THE PONTIFICAL
ACADEMY OF
SCIENCES

Scripta Varia

105

THE CULTURAL VALUES OF SCIENCE

Plenary Session
8-11 November 2002

VATICAN CITY
2003

THE CULTURAL VALUES OF SCIENCE

Address:
The Pontifical Academy of Sciences
Casina Pio IV, 00120 Vatican City

PONTIFICIAE ACADEMIAE SCIENTIARUM SCRIPTA VARIA

105

THE CULTURAL VALUES OF SCIENCE

8-11 November 2002

EX AEDIBVS ACADEMICIS IN CIVITATE VATICANA

MMIII

The opinions expressed with absolute freedom during the presentation of the papers of this meeting, although published by the Academy, represent only the points of view of the participants and not those of the Academy.

ISBN 88-7761-082-4

© Copyright 2003
PONTIFICIA ACADEMIA SCIENTIARUM
VATICAN CITY

Joannes Paulus PP. II


The Participants of the Plenary Session of 8-11 November 2002

The Pontifical Academy of Sciences, Casina Pio IV

The Academy or *The School of Athens* by Raphael, in the Vatican Palace
'In those people you will have recognised your oldest predecessors in the investigation of both matter and spirit'
(Pius XII, Address to the Plenary Session of the Academy, 3 December 1939)

CONTENTS

SCIENTIFIC PAPERS AND DISCUSSIONS

ADDRESS TO THE HOLY FATHER

NICOLA CABIBBO

Holy Father,

It is with profound gratitude that the scientists convened for the plenary session of the Academy of Sciences, where we are discussing 'The Cultural Values of Science', have received the invitation to this audience.

The Academy was founded by Federico Cesi in 1603 in the very heart of the Catholic Church, and had in Galileo Galilei one of its first and most illustrious members. Next year will mark the four-hundredth anniversary of its foundation and we are preparing to commemorate and honour this important event.

The history of the Academy is coeval with the history of modern science. In 1623 the Academy published *Il Saggiatore* by Galileo, a book that was to become the manifesto of the scientific renaissance. The great book of nature, Galileo wrote, is written in mathematical symbols, in an alphabet that should sit side by side with the alphabet of philosophy or with that of the Holy Book.

The lesson of Galileo becomes even more important today: science that abdicates its cultural values risks being perceived as an extension of technology, an instrument in the hands of political or economic power. Humanity that disavows science risks falling into the hands of superstition. These very concerns led the Academy to organise in 2001 a workshop on 'The Challenges for Science: Education for the Twenty-First Century', when we discussed the central role of science education for all children, especially those of the less developed countries where the inequality in access to knowledge is more acute, a phenomenon that is a grave peril in today's knowledge-based society.

The Academy has this year acquired nine new members, all well known in the scientific world and representative of the main scientific disciplines and geographical regions. I would like to mention their names: Antonio Battro from Argentina, Enrico Berti from Italy, Günter Blobel from the USA, Thierry Boon-Falleur from Belgium, Pierre Léna from France, Jürgen Mittelstrass from Germany, and Ryoji Noyori from Japan. The Academy is very grateful to you for your appointment of two illustrious members of the College of Cardinals, Carlo Maria Martini and Joseph Ratzinger. These appointments renew an old tradition of the Academy, which had the glory of having as one of its members Cardinal Eugenio Pacelli, who was later to become Pope Pius XII.

I would like to ask you to kindly present to Professor Stanislas Dehaene the Pius XI medal for the year 2000, and to Professor Juan Martín Maldacena the medal for 2002, who have been awarded these medals for their exceptional contributions to neuroscience and theoretical physics.

Lastly, I wish to thank you for the essential support which you have given the Academy in all its activities, which has also allowed the restoration of the Casina Pio IV in preparation for next year's four-hundredth anniversary celebrations.

ADDRESS OF JOHN PAUL II
TO THE PLENARY ASSEMBLY
OF THE PONTIFICAL ACADEMY OF SCIENCES

MONDAY, 11 NOVEMBER 2002

Dear Members of the Pontifical Academy of Sciences,

It gives me great pleasure to greet you on the occasion of your Plenary Meeting, and I offer a particularly warm welcome to the new members among you. Your discussion and reflection this year focuses on 'The Cultural Values of Science'. This theme allows you to consider scientific developments in their relation to other general aspects of human experience.

In fact, even before speaking of the cultural values of science, we could say that science itself represents a value for human knowledge and the human community. For it is thanks to science that we have a greater understanding today of man's place in the universe, of the connections between human history and the history of the cosmos, of the structural cohesion and symmetry of the elements of which matter is composed, of the remarkable complexity and at the same time the astonishing coordination of the life processes themselves. It is thanks to science that we are able to appreciate ever more what one member of this Academy has called 'the wonder of being human': this is the title that John Eccles, recipient of the 1963 Nobel Prize for Neurophysiology and member of the Pontifical Academy of Sciences, gave to his book on the human brain and mind (J.C. Eccles, D.N. Robinson, *The Wonder of Being Human: Our Brain and Our Mind*; Free Press, New York, 1984).

This knowledge represents an extraordinary and profound value for the entire human family, and it is also of immeasurable significance for the disciplines of philosophy and theology as they continue along the path of *intellectus quaerens fidem* and of *fides quaerens intellectum*, as they seek an ever more complete understanding of the wealth of human knowledge and of Biblical revelation. If philosophy and theology today grasp better than in the past what it means to be a human being in the world, they owe this in no small part to science, because it is science that has shown us how numerous and complex the works of creation are and how seemingly limitless the created cosmos is. The utter marvel that inspired the first philosophical reflections on nature does not diminish as new scientific discoveries are made. Rather, it increases with each fresh insight that is gained. The species capable of 'creaturely amazement' is transformed as our grasp of truth and reality becomes more comprehensive, as we are led to search ever more deeply within the realm of human experience and existence.

But the cultural and human value of science is also seen in its moving from the level of research and reflection to actual practice. In fact, the Lord Jesus warned his followers: 'everyone to whom much is given, of him will much be required' (*Lk* 12:48). Scientists, therefore, precisely because they 'know more', are called to 'serve more'. Since the freedom they enjoy in research gives them access to specialized knowledge, they have the responsibility of using it wisely for the benefit of the entire human family. I am thinking here not only of the dangers involved in a science devoid of an ethic firmly grounded in the nature of the human person and in respect of the environment, themes which I have dwelt on many times in the past (cf. *Addresses to the Pontifical Academy of Sciences*, 28 October 1994, 27 October 1998 and 12 March 1999; *Address to the Pontifical Academy for Life,* 24 February 1998).

I am also thinking of the enormous benefits that science can bring to the peoples of the world through basic research and technological applications. By protecting its legitimate autonomy from economic and political pressures, by not giving in to the forces of consensus or to the quest for profit, by committing itself to selfless research aimed at truth and the common good, the scientific community can help the world's peoples and serve them in ways no other structures can.

At the beginning of this new century, scientists need to ask themselves if there is not more that they can do in this regard. In an ever more globalized world, can they not do more to increase levels of instruction and improve health conditions, to study strategies for a more equitable distribution of resources, to facilitate the free circulation of information and the access of all to that knowledge that improves the quality of life and raises standards of living? Can they not make their voices heard more clearly and with greater authority in the cause of world peace? I know that they can, and I know that you can, dear members of the Pontifical Academy of Sciences! As you prepare to celebrate the Academy's Fourth Centenary next year, bring these common concerns and aspirations to the international agencies that make use of your work, bring them to your colleagues, bring them to the places where you engage in research and where you teach. In this way, science will help to unite minds and hearts, promoting dialogue not only between individual researchers in different parts of the world but also between nations and cultures, making a priceless contribution to peace and harmony among peoples.

In renewing my warm wishes for the success of your work during these days, I raise my voice to the Lord of heaven and earth, praying that your activity will be more and more an instrument of truth and love in the world. Upon you, your families and your colleagues I cordially invoke an abundance of divine grace and blessings.

COMMEMORATION OF ACADEMICIANS

ANDRÉ BLANC-LAPIERRE (1915-2001)

André Blanc-Lapierre received his first education in an 'Ecole Primaire Supérieure' and at the end of this scholarship, he got a 'Brevet Supérieur'. He was an excellent pupil and he joined the classical lycée, to obtain first his 'Baccalauréat' and then became a student of the 'Ecole normale supérieure'. The special upbringing he received in his family and his training in these schools gave him distinct characteristics, very elegant handwriting and other very good habits in organizing his life and work.

After graduating from this last school, his scientific activity may be described by four periods. The first one covers approximately the decade 1940-1950. He joined the Physics laboratory of the Ecole normale and prepared a thesis under Georges Bruhat's supervision. His dissertation, accomplished in 1944, was devoted to the study of the shot noise and to its influence on the measurement and amplification of very small photocurrents. The existence of background noise was known; but it was not known at that time how it would be possible to give a description that went further than a qualitative one. He was the first to be convinced that, to make progress in understanding the phenomenon, it would be necessary to use the tools provided by probability theory. But at that time the concept of stochastic processes was not known. He started to attack the problem and his analysis was so successful that he was in the position to uphold a new dissertation and to add a second doctorate, in Mathematics, to the one he had achieved in Physics. It is exceptional in France for anyone to have two science doctorates in two different fields. This work was the starting point of a great number of papers devoted to stochastic processes applied in various domains of physics and information theory. In 1953, with his colleague Robert Fortet, he published a book of seven hundred pages on random functions which shortly became a classic.

The second period is roughly the decade 1950-1960. He was then Professor of Physics at the University of Algiers. He founded a theoretical physics laboratory; a very active one. He encouraged young physicists to explore new areas where probabilistic methods could be applied. Among many developments, his suggestion to transpose to optics ideas known in radioelectricity deserves to be mentioned. He was the first to show that the concept of coherence in optics must be described by using appropriate correlation functions. His papers written in French remained unknown and the validity of his ideas became clear later with the development of lasers and coherent optics.

The third period covered approximately the decade 1960-1970 and was mainly devoted to nuclear physics. In fact, it started at the end of the previous one, with the creation in Algiers of an 'Institut de Physique Nucléaire' which was, for Blanc-Lapierre, the occasion to show his talents for managing such an operation. It was on the basis of his achievement there, that he was chosen as director of the linear accelerator-lineac of the faculty of Orsay in 1961, succeeding Hans Halban who had just resigned. First, he decided to upgrade the electron lineac energy from 1 GeV to 2.3 GeV, thus allowing the undertaking of K meson experiments. Moreover a positron beam was set up, a facility that proved to be crucial for the storage rings to come. Then he proposed in 1962 to start work on electron-positron collisions which presented great technological challenges which had to be faced. Two years later, such collisions were observed for the first time in a storage ring. In 1964 he invited a group of bubble chamber physicists, led by André Lagarrigue, who were working at the Ecole polytechnique, to move into his laboratory. Then jointly with this school, CEA Saclay and the CERN, the Orsay laboratory of Blanc-Lapierre participated in the Gargamelle bubble chamber program under the leadership of André Lagarrigue. This heavy liquid chamber turned out to be the most effective in neutrino interactions and allowed the famous discovery in 1973 of neutral currents.

During the last period he was the director general of the 'Ecole supérieure d'Electricité'. He showed, once again, his talents as high class administrator and manager. He succeeded in expanding the number of buildings for the school and its developments. Moreover he gave a great impulse to research in this school, in particular by the creation of a new laboratory in cooperation with the CNRS: the 'Laboratoire des signaux et systèmes' where he was working until his retirement.

André Blanc-Lapierre was a tireless worker who had a fantastic level of activity. He liked to build new schools, new offices, new laboratories for his students, his co-workers and for the people involved in the activity he was running. He was a very good supervisor, always available for those who needed help or advice. He was one among a few scientists who have contributed to the renewal of science in France. He was ready to take on successfully high responsibilities, for instance as the President of the most important Committee in the sixties, in charge of the preparation of Government decisions concerning the scientific development, its budget and its organization. Member of the French 'Académie des sciences' since 1970, he played an important role in 1983 in the creation of the CADAS, 'le Conseil des Applications de l'Académie des Sciences', which has recently become autonomous under the name of French 'Académie des Technologies'. He was President of the French Academy in 1985 and 1986, a very active one who brought many improvements to its organization. He was elected to the Pontifical Academy of Sciences in 1979 and was a very active member, as member of the Council and also as the leader of a very successful study week on energy. When he accepted a responsibility, he would take it on fully.

André Blanc-Lapierre was a warm personality, very open minded, very helpful to everybody. He was very attached to our Academy, very happy to be able to work for its development. This good Christian was convinced that our Academy would have a very important role in making science better understood and appreciated by the Church.

Paul Germain

LOUIS LEPRINCE-RINGUET (1901-2000)

Louis Leprince-Ringuet was born in March 1901. His father was an engineer who graduated from the 'Ecole Polytechnique' and was even a member of the 'Corps des Mines' composed of the best former students of this school. Louis was not an excellent student. Nevertheless, he too graduated as an engineer from the 'Ecole Polytechnique' and also from the 'Ecole supérieure d'Electricité', and became member of the 'Corps des PTT'.

Birth of his vocation as a scientist

For five years he worked in an undersea cable Company. He spent eight months each year at sea on missions to check the good general state of the communications network. He liked this outdoor activity. In addition he had personal experience of the hard conditions in which the workers operated. In 1928-1929 he was fortunate to meet Maurice de Broglie – the elder brother of Louis de Broglie who received the Nobel prize. Maurice was an enthusiastic physicist who ran in his town house, in Paris, his own laboratory working on X-rays. The young Leprince-Ringuet was fascinated by Maurice de Broglie. He decided to quit his first job in order to accept Maurice de Broglie's proposal to work in his laboratory as a research assistant. It was the start of his scientific career, a very modest beginning. The laboratory had only a few permanent physicists, around three or four, who consequently worked very closely with the 'boss'.

Physicist on Cosmic rays

When Louis Leprince-Ringuet joined this team, their research topic was undergoing change, passing from X-rays to nuclear physics. They began to be interested in the structure of atomic nuclei and in the particles produced on breaking these nuclei. At that time, it was impossible to obtain particles with an energy of more than one GeV. That is why Leprince-Ringuet decided to work on cosmic rays. These rays consist of high-energy particles which bombard the earth. Mostly, they are protons. On collision with the upper atmosphere, they create new particles which arrive on the ground. In 1933, with another young physicist, Pierre Auger, they sailed on a ship from Hamburg to Buenos Aires with an array of detectors, Geiger counters, in order to investigate the variation of intensity with the latitude and to prove that, effectively, protons were predominant. Over two decades, cosmic rays were the best source of fundamental constituents of nuclei. In order to have better conditions, physicists built laboratories on high mountains. Leprince-Ringuet, who had been appointed to a new laboratory at the Ecole polytechnique, worked frequently at the 'Pic du midi' observatory in the Pyrenées. Many new fundamental particles have been discovered by this method: the positron, the muon, the pion, the kaon, the hyperon, using a Wilson chamber and, after the war, a double Wilson chamber. Leprince-Ringuet, who became Professor at the Ecole polytechnique in 1936, had the possibility to attract many bright young students who were to become outstanding physicists, such as Lagarigue, Gregory and Astier.

Towards physics of high energy particles

After 1953, Leprince-Ringuet decided to reorient his laboratory's activity towards the physics of accelerators in order to take advantage of the first synchrotons with their intense and precise beams of particles with an energy exceeding one GeV. In conjunction with Saclay, his laboratory designed new 'bubble chambers' in order to replace the Wilson chambers and made a bright use of CERN which very often led to important discoveries.

Member of the French 'Académie des sciences' in 1949, he succeeded Frederic Joliot in 1959 in his chair at the 'Collège de France'. For more than ten years, he was the head of two famous laboratories working in particle physics. He had a great influence on the rapid development of this discipline as a member of important committees, in particular those running the CERN programme. He used it in order to give young physicists wanting to work in this field the best conditions. Leprince-Ringuet may be considered one of the greatest scientists working in particle physics in the twentieth century, not so much for his personal discoveries – although they were important – but especially for his exceptional ability to encourage bright young talent to work in this field and also to persuade the decision-makers to favour its development.

Extraordinary diversity of talents and interests

So far, I have shown that Louis Leprince-Ringuet was a great scientist. This has long been recognised by our Company with his election as member of the Pontifical Academy of Sciences. But he was not an exceptional student. He spent many years in a job which gave him the possibility to sail for two thirds of the time. He became a scientist not through special studies or reading, but through meeting and talking with a man who was a living epitome of scientific research and who devoted a part of his house and of his wealth to scientific activity.

The theme of Leprince-Ringuet's work was a very attractive one: observation of many particles which come from the universe. To capture them, he sailed for two months; he built an observatory on a mountain summit. He spent the best part of his energy in developing his own laboratory and helping create this 'marvellous cathedral' which is the CERN.

