in general. These issues also reverberate in our time's preoccupation with order and disorder, necessity, orchestration, etc.

First of all, new awareness of the temporality of events, processes, transformations in the organic as well as in the inorganic sphere has provoked great puzzlement over the nature of "developments", that is, of the irreversible processes that carry life onwards. This is now the central issue of science. Addressing it is the grand idea of formation in which becoming may be grasped – the concept of ontopoietic unfolding, which constitutes the ontologico-metaphysical axis of becoming as such as well as of becoming in its lineaments. This is the fulcrum of the phenomenology-philosophy of life.

The second pivotal point of encounter between the sciences of life and philosophy of life is the whole question of the formation of "complexities" which confronts the sciences of life and of all reality "from physics to politics".[17] Whether the complex reality we are facing be a living being, a society, a political state, a work of art, etc., we intuit that here is an ultimate manifestation of "self-organization". On all levels phenomenology of life apprehends this ontopoietic process unfolding from within and directed by the guidelines intrinsic to the complexity-in-formation, beingness, entity.

Thirdly, philosophy of life and the sciences of life meet in the intuition of the guiding entelechial sequence of life's unfolding, the linkage between individuation and speciation, the individual and the evolution of forms.

Fourthly, and most importantly, science and philosophy of life meet in the intuition of the Archimedean point that is the ground for inquiry into all existence, that is, the creative condition of the investigator, whether experimenting, or observing, or speculating.

This convergence in philosophy/phenomenology and the physical and life sciences of intuitions striking the same chords on the crucial issues of our culture has yielded an universal platform of the sntopoiesis of life upon which the great issues may be envisaged anew.

Therefore we will enter into our analysis of these essential correspondences by discussing the convergence between the "physical subject" of scientific experimentation and the creative human act and the more fundamental ontopoiesis of life.

[17] See Creation et desordre, op. cit., pp. 13-53.

Part Two

1. The Creative Act of the Human Being as the Archimedean Point of the Encounter between Science and Philosophy of Life

a. The "Physical Subject" in Scientific Inquiry and the Creative Mind

It is on the point of the inquirer as "subject", as the concrete center of any investigation, a point now recognized by the New Science, that science and philosophy of life and of the human creative condition arrive at a crucial understanding. Listening to an experimental scientist talk about his experience, we enter into the heart of the matter:

It is an experience like no other experience I can describe, the best thing that can happen to a scientist, realizing that something that's happened in his or her mind exactly corresponds to something that happens in nature. It's startling every time it occurs. One is surprised that a construct of one's own mind can actually be realized in the honest to goodness world out there. A great shock, and a great joy.[18]

The experiences of the scientific discoverer are not like any other. It is an experience of the creative mind. It is precisely the creative human mind immersed in the natural, physiological, psychic, intellectual circuits of an individual human person engaged in creative activity that calls up from its innermost core such powers as allow him or her to meet the powers of nature itself. The phenomenology of life and of the human condition proposes an evolutionary phase in which emerged the human creative condition accounting for this extraordinary synchronization of functions, energies for the constructive application of powers, for this extraordinary condensation of the entire spectrum of the universal conditions that the human creative mind emerged from, a mind that is not only capable of objectifying, differentiating, and charting the immensity of the real in which other beings are passively immersed in and participate in, but is – at the summit of its powers – capable of entering into the inner workings of that reality.

Hence it is from the point of investigation into the human creative genius that it is appropriate to enter into the exploration of reality. Here is our Archimedean fulcral point from which to probe all existence. Along these lines we pay close attention to Alexandre Kojeve as he describes his

[18] Leo Kadanoff, quoted in James Gleick, Chaos, Making a New Science (New York: Penguin Books, 1988), p. 189.

views as a physical scientist on the human subject as the reference point of scientific inquiry, of all inquiry. Kojeve – in his magisterial analysis of the basis upon which was founded the causal determinism of classical physics and of the principles by which it was undermined – elucidated the interpretation given by Niels Bohr to the arguments presented by Heisenberg on the essential and unavoidable imprecision of any attempt to examine the world physically, on the impossibility of speaking in physics of "exact causality in the structure of the world".[19] Bohr's interpretation is, according to Kojeve, a mathematical expression of an absolutely general principle according to which no physical observation is possible without the state of whatever is observed being modified "by the very fact that it is observed"[20]

It is not that physicists were not over time aware of this "gnoseological" state of affairs, but it was Heisenberg who drew all the conclusions together. These conclusions could have been drawn already within classical physics. According to Kojeve, "a necessary consequence of the classical principle of the equality of action and reaction is: if a physical entity is observed that means that it 'acts' upon the instrument of observation; this instrument has then necessarily from the outside 'acted' upon it and modified it in a certain fashion".[21] That is to say, with Heisenberg and Bohr it is the nature of experience and experimenting in physics that was brought into focus. With the theoretical assumption that physics deals with the real world and with the concepts which ultimately may be brought to experimental data, Bohr specified that physics does not deal with one world system as it is in itself but with two systems: the system of the observed and the system of the observer.

There is no way in physics to change the fact that it moves along the borderline between these two systems, which are both opposed and inseparable. Kojeve specifies: "In effect, the observed system is not accessible to experience unless insofar as it is in an interaction with the observing system, modifying it, and is in turn being modified by it".[22]

There are two consequences of this capital recognition. One of them leads Kojeve to affirm that it constitutes a principle rejecting classical causal determinism in physics, effecting the passage to modern physics which holds that physics does not study the world "in itself" as idealized

[19] Kojeve, L'Idee du determinisme, op. cit., p. 152.
[20] Ibid.
[21] Ibid., p. 154.
[22] Ibid., p. 157.

by the spirit but the world which is real and is given in experimentation and observation, in experience, that is, made by scientists with real, physical instruments, scientists who themselves are part of the real physical world that they study. The second conclusion that we may draw with Kojeve from Bohr's analysis is the clarification, elucidation of the situation of scientific experience as such. This clarification leads to the definitive acceptance of the physical subject at the center of physical inquiry, which subject belongs to the real world and simultaneously observes it and acts upon it, reaction to which in the world physics obtains in its data later.

Here comes the fascinating question of just how we should understand this subject in scientific experience. Philosophers have long since discussed these things and various of their formulations have thrown up distorting grids between the real world and the perceiving, experimenting subject. The main requirement of the new science is that the subject be seen as belonging to the same ontological region as the world and as interacting with it. In any case, I claim that given all this we cannot continue to consider cognition to be the main factor in scientific experience.

True, Heisenberg in discussing his "idealized" experiences emphasizes that he is discussing the cognition of the real but not the real itself. (This is also the view of Stanley Salthe, who throughout his book Development and Evolution, Complexity and Change in Evolution, to which we will return later, emphasizes that physics is talk about the 'discourse' concerning reality and not about reality itself.[23] But in a 'discourse' approach the subject is of the same significance discussed above, since he is the author of the discourse).

However, I propose that we ask ourselves what we must understand in speaking of the subject in the experience of scientific inquiry; we have to turn our attention to the collection of scientific data, their "verification" through technology. In the perspective of this collection we find a direct interference of the subject in the real, physical nature of the world. It is not discourse about this nature that makes it possible for the inventor to apply physical principles, to put material, physical materials to use. I submit that we must keep this point in mind as we seek a more adequate description of the subject in experimental experience and that we should seek it elsewhere

[23] Stanley Salthe, Development and Evolution, Complexity and Change in Biology (Cambridge, MA: MIT Press, 1993), p. 44: "Once more I remind the reader that what I am talking about is not the world but discourse".

than solely in the cognitive faculties of the human being. These faculties have to be acknowledged to belong essentially to processes deeper than our experimenting and law formulating. We reach the workings of nature under a yet deeper jurisdiction.