However, this scientist was fascinated not only by the particles which came from breaking the nuclei, but also by people. One of his books, the one I prefer, is called *Des atomes et des hommes*. He experienced and described beautifully the particular friendship and brotherhood among the scientists working on the same adventure. He organized for many years in September meetings of his collaborators and colleagues in his own private property in Burgundy to discuss the new discoveries or topics he wanted to present in his course at the 'Collège de France'. But what is for me the most remarkable was his gift for talking to people, to explain to any public not only scientific achievements, but also his personal views on topics of interest for the listeners. He developed this natural capacity when he was a student as member of the 'équipes sociales', an institution devoted to the organization of meetings and exchanges of views between young workers and students. He was invited over many months to give a regular prime-time television programme: 'le quart d'heure de Leprince-Ringuet', which was very successful and in which he talked about various topics, not necessarily scientific.

He had many centres of interest. He was a ranked tennis player. He was a painter whose works have often been on public display in good Parisian art galleries. He was a music lover and had been chosen to be President of the 'Jeunesses musicales de France', a very famous and popular institution of the country. He was very cultured, elected of course to the 'Académie des sciences' but also to the 'Académie française', in 1966, rather exceptional for a scientist. He did not like philosophical or abstract discussions. He was a man of action.

He was a strongly active supporter of Europe, very enthusiastic, a committed Christian, not so much attracted by theology, but deeply rooted in the Gospel which shaped his intense spiritual life. With his remarkable wife, they brought up a wonderful family, being great-grandparents of a lot of children. He was a very happy man. At ninety-five, he wrote a marvellous book: *Foi de physicien – Testament d'un scientifique.* The introduction is entitled 'the happiness of being a scientist'. The last chapter is: 'Why I am an optimist'.

Paul Germain

JACQUES-LOUIS LIONS (1928-2001)

Jacques-Louis Lions was a very bright French scientist endowed with many skills and moral qualities. He showed these on many occasions and in many responsibilities; for instance at fifteen during the war, as chairman of INRIA ('Institut National de Recherche en Informatique et Automatique'), as a President of the CNES ('Centre National d'Etudes Spatiales'), as the President of the French 'Académie des sciences' in 1997 and 1998.

But above all, he was a remarkable mathematician who, I think, deserves to be recognized as the best in applied and industrial mathematics during the second half of the twentieth century. Consequently, in order to keep this notice as usual at a reasonable length, I will concentrate on a few highlights of his wonderful mathematical work.

To characterize the field of his achievements, I will quote Philippe Ciarlet writing that 'it concerns partial differential equations in all their states: existence, uniqueness, regularity, control, homogenization, numerical analysis, and of course, their applications to mechanics, oceanography, meteorology'.

When he was a student at the 'Ecole normale supérieure', he was already considered among his schoolmates as the most hardworking. After receiving his diploma, he was appointed by CNRS as a researcher at the Nancy group of Laurent Schwartz, who had just received in 1950 the Fields Medal for his creation of the distributions theory. Jacques-Louis Lions worked on applications of this theory to various differential equations and gained his doctorate in 1954. He immediately became professor in the mathematical department of Nancy which was at that time very famous thanks to the high standard of its professors and of its research students. From the very start, Jacques-Louis was attracted by the applications and strongly encouraged by two fellow workers of the same age: Robert Lattes, also a graduate from the Ecole normale who was later director of the SEMA ('Société d'Economie et de Mathématiques Appliquées'), and Robert Dautray, a prominent graduate from the Ecole polytechnique, who had a high responsibility in the most advanced research department of the CEA ('Centre de l'Energie Atomique').

In 1962, Jacques-Louis was elected Professor at the Sorbonne, the Sciences Faculty of Paris University. He immediately created a seminar in numerical analysis which was soon very famous and, a few years later, the 'Laboratoire d'analyse numérique' which has been one of the best departments of this discipline in Europe. In 1973 he became at the same time, Professor at the 'Collège de France' in the chair: 'Analyse numérique des systèmes et de leur contrôle' and member of the French 'Académie des sciences'. In the 'Collège', his course, new each year, as required by tradition, and the weekly seminar on 'Mathématiques Appliquées' were both followed by many people, colleagues and research students. Professor at the Ecole Polytechnique between 1966 and 1986, he created in this famous school a new course of Applied Mathematics which was highly appreciated by the students. Many of them decided to work in this field after getting their diploma.

Despite all these highly time-consuming responsibilities, Jacques-Louis Lions succeeded in being a fantastic author: more than twenty books, some of them in collaboration with colleagues or students; most of them have been translated not only into English but also into many other languages. Moreover, he wrote more than five hundred papers. These figures are completely unusual in mathematics. Most of these works found a systematic presentation in a monumental treatise of four thousand pages entitled: 'Analyse mathématique et calcul numérique pour les sciences et les techniques' published in 1985 by Jacques-Louis Lions and Robert Dautray which, very often, has been rightly considered as the contemporary version of the famous Courant and Hilbert.

Let us mention briefly some of the new concepts and topics he introduced and developed. Since 1954, his collaboration with Magenes, Stampacchia, de Giorgi and Prodi gave rise to a three-volume treatise entitled *Problèmes aux limites non homogènes*. A little later, he became interested in problems of mechanics and physics, and in 1972 with Georges Duvaut, he published *Les inéquations en mécanique et en physique*. This book showed how fruitful were the functional methods for solving difficult problems arising from Bingham fluids, viscoelasticity, plasticity.

So far, the numerical solutions were obtained by methods of 'finite differences'. They were not easily applicable to many situations, for instance in a domain of complex geometry. Lions brought his attention to new methods, introduced by engineers, called 'finite elements methods'. With his coworkers, he succeeded in giving to these methods a highly satisfactory mathematical presentation. It can be found in the book *Calcul numérique des solutions des inéquations en mathématiques et en physique* written with Roland Glowinski and Raymond Trémolières. One must also mention the book *Quelques méthodes de résolution de problèmes aux limites non linéaires* in which Lions introduced systematically the methods of compacity, of monotony, of regularisation, of penalisation which are essential tools for studying for instance Navier-Stokes equations, von Karman equations, Schrödinger equation, Korteweg de Vies equation.

Many useful theories in Mechanics investigate the properties of solutions when some parameters remain small: they lead to what may be called 'asymptotic analysis of these problems'. Methods were introduced: boundary layer theory, singular perturbation, multiple scales, homogenization. Again, Lions wrote a mathematically satisfactory presentation in at least two books.

It would be important to report on all the works and books dealing with control theory, a field to which Lions gave special attention right up to his death and in which his contributions are of fundamental importance. Even if I cannot do it here, I hope that what has been said above proves how exceptional was this mathematician. He was a genius who has often been compared to Henri Poincaré or to John von Neumann.

Paul Germain

MINORU ODA (1923-2001)

Minoru Oda was born in 1923 in Sapporo. He studied physics in Osaka, where he graduated in 1944. After a few years spent in the construction of Japan's first radio telescope, he moved to MIT, were he started a long collaboration and friendship with Bruno Rossi, working first in the field of cosmic ray showers and, starting from 1962, in the study of extra solar X-ray sources with the help of satellites. Minoru Oda made important contributions to the study of X-ray sources, and in 1965 devised an original method for the localization of these sources through the invention of the modulation collimator. These collimators played a crucial role in the optical identification of the first X-ray source, Sco X-1. X-ray astronomy and space science became the lifelong mission of Minoru Oda. In Japan he became a professor in the newly founded Institute for Space and Aeronautical Sciences (ISAS) at the University of Tokyo, an institute that he directed from 1984 until his retirement in 1988. Under Oda's direction ISAS had an enviable record of successful missions, probably unequalled by other agencies, among which Hakucho and Tenma, as well as the Japanese-British satellite Ginga.

After retiring from ISAS, Oda was appointed president of RIKEN, an important Japanese research institute. When he died last year he was still very active as president of the Tokyo University of Information Sciences.

Many scientists in Italy and elsewhere will remember Oda's friendship and generosity, especially to young people. Many of us will remember Minoru through his delightful watercolours of flowers collected in different parts of the world.

Nicola Cabibbo

Max F. Perutz

I feel honoured to speak in memory of Max Perutz. I appreciated him extremely, both as a very competent scientist and as a lovely person. What also linked me to him was that twenty years ago, in 1981, we became members of this Academy at the same time. Looking back to these twenty years of having had meetings here, I still see him sitting for a short while in the – at that time – very hard seats, and then standing up and remaining standing because he had obvious back pains, but his face was with us and looked very happy. I think that he overcame his pain just by loving to talk about Science with us.

Max Ferdinand Perutz was born in 1914 in Vienna, where he grew up and studied chemistry. Doing his chemical studies, he started to pick up interest in applying his knowledge to investigating the structure and functions of proteins. This was at a very early time, in 1936, when he decided to go for his Ph.D. degree to Cambridge, England, where there was a well established X-ray crystallography group. At that moment very little work was done with bio-molecules, but that was his aim. Max Perutz chose a very particular protein which is relevant for all of us and for many other living organisms, namely haemoglobin. Haemoglobin is a rather complex molecule, and Max Perutz devoted enormous efforts and time to find access to its structure. This was not easy, because he had first to develop methodology which was not yet available; he had first to elaborate it, and I think that it is his merit together with some colleagues, to have found a way to introduce heavy metal atoms into the proteins under study and then to compare responses to X-ray irradiation of crystals with and without metal inclusions. Mathematical treatment of the obtained data allowed them to draw a picture of the three-dimensional structure of the protein. You can imagine that this gave a very big impulse to comprehend protein function. This development can be seen as a forerunner of what we now call proteomics.

On the way to his scientific breakthrough, Max Perutz spent some time in the Swiss mountains to study the formation and structure of ice crystals in glaciers. This best illustrates his efforts as a scientific investigator to find novel approaches to overcome difficulties of methodology in order to gain insight into the structure of complex biomolecules.

It was shortly after the war in 1947 that the Medical Research Council of England decided on the proposition of Max Perutz and his colleagues to create in Cambridge the MRC unit for studies of molecular structures. This institution later became the Laboratory of Molecular Biology. Max Perutz was its first Director until 1979. During those 32 years of scientific activities a remarkable amount of novel knowledge was acquired in this laboratory. I shall just remind you of a few names of investigators like Francis Crick and Jim Watson, describing the DNA structure, Fred Sanger exploring protein and later DNA sequence analysis, Sydney Brenner unravelling elements of gene expression and so on, and a big number of young investigators who received their doctoral and postdoctoral education.

The scientific success of research done in the laboratory of Molecular Biology may, in part, be due to its attraction of highly qualified investigators, but it might also be linked with the readiness of these scientists to develop new methodologies and research strategies, as exemplified by Max Perutz. From 1945, he closely collaborated with John Kendrew, joining at that time the laboratory with the aim of unravelling the structure of myoglobin, a protein related to haemoglobin. Both projects led to successful results. This found its highest recognition in 1962 when Max Perutz and John Kendrew were awarded the Nobel Prize in Chemistry for their studies of the structures of globular proteins.

Max Perutz's interests were not limited to structure, he wanted to find out the functional mechanisms of proteins. He thus investigated the binding of oxygen to haemoglobin. He was able to show that in this complex molecule the binding of different atoms of oxygen is cooperative. This important finding led him to look at differences between oxyhaemoglobin and desoxyhaemoglobin. In the same context he also studied abnormal forms of haemoglobin, such as those of some haemoglobin mutants. Following the same line, he also started to compare haemoglobins of different animals, and this gave him some insight on how these molecules must have evolved in the course of long-term history. The resulting knowledge offered explanations on how some particular adaptations to very specific life conditions, life styles, must have occurred. For example, he compared the haemoglobin of migratory birds that fly very long distances at very high altitudes requiring much energy, with that of sedentary land animals. This led Max Perutz to a deep understanding of protein functions and how living organisms can evolve to carry out their required functions.

The career of Max Perutz as a scientist, starting as a young doctoral student in Cambridge, lasted sixty-five years, until his death, which occurred last winter at the age of eighty-eight years. We still remember his reports in recent years on novel aspects of his research concerning studies of the electrostatic effects of proteins and their medical implementations as for example seen for

Huntington's disease. Thereby, he pointed to relations between stereochemistry and biological functions, such as those in aggregates of polyglutamine fibres. These are questions at the forefront of today's research.

So Max Perutz kept up with scientific progress as a passionate researcher until the end of his days. His personality was impregnated by that passion, and his influence on his colleagues and certainly on all his students is enormous and long lasting.

Lastly, in order to show the high regard and affection that he had for our Academy I would like to read out the letter that Max Perutz sent to the Chancellor shortly before his death:

'Dear Monsignor Sorondo,

It seems that my days are numbered and I feel like expressing to you and the President my deep appreciation of having been a Member. I received the Pope's telegram appointing me to the Academy at the same moment as the news of the attempt to assassinate him. It roused a terrible conflict of emotion in me, on the one hand my great pleasure about this Honour, and on the other hand my deep sorrow at that tragic crime.

I first attended a study-week in 1961, in fact organized it myself, which you could almost call 'The Birth of Molecular Biology'. People presented an extraordinary series of exciting new discoveries, and I first met some of the protagonists from other countries. Since then I have attended and organized other study-weeks and much enjoyed that privilege, but the greatest privilege was being a Member of that unique body, a truly international Academy, covering all the natural sciences. I came across there many more people whom I would never otherwise have met, such as the Indian physicist Menon, and then there was the wonderful setting, that Renaissance court, looking over the back of St. Peter's like the view of the Matterhorn from Zermatt. I think that the Pontifical Academy is a unique institution and I very much hope that the Holy Father and his successors will continue to give it their support.

I should be delighted if you were able to communicate any of this letter to the Holy Father and assure him again how much I appreciated my Membership.

With kindest regards to you and the President.

Yours, Max Perutz'

Werner Arber

MRC
Medical Research Council

MRC Laboratory of Molecular Biology
Hills Road
Cambridge, CB2 2QH
England

Tel: + 44 (0) 1223 248011 (Switchboard)
Fax: + 44 (0) 1223 213556 (General)

Dr M.F. Perutz Direct line: 01223 402200
Secretary: 01223 402214

14 January 2002

Monsignor Marcelo Sánchez Sorondo
Pontifical Academy
Casina Pio IV
V-001200 Citta del Vaticano
Rome
Fax: 0039-06 698 85218

Dear Monsignor Sorondo,

It seems that my days are numbered and I feel like expressing to you and the President my deep appreciation of having been a Member. I received the Pope's telegram appointing me to the Academy at the same moment as the news of the attempt to assassinate him. It roused a terrible conflict of emotion in me, on the one hand my great pleasure about this Honour, and on the other hand my deep sorrow at that tragic crime.

I first attended a study-week in 1961, in fact organized it myself, which you could almost call 'The Birth of Molecular Biology'. People presented an extraordinary series of exciting new discoveries, and I first met some of the protagonists from other countries. Since then I have attended and organized other study-weeks and much enjoyed that privilege, but the greatest privilege was being a Member of that unique body, a truly international Academy, covering all the natural sciences. I came across there many more people whom I would never otherwise have met, such as the Indian physicist Menon, and then there was the wonderful setting, that Renaissance court, looking over the back of St. Peter's like the view of the Matterhorn from Zermatt. I think that the Pontifical Academy is a unique institution and I very much hope that the Holy Father and his successors will continue to give it their support.

I should be delighted if you were able to communicate any of this letter to the Holy Father and assure him again how much I appreciated my Membership.

With kindest regards to you and the President.

Yours,

Max Perutz

Figure. Facsimile of Prof. Max Perutz's letter.

FRANCO RASETTI (1901-2001)

Franco Rasetti started his career as a physicist in Pisa and then in Rome since 1927, where he was called by Orso Maria Corbino to be a member of the famous Via Panisperna group led by Enrico Fermi. Although he was for a long time identified as Fermi's collaborator, Rasetti is to be considered one of the great experimental physicists of the last century. I presume that everybody remembers the experiments of the Panisperna group which led to the discovery of the properties of slow neutrons and paved the way for the exploitation of nuclear energy, but other results by Rasetti have given important contributions to the development of modern physics. In 1928-29, while working at Caltech, he determined the statistical behaviour of nitrogen nuclei. This result definitely proved that the atomic nucleus cannot contain electrons, and opened the way for the discovery of the neutron and for Pauli's neutrino hypothesis and Fermi's theory of beta decay.

After emigrating to Canada in 1938, where he accepted an appointment to the Catholic University of Laval, Rasetti refused to take part in the nuclear weapon programme, an example which was not followed by many of his contemporaries. He decided to leave physics and to devote himself to his erstwhile interests in the natural world. He soon became a world authority on trilobites, and on alpine flora. Our sister institution, the Italian Lincei Academy, has recently reissued his magnificent atlas of alpine flowers.

Rasetti returned briefly to physics in the seventies, when he engaged in Rome in the measurement of the refractive index of a gas of free electrons. Some of the techniques he developed on this occasion have become widely used in the diagnostics of plasmas.