To state our problem in its fullness let us call it after Bohr the problem of the relationship between the system of the observer and the system being observed.[24]

A. If we attempt to analyze these systems, we find that the subject in the experience has to be a real physical, physiological being in order to belong to the real world. But physics, and science generally, is not interested in the variables that account for the singular features of a phenomenon. On the contrary, science is concerned with the constants. Consequently, we cannot conceive of the subject as being a singular individual with varying tastes, capacities, tendencies, etc. Inasmuch as the subject has to be concrete living being, we have to make an abstraction of its singularities and focus on its universal/concrete individuality. According to Kojeve, the "physical subject" is a physical entity insofar as it is represented by a system of physical entities".[25]

B. To its system must belong the entire schema of a specifically human personality embodied within a physical, biological framework. Here is a specific type of personality which is inclined toward and endowed with the capacities for scientific inquiry and it assumes various constant forms in accord with the special scientific interests of scholars.

C. How could we conceive of the scientific subject otherwise than as one endowed not only with all the elementary sensory, emotional, and valuating faculties making it an integral participant in nature/world, but with a mature human mind with its focusing, deliberating, calculating, and speculative powers? How could any observer not endowed with these three modes of operating even approach reality?

And yet, this is not enough. In order to complete the picture we have to acknowledge the great lights that throw it in relief. This entire system would not fulfill the expectations we commonly have of it if it did not rotate in all its aspects around the Archimedean point that is its specific but constant axis: the creative virtualities subtending the mind – the creative imagination inspiring it and the creative act bringing that imagination to its unique fruition.

[24] Niels Bohr, Die Naturwissenschaften (quoted by Kojeve, op. cit.).
[25] Kojeve, op, cit., p. 167.

If we unfold the "creative system" of the human being as the scientific subject, we will understand it in the light of what is accomplished in this extraordinary interaction between the technical application of science and the workings of nature. We will also unroll and circumscribe the creative compass of all the spheres of reality/life in which the living creative subject has to participate in order to assume the role of the observer or experimenter, or discoverer, inventor, creator.

In short, I submit that only the creative mind of the human being can fulfill all the conditions set by Kojeve, first, and most significantly, by legitimating its extraordinary vantage point and second by introducing us into the hidden spheres of reality itself.

b. The Circuits of Reality Revealed through the Creative Act of the Human Being

The thesis of the argument we will present may be summarized as follows. Within the mental, cultural, and vital expanse of the living human being there are present peculiar vestiges of all the molds in which living beingness has progressively unfolded from the womb of the biosphere, of all the degrees of life's inward/outward directed system of unfolding. As the study of phylogeny and ontogeny shows us, none of these constructive steps can be omitted in the progression to the next level. This means that the human individual stretches vitally throughout space within the Human Condition.

But let us now begin our argument within our own context, showing that it is in the creative act that the human being retrieves the fruits of its unfolding.[26] Where physics begins with the most fundamental elements of the real, in following the creative act of the human being, we have to distinguish first the sphere of the spirit and intellect of the human being – what is most directly engaged in the intuitive, exploratory, inventive, and creatively imaginative processes. But following this thread we are led to the vast turmoil of the individual psychic life of the human person. Here, first of all, a person gathers a conundrum of habits, predilections, scales and categories of evaluation which permeate his or her functional system. All this, however, is to some or other degree conducted or inclined by the per-

[26] For this context, see Anna-Teresa Tymieniecka, Logos and Life, Book 1: Creative Experience and the Critique of Reason, Analecta Husserliana, Vol. XXIV (Dordrecht: Kluwer Academic Publishers, 1988).

sons's will, aspirations, curiosities. We must recognize that personal factors in our psychic functional system command our feelings, emotions, wishes, aspirations, and the like and have an overall combinatorial tendency to bring the turmoil of disparate acts into some cohesive constructive composition whether merely to serve the demands of survival or at higher levels personal satisfaction, a sense of accomplishment.

We will see this psychic openness to constitutive modes much more clearly still if we will consider that it is immersed in a quite different preconscious turmoil, a turmoil involving the arbitrary and deformed.

And the intuition of Heraclitus comes to mind who, as interpreted by William Capelle, says: "Die Natur der Welte enthuelle sich ihm als er in die Tiefen seiner eigenen Natur hinabsteig".[27]

The idea of the human being as a cosmos in filigree is as old as Western Philosophy. Already with the Pre-Socratics Anaximander speaks of the cosmos as mirroring the human social order insofar as it indicates that its composite elements are to be kept within the confines of "justice" and "retribution".[28] Pythagoras draws a parallel between the "harmony" he conceives to be central to the order of the cosmic spheres and the human being in whom body and soul have to work together in harmony on a miniature scale.

This idea of the human being as presenting in miniature the whole of cosmos is reflected in Plato – in the Timaeus 35 A – when he draws a figure of the human soul and its combining opposite strivings toward the "pure" world of ideas and the "lower" world of the body as a charioteer driving two horses with great difficulty, for reason and irrational desires do not easily carry on together. The soul by partaking in both worlds plays a median role between them.

But it is in Leibniz's concept of the monad that we find the most striking picture of all living beings – each is animated, alive, and reflects the entire universe. It does so according to its own expansion and in its own perspective. Each living being is an embodiment of the universe, its living

[27] William Capelle, Die Vorsokratiker, die Fragmente und Quellenberichte übersetzt und eingeleitet (Leipzig: A. Kroner, 1935), p. 148. In my monograph "The Great Plan of Life" in Anna-Teresa Tymieniecka (ed.), Phenomenology of Life and the Human Creative Condition. Book 1: Laying Down the Cornerstones of the Field, Analecta Husserliana, Vol. LII (Dordrecht: Kluwer Academic Publishers, 1997), I quote and discuss this fragment.

[28] Rudolf Allers, "Microcosmos from Anaximander to Paracelsus", Traditio 2 (1944), pp. 319-409.

transposition in filigree, pulsating with the universe's life on its very own. Leibniz saw infinite gradations in the complexity and modes of nature, each of them reflecting the universe in its making.[29]

In his conceiving of the individual living being as a monad, Leibniz emphasized the reasons why "each created monad represents the whole universe".[30] He brings out first his general metaphysical concept that all there is interconnected. We read earlier,

For everything is a plenum, so that all matter is bound together, and every motion in this plenum has some effect upon distant bodies in proportion to their distance, in such a way that every body not only is affected by those which touch it and somehow feels whatever happens to them but is also, by means of them, sensitive to others which adjoin those by which it is immediately touched. It follows that this communication extends to any distance whatever. As a result, every body responds to everything which happens in the universe, so that he who sees all could read in each everything that happens anywhere, and, indeed, even what has happened and will happen, observing in the present all that is removed from it, whether in space or in time "All things are conspirant", as Hippocrates said.[31]

And then, to come back to the passage previously quoted explaining how the monad may mirror the entire universe, he writes:

Thus, although each created monad represents the whole universe, it represents more distinctly the body which is particularly affected by it and of which it is an entelechy. And, as this body represents the whole universe by the connection between all matter in the plenum, the soul also represents the whole universe in representing the body which belongs to it in a particular way.[32]

The great question is what is the "position" of the human mind such that we may attribute to it the power to descend into the inner workings of becoming and to then lift them up from their particular irregular/regular, chaotic/leading mix to an ordering, seemingly separated from that mix and in fact involving intermediary territories. What "sight" sees into this

[29] Gottfried Wilhelm Leibniz, Monadology, ed. and trans. Leroy E. Loemker, in Gottfried Wilhelm Leibniz, Philosophical Papers and Letters (Chicago: University of Chicago Press, 1956), 2 vols.