With Franco Rasetti disappears the last of the original members of our Pontifical Academy of Sciences, which were nominated on the occasion of its re-foundation in 1936.

Nicola Cabibbo

VICTOR FREDERICK WEISSKOPF (1908-2002)

Victor F. Weisskopf
The Father of Virtual Reality
A Scientist to Whom Europe Owes Much

What makes Victor F. Weisskopf unique in the 20th century is his being a great scientist and an exceptional mentor who was endowed with a nearly unmatchable humaneness. Scientific Europe owes him an enormous debt. CERN (European Subnuclear Research Center) had him as a scientific, moral and effective leader in the crucial years of its younger existence, from 1961 to 1965. During these years, CERN was the first European scientific enterprise to find itself in competition with the colossal USA. His responsibility as Director General of CERN was decisive for creating that which today is known throughout the world as the 'spirit of CERN', which means scientific excellence. In Subnuclear physics Europe is top rank, thanks to the great Weisskopf.

To us young fellows he said:

> Guys, when one day you will have the opportunity to speak about all that I've done in my life, please forget titles and honors. Tell instead about something I did in physics.

This is what I will try to do now, having had the privilege of knowing him when he was at the peak of his scientific strength. He was my teacher and an unwavering supporter of my scientific activity. He loved to recall his first steps. And what steps! I will recount the most beautiful episode. This was how the calculations of 'virtual' reality got started. We physicists call it 'radiative effects'.

It was he, in fact, who was the first to venture into the unexplored territory of the phenomena called 'virtual'. Let us imagine an instrument so full of power that it could observe any phenomenon; even within the intimate heart of matter itself. An instrument from which nothing can hide. Well, almost nothing. This super-powerful instrument would never be able to observe directly the phenomena we call 'virtual'. Prior to the 1930s, it would have been impossible to imagine the existence of this reality. And yet – now that it has become daily bread in our laboratories – it seems to be practically taken for granted.

Start with a single grain of coffee. It is made up of billions and billions of atoms. Each atom has, as an external 'cloud', one (if it is Hydrogen) or many electrons. The electron is endowed with an electric charge. The taste of coffee depends on this charge. The light of a light bulb is emitted from the electrons of atoms that constitute the filament of the light bulb. If the electron did not have an electric charge, it could not produce light, which is made up of 'pieces', 'quanta', which we call 'photons'. It has been noted that photons that are emitted from one electron can be absorbed by other electrons. If this was not so, how could we detect them at all? It is from this question that 'virtual' reality is born.

If it is true that an electron can emit a photon, could the same electron absorb that very same photon? The answer is affirmative, but the phenomenon is not observable. In fact, if we could actually observe that photon, the electron could no longer absorb it directly. This is a very simple example of 'virtual' reality. Even though it is not directly observable, it nevertheless produces calculable and rigorously reproducible effects. This is what the young Weisskopf discovered.

The history of this formidable new reality is incredible. In contrast to the very simple 'virtual' phenomenon I have just described (thanks to 'hindsight'), the young Weisskopf – driven by his interest to understand the 'radiative effects' – calculated a very complex 'virtual' phenomenon, called '*vacuum polarization*', and concluded that the effect was small, but that one day it might be measurable. In 1947, a physicist, Willis Lamb, and one of his collaborators from Columbia University (New York), measured the much simpler virtual effect I described above; they discovered that it was 10 times greater than predicted by the young Weisskopf. And of the opposite sign. It is easy (with 'hindsight') to understand the reason. The more complicated the virtual phenomena at stake, the smaller are their measurable effects. When Lamb measured the virtual effect that bears his name, Weisskopf estimated the value and sign very quickly. It was a calculation much simpler than that which he had done years before. The contributions of Weisskopf to the progress of physics and of scientific culture are so many that a conference would be necessary in order to review all of them.

Let me close by recalling a few of his substantive contributions to making CERN a great European Lab. In the era dominated by Bubble-Chamber-Technology, he encouraged the construction of the highest intensity negative beam; this allowed the discovery of the first example of Nuclear Antimatter, the discovery of the time-like structure of the proton and the first search for the third lepton. It is thanks to Weisskopf that the high-precision neutron missing mass spectrometer was invented and constructed at CERN; this allowed the direct measurement of a basic quantity (the so-called 'mixing' angle) in the structure of the Subnuclear particles called ‘vector’ and ‘pseudoscalar’ mesons. This ‘mixing’ is still of great interest because it requires the most advanced theoretical understanding in Subnuclear Physics, the so-called ‘instantons’.

These are just a few examples strictly related to my own research work. Consider how many fellows he has encouraged, inspired and guided, and you will understand why Victor Weisskopf as a physicist and a leader in Europe and in the world will be unique in the history of Science of the 20th century.

Antonino Zichichi

SELF-PRESENTATIONS OF THE NEW MEMBERS

ANTONIO M. BATTRO

I was born in Mar del Plata, Argentina in 1936. My field of research is the neuro-developmental study of cognition and education in children and adults. I am a physician (MD, University of Buenos Aires) and psychologist (Docteur de l'Université de Paris).

I trained in neuroanatomy in Buenos Aires, in experimental psychology with Paul Fraisse in Paris and in genetic epistemology with Jean Piaget in Geneva. I helped to introduce the computer as a relevant tool in education in South America, following Seymour Papert's research at MIT. I applied those powerful information tools as prostheses for disabled persons, a new field of research in rehabilitation and special education. In the last few years I have been focusing my activities on educational cognitive neurosciences, using the computer as a 'tool for the brain'. My effort is to join the two fields of educational computer technology and cognitive neuroscience in order to open a new frontier of research. A first approach towards this synthesis is my recent book *Half a brain is enough* (Cambridge, 2000) where I describe the impact of the digital technologies in the education of a hemispherectomized child. I am now expanding this model to span a larger spectrum of problems related to the effect of neuroplasticity in the 'educated brain'. I am currently the Robert F. Kennedy visiting professor of Latin American Studies at Harvard.

ENRICO BERTI

My education was essentially in philosophy and for this reason, perhaps, I am not worthy of belonging to this famous Academy, which is mainly composed of renowned scientists. I studied philosophy at the University of Padua, which was a famous centre for the diffusion of Aristotelianism during the Renaissance, but which has conserved some traces of this tradition also in our time. I have been professor of philosophy at the Universities of Perugia, Geneva and Brussels, and I am now professor of philosophy in Padua, where I am leading a Centre for the history of the Aristotelian tradition. As a philosopher I have been elected member of the Accademia Nazionale dei Lincei (Rome), which contends with this Pontifical Academy of Sciences the heritage of the ancient Accademia dei Lincei, to which Galileo Galilei belonged, and as a philosopher I have been elected member of the Institut International de Philosophie (Paris). I am now organizing, as the chairman of the International Programme Committee, the XXI World Congress of Philosophy on behalf of the FISP (Fédération Internationale des Sociétés de Philosophie).

However, if someone generously proposed my name for this Academy, there must be a reason and I suppose that it concerns the main field of my philosophical interests, and this is the philosophy of Aristotle. I have dedicated to this philosopher and to the history of his influence on European culture more than 40 years of my life, with the result of being known essentially as an Aristotelian scholar. The study of Aristotelian philosophy, obviously, gave me the basis for developing some philosophical reflections in most of the fields of philosophical thought: logic, philosophy of language, philosophy of nature, metaphysics, ethics, politics, etc. Moreover, since Aristotle was not only a great philosopher, but also a great scientist, especially in the field of biology, psychology, anthropology and human sciences, the study of his works has necessarily implied for me an interest ancient science as a whole. And because the thought of Aristotle influenced the history of science during the whole of antiquity and the Middle Ages, not only in Christian but also in Muslim Countries, the reconstruction of the Aristotelian tradition obliged me to study the sciences of late antiquity and the Middle Ages in their whole extension.

In modern times, as it is well known, the thought of Aristotle was abandoned and refused by the development of some sciences such as astronomy, mechanics and chemistry, and this refusal gave rise to the birth of modern science. But his teaching has maintained a fundamental role in the development of other sciences, such as biology, medicine and human sciences (psychology, linguistics, rhetoric). In the next few weeks my university will commemorate the fourth centenary of the degree in medicine obtained in Padua by William Harvey, the discoverer of the blood circulation, who was essentially an Aristotelian. And even where Aristotle's influence was refused and fought, as in the case of Galilei, his logic and his method remained as a model for the modern sciences.

In my studies on the presence of Aristotelian philosophy in the 19th and 20th centuries I discovered that it had been striking not only in philosophers such as Hegel, Trendelenburg, Brentano, Moore, Heidegger, Gadamer, Austin, Ryle and others, by also in scientists such as Darwin, Jacob, Delbrück, Mayr, Prigogyne, Thom and others. The French mathematician Réné Thom, who died recently, during the last years of his work experienced a true conversion to Aristotelian physics. For these reasons I have realized that it is impossible to study adequately the philosophy of Aristotle and its connections to the contemporary philosophical debate without knowing the status of the discussion in the main fields of contemporary science, and this has forced me to engage myself in some of them. I am not a philosopher of science, nor a logician who analyses the methods of science, but a philosopher deeply interested in the contents of contemporary sciences, and for this I hope to be not completely unworthy of belonging to this Academy and to be able to contribute in some measure to its proceedings.

THIERRY BOON-FALLEUR

My field is cancer genetics and immunology.

I studied biology and medicine for 3 years at the University of Louvain, but I never completed the medical curriculum because I moved to Rockefeller University, New York, to pursue a doctorate in the field of molecular genetics.

Later I moved to the Pasteur Institute in Paris. There, in 1972 I made a fortuitous observation. It suggested that mouse tumors that were not rejected by the immune system nevertheless carried specific antigens that had the potential to serve as targets for rejection by T lymphocytes, provided proper immunization could be applied. Starting from this observation, we applied the approaches of molecular and cellular genetics to the field of tumor immunology. This led to the demonstration that our initial observation applied to all mouse tumors. Moreover, the genetic mechanisms that lead to the expression of tumor-specific antigens were elucidated. These are mutations of ubiquitously expressed genes and reexpression in cancer cells of genes that are only expressed in germline cells. One conclusion of this work is that the T lymphocytes can exert an immunosurveillance of the integrity of our genome: genetic defects lead to the expression of new antigens that can serve as targets for the destruction of the cell by T lymphocytes.

The observations made on mouse tumors have been extended to human tumors: it is now clear that most, if not all, human tumors carry tumor-specific antigens. As it is equally clear that tumors do not elicit an effective immune rejection response, we are engaged in a program of therapeutic vaccination of cancer patients, mainly melanoma patients, using purified antigens known to be expressed on their tumor. At the present time this treatment induces some degree of tumor rejection in only 20% of the patients. Medically significant rejections are only observed in 10% of the patients. Our present approach is to compare systematically the T lymphocyte responses of the few patients who reject their tumor to the responses of the many who do not, in order to identify critical differences. Hopefully, this will enable us to improve our treatments.

My research is being pursued at the Brussels branch of the Ludwig Institute for Cancer Research, at the Christian de Duve Institute of Cellular Pathology and at the Faculty of Medicine of the University of Louvain in Brussels.

GÜNTER BLOBEL

Omnis cellula e cellula, that each cell derives from a pre-existing cell by division, is the culmination of a profound insight of the late 19th century and a dictum articulated by the German pathologist Rudolf Virchow.

It is estimated that the earth is 5 billion years old that the first cell arose 3.5 billion years ago. Since that time, cells have continuously divided. At first they existed as single cells. Over time they got together and formed ever more complex organisms, culminating in man.

Each of us starts life by the joining of one cell from our father and one cell from our mother. Likewise, our father and mother began their lives from the union of a single cell from each of their parents. If we continue to trace our ancestors back in time we will eventually arrive at the cells that developed 3.5 billion years ago. So as we sit here, each of us represents 3.5 billion years of *continuous cellular life!* All of us are 3.5 billion years old!

Because all forms of life evolved from cells that developed 3.5 billion years ago, we are all related to each other!

This kinship among cells of bacteria, plants, animals and man is reflected in their organization as revealed by the modern tools of molecular biology and cell biology. Many of the organizational features and of the machineries in these cells have been highly conserved.

My own studies have touched on one of these highly conserved mechanisms, namely the intracellular targeting of protein molecules. An average mammalian cell possesses about one billion molecules of proteins. Proteins are polymers consisting of 20 building blocks (amino acids) up to 10,000 building blocks in length. Proteins are steadily degraded and therefore have to be continuously synthesized de novo. Newly synthesized proteins are transported out of the cell, or are shipped to various cellular compartments or are woven into intracellular membranes, each in a specific asymmetric orientation. We found that this is achieved by short sequence elements built into each protein. Each of these address-specific 'zip codes' is recognized by specific recognition factors followed by targeting and routing. These processes are aided by other accessory elements, such as receptors, channels, tracks, motors etc. We found that the zip codes as well the cognate sorting machineries are highly conserved in all cells.

Besides science, I am interested in the arts, particularly music and architecture.

I was born in 1936 in the small Silesian village of Waltersdorf near Sprottau. In February 1945 we fled from the approaching Red Army. On our way to relatives in Saxony, in the centre of Germany, we stopped briefly in Dresden. As a nine-year-old, I was very impressed by the beauty of this city, by its many palaces and churches, particularly by the huge cupola, the 'Stone Bell', of the Frauenkirche. A few days later, from about 60 km away, we witnessed the destruction of this magnificent city. The midnight sky turned red from the raging firestorm that killed tens of thousands of people and destroyed one of the world's most beautiful cities. It was one of the saddest days of my life. I decided then: I will contribute to the reconstruction of that city. More than fifty years later this dream came true, when I was able to donate the proceeds of my 1999 Nobel Prize in Medicine to the reconstruction of the Frauenkirche. It was one of the happiest days of my life.

A smaller portion of the proceeds of the Nobel Prize, I donated to the rebuilding of the Synagogue in Dresden and to the restoration of two churches in the historic center of Fubine, Alessandria in Piemonte. The Synagogue of Dresden was destroyed on Kristallnacht in November 1938. Fubine is the hometown of the parents of my wife, Laura Maioglio, who preserves their ancestral 17th century home.

Presently, I am campaigning for the reconstruction of the Paulinerkirche in Leipzig. This magnificent, over 800-year-old church was, for hundreds of years, also used as the Aula of the University of Leipzig and was witness to many of the most important events in German cultural history. The Paulinerkirche survived the Second World War completely intact. In an act of barbarism, the Paulinerkirche and its surrounding buildings were blown up in 1968 by the East German dictator Ulbricht in order to obliterate religion. The buildings that replaced the Paulinerkirche are now in disrepair and have to be torn down. The University Administration and the Mayor of Leipzig, however, campaign against the reconstruction of the Paulinerkirche. More than 80% of its interior had been saved before the wanton destruction by Ulbricht. I hope that by 2009, on the occasion of the 600th anniversary of the University of Leipzig, the Paulinerkirche will be rebuilt.

PIERRE J. LÉNA

I was born in Paris in 1937, the elder of a family of six children. After secondary school, I decided to study physics and entered the *Ecole normale supérieure* in 1956. I found there an exceptional intellectual atmosphere between humanities and science students, great masters such as Laurent Schwartz or Alfred Kastler, and an extreme sensitivity to injustices and world conflicts, at the time of the Algeria war, the decolonization and the emergence of the Third World. I began to teach at the Sorbonne (Orsay) and decided to go to astrophysics, at a moment when access to space was going to deeply transform this field. The immense infrared spectral range was entirely virgin of exploration and I spent the next two decades on it. My Doctorat d'Etat was prepared partly in Arizona, on the infrared radiation of the Sun, one of the very few objects to be bright enough to be detectable at that time! I was lucky to use a NASA airborne telescope, and, back in France, we created a modest airborne observatory, which made some of the early observations of molecular clouds and dust emission in our Galaxy.

At the end of the 70s, while Professor at the University of Paris VII and inspired by the work of the French astronomer Antoine Labeyrie, I made every effort to obtain astronomical images with high angular resolution and to reach the diffraction limit of large telescopes by gaining one and later almost two orders of magnitude on image sharpness, beating the effects of the Earth's atmosphere. Working with a small team, this led us in 1989 to success with the first astronomical use of adaptive optics, a technique now adopted worldwide by all large telescopes.

While my colleagues or students were exploiting it to study many solar system objects or the star formation process, I became involved in the project of the European *Very Large Telescope*, for which, again following Labeyrie's ideas, we proposed an interferometric mode, using the coherence of light and combining several independent telescopes to gain another order of magnitude in resolution. Although this had never been done at such a scale, the project was adopted in 1987 and is now practically in operation, just in time to plan observations of the extrasolar planets discovered in large number since 1995.