[30] Ibid., p. 1055.

[31] Ibid., pp. 1054-1055.

[32] Ibid., p. 1055.

immeasurable turmoil in which no order, no reason is visible and then distills sense from its fragments, truncated pieces, segments of ordering-in-process and by innumerable nudges provokes recognition of the wealth of rationalities which are projected by the conjunction of hazard and necessity in their constructive game?

We submit that it is precisely in the transitory phase of the Human Condition that we have within the topsy-turvy flux of constructive/destructive, advancing/receding progress within the distorted and yet constant "unity-of-everything-there-is-alive" an effervescence of the vast intermediary phase stretching from the life process getting ready for its constructive swing to the radical transition in which self-enclosed inner direction shifts toward an ever widening opening for interaction with the environment, interaction in which the soul in its "highest" swing enters into the entire spread of the "lower" bodily, organic and inorganic functioning of nature-life as well as the cosmic dynamism.

The imaginary intuitions of the Greeks, the metaphysical speculations of the moderns find an echo in the contemporary approach with its reformulations and adumbrations – its opening horizons. First, the human microcosmic realm at every moment gathers into its composition the functioning of the various preceding phases of the evolutionary process; nothing is lost; all is revaluated with respect to the new virtualities currently being activized.

We have confirmation of this in science. Paleolontologists in reconstructing the intermediary stages of the brain's development from anthropoid to full human being have found an incremental enlargement of the brain. At the same time neuropsychologists have demonstrated that the human brain is composed of three spheres of functioning that are all the time actively adjusting to each other. That is to say, homo sapiens has three brain centers, the reptilian brain, the mammalian brain, and the human brain. The reptilian brain evolved first and is still maintained in the human brain. Reptiles are characterized by lack of care for their offspring. When the mammalian brain evolved millions of years later as an extension of the reptilian brain, the reptilian brain did not vanish. It remained to provide the instinctive responses needed for individual survival, while the mammalian brain extended the individual's concern to the care and survival of its offspring and its group as well, but not beyond that. We see this at work in present-day animals. Some of them, like birds, display a solidarity with their whole flock. The brain specific to humans sustains what I call "creative" activity. It allows the expansion of the social, cultural world, while relying on the instinctive and caring responses of the reptilian and mammalian brains.[33]

This "third phase" in the human brain's development was marked by the growth of the neocortex. Its development made the median position of the human being possible. Self-individualizing beingness unfolded its latent powers, virtualities, valuating capacity at this stage allowing an outburst of personal freedom by which the individual may take in hand, at least partly, its own course, forging its own identity and destiny. This is the grand transitory phase in which all that was tending precisely toward such a liberation of the latent faculties of living beings saw the dawn of the Human Condition. A measure of freedom was realized within individualizing existence. All the preceding threads of the self-individualization of life have been gathered up and reworked in the accomplishment of this transition. The individual may now employ for itself all of life's streaks of energy, forces, segmented integrations, disintegrations, powers to mold its own functioning in novel significant fashions. This is what the creative virtualities of the Human Condition offer.

Thus the human condition becomes a relatively stable station in the process of life's game, a station processing all the material coming from the "lower" circuits of existence for the establishment of a "higher" region, that of the creative mind. The novum which the human condition as a phase in the progress of life presents is precisely creative virtualities attuned to the unique conglomerate of functions gathered up in this constructive passage.

The creative act of the human being in its meanders yields insight into the "creative forge", the sphere in which our specific, singular objective oriented creative process encounters its source. The source is the human being who carries out the creative quest. In this quest the human being descends not only into the originary moment of the singular creative process but most significantly into the networks of its existential/vital functions, which carry the creative quest as such. He discovers that the specific creative search after a shape, a form, or a substance for an object in view is carried on by a shifting schema of functions in which all of the individual's powers – the intellectual, imaginative, sentient, volitional, physiological – are involved in specific ways, employed from a center, this center being the fulcrum of force, the agency in which all the powers are gathered and from which they flow with roles being assigned them. In short, there is an "agency" in the performance of the creative act who plays all the strings that radiate in all direc-

[33] Stephen Jay Gould, Ontogeny and Phylogeny (Cambridge, MA: Belknap Press, 1977).

tions, a “power” that gathers and distributes, directs and controls every move, a central distributor of forces and roles, a full-fledged conscious being who is obviously self-governing and self-initiating in its acts. This so ramified, versatile, imaginative, and powerful constitutive act fulgurates from its innermost. It is a simultaneous orchestration of all the faculties under the aegis of a creative imagination that projects possibilities, of an intelligence that scrutinizes, compares, differentiates, etc., and of an effective will which prompts the search and the progress. All of these faculties represent the dynamic complex of the living individual carrying the process and determining its self-promoted constructive/interpretive route. Here we gain access to the inner virtualities, freely projected from within in consistent albeit fluctuating and changeable directions as trial and error dictate – directions whose sequence itself knows interchangeability and mutability, is uncertain in its steps, and yet, as fragile as it may be and as unpredictable as its outcome may be, being subject to disruption and periods of stagnation, still advances with a discrete continuity/discontinuity of purpose. In all its potentialities, virtualities, advantageous situations for their actualization as well as hindrances, through progressive steps, this is a self-projecting, self-organizing system of meaning by which an entity, an object, a creation is produced by human acumen and power as it were crystallized.[34] These poietic threads reveal the lines human functional powers follow and the poietic selfhood of the human being as a projecting and effectuating agent.

Drawing a conclusion from the above, we may recapitulate by stating that it is due to the creative virtualities of the human condition – as a station in the evolving progress of types with all their ties to the cosmos and its laws and to the biosphere – that the human creative act may progressively penetrate into all the spheres of existence, of life, the reality in which this station is not always openly rooted but out of which it has developed in stages maintaining permanent ties.[35] Since these developmental stages represent the becoming of the universe of life, we find here a new version of the Leibnizean monad that “reflects” the entire universe. But as we will see in our further analysis, this is a different type of monad.

[34] For a fuller treatment of cultural creation, see Anna-Teresa Tymieniecka, Logos and Life, Book 3: The Passions of the Soul and the Elements in the Ontopoiesis of Culture. The Life Significance of Literature (Dordrecht: Kluwer Academic Publishers, 1990).

[35] See my elaboration of the Human Condition in Anna-Teresa Tymieniecka, “The First Principles of Phenomenology of Life”, Analecta Husserliana, Vol. XVII (Dordrecht: D. Reidel, 1978).

The significance lies in the elucidation of in virtue of what the creative act of the human being may penetrate into the innermost workings of nature, existentially partaking of the interaction which the living being maintains with them. For this is what makes the creative human individual unique and what must be taken into account in appreciating him or her as the "subject" in scientific experimentation and experience.

c. Having reached with the human creative act not only the point of the encounter with the discovery endeavor of the scientist but also with that of the writer, artist, choreographer, poet and of every undertaking of the human being aiming at the grasp, ciphering and formulation of reflective experience, we may indeed, establish a platform for the investigation of all human endeavor in respect to the functions of the mind and of their life significance. A vast field upon which education may seek to project the ordering of its "choral dance".

THE PONTIFICAL ACADEMY OF SCIENCES: A HISTORICAL PROFILE

MARCELO SÁNCHEZ SORONDO

Pio XI, 'Motu proprio De Pontificia Academia Scientiarum, 28.10.1936', in *AAS 28* (1936), pp. 421-452; Giovanni Paolo II, 'Discorso alla Pontificia Accademia delle Scienze in occasione del 1000 anniversario della nascita di A. Einstein, 10.11.1979', in *Insegnamenti II*, 2 (1979), pp. 1115-1120; 'Discorso in occasione del 500 della Rifondazione', in *Insegnamenti IX*, 2 (1986), pp. 1274-1285; 'Discorso in occasione della presentazione dei risultati della Commissione di studio sul caso Galileo, 31.10.1992', in *Insegnamenti XV*, 2 (1992), pp. 456-465; 'Messaggio in occasione del 600 della Rifondazione, 22.10.1996', in *EV 15*, pp. 1346-1354.

I. The nature and goals of the Academy. II. A historical survey: from the Accademia dei Lincei to today's Pontifical Academy of Sciences. III. The role of the Academy in the dialogue between scientific thought and Christian faith.

I. The Nature and Goals of the Academy

The Pontifical Academy of Sciences has its origins in the Accademia dei Lincei ('the Academy of Lynxes') which was established in Rome in 1603, under the patronage of Pope Clement VIII, by the learned Roman Prince, Federico Cesi. The leader of this Academy was the famous scientist, Galileo Galilei. It was dissolved after the death of its founder but then recreated by Pope Pius IX in 1847 and given the name 'Accademia Pontificia dei Nuovi Lincei' ('the Pontifical Academy of the New Lynxes'). Pope Pius XI then refounded the Academy in 1936 and gave it its present name, bestowing upon it statutes which were subsequently updated by Paul VI in 1976 and by John Paul II in 1986. Since 1936 the Pontifical Academy of Sciences has been concerned both with investigating specific scientific subjects belonging to individual disciplines and with the promotion of interdisciplinary co-operation. It has progressively increased the number of its Academicians and the international character of its membership.

The Academy is an independent body within the Holy See and enjoys freedom of research. Although its rebirth was the result of an initiative promoted by the Roman Pontiff and it is under the direct protection of the ruling Pope, it organises its own activities in an autonomous way in line with the goals which are set out in its statutes: 'The Pontifical Academy of Sciences has as its goal the promotion of the progress of the mathematical, physical and natural sciences, and the study of related epistemological questions and issues' (Statutes of 1976, art. 2, § 1). Its deliberations and the studies it engages in, like the membership of its Academicians, are not influenced by factors of a national, political or religious character. For this reason, the Academy is a valuable source of objective scientific information which is made available to the Holy See and to the international scientific community.

Today, the work of the Academy covers six main areas: a) fundamental science; b) the science and technology of global questions and issues; c) science in favour of the problems of the Third World; d) the ethics and politics of science; e) bioethics; and f) epistemology. The disciplines involved are sub-divided into nine fields: the disciplines of physics and related disciplines; astronomy; chemistry; the earth and environment sciences; the life sciences (botany, agronomy, zoology, genetics, molecular biology, biochemistry, the neurosciences, surgery); mathematics; the applied sciences; and the philosophy and history of sciences.

The new members of the Academy are elected by the body of Academicians and are chosen from men and women of every race and religion on the basis of the high scientific value of their activities and their high moral profile. They are then officially appointed by the Roman Pontiff. The Academy is governed by a President, appointed from its members by the Pope, who is helped by a scientific Council and by the Chancellor. Initially made up of eighty Academicians, of whom seventy were appointed for life, in 1986 John Paul II raised the number of members for life to eighty, side by side with a limited number of Honorary Academicians chosen because they are highly qualified figures, and others who are Academicians because of the posts they hold, amongst whom: the Chancellor of the Academy, the Director of the Vatican Observatory, the Prefect of the Vatican Apostolic Library, and the Prefect of the Vatican Secret Archive.

In conformity with the goals set out in its statutes, the Pontifical Academy of Sciences 'a) holds plenary sessions of the Academicians; b) organises meetings directed towards the progress of science and the solution of technical-scientific problems which are thought to be especially important for the development of the peoples of the world; c) promotes scientific inquiries and research which can contribute, in the relevant places and organisations, to the investigation of moral, social and spiritual questions; d) organises conferences and celebrations; e) is responsible for the publication of the deliberations of its own meetings, of the results of the scientific research and the studies of Academicians and other scientists' (Statutes of 1976, art. 3, § 1). To this end, traditional 'study-weeks' are organised and specific 'working-groups' are established. The headquarters of the Academy is the 'Casina Pio IV', a small villa built by the famous architect Piero Ligorio in 1561 as the summer residence of the Pope of the time. Surrounded by the lawns, shrubbery and trees of the Vatican Gardens, frescoes, stuccoes, mosaics, and fountains from the sixteenth century can be admired within its precincts.

Every two years the Academy awards its 'Pius XI Medal', a prize which was established in 1961 by John XXIII. This medal is given to a young scientist who has distinguished himself or herself at an international level because of his or her scientific achievements. Amongst the publications of the Academy reference should be made to three series: *Scripta Varia*, *Documenta*, and *Commentarii*. The most important works, such as for example the papers produced by the study-weeks and the conferences, are published in the *Scripta Varia*. In a smaller format, the *Documenta* series publishes the short texts produced by various activities, as well as the speeches by the Popes or the declarations of the Academicians on subjects of special contemporary relevance. The *Commentarii* series contains articles, observations and comments of a largely monographic character on specific scientific subjects. The expenses incurred by the activities of the Academy are met by the Holy See.

During its various decades of activity, the Academy has had a number of Nobel Prize winners amongst its members, many of whom were appointed Academicians before they received this prestigious international award. Amongst these should be listed: Lord Ernest Rutherford (Nobel Prize for Physics, 1908), Guglielmo Marconi (Physics, 1909), Alexis Carrel (Physiology, 1912), Max von Laue (Physics, 1914), Max Planck (Physics, 1918), Niels Bohr (Physics, 1922), Werner Heisenberg (Physics, 1932), Paul Dirac (Physics, 1933), Erwin Schroedinger (Physics, 1933), Sir Alexander

Fleming (Physiology, 1945), Chen Ning Yang (Physics, 1957), Rudolf L. Mössbauer (Physics, 1961), Max F. Perutz (Chemistry, 1962), John Eccles (Physiology, 1963), Charles H.Townes (Physics, 1964), Manfred Eigen and George Porter (Chemistry, 1967), Har Gobind Khorana and Marshall W. Nirenberg (Physiology, 1968). Recent Nobel Prize winners who have also been or are presently Academicians may also be listed: Christian de Duve (Physiology, 1974), Werner Arber e Geroge E. Palade (Physiology, 1974), David Baltimore (Physiology, 1975), Aage Bohr (Physics, 1975), Abdus Salam (Physics, 1979), Paul Berg (Chemistry, 1980), Kai Siegbahn (Physics, 1981), Sune Bergström (Physiology, 1982), Carlo Rubbia (Physics, 1984), Rita Levi-Montalcini (Physiology, 1986), John C. Polanyi (Chemistry, 1986), Jean-Marie Lehn (Chemistry, 1987), Joseph E. Murray (Physiology, 1990), Gary S. Becker (Economics, 1992), Paul J. Crutzen (Chemistry, 1995), Claude Cohen-Tannoudji (Physics, 1997) and Ahmed H. Zewail (Chemistry, 1999). Padre Agostino Gemelli (1878-1959), the founder of the Catholic University of the Sacred Heart and President of the Academy after its refoundation until 1959, and Mons. Georges Lemaître (1894-1966), one of the fathers of contemporary cosmology who held the office of President from 1960 to 1966, were eminent Academicians of the past. Under the Presidency of the Brazilian biophysicist Carlos Chagas and of his successor Giovanni Battista Marini-Bettòlo, the Academy linked its activity of scientific research to the promotion of peace and the progress of the peoples of the world, and dedicated increasing attention to the scientific and health care problems of the Third World. The Presidency of the Academy is presently entrusted to the Italian physicist, Nicola Cabibbo.