I have always cultivated my interest for education, and in 1991 became president of the French *Institut national de recherche pédagogique*, while in charge of the Graduate School of astrophysics in Ile-de-France. With Georges Charpak and Yves Quéré, we founded in 1995 *La main à la pâte*, a nation-wide movement to renovate science education in primary schools, soon to be expanded to many countries. It led me to discover the urgency and magnitude of science education issues in the world and to spend large efforts on it.

Four children and their spouses and eight grandchildren form a happy circle, while many former students or young colleagues extend this circle: among them I would like to mention especially Daniel Rouan, Christian Perrier, Guy Perrin, Marie Glanc and the regretted Jean-Marie Mariotti.

Carlo Maria Cardinal Martini

Thank you very much, Mr. President. I was born in Turin, in the North of Italy, seventy-five years ago. I entered the Society of Jesus in 1944.

After my studies in theology, I graduated in fundamental theology at the Pontifical Gregorian University, writing a study on the historical traditions of the Resurrection of Jesus. I then taught fundamental theology for five years. In 1962 I was called by the Pontifical Biblical Institute to teach textual criticism of the Bible, and I graduated at the same Institute with a dissertation on Papyrus Bodmer XIV, which is the oldest papyrus containing the text of the Gospel of Luke (second century) and throws new light on the history of the text of the Gospel of Luke.

I taught textual criticism for seventeen years. During that time I became a member of the small ecumenical and international committee that was responsible for the publication of the critical edition of 'The Greek New Testament', which forms the basis of the translation of the New Testament in about eight hundred languages. In 1979 I was called by Pope John Paul II to become the Archbishop of Milan. This is a very large diocese and I had very little time to continue studying textual criticism. I have recently retired from this position and have now returned to the study of textual criticism.

I am presently engaged in research on a papyrus which is in the Vatican Library (the two Epistles of Peter), of the third century. I plan to work most of the time in Jerusalem, to be near the place where the Bible originated. I am privileged to be a member of this great Academy. Thank you very much.

JÜRGEN MITTELSTRASS

I am a professor at the University of Constance, one of the younger universities in Southern Germany, where I have taught philosophy since 1970. Since 1990, I have been Director of the Centre for Philosophy of Science at the university.

I was educated in Erlangen, Bonn and Hamburg, where I studied philosophy, classical philology and theology, also attending lectures in German literature, mathematics and physics. After taking my Ph.D. in philosophy in Erlangen in 1961 with a dissertation on the history of a Greek research principle in astronomy, I was a post-doctoral student in Oxford. Before I went to Constance, I spent some time as visiting professor in Philadelphia. From 1997 to 1999 I was President of the German Philosophical Association; a few weeks ago I became President of the Academia Europaea (the European Academy of Science).

My main research interests are in epistemology, the history and philosophy of science, the philosophy of mind, as well as, in recent years, in ethics, particularly ethics and the sciences. Within the philosophy of science, I am mainly interested in topics such as theory dynamics, theory structure, and the philosophy of time. My work on the history of science has dealt mostly with the history of physics and astronomy from the Greeks to Newton, in which research Galileo has been a principal focus. I am the editor of an encyclopaedia (*Enzyklopädie Philosophie und Wissenschaftstheorie*) whose four volumes also deal with the history and philosophy of science.

I am greatly honoured to be here, and to have been elected a member of this distinguished Academy; indeed, in all modesty, I am proud to belong to you. A philosopher among scientists – this is no easy thing to be. But I am convinced that we should aim at restoring to science its philosophical core, all while making philosophy more scientific in its methods. And this, as I understand it, is also one of the major aims of the Pontificia Academia Scientiarum.

Ryoji Noyori

Mr. President and Distinguished Members of the Academy,

First of all, please accept my heartfelt gratitude on this splendid occasion for having been honored with the appointment as academician of the world's most prestigious Pontifical Academy of Sciences. I do appreciate the members of the selection committee who recognized my lifelong accomplishments in the area of chemistry. I feel particularly honored to be the sole member who has currently been elected from Japan.

Born in Kobe, Japan, I was educated at Kyoto University to complete my bachelor and then master degrees and immediately became an Instructor at the same university. In 1968 I was invited by Nagoya University to chair a newly created laboratory of organic chemistry. Since then I have stayed there to teach and to conduct research for more than 30 years, while I have been warmly guided and encouraged by many colleagues worldwide. Then, fortunately, I was awarded the Nobel Prize in Chemistry last year.

I am a chemist. One of the major characteristics of our science is that we can design and synthesize any molecules at will, thereby generating a diverse array of molecular functions. We are very proud that our accumulated knowledge can now convert natural resources, including petroleum and biomass, to various chemical substances of a high-added value, thereby contributing to human welfare. Chemistry can generate high values from almost nothing.

My major research interest is in the molecular chirality or handedness. For many molecules, right-handed and left-handed shapes are possible, which are called enantiomers. Two enantiomers are mirror images of one another and have identical free energy. The difference is small indeed. These subtle differences, however, become distinct when these are involved in biological or physiological phenomena. Right-handed and left-handed molecules often smell and taste different from each other. The structural difference between them becomes a serious problem in the administration of pharmaceutical drugs. A compelling example of the relationship between pharmacological activity and molecular handedness was provided by the tragic administration of thalidomide to pregnant women in the 1960s. Right-handed thalidomide has desirable analgesic properties; however, left-handed thalidomide is teratogenic and induces fetal malformation. The actual thalidomide drug, unfortunately, was a 50:50 mixture of right- and left-handed molecules. Such problems should be avoided at all costs.

However, selective chemical synthesis of right-handed or left-handed molecules, called asymmetric synthesis, remained extremely difficult for many years. Early in 1851, some 150 years ago, Louis Pasteur claimed that 'Dissymmetry is the only and distinct boundary between biological and nonbiological chemistry. Then, symmetrical physical or chemical force cannot generate molecular dissymmetry'. Scientifically speaking, this is not true. However, this statement remained valid from a practical or technical point of view until 20 years ago. Therefore, access to pure right- or left-handed compounds has indeed relied largely on biotechnology using microorganisms that contain natural enzymes. However, since biological methods allow for access to only a limited class of substances, an efficient chemical means toward this goal is needed.

We could solve this long-standing problem by inventing efficient man-made molecular catalysts which consist of a metallic element and a chiral organic molecule. In 1966, we discovered the general principle which is now widely practiced in research laboratories and industry. Later we developed a general method to synthesize a wide range of chiral compounds by simply adding a hydrogen molecule to organic substances. Such accomplishments, together with the efforts of other scientists worldwide, have changed the chemist's dream to reality. Application of our original and versatile chemistry has allowed us and other people to achieve a truly efficient synthesis of organic molecules of theoretical and practical importance. Our methods have in fact been utilized for the large-scale production of certain fragrances, antibiotics, and antibacterial agents. Such invention has dramatically changed the processes of chemical synthesis of pharmaceuticals, agrochemicals, flavors, and fragrances among others. The growth of this core technology has given rise to enormous economic potential in the manufacture of precious chemicals. I am very pleased to be involved in contributing to the initiation and progress of this significant scientific realm.

Thank you very much.

JOSEPH CARDINAL RATZINGER

Mr. President, dear colleagues, I was born in 1927 in Marktl, in Upper Bavaria. I did my philosophical and theological studies immediately after the war, from 1946 to 1951. In this period, theological formation in the faculty of Munich was essentially determined by the biblical, liturgical and ecumenical movement of the time between the two World Wars.

Biblical study was very fundamental and essential in our formation, and the historical-critical method has always – even if I am not a specialist like Cardinal Martini – been very important for my own formation and subsequent theological work.

Generally, our formation was historically oriented, and so, although my area of speciality was systematic theology, my doctoral dissertation and my postdoctoral work presented historical arguments. My doctoral dissertation was about the notion of the people of God in Saint Augustine; in this study, I was able to see how Augustine was in dialogue with different forms of Platonism, the Platonism of Plotinus on the one hand and of Porphyry on the other. The philosophy of Porphyry was a re-foundation of Politeism and a philosophical foundation of the ideas of classical Greek religion, combined with elements of oriental religions. At the same time, Augustine was in dialogue with Roman ideology, especially after the occupation of Rome by the Goths in 410, and so it was very fascinating for me to see how in these different dialogues and cultures he defines the essence of the Christian religion. He saw Christian faith, not in continuity with earlier religions, but rather in continuity with philosophy as a victory of reason over superstition. So, to understand the original idea of Augustine and many other Fathers about the position of Christianity in this period of the history of the world was very interesting and, if God gives me time, I hope to develop this idea further.

My postdoctoral work was about St. Bonaventure, a Franciscan theologian of the thirteenth century. I discovered an aspect of Bonaventure's theology not found in the previous literature, namely, his relation with the new idea of history conceived by Joachim of Fiore in the twelfth century. Joachim saw history as progression from the period of the Father (a difficult time for human beings under the law), to a second period of history, that of the Son (with more freedom, more openness, more brotherhood), to a third period of history, the definitive period of history, the time of the Holy of Spirit. According to Joachim, this was to be a time of universal reconciliation, reconciliation between east and west, between Christians and Jews, a time without the law (in the Pauline sense), a time of real brotherhood in the world. The interesting idea which I discovered was that a significant current among the Franciscans was convinced that Saint Francis of Assisi and the Franciscan Order marked the beginning of this third period of history, and it was their ambition to actualise it; Bonaventure was in critical dialogue with this current.

After finishing my postdoctoral work I was offered a position at the University of Bonn to teach fundamental theology, and in this period ecclesiology, history and the philosophy of religion were my main areas of work.

From 1962 to 1965 I had the wonderful opportunity to be present at the Second Vatican Council as an expert; this was a very great time of my life, in which I was able to be part of this meeting, not only between bishops and theologians, but also between continents, different cultures, and different schools of thinking and spirituality in the Church.

After this I accepted a position at the University of Tübingen, with the idea of being closer to the 'school of Tübingen', which did theology in a historical and ecumenical way. In 1968 there was a very violent explosion of Marxist theology, and so when I was offered a position at the new University of Regensburg, I accepted not only because I thought it would be interesting to help develop a new university, but also because my brother was the choirmaster of the Chapel of the Cathedral. I hoped, too, that it would be a peaceful time to develop my theological work. During my time there I wrote a book about eschatology and a book about the principles of theology, such as the problem of theological method, the problem of the relationship between reason and revelation, and between tradition and revelation. The Bible was also always the main point of interest for me.

While I was beginning to develop my own theological vision, in 1977 Pope Paul VI named me Archbishop of Munich, and so, like Cardinal Martini, I had to stop my theological work. In November of 1981, the Holy Father, Pope John Paul II, asked me to become the Prefect of the Congregation for the Doctrine of the Faith. The Prefect of the Congregation is also President of two important Commissions, the International Theological Commission and the Pontifical Biblical Commission. The work of these two bodies, each composed of twenty or thirty professors proposed by the Bishops of the world, is carried out in complete freedom and acts as a link between the Holy See and the offices of the Roman Curia on the one hand, and the theological world on the other. It has been very helpful to me to serve as the President of these two Commissions, because it has permitted me to continue somewhat my contact with theologians and with theology. In these years, the two Commissions have published a good number of very important documents.

In the Biblical Commission two documents in particular were very well received in ecumenical circles and in the theological world in general. The first was a document about the methods of exegesis. In the fifty years since the Second World War we have seen interesting developments in methodology, not only the classic historical-critical method, but also new methods that take into account the unity of the Bible in the diverse developments in this literature, and also new methods. I think this document was really a milestone; it was very well accepted, as I said, by the scholarly community. The second document was published last year and concerns the relationship between the Holy Bible of the Jewish people, the Old Testament, and the New Testament. It treats the question of the sense in which the two parts of the Bible, each with very different histories, can be considered one Bible, and in what sense a Christological interpretation of the Old Testament – not so evident in the text as such – can be justified, as well as our relationship to the Jewish interpretation of the Old Testament. In this sense, the meeting of two books is also the meeting of two histories through their cultures and religious realisations. We hope that this document will also be very helpful in the dialogue between Christians and Jews.

The Theological Commission published documents on the interpretation of dogma, on the past faults of the Church – very important after the confessions made repeatedly by the Holy Father – and other documents. At the moment we are publishing a document on the Diaconate and another on revelation and inculturation.

This last argument, the encounter between different cultures, that is, intercultural and interreligious dialogue, is at the moment the main topic for us in our Congregation. After the disappearance of liberation theology in the years following 1989, there developed new currents in theology; for example, in Latin America there is an indigenous theology. This idea is to re-do theology in the light of the pre-Columbian cultures. We also are dealing with the problem of how Christian faith can be present in the great Indian culture with its rich religious and philosophical traditions.

The meetings of the Congregation for the Doctrine of the Faith with Bishops and with theologians, aimed at finding how an intercultural synthesis in the present moment is possible without losing the identity of our faith is exciting for us, and I think it is an important topic even for non-Christians or non-Catholics.

Thank you for the honour of being present with you.

AWARD OF THE PIUS XI MEDAL

STANISLAS DEHAENE

Summary of Scientific Activity

When I was a student in mathematics, I was always intrigued by the peculiar mental activity that characterizes mathematical thought, with moments of quick insight followed by periods of tedious, almost mechanical computation. Intuition and computation both seemed essential, but in strikingly different, indeed complementary ways. Following this lead, my scientific research has attempted to shed some light on the mental and cerebral bases of mathematical thought.

Joining Jacques Mehler's Laboratory for Cognitive Science and Psycholinguistics in 1985, I learned that the methods of cognitive science could be applied to study mathematical thought. I focused on what is perhaps its most elementary constituent, the comprehension and manipulation of numbers. My first experiments concerned number comparison. How do we know that 63 is larger than 55? Using chronometric tests, I showed that the time that our brain takes to compare two numbers is a highly regular psychophysical function of the distance between them, as well as of their size. This indicated that numbers were represented internally, not by discrete symbols, but by analogical quantities on an internal continuum that could be likened to a mental 'number line'.

Of course, there were also many indications in my experiments that humans could manipulate numerical symbols mentally if the task required it. In 1991, I discovered that the intuition of quantity and the manipulation of symbols rely on separable brain systems. With Laurent Cohen, at the Hôpital de la Salpêtrière in Paris, I studied a patient who had suffered a large left-hemispheric lesion and experienced devastating impairments in language, calculation, and memory. Remarkably, in all of these domains, he showed a spared ability to approximate the correct quantity. For instance, he could not perform an operation as simple as 2+2 – he sometimes stated that this made 3, or 4, or 5 –, but he knew that 2+2=9 was false because the quantities involved were too distant.

Based on this and many other cases, I proposed a formal model of the mental representations that contribute to number processing, the 'triple code model'. This model helped to predict and to understand the many experimental observations that followed.

When brain imaging techniques became available in the late 1980s, it was clear that they provided a whole set of new tools to test the model. I therefore engaged in a large number of studies that used brain-imaging techniques to probe the functional anatomy of calculation networks with positron emission tomography (PET) and later functional magnetic resonance imaging (fMRI). I also attempted to specify the temporal sequence of number processing stages by recording event-related potentials (ERPs). In particular, by combining fMRI and ERPs, I was able to confirm that approximation and exact calculation tap two distinct cerebral circuits.

My studies pointed to the crucial role of a small region in the horizontal segment of the intraparietal sulcus (HIPS), in the left and right hemispheres. This region can be systematically identified in all subjects. It occupies a fixed location relative to other functional areas in the parietal lobe that are engaged in various sensori-motor tasks. My research suggests that this region is systematically activated whenever a person manipulates numerical quantities mentally. During number comparison, the activity of this region is a direct function of the semantic distance between the numbers to be compared; and during calculation, its activity increases in proportion to the size of the numbers involved. This region is therefore a good candidate for a cerebral map of numerical quantity.

In 1993, with Jean-Pierre Changeux, I proposed a formal theoretical model that specified how numbers could be encoded by a population of neurons. The model proposed the existence of 'numerosity detectors', neurons that were coarsely tuned to a specific quantity of items. In 2002, this prediction was verified when electrophysiologists identified a population of number-sensitive neurons in the monkey parietal lobe, at a location homologous to the human HIPS area. Together with other observations that preverbal infants, in their first year of life, already possess elementary quantity manipulation abilities, those data indicate that 'number sense' is a basic ability which has been laid down in our brains in the course of evolution.

Intuitions are often unconscious. Would it be possible to show that the human sense of number can be triggered automatically and unconscious-ly? Intrigued by this idea, I designed a paradigm where we could flash subliminal words or digits that were masked by other shapes and therefore could not be consciously seen. Behavioral and brain imaging methods revealed an unsuspected depth of processing of those masked symbols. I discovered that masked stimuli could activate a case-independent fusiform representation of visual words, but also the parietal representation of number, and even the motor cortex when subjects were engaged in a fast chronometric task.