The goals and the hopes of the Academy, within the context of the dialogue between science and faith, were expressed by Pius XI (1922-1939) in the following way in the *Motu Proprio* which brought about its refoundation: 'Amongst the many consolations with which divine Goodness has wished to make happy the years of our Pontificate, I am happy to place that of our having being able to see not a few of those who dedicate themselves to the studies of the sciences mature their attitude and their intellectual approach towards religion. Science, when it is real cognition, is never in contrast with the truth of the Christian faith. Indeed, as is well known to those who study the history of science, it must be recognised on the one hand that the Roman Pontiffs and the Catholic Church have always fostered the research of the learned in the experimental field as well, and on the other hand that such research has opened up the way to the defence of the deposit of supernatural truths entrusted to the Church...We promise again, and it is our strongly-held intention, that the 'Pontifical Academicians', through their work and our Institution, work ever more and ever more effectively for the progress of the sciences. Of them we do not ask anything else, since in this praiseworthy intent and this noble work is that service in favour of the truth that we expect of them' (*AAS* 28, 1936, p. 427; Italian translation, *OR*, 31.10.1936).

After more than forty years, John Paul II once again emphasised the role and the goals of the Academy at the time of his first speech to the Academicians which was given on 10 November 1979 to commemorate the centenary of the birth of Albert Einstein: 'the existence of this Pontifical Academy of Sciences, of which in its ancient ancestry Galileo was a member and of which today eminent scientists are members, without any form of ethnic or religious discrimination, is a visible sign, raised amongst the peoples of the world, of the profound harmony that can exist between the truths of science and the truths of faith...The Church of Rome together with all the Churches spread throughout the world, attributes a great importance to the function of the Pontifical Academy of Sciences. The title of 'Pontifical' given to the Academy means, as you know, the interest and the commitment of the Church, in different forms from the ancient patronage, but no less profound and effective in character. As the lamented and distinguished President of the Academy, Monsignor Lemaître, observed: 'Does the Church need science? But for the Christian nothing that is human is foreign to him. How could the Church have lacked interest in the most noble of the occupations which are most strictly human – the search for truth?...Both believing scientists and non-believing scientists are involved in deciphering the palimpsest of nature which has been built in a rather complex way, where the traces of the different stages of the long evolution of the world have been covered over and mixed up. The believer, perhaps, has the advantage of knowing that the puzzle has a solution, that the underlying writing is in the final analysis the work of an intelligent being, and that thus the problem posed by nature has been posed to be solved and that its difficulty is without doubt proportionate to the present or future capacity of humanity. This, perhaps, will not give him new resources for the investigation engaged in. But it will contribute to maintaining him in that healthy optimism without which a sustained effort cannot be engaged in for long' ('Discorso alla Pontificia Accademia delle Scienze, 10.11.1979', in *Insegnamenti*, II, 2 (1979), pp. 1119-1120).

It was precisely in that speech that John Paul II formally called on historians, theologians and scientists to examine again in detail the Galileo case.

And he asked them to do this 'in the faithful recognition of errors, by whomsoever committed', in order to 'remove the distrust that this case still generates, in the minds of many people, placing obstacles thereby in the way of fruitful concord between science and faith' (*ibidem*, pp. 1117-1118).

II. A historical survey: from the Accademia dei Lincei to today's Pontifical Academy of Sciences

The historical itinerary of the Academy is summarised in the articles written by Marini-Bettòlo (1986) and by Marchesi (1988), and in broader fashion in the monograph by Régis Ladous (1994). As was observed at the beginning of this paper, the roots of the Pontifical Academy of Sciences are to be traced back to the post-Renaissance epoch. Its origins go back to the ancient Accademia dei Lincei, established in 1603 by Prince Federico Cesi (1585-1630) when he had just reached the age of eighteen. Cesi was a botanist and naturalist, the son of the Duke of Acquasparta, and the member of a noble Roman family. Three other young men took part in this initiative: Giovanni Heck, a Dutch physician aged twenty-seven; Francesco Stelluti di Fabriano; and Anastasio de Filiis de Terni. Thus it was that the first Academy dedicated to the sciences came into being, and it took its place at the side of the other Academies – of literature, history, philosophy and art – which had arisen in the humanistic climate of the Renaissance. The example of Cesi and of the group of scholars led by him was followed some years later in other countries – the Royal Society was created in London in 1662 and the Académie des Sciences was established in France in 1666.

Although he looked back to the model of the Aristotelian-Platonic Academy, his aim was altogether special and innovative. Cesi wanted with his Academicians to create a method of research based upon observation, experiment, and the inductive method. He thus called this Academy 'dei Lincei' because the scientists which adhered to it had to have eyes as sharp as lynxes in order to penetrate the secrets of nature, observing it at both microscopic and macroscopic levels. Seeking to observe the universe in all its dimensions, the 'Lincei' made use of the microscope (*tubulus opticus*) and the telescope (*perspicillus-occhialino*) in their scientific research, and extended the horizon of knowledge from the extremely small to the extremely large. Federico bestowed his own motto on the 'Lincei' – '*minima cura si maxima vis*' ('take care of small things if you want to obtain the greatest results').

The Cesi group was also interested in the new scientific and naturalistic discoveries then coming from the New World, as is demonstrated by the most significant works of the college of the first 'Lincei' – the *Rerum medicarum thesaurus novae Hispaniae*, later known as the *Tesoro Messicano*, which was printed in Rome in 1628. This was a very extensive collection of new geographical and naturalistic knowledge, and contained in addition accounts of explorations carried out in the Americas.

From the outset the Academy had its ups and downs. A few years after its foundation it was strongly obstructed by Cesi's father because he believed that within it activity was being engaged in which was not very transparent in character – for example, studies in alchemy. But after the death of Federico's father, the abundant economic resources which were now obtained thanks to Federico's inheritance, as well as the fact that renowned scholars such as Galileo Galilei, Giovan Battista della Porta, Fabio Colonna, and Cassiano dal Pozzo joined its ranks, enabled the Academy to progress and advance.

The religious character of the Academy cannot be overlooked. It was placed under the protection of St. John the Evangelist who was often portrayed in the miniatures of its publications with an eagle and a lynx, both of which were symbols of sight and reason. It was therefore conceived as an assembly of scholars whose goal – as one can read in its Rules, described as the 'Linceografo' – was 'knowledge and wisdom of things to be obtained not only through living together with honesty and piety, but with the further goal of communicating them peacefully to men without causing any harm'. Nature was seen not only as a subject of study but also of contemplation. Amongst the suggestions of the 'Linceografo' there is also that of preceding study and work with prayer – 'for this reason the Lynxes, near to doing anything at all, must first raise their minds to God, and humbly pray to him and invoke the intercession of the saints' (cf. di Rovasenda and Marini-Bettòlo, 1986, p. 18). Amongst the practices of the spiritual piety of the members there was the reciting of the liturgical office of the Blessed Virgin Mary and the Davidic Psalter. For this reason, as Enrico di Rovesanda observes, 'the religious inspiration of the Lincei cannot be overlooked, as is done in many quarters, nor can it be reduced to an 'almost mystical glow of the school of Pythagoras', as has also been suggested. The high moral figure of Cesi acts to guarantee the sincere and loyal profession of its religious faith' (*ibidem*, p. 19). One of the mottoes of the Academy – *Sapientiae cupidi* – indicated the striving for constant research into truth through scientific speculation, based upon the mathematical and natural sciences but always located within a sapiential horizon.

Like Galileo, whose great supporter he was, Cesi admired Aristotle but not the Aristotelians of the University of Padua who had refused to look at things through the telescope of the Pisan scientist. He was in addition rather critical of the university culture of his day. Federico Cesi also engaged in important activity of mediation between the Roman theological world and Galileo, reaching the point of advising the latter to not insist in his polemics about the interpretation of Holy Scripture so that he could dedicate himself in a more effective way to scientific research. Death struck Cesi down in 1630 when Galileo was about to finish his *Dialogo sui Massimi Sistemi*, the manuscript of which Galileo wanted to send to Cesi himself so that the latter could organise its publication. After Cesi's death the activities of the Academy diminished to such an extent as to bring about its closure.

The first attempts to bring the 'Lincei' back into existence took place in 1745 in Rimini as a result of the efforts of a group of scientists belonging to the circle made up of Giovanni Paolo Siomne Bianchi (known as Janus Plancus), Stefano Galli and Giuseppe Garampi. But the new Academy had a very short life. The attempt at refoundation made by Padre Feliciano Scarpellini (1762-1840) in Rome at the beginning of the nineteenth century met with greater success. He gave the name of 'Lincei' to a private academy that he had established in 1795. Despite a lack of funds and a whole series of difficulties, Scarpellini managed to keep the name of 'Lincei' alive and to bring together in a single academic body the various scientists working in the Papal States such as the mathematician Domenico Chelini, the naturalist Carlo Bonaparte, the anatomist Alessandro Flajani, the chemists Domenico Morichini and Pietro Peretti, Prince Baldassarre Odescalchi, the physicists Gioacchino Pessuti and Paolo Volpicelli, and the physician Benedetto Viale (cf. Marini-Bettòlo, 1986, p. 10).

The authorities of the Papal States took new practical initiatives to refound the Academy during the first half of the nineteenth century in response to the wishes of Pope Pius VII (1800-1823) and Leo XII (1823-1829), with the allocation of the second floor of Palazzo Senatorio in Capidoglio to the Academy as its headquarters. But in 1847 it was Pius IX who officially renewed the Academy with the name (which had already been suggested by Gregory XVI in 1838) of 'Accademia Pontificia dei Nuovi Lincei' ('the Pontifical Academy of the New Lynxes'), ensuring the drawing up of new statutes which envisaged, amongst other things, the presence of thirty resident members and forty correspondent members. During this period of activity famous astronomers and priests were present within its ranks, such as Francesco de Vico and Angelo Secchi. During the revolutionary upheavals of 1848 the Roman Republic sought to expel the Academy from the Campidoglio. However, the institution managed to keep its headquarters by using various bureaucratic manoeuvres. In 1870, following the fall of the independent Papal States and the unification of the Kingdom of Italy, the Academy divided into two different institutions: the 'Reale Accademia dei Lincei', which later became the present Accademia Nazionale dei Lincei with its headquarters in Palazzo Corsini alla Lungara, and the 'Accademia Pontificia dei Nuovi Lincei', which was transferred from the Capidoglio to the Casina Pio IV villa in the Vatican Gardens.

One had to wait, as has already been observed, until 28 October 1936 for a further renewal of the institution, which took place in response to the insistent requests of the Jesuit Giuseppe Gianfranceschi. This scientist was Professor of Physics at the Gregorian University and had been the President of the Accademia Pontificia dei Nuovi Lincei since 1921. A new Pontifical Academy of Sciences was thus created by Pope XI by the Motu Proprio *In Multis Solaciis* (for an Italian translation see Marini-Bettòlo, 1987, pp. 199-203. This work has an accurate summary of the life of the Academy for the years 1936-1986). The Presidency was entrusted to the Rector of the Catholic University Padre, Agostino Gemelli, who was flanked by the Chancellor, Pietro Salviucci, and by a Council composed of four Academicians. Annual (and later two-yearly) plenary sessions were proposed for all the Academicians. The accounts of the activities and the contributions of the members were published in the *Acta Pontificiae Academiae Scientiarum* and later on in the *Commentationes*. The first assembly was inaugurated on 1 June 1937 by the then Cardinal Secretary of State, Eugenio Pacelli, the future Pope Pius XII. In discussing this period of the Academy reference should be made to the presence of such distinguished members as Ugo Armaldi, Giuseppe Armellini, Niels Bohr, Lucien Cuenot, Georges Lemaître, Tullio Levi-Civita, Guglielmo Marconi, Robert Millikan, Umberto Nobile, Max Planck, Ernest Rutherford, Erwin Shrödinger, Francesco Severi, Edmund Whittaker, and Pieter Zeeman.

During the years 1937-1946 the publications of the Academy had a largely Italian character, presenting, for example, the work of the Italian Academicians Pistolesi, Crocco, and Nobile on aerodynamics. But there were also papers by foreign Academicians such those as by E. Schrödinger in 1937 on quantum physics and by M. Tibor in 1937-1939 of an astronomical character. During the Second World War the Academy greatly reduced its activity but nonetheless found space for the publications of Jewish Italian scientists who had been marginalised by the race laws of 1938, amongst whom should be mentioned a group of mathematicians of Jewish descent including Tullio Levi-Civita and Vito Volterra, and others such as Giuseppe Levi, Rita Levi-Montalcini, E. Foà and G.S. Coen. Pius XII (1939-1958), who succeeded Pius X, did not fail to make addresses to the Academicians, even during the war years, such as the address of 30 November 1941 on the occasion of the inauguration of the fourth academic year. This address was dedicated to a long and profound reflection on the position of man in relation to the Creation and God (cf. *Discorsi e Radiomessaggi*, III, pp. 271-281).

In the post-war period, at a time of sensitive reconstruction and the rebuilding of international relations, in the face of the great difficulties encountered at the level of scientific contacts and exchange, the Academy undertook the publication of the research results of greatest interest of the various fields of science which had been achieved during the war in its work *Relationes de Auctis Scientiis tempore belli* (aa. 1939-1945). This publication was of marked importance in fostering the renewal of scientific contacts between the nations which had previously been at war. In 1946 Alexander Fleming (1881-1955) was appointed an Academician in recognition of his discovery of penicillin – a discovery which opened the way to the pharmacological production of antibiotics.

During the 1950s, in parallel with the problems of reconstruction and the development of under-developed regions, the activity of the Pontifical Academy of Sciences centred around the questions and issues of applied science. In 1955 the study-week on trace elements was held, when for the first time the problem of agrarian production and food sources was addressed. After the election to the papacy of John XXIII (1958), Padre Gemelli died in 1959. The Presidency of the Academy was then held by G. Lemaître.

The 1960s witnessed an exponential growth and development of science connected with electronics and the conquest of space. This gave new impetus to industry and technological advance but also to nuclear armaments. In astrophysics the discovery of new sensors and the development of radio-astronomy opened up the universe to new interpretations. Biology became directed towards the molecular study of genetics. In 1961 the Pontifical Academy of Sciences organised a study-week on the macromolecules of interest to biology, and in particular on the nucleoproteins, a subject which was then of major importance for international research. On that occasion, when meeting the Academicians, John XXIII reaffirmed the educational and cultural mission of the Church and the function of scientific progress in relation to the positive appreciation of the human person. The Pope recalled in addition that science is directed above all else towards the development and growth of the personality of man and the glorification of God the Creator: 'indeed, far from fearing the most audacious discoveries of men, the Church instead believes that every advance in the possession of the truth involves a development of the human person and constitutes a road towards the first truth, and the glorification of the creative work of God' ('Discorso in occasione del XXV dell'Accademia, 30.10.1961', in *Discorsi, Messaggi e Colloqui del Santo Padre Giovanni XXIII*, vol. III, p. 493). In 1962, at the time of the plenary session of that year, a study-week dedicated to astronomy which addressed the subject of cosmic radiation in space was held, guided in first person by the President of the Academy, Monsignor Lemaître.