This research lead me to ask what was special about the conscious state. What aspects of human cerebral organization make it possible to slowly but flexibly perform a large variety of mental operations, and give rise to the feeling of conscious access and conscious direction? For many years, I had been working with molecular neurobiologist Jean-Pierre Changeux on the development of neuro-realistic models of cognitive functions. Those models accounted for neuropsychological tests associated with the prefrontal cortex, and their impairments reproduced the deficits exhibited by frontal patients. Recently, we realized that their architecture could be synthesized into a broader proposal, the 'neuronal workspace hypothesis'. Inspired by Bernard Baars' workspace view of consciousness, our model proposes that the neural basis of conscious thought is the sudden and coordinated activation of a highly interconnected network of neurons with long-distance axons. This model serves as a theoretical framework for new imaging studies of conscious and subliminal processing. Most recently, my studies have confirmed that conscious processing is associated with a brain-scale state of coordinated activity at distributed sites in parietal, prefrontal and cingulate cortex.

In the future, I plan to continue to search for the cerebral bases of high-level mental activity in humans. Brain-imaging techniques are providing us with remarkable insights into the organization of the brain and how it supports abstract thought. Mathematical thought remains my central theme, but I also apply the methods of cognitive neuroscience to other fields. With Jacques Mehler and other colleagues, I study the organization of language comprehension and, in particular, how bilinguals manage to fit two languages in the same brain. With Laurent Cohen, I study how written words are decoded and how this changes when the brain learns to read in a given culture. Finally with my wife Ghislaine Dehaene-Lambertz, I attempt to specify how the brain systems that we can visualize in human adults are laid down in the course of child development.

JUAN M. MALDACENA

Research Interests

My research has always been directed towards understanding different aspects of quantum gravity using string theory. In string theory there are certain black holes that can easily be described in terms of D-branes. D-branes are some excitations that string theory has. D-branes are objects that have a very precise and explicit mathematical description. Furthermore, they are rather heavy so that they curve the spacetime rather easily. Due to these properties they can be used to describe black holes, which arise when we have very heavy objects in a small region of space. With this description it is possible to understand the microscopic origin of black hole entropy, and to obtain a microscopic picture of Hawking radiation. Some of these formulas seemed to work too well and outside their naïve region of validity.

Motivated by this, in 1997 I conjectured that a certain region of spacetime near the horizon of these black holes could be given an equivalent description in terms of an ordinary quantum field theory, very similar to the quantum field theories that describe particle physics. This gave a novel relationship between quantum field theories and gravity which illuminated aspects of both of these theories. In other words, this relationship could be used both ways in order to learn about properties of quantum field theories or to learn about properties of gravity. Interestingly this gave a relationship between quark confinement and black holes. In the field theory description the strings are composite objects made with particles while in the gravity description they are the fundamental objects. I have spent the past few years studying different aspects of this relationship in order to learn more about gravity and field theories. One interesting consequence of the conjecture is that the process of black hole formation and evaporation does obey the standard rules of quantum field theory.

In the future I plan to continue these studies with the objective of understanding more precisely how to describe in a precise way situations where the spacetime is time dependent in an important fashion, such as what happens in the beginning of the Big Bang or in the interior of black holes.

Quantum Gravity

Our present description of nature is based on two kinds of fundamental theories.

One is the theory of gravity, which describes the dynamics of space-time. This is the General Relativity theory that Einstein formulated. It describes very successfully the motion of planets around the sun, the dynamics of very heavy and fast moving objects in the universe, and most notably the expansion of the universe as a whole. The second theory that we have is the theory of particle physics. This theory formulates a certain number of elementary particles and their interactions. Among these particles are the electrons and quarks that make up ordinary matter as well as the force carriers like the photon, which carries the electromagnetic force. This theory obeys the rules of quantum mechanics. Moreover, quantum mechanics is crucial in order to explain correctly most properties of matter.

These two theories, gravity and quantum particle physics, are extremely successful theories, they can explain a huge number of observations and they are not inconsistent with any experiment that has been done so far. (It might be necessary to include new particles in order to explain dark matter, but that can be done without changing the framework). Nevertheless this is an inconsistent picture of reality. It is mathematically, or logically, inconsistent. The inconsistency arises because we treat gravity as a classical theory, we would need to treat gravity in a full quantum mechanical form. There is no disagreement with current experiments because it is expected that quantum gravity effects, if present, would be very small and undetectable with the resolution of current experiments. On the other hand, there are certain physical processes that cannot be understood without quantum gravity. The most interesting and important one is the beginning of the Big Bang, the explanation of the initial stages of the Big Bang. Another question we cannot describe using the standard physical laws is what happens in the interior of black holes. When matter falls into black holes it is crushed into a region of very large density (formally infinite if computed with the current theories). To understand what is happening there we need a quantum theory of gravity. The basic reason that quantum gravity can be ignored for experiments we can do in the laboratory is the following. Gravity is important if an object is heavy while quantum mechanics is important if it is small. Ordinary objects are either small and light, so that we can neglect gravity, or are heavy and large, so that we can neglect quantum mechanics. On the other hand, in the beginning of the Big Bang the whole universe, which is heavy, is concentrated in a very small region. For this reason quantum gravity is important.

When one tries to quantize Einstein's theory of gravity one encounters difficulties since the straightforward methods, that worked very well for particle physics, now produce nonsensical infinite answers. So a quantum theory of gravity requires some new idea. The most serious contender, as a theory of quantum gravity, is the so-called 'String Theory'. This is a theory under construction. Many aspects of this theory are known but its final formulation is not yet known. Instead of describing the theory, let me just give a flavor of some of the new ingredients that String Theory uses. The first is the idea that fundamental objects can be one-dimensional instead of point-like. In particle theories the particles are points, they have zero dimensions. In string theory the fundamental objects have one dimension, i.e. they look like a tiny string, hence the name 'String' Theory. When strings oscillate in different ways they produce different elementary particles. So an electron would be a string oscillating in one way while a photon is a string oscillating in a different way. The second ingredient is the presence of some extra dimensions. So instead of having a spacetime with 1+3 dimensions (one time and three spatial dimensions) the universe can have 1+9 dimensions. Six of these dimensions have to be very small since we have not yet observed them. The third ingredient is supersymmetry. This is a symmetry that postulates that each known particle has a partner with different spin but otherwise similar properties. It is a symmetry that relates bosons and fermions. Bosons are particles that carry integer spin and fermions carry half integer spin. Fermions make matter while bosons carry forces.

The main virtue of string theory is that it can put together gravity and quantum mechanics into a consistent set of equations. It gives a very tight mathematical structure which is intimately connected with many ideas in particle physics and gravity. String theory gives rise to particles and interactions that are very similar to the ones in the standard model such as chiral gauge interactions, family structure and grand unified gauge groups. The precise nature of the particles one obtains depends on the precise nature of the six-dimensional space spanned by the six small dimensions. We have not yet found the space that gives precisely the standard model of particle physics. Finally another very nice aspect of string theory is that it leads to a precise understanding of various quantum properties of black holes, such as their entropy. The entropy of black holes gives the number of microscopic configurations that a black hole can be in. It is intimately associated with the fact that black holes have a temperature, which leads to the so-called Hawking radiation.

Finally let me point out some of the main challenges and unsolved problems that we are faced with. The first is to understand the beginning of the Big Bang. The second is to find the six-dimensional space that gives precisely the standard model of particle physics. And finally and most important is to find some experimental evidence that this is really the theory that describes nature.

PROGRAMME

Plenary Session *The Cultural Values of Science*
8-11 November 2002

FRIDAY, 8 NOVEMBER 2002

9:00 *Welcome Speech*:
Prof. N. Cabibbo, President of the Academy

9:15 *Commemorations of Deceased Academicians*:
André Blanc-Lapierre by Prof. P. Germain; Louis Leprince-Ringuet by Prof. P. Germain; Jacques-Louis Lions by Prof. P. Germain; Minoru Oda by Prof. N. Cabibbo; Max F. Perutz by Prof. W. Arber; Franco Rasetti by Prof. N. Cabibbo; Victor F. Weisskopf by Prof. A. Zichichi

10:15 *Self-presentation of the New Academicians*:
Prof. A.M. Battro, Prof. E. Berti, Prof. G. Blobel, Prof. T. Boon-Falleur, Prof. P.J. Léna, Card. Prof. C.M. Martini, Prof. J. Mittelstrass, Prof. R. Noyori, Card. Prof. J. Ratzinger

11:00 Break

11:30 *The Subject of the Plenary Session*:
H.E. Prof. M. Sánchez Sorondo, Chancellor of the Academy

12:10 Chairperson: W. Arber
Science and Culture
Prof. M. Iaccarino
Discussion

13:20 Lunch

15:00 Chairperson: P. Germain
Que la science s'inscrit dans la culture comme "pratique théorique"
Prof. P. Ricœur
Discussion

15:40 *The Cultural Values of Science*
Prof. L. Arizpe
Discussion

16:20 *Cultural Aspects of the Theory of Molecular Evolution*
Prof. W. Arber
Discussion

17:00 Break

17:30 Chairperson: N.M. Le Douarin
Science and Dreams
Prof. P. Germain
Discussion

18:10 *The Facts of Life*
Prof. C. de Duve
Discussion

19:15 Dinner

SATURDAY, 9 NOVEMBER 2002

9:00 Chairperson: V.I. Keilis-Borok
Modern Cosmology and Life's Meaning
Prof. Father G.V. Coyne
Discussion

9:40 *The Different Paces of Development of Science and Culture: the Considerations of a Demographer*
Prof. B.M. Colombo
Discussion

10:20 *From World View (Weltanschauung) to Science and Back*
Prof. S.L. Jaki
Discussion

11:00 Break

11:30 Chairperson: E. Berti
Science Education in the Twenty-first Century: a Challenge. Summary of the PAS Workshop held in November 2001
Prof. P. Léna
Discussion

12:10 *Nouveaux paradigmes scientifiques et déplacement du sacré*
Prof. Father J.-M. Maldamé
Discussion

12:50 General Discussion

13:15 Lunch

15:00 Chairperson: G.V. Coyne
The Moral Substance of Science
Prof. J. Mittelstrass
Discussion

16:00 *Reconnecting Science with the Power of Silence*
Prof. T.R. Odhiambo
Discussion

16:40 Chairperson: J.E. Murray
Towards a Culture of Scientific Excellence in the South
Prof. M. Hassan
Discussion

17:00 Break

17:30 *Science as a Culture: a Critical Appreciation*
Prof. C.N.R. Rao
Discussion

18:30 *On the Predictability of Crime Waves in Megacities*
Prof. V.I. Keilis-Borok
Discussion

19:15 Dinner

SUNDAY, 10 NOVEMBER 2002

9:30 Holy Mass celebrated by His Eminence Card. Prof. C.M. Martini, Church of St. Stephen of the Abyssinians (Vatican City)

10:30 Private Guided Visit to the Sistine Chapel

12:00 Closed Session

13:00 Award of the Pius XI Medal (Casina Pio IV) to Dr. S. Dehaene and Dr. J.M. Maldacena

13:30 Lunch at the Academy

MONDAY, 11 NOVEMBER 2002

9:00 Chairperson: H. Tuppy
The Impact of Neuroscience on Human Culture
Prof. W.J. Singer
Discussion

9:40 *The Art and Science of Medicine*
Prof. A. Szczeklik
Discussion

10:20 Break

10:45 Papal Audience and photograph with the Holy Father

13:15 Lunch

15:00 Chairperson: N. Cabibbo
The Why and the How of Our Origins
Prof. W.R. Shea
Discussion

15:40 *Science Never Ends: a New Paradigm is Coming into Being in Biology*
Prof. R. Vicuña
Discussion

16:20 *The Unique and Growing Influence of the Neurosciences on the Development of our Culture*
Prof. R.J. White
Discussion

MONDAY, 11 NOVEMBER 2002

17:00 Break

17:30 Chairperson: Cabibbo
Surgery of the Soul
Prof. J.E. Murray

17:45 *Scientific Culture and the Ten Statements by John Paul II*
Prof. A. Zichichi
Discussion

18:10 General Discussion

19:00 Dinner

LIST OF PARTICIPANTS

Prof. Nicola CABIBBO, President
H.E. Msgr. Prof. Marcelo SÁNCHEZ SORONDO, Chancellor
The Pontifical Academy of Sciences
Casina Pio IV
V-00120 Vatican City
Tel.: +39 0669883195 – Fax +39 0669885218
E-mail: academy.sciences@acdscience.va

Academicians:

Prof. Werner ARBER
University of Basel
Department of Microbiology
Biozentrum
Klingelbergstrasse 70
Ch-4056 Basel (Switzerland)
Tel.: +41 61 2672130 – Fax: +41 61 2672118
E-mail: arber@ubaclu.unibas.ch

Prof. Antonio M. BATTRO
Robert F. Kennedy Visiting Professor of Latin American Studies
Harvard University
Graduate School of Education
Larsen Hall, Room 601
Appian Way
Cambridge, MA 02138 (U.S.A.)
Tel.: +1 617 4953446 or 4960636 – Fax +1 617 4953626
E-mail: battroan@gse.harvard.edu

Prof. Enrico BERTI
Università degli Studi di Padova
Dipartimento di Filosofia
Piazza Capitaniato, 7
I-35139 Padova (Italy)
E-mail: enrico.berti@unipd.it

Prof. Günter BLOBEL
The Rockefeller University
Howard Hughes Medical Institute
Laboratory of Cell Biology
1930 York Avenue
New York, NY 10021 (U.S.A.)
Tel.: +1 212 3278096 – Fax: +1 212 3277880
E-mail: blobel@rockvax.rockefeller.edu

Prof. Thierry BOON-FALLEUR
Ludwig Institute for Cancer Research
Ucl 7459 – 74, Avenue Hippocrate
B-1200 Brussels (Belgium)
Tel.: +32 2 7647580 – Fax: +32 2 7647590
E-mail: thierry.boon@bru.licr.org

Prof. Bernardo M. COLOMBO
Università degli Studi di Padova
Dipartimento di Scienze Statistiche
Via VIII Febbraio, 2
I-35122 Padova (Italy)
Tel.: +39 049 8274144 – Fax: +39 049 8274170
E-mail: colber@stat.unipd.it

Rev. P. Prof. George V. COYNE, S.J.
Specola Vaticana
V-00120 Vatican City
Tel.: +39 0669885266 – Fax: +39 0669884671
E-mail: gcoyne@as.arizona.edu – gcoyne@specola.va

Rev. Prof. Renato DARDOZZI
Via delle Montagne Rocciose, 68
I-00144 Roma (Italy)
Tel.: +39 065913657

Prof. Christian DE DUVE
Christian de Duve Institute of Cellular and Molecular Pathology
75.50 Avenue Hippocrate 75
B-1200 Bruxelles (Belgium)
Tel.: +32 2 7647550 – Fax: +32 2 7647573
E-mail: deduve@icp.ucl.ac.be

and

The Rockefeller University
1230 York Avenue
New York, N.Y. 10021 (U.S.A.)
Tel.:+1 212 3278149 – Fax: +1 212 3277974
E-mail: polowek@rockvax.rockefeller.edu

Prof. Rev. Raffaele FARINA, S.D.B.
Biblioteca Apostolica Vaticana
V-00120 Vatican City
Tel.: +39 0669883301 – Fax: +39 0669885327
E-mail: prefetto@vatlib.it

Prof. Paul GERMAIN
Académie des Sciences
23, quai de Conti
F-75006 Paris (France)
Tel.: +33 1 44414352 – Fax : +33 1 44414363

Rev. Prof. Michael HELLER
ul. Powstańców Warszawy, 13/94
Pl-33-110 Tarńow (Poland)
Tel.: +48 14 6263326 – Fax: +48 14 6224040
E-mail: mheller@wsd.tarnow.pl

Rev. P. Prof. Stanley L. JAKI, O.S.B.
P.O. Box 167
Princeton, NJ 08542 (U.S.A.)
Tel.: +1 609 8963979 – Fax: +1 609 8969307
E-mail: sljaki@ibm.net

Prof. Vladimir I. KEILIS-BOROK
International Institute of Earthquake
Prediction Theory and Mathematical Geophysics
Warshavskoye Sh. 79, Kor 2
Moscow 113556 (Russia)
Tel.: +7 095 1107795 – Fax : +7 095 3107032
E-mail: vkb@ess.ucla.edu

and

University of California, Los Angeles
Institute of Geophysics and Planetary Physics
3845 Slichter Hall, Box 951567
Los Angeles, CA (U.S.A.) 90095-1567
Tel.: +1 310 8253939

Prof. Nicole M. LE DOUARIN
C.N.R.S. – Collège De France
Institut d'Embriologie Cellulaire et Moléculaire – UPR 9064
49 Bis, Avenue de la Belle Gabrielle
F-94736 Nogent-sur-Marne (France)
Tel.: +33 1 45141515 – Fax: +33 1 48734377
E-mail: nicole.le-douarin@infobiogen.fr

Prof. Pierre J. LÉNA
Université Paris VII Denis Diderot
Observatoire de Paris
Départment de Recherche Spatiale
place Jules-Janssen
F-92195 Meudon (France)
Tel.: +33 1 45077951 – Fax : +33 1 45077102
E-mail: pierre.lena@obspm.fr