In 1964, at the time of the pontificate of Paul VI (1963-1978), there appeared amongst the publications of the Pontifical Academy of Sciences the *Miscellanea Galileiana* of Monsignor Pio Paschini, who was Professor of History at the Lateran University. The Galileo case was slowly reopened, a development favoured by the reference made to it by Vatican Council II in n. 36 of *Gaudium et Spes*. This led to the address by John Paul II of 1979 to which reference has already been made. After the death of Georges Lemaître, in 1966 Padre Daniel O'Connell was made President of the Academy. A Jesuit and Irish astronomer, he had previously been Director of the Vatican Observatory and had been an Academician for life since 1964. He was also the author together with other astronomers of an important general atlas of the stars. The year 1967 was marked by the publication of the encyclical *Popularum Progressio*, in which Paul VI brought to worldwide attention all the major problems inherent in the development of the Third World. This document also contained an appeal to engage in international scientific co-operation so that this could in all forms favour developing countries. It introduced the idea that scientific progress and advance must be guided by a 'new humanism': 'every advance of ours, each one of our syntheses reveals something about the design which presides over the universal order of beings, the effort of man and humanity to progress. We are searching for a new humanism, which will allow modern man to refind himself, taking on the higher values of love, friendship, prayer and contemplation' (n. 20). In harmony with the themes of the encyclical, the Academy thought it was necessary to open itself to collaboration with the scientists of the Third World and by 1968 it was already holding a study-week on the subject of 'organic matter and soil fertility', a subject which dealt with the applications of science to agricultural production and the solution of the problems of hunger in the world.

In 1972 for the first time a secular President was elected – the Brazilian Carlos Chagas, who had already been a member of the United Nations and the General Secretary of the first conference of the United Nations on Science and Technologies for Development. The new President imparted a new direction to the activities of the Academy which were now more centred around solving the great problems of post-industrial society (cf. di Rovesanda, 2000). The scientific activity of the Academy was thus directed not only towards the subjects of science which were more specific to Western culture but also began to be concerned, with the co-operation of Giovanni Battista Marini-Bettòlo (who succeeded Chagas in 1988), with the scientific and health care problems connected with the growth and development of the Third World ('development ethics').

The 1980s witnessed the development of new directions in scientific research which moved in the direction of the life sciences, the earth sciences, and ecology. Mankind had to face up to new problems, such as pollution, changes in the biosphere, energy reserves, and genetic manipulation. In 1982 the Academy committed itself at an international level to the promotion of peace with the drawing up of a document on nuclear armaments (cf. 'Dichiarazione sul disarmo nucleare' ('Declaration on Nuclear Disarmament'), *EV*, 7, pp. 1811-1825) and devoted the next plenary session (of 1983) to the subject of 'science for peace'. In connection with that event, John Paul II appealed to members of governments to work in an effective fashion in order to remove the danger of a new war and invited States to engage in nuclear disarmament (cf. 'Il sapere scientifico edifichi la pace, 12.11.1983' ('Scientific Knowledge should Build Peace, 12.11.1983'), in *Insegnamenti*, VI, 2 (1983), pp. 1054-1060). This document and appeal achieved a strong resonance in the United States of America and the Soviet Union. During the 1990s meetings and study-weeks were held which were dedicated to analysing the question of the prolonging of life; the question of determining the moment of death; the question of transplants and xenografts; and the question of sustainable growth and development. The issues of artificial fertilisation, cloning, and genetic manipulation were also considered. These were subjects which increasingly involved issues of an ethical character (bioethics) and which drew scientists, philosophers and theologians into dialogue. Although the usual practice of involving various disciplines was maintained, the research and the debates of the

Academicians were directed in a special way towards reflection on the anthropological and humanistic dimensions of science. In November 1999 a working-group was held on the subject of 'science for man and man for science', and the Jubilee session of November 2000 was dedicated to the subject 'science and the future of mankind'.

III. The Role of the Academy in the Dialogue between Scientific Thought and Christian Faith

In the relations which exist between Academies and the States in which they carry out their activities, the case of the Pontifical Academy of Sciences can be seen as a singular case, as indeed in basic terms the role of the small State which hosts it is also singular. During these long years this relationship has become very fertile. The Church has paid careful attention to the Academy. She has respected its work and fostered the autonomy of its scientific and organisational dynamics. Through the Academy, the Magisterium of the Church has sought to make the scientific world understand her teaching and her orientations in relation to subjects which concern the good of man and society, the complete human development of all the peoples of the world, and the scientific and cultural co-operation which should animate the relations between States. On the occasion of numerous addresses and messages directed towards the Academy by five pontiffs, the Church has been able to repropose the meaning of the relationship between faith and reason, between science and wisdom, and between love for truth and the search for God. But through the Academy the Church has also been able to understand from nearer to hand, with speed and in depth, the contents and the importance of numerous questions and issues which have been the object of the reflection of the scientific world, whose consequences for society, the environment and the lives of individuals could not but interest her directly, 'given that there is nothing which is genuinely human which does not find echo in her heart' (cf. *Gaudium et Spes*, 1). The Pontifical Academy of Sciences has thus become one of the favoured *forums* for the dialogue between the Gospel and scientific culture, gathering together all the stimulating provocations but also the inspiring possibilities that such dialogue brings with it, almost thereby symbolising a shared growth – of both the scientific community and the Magisterium of the Church – of their respective responsibilities towards truth and good.

The above survey, although general in character, dealing with the activity carried out over the sixty years since the foundation of the Pontifical Academy of Science, the subjects of the numerous meetings and study-weeks, and the publications which the Academy has produced, brings out all the contemporary relevance and the importance of the subjects which have been addressed. Scientists from all over the world, often co-operating closely with a group of philosophers and theologians, have examined questions and issues which have ranged from genetics to cosmology, from agriculture to the distribution of resources, from the surgery of transplants to the history of science, and from ecology to telecommunications. The speeches addressed by the Pontiffs to the Academicians, from Pius XI to John Paul II, have offered important elements of reflection not only in relation to the ethical and moral responsibility of their activities but also on the very meaning of scientific research, and on its striving for truth and an increasingly profound knowledge of reality. The subject of the relationship between science and faith, both at an epistemological and an anthropological level, has been the usual framework of almost all these papal addresses. The forms of language employed have been different as these decades have passed, and different emphases have been placed on the various questions and issues, but the attention paid to scientific work has been unchanging, as has been the case in relation to the philosophical and cultural dimensions which that work involves.

Side by side with such dialogue, which we could call ‘ordinary’, international public opinion has been witness to certain ‘out of the ordinary’ events. From the mass media it has learnt about speeches of special importance for the relationship between science and faith, speeches given at the Academy in particular during the pontificate of John Paul II. Of these reference should be made to the address with which, as has already been observed (see above section I), John Paul II spoke to the plenary session of the Pontifical Academy of Sciences in November 1979 to express his wish for, and then formally request, the establishment of a committee of historians, scientists, and theologians which would re-examine the Galileo case and present public opinion with a serene analysis of the facts as they occurred (Galileo, IV). The aim of this was not in a historical sense to recognise the inadvisability of the condemnation of the heliocentrism carried out four centuries beforehand by the Sant’Uffizio (something which had already been effected in 1757 with the removal of the works in question from the list of prohibited books), but rather to ensure that the historical-philosophical context of the episode, as well as its implications at a cultural level, were more illuminated, thereby clarifying in a public way which would be comprehensible to everybody what had already been made clear in a narrower circle of intellectuals and experts. During a new assembly of the Academy which was held on 31 October 1992, Cardinal Paul Poupard, in the presence of the Holy Father, presented the results of the committee and commented on the work which it had carried out.

Four years later, on 22 October 1996, this time in the form of a message on the occasion of the sixtieth anniversary of its refoundation, John Paul II once again chose the Pontifical Academy of Sciences as a qualified interlocutor to expound certain important reflections on the theory of evolution (*Magistero,* V.2; *Uomo, Identità Biologica e Culturale,* V.3). Returning to and developing certain observations made by his predecessor Pius XII in the encyclical *Humani Generis* (cf. *DH* 3896-3899), he now added that 'new knowledge leads the theory of evolution to be no longer considered as a mere hypothesis', thereby recognising 'that this theory has progressively imposed itself on the attention of researchers following a series of discoveries made in the various disciplines of knowledge', imposing itself also therefore on the attention of theologians and bible experts (*Scienze Naturali, Utilizzo in Teologia*).

It would not however be exact to confine only to recent years the climate of mutual listening and serene encounter on subjects of great relevance. History has also been a witness to other episodes of intense dialogue with the Roman Pontiffs of which the Academy or some of its members were the protagonists. This is the case, for example, of Max Planck, who wanted to make himself the interpreter in a direct way with Pius XII in 1943 of the risks of war connected with the use of armaments based upon nuclear fission (cf. Ladous, 1994, p. 144), or the close relationship between Pius XII and Georges Lemaître, who enabled the Pontiff to understand from closer to hand at the beginning of the 1950s the meaning of the new cosmological models which were by then beginning to become established in the scientific world, and the philosophical, or even theological, questions which at first sight appeared to be involved (Lemaître, IV). In more recent years, Carlos Chagas was especially concerned in 1981 to take on board the worries of John Paul II, who was still convalescing after the attack on his life, about the consequences for the planet of a possible nuclear war. He decided to himself present the studies carried out on the subject to the principal Heads of State in his capacity as President of the Academy (cf. di Rovesanda, 2000).

In the letter sent to Padre George Coyne, the Director of the Vatican Observatory and a member of the Council of the Academy, a document which is certainly one of the most profound there is on the subject of the dialogue between science and faith, John Paul II observed that science has acted to purify faith and that faith has acted to generate scientific research, a truth demonstrated by the fact that Galilean modern science was born in a Christian climate with the increasing assimilation of the message of freedom placed in the heart of man. Thus, in the same letter, referring to the wider context of universities, the Pope declared that: 'The Church and academic institutions, because they represent two institutions which are very different but very important, are mutually involved in the domain of human civilisation and world culture. We carry forward, before God, enormous responsibilities towards the human condition because historically we have had and we continue to have a determining influence in the development of ideas and values and the course of human actions' ('Lettera al Direttore della Specola Vaticana, 1.6.1988' ('Letter to the Director of the Vatican Observatory, 1.6.1988, *OR* 26.10.1988, p. 7) For this to come about, the Pope stressed the importance of there being experts and places especially dedicated to such a dialogue: 'the Church for a long time has recognised the importance of this by founding the Pontifical Academy of Sciences, in which scientists of world renown regularly meet each other to discuss their research and to communicate to the wider community the directions research is taking. But much more is required' (*ibidem*).

And in this 'more' John Paul II saw the need, in their irreplaceable dialogue, for scientific institutions and the Catholic Church not to think in a reductive way about the settling of ancient conflicts, and also saw the more important need for mutual help in the investigation of truth and a shared growth in their responsibility for the good of the peoples of the world and their future. And it in this logic, with this new readiness to engage in service, that the present President of the Academy, Professor Cabibbo, in his address to John Paul II on the occasion of the Jubilee plenary session on the subject of 'science and the future of mankind' (*OR* 13-14.11.2000, p. 6) was able to speak about the 'renewed commitment' of the Pontifical Academy of Sciences together with the Holy See to the good of the whole Church, of the scientific community, and of those men and women who search and believe.

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STATEMENT ISSUED AFTER THE WORKSHOP HELD AT THE PONTIFICAL ACADEMY OF SCIENCES ON 19-20-21 NOVEMBER 2001, AND APPROVED BY THE COUNCIL OF THE ACADEMY ON 17 FEBRUARY 2002

The challenges for science: education for the twenty-first century

We, members of the *Pontifical Academy of Sciences* and experts, after meeting in the Vatican on 19-20-21 Nov. 2001, declare as follows.

The immense and increasingly rapid development of science as an important element in culture bestows a new responsibility on the scientific community, beyond its traditional role of creating new knowledge and new technology. Ensuring proper education in science for every child in the world and, consequently, a better public understanding of science and what science stands for, has become both a necessity and a challenge.

As a belief in the constant capacity of humanity to progress, education requires caring for the children of today and preparing the citizens of tomorrow. Access to knowledge, therefore, is a human right, even more so in the knowledge-based society of the future.

The extremely uneven access to education in today's world generates profound inequalities. Let us not tolerate the existence of a knowledge divide, in addition to an unacceptable economic divide which also includes a 'digital divide'. For, unlike the possession of goods, knowledge, when shared, grows and develops.

Education in science for all girls and boys is essential for several reasons. In particular, this education helps:

– to discover the beauty of the world through emotion, imagination, observation, experimentation, reflection and understanding;

– to develop the creativity and rationality which enable humans to understand and communicate;

– to contribute to moral development and sense of values: the search for truth, integrity, humility, and man's responsibility towards his neighbours and future generations;

– to share the accumulated wealth of knowledge amongst all people, as required by justice and equity;

– to be aware of mankind's interdependence with the environment and the Universe;

– to enable contributions to the solution of the acute problems facing humanity (poverty, food, energy, the environment).

From the perspective of these objectives, it is our conviction that the present state of education in science is of great concern throughout the world, regardless of the local stage of development. In the case of developing countries, in particular, the magnitude of the problem is immense.

After consideration of a number of encouraging experiences in various countries, and the actions of several Academies, we conclude that the following initiatives should be taken without delay, both at a national and an international level. Moreover, they should be shared and integrated within the diversity of cultures found in contemporary societies.

1. The highest level of attention has to be given to science education in primary and secondary schools, including children with special needs.

2. Education in science must be seen and implemented as an integral part of the whole of a person's total education (language, history, art, etc.).

3. The most important contribution to improving education in science in elementary and secondary education lies in helping teachers and parents to cope with this difficult task. This will involve increased resources, partnership, professional development, social recognition and support for teachers.

4. Such a challenge cannot be met without the deepest commitment on the part of the various members of the world's scientific and technological community. Meeting this challenge must be viewed as a new moral obligation.

5. Every means should be used to convey the urgency of the situation to governments. They alone have the capacity to deal with the magnitude of the problem, to provide the necessary resources, and to implement suitable policies. Non-governmental organisations and financial institutions should also participate in such an initiative.

6. Relevant research on science education should be stimulated and encouraged, and should consider the potential of communication technologies.

What is being called for is a global commitment to revitalize science education at school level with support not only from the teachers, parents and scientists, but entire communities, organisations and Governments, for a better and more peaceful world to live in.

Success along these lines, pursued with perseverance and dedication, will constitute a decisive contribution to the socio-economic and cultural development of humanity, the achievement of social justice, and the promotion of human dignity.