Prof. Rita Levi-Montalcini
C.N.R. – Institute of Neurobiology
Viale Marx, 15
I-00137 Roma (Italy)
Tel.: +39 0686090510 – Fax: +39 0686090269

Prof. Stanisław Łojasiewicz
Jagiellonian University
Institute of Mathematics
Ul. Reymonta 4
Pl-30059 Kraków (Poland)
Tel.: +48 12 6324888 Ext. 5230 – Fax: +48 12 6324372
E-mail: lojasiew@im.uj.edu.pl

Rev. P. Prof. Jean-Michel Maldamé, O.P.
Couvent Saint-Thomas D'Aquin
Impasse Lacordaire
F-31078 Toulouse Cedex (France)
Tel.: +33 562173145 – Fax : +33 562173117
E-mail: jean-michel.maldame@tradere.org

H.E. Card. Prof. Carlo M. Martini
Santuario di Galloro
Via Appia, 54
I-00040 Galloro, Roma (Italy)

Prof. Govind K.M. Menon
K – 5(Rear), Hauz Khas
New Delhi 110 016 (India)
Fax: +91 11 6511454; +91 11 6510825
E-mail: mgkmenon@ren02.nic.in

Prof. Jürgen Mittelstrass, Director
Zentrum Philosophie und Wissenschaftstheorie
Universität Konstanz – Fach D 24
D-78457 Konstanz (Federal Republic of Germany)
Tel.: + 49 7531 882498 – Fax: +49 7531 882502
E-mail: Juergen.Mittelstrass@uni-konstanz.de

Prof. Rudolf L. MÖSSBAUER
Technical University of Munich
Department of Physics, E15 E15
James-Franck-Strasse
D-85748 Garching bei München (Federal Republic of Germany)
Tel.:+49 89 28912511 Fax +49 89 28912680
E-mail: beatrice.vbellen@ph.tum.de

Prof. Rudolf MURADIAN
Universidade Estadual de Santa Cruz
Departamento de Ciências Exatas e Tecnológicas
Rodovia Ilhéus / Itabuna, Km. 16
BR-45650-000 Ilhéus, Bahia (Brazil)
Tel.: +55 73 6322739
E-mail: Rudolfmuradian@hotmail.com

Prof. Ryoji NOYORI
Nagoya University
Department of Chemistry
Chikusa
Nagoya 464-8602 (Japan)
Tel.: +81 (52) 7892956 – Fax: +81 (52) 7834177
E-mail: noyori@chem3.chem.nagoya-u.ac.jp

Prof. Thomas R. ODHIAMBO
The African Academy of Sciences (AAS)
Miotoni Lane off Miotoni Road, Karen
P.O. Box 14798
Nairobi (Kenya)
Tel.: +254 2 884401 up to 5 – Fax: +254 2 884406
E-mail: Aas@africaonline.co.ke

Prof. Crodowaldo PAVAN
Universidade de São Paulo, USP
Instituto de Ciências Biomédicas
Lab. de Microbiologia
São Paulo, S.P. 05389-970 (Brazil)
Tel.: +55 11 38187346 – Fax: +55 11 38130845
E-mail: crodowaldo@hotmail.com

Prof. Chintamani N.R. Rao
Jawaharlal Nehru Centre for Advanced Scientific Research
Jakkur Post
Bangalore 560064 (India)
Tel.: +91 80 8563057 – Fax: +91 80 8462766
E-mail: cnrrao@jncasr.ac.in

H.E. Card. Prof. Joseph Ratzinger
Congregation for the Doctrine of Faith
V-00120 Vatican City
Tel.: +39 0669883296 – Fax: +39 0669883409

Prof. Carlo Rubbia, President
Ente per le Nuove Tecnologie, l’Energia e l’Ambiente (E.N.E.A.)
Lungotevere Thaon di Revel, 76
I-00196 Roma (Italy)
Tel.: +39 063227554 – Fax: +39 0636272313
and
European Organization for Particle Physics (C.E.R.N.)
Ch-1211 Geneva 23 (Switzerland)
Tel.: +41 22 7676338 – Fax: +41 22 7677555
E-mail: carlo.rubbia@cern.ch

Prof. Wolf J. Singer
Max-Planck-Institute for Brain Research
Deutschordenstrasse 46 – Postfach 710662
D-60528 Frankfurt Am Main (Federal Republic of Germany)
Tel.: +49 69 96769218 – Fax: +49 69 96769327
E-mail: singer@mpih-frankfurt.mpg.de

Prof. Andrzej Szczeklik
Jagellonian University
School of Medicine
Department of Medicine
Ul. Skawinska 8
Pl-31066 Krakow (Poland)
Tel.: +48 12 4305169 – Fax: +48 12 4305204
E-mail: mmszczek@cyfr-kr.edu.pl

Prof. Charles H. TOWNES
University of California, Berkeley
Department of Physics
366 Leconte Hall, #7300
Berkeley, CA (U.S.A.)
Tel.: +1 510 6421128 – Fax: +1 510 6438497
E-mail: cht@sunspot.ssl.berkeley.edu

Prof. Hans TUPPY
University of Vienna
Institute of Biochemistry
Dr. Bohr-Gasse 9,3. Stock
A-1030 Vienna (Austria)
Tel.: +43 1 427761670 – Fax: +43 1 42779616
E-mail: hans.tuppy@univie.ac.at

Prof. Rafael VICUÑA
Pontificia Universidad de Chile
P.O. Box 114-D
Santiago de Chile (Rep. de Chile)
Tel.: +56 2 6862663 – Fax: +56 2 2225515
E-mail: rvicuna@genes.bio.puc.cl

Prof. Robert J. WHITE
Metrohealth Medical Center,
Division of Neurological Surgery
and Brain Research Laboratory
2500 Metrohealth Drive
Cleveland, OH 44109-1998 (U.S.A.)
Tel.: +1 216 7784383 – Fax: +1 216 7785616
E-mail: patedkav@aol.com

Prof. Antonino ZICHICHI
European Organization for Particle Physics (C.E.R.N.)
Ch-1211 Geneva 23 (Switzerland)
Tel.: +41 22 7677755 – Fax: +41 22 7850207

Experts:

Dr. Lourdes ARIZPE
Assistant Director-General for Culture at Unesco, Paris
Universidad Nacional Autónoma de México
Centro Regional de Investigaciones Multidisciplinarias
Av. Universidad s/n, Circuito 2, C.P. 62210
Cuernavaca, Morelos, Ciudad Universitaria de la UAEM (Mexico)
Tel.: +52 777 3130316 – Fax: +52 777 3175981
E-mail: larizpe@correo.crim.unam.mx

Dr. Mohamed H.A. HASSAN, Executive Director
The Third World Academy of Sciences (TWAS)
c/o The Abdus Salam International Centre for Theoretical Physics (ICTP)
Strada Costiera 11
I-34014 Trieste (Italy)
Tel.: +39 0402240327 – Fax: +39 040224559
E-mail: info@twas.org

Prof. Maurizio IACCARINO
Istituto Internazionale di Genetica e Biofisica
Via Marconi, 10
I-80125 Napoli (Italy)
Tel.: +39 0817257111 0815932547– Fax: +39 0817257304
E-mail: Iaccarin@iigb.na.cnr.it

Prof. Paul RICŒUR
19, rue Henry Marrou
F-92290 Chatenay-Malabry (France)
E-mail: jpgold@club-internet.fr

Prof. William R. Shea
Université Louis Pasteur De Strasbourg
Institut d'Histoire des Sciences
7, rue de l'Université
F-67000 Strasbourg (France)
Tel.: +33 3 90240580 – Fax: +33 3 90240581
E-mail: william.shea@ihs-ulp.u-strasbg.fr

Recipiens of the Pius XI Medal:

Prof. Stanislas DEHAENE
Institut National de la Santé (INSERM)
Service Hospitalier Frederic Joliot-Cea – Laboratoire U334
4 Place du General Leclerc
F-91401 Orsay Cedex (France)
Tel.: +33 1 69867848 – Fax +33 1 69867816
E-mail: baju@shfj.cea.fr

Prof. Juan M. MALDACENA
Institute for Advanced Study
Einstein Drive
Princeton, NJ 08540 (U.S.A.)
E-mail: malda@ias.edu

Observers:

P. Jacques ARNOULD, O.P.
c/o Centre National d'Etudes Spatiales
2, place Maurice Quentin
F-75039 Paris Cedex 1 (France)

Prof. Anna S. KASHINA
1000, Spanish River Road # 3t
Boca Raton, FL 33432 (U.S.A.)
Tel.: +1 561 3478968
E-mail: akashina@yahoo.com

Rev. Prof. Giuseppe TANZELLA-NITTI
Pontificia Università della Santa Croce
Piazza di S. Apollinare, 49
I-00186 Roma (Italy)
Tel.: +39 06681641 – Fax: +39 0668164400

Prof. Anna-Teresa TYMIENIECKA
World Phenomenology Institute
1, Ivy Pointe Way
Hanover, New Hampshire 03755 (U.S.A.)
Tel.: +1 802 2953487 – Fax: +1 802 2955963
E-mail: Wphenomenology@aol.com – info@phenomenology.org

PREFACE

The Pontifical Academy of Sciences devoted its plenary session of November 2002 to a debate on The Cultural Values of Science. Most of the talks delivered represent personal views of Academy members, and only a few non-members had been invited to complement the programme. For this reason, there is no claim for completeness of the transdisciplinary topical contributions. However, these proceedings clearly show that and how the progress of scientific knowledge and its applications also enrich the cultural heritage of our civilization.

One of the motivations to discuss this important topic was to contribute actively to the follow-up of the fruitful debate on science and society held in June 1999 at the World Conference on Science in Budapest, jointly organized by UNESCO and the International Council for Science (ICSU). The Pontifical Academy of Sciences is grateful to UNESCO for having welcomed its contribution on the cultural values of science in a wider debate on the relations between science and society and more specifically as regards a strengthening of the social contract between science and society. Our Academy also thanks UNESCO for its readiness to help diffuse the present publication to a wider interested readership. Any feedback from readers will be welcome and can help to intensify the dialogue between the natural sciences on the one hand and other fields of academic activities as well as the general public on the other hand. The readers are invited to take this publication and in particular the included Statement by the Pontifical Academy of Sciences on The Cultural Values of the Natural Sciences as a stimulus for further debates on a topic concerning all human beings.

Werner Arber

PRESENTATION

PROPOSAL TO DEVOTE THE PLENARY SESSION OF THE PONTIFICAL ACADEMY OF SCIENCES IN THE AUTUMN OF THE YEAR 2002 TO THE SUBJECT: 'THE CULTURAL VALUES OF SCIENCE'

WERNER ARBER

Research in the natural sciences has brought mankind many forms of enlightenment with regard to natural laws. The knowledge which has been acquired through such research has been, and is still, useful for numerous practical and technological applications which help to facilitate the daily lives of human beings, including their health and wealth. Acquired scientific knowledge also 'modulates' our world-view, our deeper understanding of what nature (both the inanimate and the living world) is and how it functions. The internalised world-view greatly influences man's multiple relations with his environment. This is true both of technological development and the psychological and sociological aspects of human behaviour. Indeed, the history of scientific discoveries and their impact on our world-view and on technological progress is closely bound up with the history of our civilisation. It could be the aim of the proposed debate at the Plenary Session to collect case studies and to propose general conclusions on the obvious cultural values of science in a broad context, both as regards the evolution of our world-view and the evolution of the opportunities and possibilities of our lives.

Many of the contributions could be made by Academicians but the programme might be complemented by papers and comments given by a few invited speakers who are experts in the field.

This debate could represent a contribution of the Academy to the follow-up to the World Conference on Science held in Budapest in 1999 and more specifically to the subject of the renewal of the social contract between science and society. The Academy might possibly aim to draw up an appropriate statement and a set of recommendations on the basis of the conclusions reached during this Plenary Session.

INTRODUCTION

A CONTRIBUTION TO THE PREPARATIONS FOR THE PLENARY SESSION ON 'THE CULTURAL VALUES OF SCIENCE', FOLLOWING THE DISCUSSIONS OF THE COUNCIL MEETINGS OF 18 NOVEMBER 2001 AND 17 FEBRUARY 2002

H.E. MSGR. MARCELO SÁNCHEZ SORONDO

The First Homes of Science

All anthropologists agree that culture should be seen as a set of *learned* ways of behaving and adapting as opposed to inherited patterns of behaviour or instincts. Aristotle writes: 'While the other animals live by impressions and memories, and have but a small share of experience, the human race lives also by art (τέχνη) and reasoning (λογισμός)' (*Metaph*. 980 b 21). Culture is a typical characteristic of man who is not rigidly guided by determining laws which establish him within a given horizon. On the contrary, he is a self-interpreting animal, a self-made man. He never ceases to express himself and to give himself a name, and this development, at the centre of which is to be found man's freedom, is called 'culture', which is different from nature. When did culture experience the transition to science? If by science we mean the sophisticated arts of mathematics, aesthetics, architecture, metallurgy, and the written documents that describe such disciplines and their philosophical significance, then it is possible to describe ancient Egypt, China and Greece as the first homes of science. The wonders that Plato and Aristotle perceived as the starting point for engaging in philosophical thought are still applicable to the knowledge of children and adults, and to science itself, only that science makes the subject of these wonders move from the outside to the inside of things and is dedicated to the discovery of new laws, at the same time answering old questions and raising new ones.

The Scientific Revolution

Perhaps the most important event in European culture during the sixteenth and seventeenth centuries, which indeed gave rise to the modern age, was the so-called 'scientific revolution'. The wish to obtain in all the sciences (astronomy, physics, chemistry, biology) the same kind of rigorous demonstration that was to be found in mathematics, led the first modern scientists to apply mathematics to the study of nature. They dedicated attention to those aspects that could be measured. Given that mathematical hypotheses did not in themselves ensure a direct correspondence with reality, these modern scientists tried to verify such hypotheses not only by simple observations which could at times be deceptive (e.g., the perception that the earth is stationary) but also by more precise instruments (the telescope, the microscope, and others, which were constantly being improved), and above all by experiments, that is to say attempts to reproduce phenomena in more rigorous and controlled conditions. The synthesis of these two procedures, i.e. mathematical demonstration applied to nature on the one hand, and experimentation on the other, was the experimental-mathematical method. Matter, indeed, because of its quantity, could demonstrate its intelligibility through mathematical calculations that expressed themselves in relationships of a formal identity of reality in an abstract way. For example, two cells and two elephants, because they were each two in number, were the same in their 'twoness'. But in reality things do not exist equally, not even individuals of the same species. Therefore, contemporary science affirms the plurality and differences of physical forces (mass, energy, space, time, nuclear and sub-nuclear electric charges) and the plurality of life energies (cells, chromosomes, genes, the genetic code, the teleomatic structure) in living things. Today, macrophysics and microbiology seem to be moving towards an awareness that quality is in a dialectic relationship with quantity and vice versa, although on the physical level they are co-existent.

The Impact of Modern Science

For this reason, modern science has been one of the most important factors in the evolution of our civilized world for at least three centuries.

Indeed, it cannot be doubted that scientific knowledge has led to remarkable innovations that have been of great benefit to humankind. Life expectancy has increased strikingly, and cures have been discovered for many diseases; agricultural output has risen significantly in many parts of the world to meet growing population needs; technological developments and the use of new energy sources have created the opportunity to free humankind from manual labour; and technologies based on new methods of communication, information handling and computation have brought unprecedented opportunities and challenges for the scientific endeavour as well as for society as a whole.

Science and Values

The question whether the values by which 'improvement' is measured should come from outside or inside science (or a combination of both), that is to say whether they are purely scientific or philosophical, ethical, political, religious, etc. (or a mixture of the first and some or all of the rest), is a subject of primary importance in the contemporary debate. The determination of the character of an action with reference to the predicates of 'good', 'values' and 'obligatory', which represented a radical break with everything that had gone before, began for the first time in history with the tradition of thought generated by David Hume. For this tradition, one cannot derive an 'ought' from an 'is' and there can be no direct step from one to the other. Put in more contemporary terminology, no set of descriptive statements can entail an evaluative statement. Thus Bertrand Russell concluded 'that, while it is true that science cannot decide questions of value, that is because they cannot be intellectually decided at all, and lie outside the realm of truth and falsehood. Whatever knowledge is attainable, must be attained by scientific methods; and what science cannot discover, mankind cannot know' (*Religion and Science*, OUP, 1961, p. 243).

The Rejection of Ethical Neutrality

The rejection of ethical neutrality and the problem of the justifiability and objectivity of value judgements began to manifest themselves, under the impact of the circumstances of the time, after the end of the Second World War, when it appeared clear, as Russell was to write, that it was no longer possible to place on the same level a discussion of the goodness or otherwise of oysters and a discussion of the rightness or otherwise of torturing Jews. After what has been termed the capital sin of science, the atomic bomb, and the arrival of the greenhouse effect (which scientists are the first to recognise and strongly condemn), the most serious problem to emerge today is the relationship between the science of nature, in itself perhaps neutral in relation to values (in Max Weber's view 'without values', value-neutral and ethically neutral), and its freedom to engage in research, with all that this implies for the morally and socially relevant responsibility of science itself. This responsibility, which in the first instance concerns the technical and economic application of scientific results, also regards the planning and implementation, linked to both technical and economic assumptions, of research programmes.

Emerging Questions

There thus emerges first of all the strictly theoretical question of the relationship between what is and what ought to be, and the question of the relationship between ontology, deontology and teleology, or between scientific rationality and ethical rationality; and secondly, the question of how to compensate for the powerlessness of the responsibility attributable to individuals who become effective only within the context of institutions which themselves should be transformed so that science may do good. As is often observed, science is one of the very few human activities where errors are systematically criticised and fairly often, in time, corrected. This is why we can say that in science we frequently learn from our mistakes, and why we can speak clearly and sensibly about making progress. Naturally enough, the Pontifical Academy of Sciences, which has studied this subject on many other previous occasions, cannot but take part in this debate, and this plenary session seeks to make a contribution to its positive development. The new horizons generated by globalisation, a process which has acted to reduce the distances of time and space (in part because of the impact of science itself), cannot neglect the question of the sustainable development of the whole world but in particular of developing countries. 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 material goods, knowledge, science, and values, when shared, grow and develop. Aristotle argued that it was a principal task of the wise man to expound what he knows to others (*Metaph*. 982 a 14). Today, in a world which is increasingly globalised and where communication travels almost at the speed of light, it is the task, more than ever before, of wise men not only to engage in research but also to teach, to advise, and to orientate.

The Aims of the Deliberations of the Plenary Session

To provide examples of the progress of knowledge acquired by scientists during the course of the twentieth century in the various scientific disciplines;

to observe that an expansion in knowledge in itself has an incontestable value for humankind: universality; an increase in life opportunities; and a strengthening of the bases of human dignity;

to uphold the wish to share these cultural values with all our fellow citizens and with all the peoples of the world;

to secure democratic agreement about the principles and values to be applied to experiments required by research and to the critical assessment of the consequences of research.

SCIENCE AND CULTURE

MAURIZIO IACCARINO

Modern Science had its beginnings in the 17th century in Europe with the natural philosophy of Galileo and Newton. Different factors contributed to its flourishing. Among them: (i) a process that led to the independence of scientific theories from myths, religion and theology; (ii) the interaction among the different European cultures, that stimulated creativity through new ways of thinking and new paradigms for the observation of Nature; (iii) the foundation of the scientific academies, notably the Accademia dei Lincei, the Royal Society and the Académie des Sciences, which contributed to scientific progress through the dissemination of new knowledge.

Science aims at a description of causes and effects of the events occurring in Nature and it is based on the philosophy common to the European cultures, deeply influenced by Aristotle and Plato. According to them our understanding of the natural world is based on a set of *a priori* beliefs that cannot be subject to scientific enquiry, namely on ideal objects, or universal values, allowing us to imagine and describe the world around us. Religious people believe that God dictates the universal values; while agnostic or atheistic people believe that universal values are inherent in the Human Reason [3]. Transcendental values are the source of human beliefs that guide humanity to social and ethical rules and to the observation of Nature. Thus, belief in God or in the Human Reason is the essential prerequisite for scientists to be able to describe the outside world [8]. In other words, science is deeply rooted in metaphysics and there is no conflict between Religion and Science. Moreover, although the language of Science is often specialized and thus inaccessible to non-specialists, Science and Culture are not different entities: Science is part of Culture.

Science has had a strong influence on European culture. In the 19th century the key word for Science was order. Scientists had found that the movement of stars is highly predictable: all terrestrial and celestial phenomena follow the same scientific laws and the Universe is like a clock. They believed, according to the Galileian vision, that the book of Nature was written in the language of mathematics with characters represented by geometric objects, like triangles or circles. They affirmed that the mission of science was to discover the laws of Nature and that all natural phenomena could be explained with scientific laws. This faith in science gave rise to the philosophical movement called Positivism, which contributed to a diffused trust in Science and Technology and influenced social theories. Even after the fading out of Positivism the Darwinian theory of evolution influenced social phenomena like eugenics and racism. The faith in the possibilities offered by scientific progress still shapes the beliefs and actions of many people. In fact, expressions like 'this has been scientifically demonstrated', are often used to cut short a discussion.

Science shapes the personality of those that deal with it. In fact the work of scientists implies the proposition of new and original ways of interpreting the accepted explanations of facts. Originality, independence and dissent are characteristic of the scientific culture. However, originality means independence of thought and therefore a challenge of the established cultural values. Therefore, scientific progress requires encouragement and protection of cultural independence. The safeguards that independence requires are free inquiry, free thought, free speech, tolerance, and the willingness to arbitrate disputes on the basis of evidence. These values are of course important also in other domains of social life. Thus, science promotes values that yield a more tolerant society, able to adapt to changes and to novelties.

Science and Technology are interrelated and reinforce each other. Science and the use of scientific knowledge have profoundly changed everyday life, mainly in developed countries. Life expectancy has increased strikingly and cures have been discovered for many diseases; agricultural productivity has until now matched the demographic increase; and technological developments and the use of new energy sources have created the opportunity of freeing humankind from arduous labour. Technologies based on new methods of communication, information handling and computation have brought unprecedented opportunities and challenges [2, 4]. Figure 1 shows some of the discoveries or inventions that in the 20th century have radically changed our way of describing the natural world, or have influenced our everyday life. Today, science and scientific applications exert a profound influence on the cultural values of society and even the organization of society itself owes much to scientific thinking [9].

Much of this progress took place in Europe and in North America and, if we take the award of the Nobel prizes for science as an indicator of scientific excellence, we can see from Figure 2 that more than 90% of the laureates in the natural sciences come from Western Europe and North America, even though these countries include only 10% of the world population. Figure 3 shows that three quarters of the world scientific publications come from Western Europe and North America. The low number of Nobel laureates from the rest of the world reflects differences in culture and in the type of education, as well as in the level of financial support to scientific research. Even within a single country there are sectors of the population that do not contribute to Science because of lack of education. Fig. 4 reports a statement made in 1913 by the Vice President of the American Association for the Advancement of Science. The cultural attitude at the turn of the 20^{th} century in the USA deprived black people of an appropriate education and as a consequence made them less interested in pursuing a career in Science.

The governments of developed countries consider Science and Technology essential for economic progress and military power and therefore allocate abundant financial resources to science education and to public scientific research. In turn, a stimulating cultural environment, partially due to the high level of scientific education, attracts investments in private scientific research, thus adding to public commitment. The governments of newly industrialized countries have recently realized that the competitiveness of their industrial products needs scientific education and scientific research and therefore have increased the financial resources in this field. In developing countries public opinion realizes the importance of scientific research and stimulates the governments to increase the resources for science, although budget restrictions are often prohibitive. In all countries the use of new technological products stimulates the curiosity of people not only for technology, but also for science. It is therefore fair to state that in the last few centuries Science has had a strong influence on cultural values all over the world. This is not always positive. In developing countries science education based on Western concepts and culture, and taught by teachers for whom Science is often unrelated to their culture, leads children to deny the validity and authority of the knowledge transmitted to them by their parents and grandparents. Moreover, the widespread interest in new technologies causes an increased interest in foreign civilizations and cultures, not always accompanied by an appropriate elaboration harmonising it with the local culture. This creates tension in several societies.

The birth of modern Science is built on the past. Islamic civilization had a strong influence on the foundation of modern Science in Europe. The Muslims were the leading scholars in Science between the 7^{th} and the 15^{th} centuries. They were the heirs of the scientific traditions of Greece, India and Persia and, after appropriation and assimilation, they built on them and developed a truly Islamic science that was leading in all fields of science and technology, including medicine. These activities were truly cosmopolitan, in that the participants were Arabs, Persians, Central Asians, later on also Indians and Turks. They were mainly Muslims, but also Christians and Jews. The transfer of the knowledge of Islamic science to the West through various channels paved the way to the Renaissance and to the Scientific Revolution in Europe.

The general public in the West is unaware of the important contributions of Islamic civilization to modern Science and to Middle Age culture. When I was Assistant Director General of UNESCO I promoted the organization of an Exhibition on Science, Technology and Medicine in Islam. Its purpose is to bridge this gap in knowledge and to present in an effective and visual manner the major achievements of Islamic civilization. The Exhibition aims at illustrating the outstanding achievements of Islamic scientists and craftsmen, and the extent of their contribution to the general progress of science and technology. It will show Islamic civilization as an important link in the general cultural and scientific history of mankind, and the strong bonds between Islamic civilization and the later civilization of the West. Because of the unresolved political problems confronting the Middle East, the Western world has always been given a distorted picture of Islam and of the Arabs. The exhibition will remind people that Islamic science is part of our own heritage, and that the great Islamic scientists whose works were translated into Latin, like Jabir ibn Hayan (Geber), ibn Sina (Avicenna), al-Razi (Rhazes), ibn al-Haytham (Adhazin) and al-Khuwarizmi, are as important as any other great later European scientist. The following Figures (5, 6, 7 and 8, see pages 378-381) illustrate some of the objects that will appear in the exhibition.

What do we mean by Science? The scientific approach to the understanding of nature aims at analysing each phenomenon according to a predetermined set of rules that have a more general validity. Scientific work may be a description, like in the case of cosmology, or palaeontology or anatomy. These descriptions may lead to the formulation of theories, or paradigms according to Kuhn [1], that provide an interpretation of the causes and effects of the described events and that can be tested through experiments. When these experiments prove that the theory is wrong new hypotheses are made and tested. To quote Bertold Brecht in his play about Galileo: 'the aim of science is not to open the door to infinite wisdom, but to put a limit to infinite error'.

Another characteristic of scientific knowledge is that it builds on the past, namely it is incremental. The aim of a scientific discipline is to describe a specific field according to a subset of rules: for example, biology to be described at the anatomical, histological, cellular or biochemical level. This means that each type of description may become more and more complete with time. Does it come to an end, as Gunther Stent stated in 1968 [7] in the case of molecular biology? Gunther Stent started his scientific career when many people believed, in the framework of vitalistic theories, that it was not possible to interpret the inheritance of genetic traits in chemical terms. The elucidation of the genetic code was a victory for him, but at the same time the end of a challenge. Stent's statement upset many scientists of the time who believed that molecular biology was still alive. Later on we have witnessed an enormous amount of new discoveries and new knowledge in this field. However, it is true that, after 1968, work on the elucidation of the genetic code consisted only in finding out about details. I believe that specific types of scientific description approach an end, like in the case of anatomy, which was actively studied many years ago, while today this knowledge is mostly obtained through textbooks.

Scientists have been very successful when studying specific aspects of the natural world that were amenable to observation and experimentation, because the necessary theoretical and technical tools were available: this is the case of microbiology and the discovery of the causative agents of infectious diseases at the end of the 19th century; or the discovery of vitamins in the first decades of the 20th century. Scientists work on simple systems, which are usually idealizations or primitive models of a real situation. In this way scientists ignore many facts that occur during their experimentation. They also work at a specific level of analysis: for example the physics of elementary particles does not contribute to the interpretation of the mechanism of muscle contraction. To use the words of Albert Szent-Gyorgyi:

> In my quest for the secret of life I started my research in histology. Unsatisfied by the information that cellular morphology could

> give me about life, I turned to physiology. Finding physiology too complex, I took up pharmacology. Still finding the situation too complicated, I turned to bacteriology. But bacteria were even too complex, so I descended to the molecular level, studying chemistry and physical chemistry. After twenty years' work, I was led to conclude that to understand life we have to descend to the electronic level and to the world of wave mechanics. But electrons are just electrons and have no life at all. Evidently on the way I lost life; it had run out between my fingers.

Science today is confronted with the difficulty of integrating results and concepts coming from different approaches and levels of analysis. Sometimes the experimental observations are so numerous that they cannot be analysed within a simple model. The reductionistic approach of most scientists is to ignore a set of facts considered to be irrelevant and to propose a model that is based on what they consider to be the key observations. This approach is certainly useful when the model can be experimentally tested. Otherwise, new ways of approaching the study of complexity are needed today. It has been proposed that a network of objects has emergent properties that cannot be explained through the study of the single components. For example the Internet requires single users, but it is made up by connections. Biological phenomena are studied at different levels of organization and the theories formulated at each level can explain only a set of facts. When proceeding from a simple level towards a more complex one, new behaviours emerge. In other words, the whole is more than the sum of the parts, or different from the sum of the parts. For example, the properties of a protein are different from the sum of the properties of each amino acid that composes it. The properties of biological structures made of macromolecules interacting through non-covalent bonds are different from the sum of the properties of each macromolecule. Therefore, the understanding of a biological phenomenon does not necessarily require knowledge of the smallest details. The study of complex systems is a major challenge for the future and may require a different approach to the study of the world around us. In this endeavour we might find it useful to compare Western Science with Traditional Knowledge.

The observations of Nature that are not part of Western Science are generally defined as Indigenous or Traditional Knowledge. While Western Science favours reductionism and mechanicistic and quantitative approaches, Traditional Knowledge emphasizes the observation of natural phenomena from a global point of view. These observations are strictly linked to the local culture and to the predominant philosophy. In precolonial times in Africa there were specialists that knew well the characteristics of climate and soil, and were able to give expert advice on where and when to grow crops. They had a precise knowledge of the tropical flora and of desert bushes and developed a sophisticated classification of plants in families and groups, based on their cultural and ritual properties. The medical theories of Nigerian Yorubas included the concept of invisible entities causing infectious diseases, analogous to the bacteria of Western medicine. Science and technology in Africa were quite advanced, compared to European levels, in the fields of human and veterinary medicine, agriculture, food conservation, fermentation, metallurgy and the preparation of soap and cosmetics [5]. After colonization the educational and political system introduced European values and consequently devalued traditional knowledge. Moreover, the importance of traditional knowledge in the countries where it has been produced is today diminished because of the success of modern science and technology and of the economic power that accompanies it. For these reasons the knowledge systems of other cultures concerning the observation of Nature are not well known in the Western world.

Cultures from all regions of the world have developed a complex view of Nature, rooted in their philosophy, and leading to their understanding and explanation of the natural world. The traditional knowledge of non-European cultures is the expression of specific ways of living in the world, of a specific relationship between society and culture, and of a specific approach to the acquisition and construction of knowledge. This knowledge provides much of the world's population with the principal means by which they fulfil their basic needs. Although modern Science, with the ensuing technologies, has attained a particularly dominant position, other knowledge systems do exist and we should accept that Science is one knowledge system among many others [6]. Traditional Knowledge does not divide the observations into different disciplines to the same extent as Science, and this more synthetic and holistic approach may give indications to develop new paradigms for the observation and study of complex phenomena.

Most of our observations of the natural world are empirical and scientists try to give a scientific explanation to only a part of them. Occasionally a new field of science, or a new discipline, is opened because of new tools permitting the observation of specific phenomena, but most of our observations of the natural world are empirical. The traditional knowledge of non-Western cultures puts empirical observations in a different philosophical context. Thus, in all cultures the attempt is to harmonize empirical observations into a context aiming at the description of Nature and to be able to interpret them through models that lead to predictions. Much of the empirical knowledge existing in the culture of Western countries is based on traditional beliefs and is called local or vernacular. It is not different from Traditional Knowledge, although this term is generally used for the knowledge of non-Western cultures.

In conclusion, Western Science is deeply rooted in Western Culture and has a great influence not only in Europe and North America, but also all over the world. Science educates people to a rational and tolerant approach to everyday problems. On the other hand Science and the use of scientific knowledge causes social tensions of different types in different parts of the world. Western Science is a specific way of analysing Nature and the Traditional Knowledge of other cultures represents a different approach to the study of Nature.

REFERENCES

[1]. Kuhn, T.S., *The Structure of Scientific Revolutions*. The University of Chicago, 1970.

[2]. Iaccarino, M., 'A Vision for European Science'. *EMBO Reports 2*, pp. 259-262 (2001).

[3]. Iaccarino, M., 'Science and Ethics'. *EMBO Reports 2*, pp. 747-750 (2001).

[4]. Iaccarino, M., *Introduction to the Proceedings of the World Conference on Science*. A.M. Cetto, ed. Banson, UK, 2000: http://www.unesco.org/science/wcs/newsletter/proceedings.htm

[5]. Mazrui, A.A., Ade Ajayi J.F., *Tendances de la philosophie et de la science en Afrique*. In: Histoire Générale de l'Afrique, Vol. VIII, A.A. Mazrui and C. Wondji, eds. UNESCO publishing, 1998.

[6]. Nakashima, D., *What relationship between scientific and traditional systems of knowledge? Some introductory remarks*. In: Proceedings of the World Conference on Science. A.M. Cetto, ed. Banson, UK, 2000.

[7]. Stent, G.S., 'That was molecular biology that was'. *Science*, 160, pp. 390-395 (1968).

[8]. Stent, G.S., 'Molecular Biology and Metaphysics'. *Nature*, 248, pp. 779-781 (1974).

[9]. UNESCO/ICSU. Declaration on Science and the Use of Scientific Knowledge: http://www.unesco.org/science/wcs/eng/declaration_e.htm

SCIENCE AND TECHNOLOGY IN THE 20th CENTURY

1900	Quantum theory (M. Planck)
1901	Transatlantic telegraph signal (G. Marconi)
1903	Airplane flight (Wright brothers)
1905	Theory of relativity (A. Einstein)
1922	Insulin discovered (F. Banting and C. Best)
1923	Television camera (V. Zworykin)
1928	Penicillin (A. Fleming)
1929	Theory of universe expansion (E. Hubble)
1932	Protons and neutrons in the atom (J. Chadwick)
1935	Nylon and plastics
1942	Controlled nuclear reaction (E. Fermi)
1945	Electronic computer
1947	Transistor (W. Shockley)
1950	Chemotherapy to treat leukemia (G. Elion)
1953	DNA tertiary structure (J. Watson and F. Crick)
1954	Kidney transplant (J.E. Murray)
1957	Sputnik satellite
1975	Monoclonal antibodies (C. Milstein)
1980	Software for the Internet (CERN, T. Bernes-Lee)
1996	Cloning of a sheep (I. Wilmut)

Fig. 1

NOBEL LAUREATES IN NATURAL SCIENCES,
(1901-1998) BY GEOGRAPHICAL REGION

Region	Number of laureates	Percentage
Western Europe	230	50
North America	200	43
Eastern Europe	13	2.8
Asia	9	1.9
Australasia	4	0.8
Latin America	3	0.6
Africa	1	0.2
Arab Region	0	0

Fig. 2.

SCIENTIFIC PUBLICATIONS IN THE WORLD

	1997 (%)	% change over 1990
Western Europe	37.5	110
North America	36.6	92
Industrial Asia	10.8	126
Former Soviet Union	3.7	51
Oceania	2.8	107
China	2.0	170
India	1.9	89
Latin America	1.8	136
S. & E. Mediterranean	1.9	120
Sub-Saharan Africa	0.7	72
Rest of Asia	0.5	98

Fig. 3. Source: OST, Paris: Indicateurs 2000.

SCIENCE AND EDUCATION

'There is not a single mulatto who has done creditable scientific work'

Fig. 4. From the speech entitled 'Science, Education and Democracy', delivered in 1913 at the annual meeting of the American Association for the Advancement of Science by the Vice-President, J. McKeen Cattell. *Science*, vol. 39, pp. 154-164 (1914).

DISCUSSION ON THE PAPER BY IACCARINO

ZICHICHI: I've three remarks and a final comment. Remark number one: in your interesting list of achievements, one of the greatest conquests of the human intellect, the Dirac equation, is missing. The Dirac equation opened up a new field in our knowledge of nature. This field is our greatest contemporary activity, going on all over the world. I am referring to the existence of the virtual phenomena. Due to the fact that if the electron exists, Dirac discovered that the anti-electron must exist, thus opening up a new horizon. So you should add the Dirac equation to your list. You cite Einstein for relativity. The father of relativity is Galilei. If you read how he formulated relativity, he included what is called restricted relativity. Einstein is the father of his cosmological equation, not of relativity.

Now, I would like to turn to science and culture. I wish you were right that science is part of our culture. It is not. Modern culture is based on language. Of the three greatest achievements of our intellect, language, logic and science, only one is in our so-called modern culture. Neither logic nor science belong to our present-day culture. So, I wish you were right, but you're too optimistic.

A final comment: you speak about elementary particles not being able to explain the contraction of muscles. This is presently going on in nanotechnology, and a contracting muscle has been reproduced at the nanotechnological level. If nanotechnology exists, this is because of us. No one could imagine the existence of nanotechnology before the discovery of atoms and molecules. So, it is my duty to state that in fact our field is the basis of the most advanced technological development.

To conclude: you say that European science is built on Islamic science. I've a lot of friends in the Arab world, and they fully agree with me on the following statement: the father of science is Galilei. The proof is this: in four hundred years, we went from the world to the super-world. If Islamic science was real science, why did it take a thousand years to discover the first laws of nature, and why, for example, did it take thousands of years to improve our knowledge of time? What you call Islamic science left us blocked on the meridian instead of switching to the pendulum. One thousand years is an immense amount of time. Galilei is the father of science because after Galilei everything exploded: so our science is not built on Islamic science, because it is Galilei, not the Islamic culture, who discovered the logic of nature.

IACCARINO: Just a very brief counter comment. When I said science, or modern science, or European science, I meant science after Galileo. When I talked about other science, Islamic science, I meant a different knowledge system.

GERMAIN: Dr. Iaccarino, do you imply that complexity cannot be approached through the scientific method?

IACCARINO: I think nobody knows the answer. We all try to study complex systems with our present philosophical tools and we're succeeding in doing quite a lot. We'll see ten years from now, twenty years from now, if we succeed or not.

MITTELSTRASS: A very short question: your result was that traditional culture represents an alternative approach to science as we know it. What kind of alternative? In terms of aims? In terms of means? In terms of explanations? Are they not on a very different level?

IACCARINO: Maybe I said 'alternative', but now that I listen to you I would use a different term, a different knowledge system, but not alternative.

QUE LA SCIENCE S'INSCRIT DANS LA CULTURE COMME "PRATIQUE THÉORIQUE"

PAUL RICŒUR

La ligne générale de ma contribution est la suivante: si l'on veut s'interroger sur les "valeurs culturelles de la science", selon le titre donné à la session plénière de notre Académie, il ne faut pas limiter la discussion à l'épistémologie des sciences prises une à une, ni même à un aperçu de leurs applications susceptibles de changer les comportements humains à court terme et leurs visions du monde à long terme. Il faut tenter d'appréhender dans l'unité de son projet l'aventure intellectuelle et spirituelle que constitue la science. Ainsi serait prise en compte la désignation au singulier *de la science*. L'épistémologie des sciences honore le pluriel et la pluralité des disciplines scientifiques en fonction de leur référent spécifique qui font de chacune la science de... Suivent les applications et leur impact bénéfique ou non. Le choix de mon titre exprime l'intention de mon intervention. Je laisse de côté pour l'instant la question que pose l'évocation de *la culture* comme un certain intégrateur de multiples facteurs sur des échelles de temps variant du court terme au moyen et long terme, intégrateur justifiable lui aussi de l'emploi du mot au singulier.

S'il y a quelque sens à tenter d'appréhender la science comme un unique projet insistant et cohérent, présidant à une aventure intellectuelle et spirituelle à laquelle chacune des sciences prises une à une se reconnaît participer, et qui les autorise tacitement à se revendiquer comme science, – quel nom donner à l'approche en question? Je propose celui de "pratique théorique", dans l'idée que c'est à ce titre que la science au singulier s'inscrit dans la culture, en tant qu'intégrale d'autres pratiques qui ne se caractérisent pas comme théoriques. Désignons dès maintenant deux des plus remarquables pratiques non théoriques: les techniques et la politique.

I. *Le projet instaurateur de la science*

Je veux justifier le choix de l'expression pratique théorique contre l'objection préalable qu'elle produit un brouillage au niveau d'un départage qui paraît acquis entre le théorique et le pratique. Cette séparation ne date pas de Kant et de la distinction entre les deux *Critiques*, celle de la raison théorique et celle de la raison pratique, elle remonte même au-delà de la distinction médiévale entre les grands "transcendantaux": du vrai, du bien (ou du juste), et du beau; elle remonte aux Grecs soucieux de mettre la *theoria* à distance des techniques et même du politique en tant que "genre de vie". Si je prends le risque de cette contestation préalable, c'est afin de faire apparaître sous le nom de pratique théorique une dimension du phénomène scientifique qui ne réduit pas aux procédures véritatives spécifiques à chaque science, concernant la formation des hypothèses, leur vérification par l'observation ou l'expérimentation et, entre hypothèse et vérification/falsification, le recours à la modélisation comme expression de l'imaginaire scientifique. À l'arrière de ces procédures véritatives, il y a un acte fondateur, instaurateur, qui est le projet même de l'*epistémé* comme forme de *vérité*. Cet acte a trouvé dans la mathématique grecque, dans sa géométrie, sa théorie des proportions, son critère du nombre et de la mesure, son identification comme fondation et instauration d'un projet qui a distingué pour toujours la culture occidentale de toute autre culture.

Arrêtons-nous sur cette idée de *projet de l'epistémé*: il définit la théorie comme pratique. En effet, ce projet, en tant qu'instauration, n'est pas transparent à lui-même, alors qu'il ne peut être compris que de l'intérieur à lui-même. Il ne peut réapproprier ce que Jean Ladrière appelle "sa propre vertu auto-posante", au niveau du principe de son instauration, qu'à travers des aspects très singuliers de son historicité; si son avènement peut prétendre à un statut supra-historique, cet avènement ne se laisse appréhender qu'à travers ce qu'on peut appeler des "événements de pensée", avec leur côté aléatoire, improbable, non déductible d'une situation historique donnée, même si après coup on peut trouver une explication à l'événement et à son surgissement en tel lieu, la Sicile et Athènes et en tel temps, le cinquième siècle avant notre ère. En liant son sort à la mathématique, la pensée grecque dans la personne de ses *sophoi*, a fait un choix qui la dépasse et qui engage l'avenir entier du savoir occidental. Une chaîne d'événements de pensée, tous aléatoires, et tous nécessaires après coup, ont transformé le projet en destin. Il appartient à l'idée d'événement de pensée de créer de l'irréversible. Après, on ne pense pas comme avant.

Le projet en tant qu'instaurateur n'est pas, ai-je dit, transparent à lui-même: mais il n'est pas non plus inintelligible. S'il n'est pas réductible au premier de ces événements de pensée, le projet se reconnaît à mesure, dans la capacité des événements de pensée ultérieurs de faire suite avec les premiers. Les exemples ne manquent pas de cet aléatoire consolidé. Citons le principe d'inertie, qui a révolutionné la théorie du mouvement et achevé le démantèlement de la physique aristotélicienne en tant que rationalisation de l'expérience perceptive en écho et en convergence avec une théorie de l'âme. Avec le modèle galiléen, la nature ne sera plus considérée que selon le nombre, la figure et le mouvement: l'héliocentrisme, qui aurait dû n'être qu'une péripétie après Copernic et Tycho-Brahé, a pris figure de révolution culturelle avec Galilée parce que le savoir scientifique s'est heurté à une vision du monde issue d'une autre région de la culture de l'époque. Cette crise est d'autant plus absurde que la symbolique de la lumière avait dès toujours placé la terre, l'humus de l'Adam, le terreux, en bas, et la source de lumière en haut. C'est là un exemple des interférences et des empiètements dont l'*epistémé* a été victime de la part d'autres grandeurs et puissances culturelles. Continuant cette évocation d'exemples qu'on rattache à la révolution scientifique de l'âge classique, on aurait davantage de raison d'attacher de l'importance au passage du monde fini au monde infini, que commentait Koyré, et qui avait trouvé dans la méditation pascalienne sur l'égarement de l'homme en un lieu en apparence quelconque de l'univers, et dans l'intervalle étroit de deux infinis. Je n'irai pas au-delà de la grande synthèse cosmologique de l'ère newtonienne, qui restera le grand référent culturel jusqu'aux événements de pensée auxquels nous devons la physique quantique, la microphysique et une nouvelle conception des relations interstellaires. Mais il ne faut refuser le titre d'événement de pensée à la découverte de la circulation sanguine, puis à celle de la respiration par combustion de l'oxygène.

De véritables conflits au niveau culturel ont procédé des événements de pensée liés aux sciences de la vie et attachés au titre emblématique de l'évolution des espèces. Avec l'extension des modèles explicatifs relevant des sciences de la nature aux sciences de l'homme, les entrecroisements se sont produits entre des positions se réclamant du projet épistémique et les requêtes ressortissant aux autres compartiments de la culture commune, à savoir, pour faire bref, la dimension éthico-juridico-politique de la pratique humaine. J'y reviendrai plus loin.

Mais je ne veux pas abandonner l'idée de projet épistémique – et les difficultés conceptuelles attachées aux idées d'instauration, d'avènement-événement, d'événements de pensée, de nécessité après coup de l'enchaînement des événements fondateurs, – sans avoir insisté sur le mélange de l'aléatoire et du nécessaire qui caractérise le projet instaurataur; la réflexion est ici confrontée à une "démarche qui trace son chemin au fur et à mesure qu'elle s'y avance" (Ladrière). Car le chemin n'est pas tracé d'avance; le projet n'est pas un schéma que l'on peut tenir devant soi comme l'image de ce qui est à réaliser. "Il se propose dans l'agir même qui le promeut" (*ibid.*). Nous avons là un cas inédit d'intrication du fondamental et de l'historique, dont d'autres pratiques humaines, disons le technique et le politique, abondent en exemples, mais sans peut-être porter cette marque d'insistance et de persévérance propre au projet instaurateur de scientificité. Pour nous, au début du XXIème siècle, l'instauration du projet de la science apparaît comme un événement qui a déjà eu lieu, qui s'enveloppe dans les grands discours des inventeurs. On reprend conscience de son caractère aléatoire lorsque l'on est confronté à la question du futur de la science. À la question: où va la science? il n'y a pas à vrai dire de réponse, s'il est vrai qu'elle trouve son chemin en le parcourant et en accumulant les traces de son avancée. Aléatoire reste le grand dessein quant à son avenir.

Ce côté aléatoire d'un projet dont l'instauration est pourtant irrécusable se vérifie dans la pratique quotidienne de l'activité scientifique; on a tendance à dissocier l'histoire des inventions de l'enseignement de l'épistémologie et à exiler cette histoire dans la psychologie et la biographie ou à la noyer dans l'histoire des idées: on élimine ainsi le caractère énigmatique de l'avancée des sciences joignant, comme on l'a suggéré, le fondamental et l'historique; ce lien secret empêche l'histoire des sciences de virer à l'anecdotique. Il en va de même des querelles d'écoles, de luttes de pouvoir, de la course aux subventions publiques, au mécénat privé, aux contrats avec l'industrie. Tout cela fait partie de ce que Ladrière, déjà cité, appelle l'*historicité instauratrice,* dans laquelle se résume le régime intellectuel et spirituel de l'aventure scientifique. Le scientifique fait front à l'absence de transparence du projet instaurateur en le vivant quotidiennement comme une tâche, une injonction dont le sens se découvre en lui obéissant, de la même façon que le chemin se découvre en le traçant.

II. *La pratique théorique et les autres pratiques*

Cela dit, je voudrais esquisser ce que dans mon titre j'appelle l'*inscription* de la science dans la culture. Cette inscription consiste dans les interférences entre la pratique théorique et les autres pratiques. J'en ai nommé deux en passant, les techniques et la politique. Il n'est pas sûr qu'elles puissent être caractérisées comme la science par un projet instaurateur, cette notion ne paraissant pouvoir s'appliquer qu'à l'*epistémé* comme projet de vérité.

Quoi qu'il en soit de cette question et de ce parallélisme au niveau du projet instaurateur, il n'est pas douteux que les pratiques susceptibles d'être définies comme des techniques ont une histoire distincte de celle des sciences, même si aujourd'hui elles leur sont subordonnées à titre d'applications et aussi en raison de leur incorporation aux procédures de vérification des hypothèses scientifiques exigeant un appareillage technique de haut niveau. Il reste que la technique est née de gestes qu'on peut dire eux aussi fondateurs, tels que: capter le feu, tailler le silex, produire et conserver l'outil, inventer la roue, suppléer l'énergie corporelle par le dressage des animaux de charge, inventer la mécanique des machines, passer de la vapeur à l'électricité, et, depuis quelques décennies, substituer le calcul aux énergies relayant le muscle. C'est une question discutée par certains philosophes de savoir si l'on peut parler d'un dessein dissimulé d' "arraisonnement" du monde de la vie par ce qu'on appelle la Technique, le singulier du terme singeant celui du projet instaurateur de *la* Science.

Avouant mon incompétence sur ce sujet, je préfère diriger notre projecteur sur les conduites humaines placées depuis Socrate sous le signe de l'idée de *justice*. Cette idée normative embrasse les conduites privées et publiques auxquelles on a donné le nom de "mœurs"(*ëthë*), qui a donné le mot "éthique", dont la justice est un des fleurons. Dans son noyau premier, l'éthique est à la fois une province du politique concernant la pluralité humaine, et l'enveloppe commune de la morale privée et de la morale publique. C'est pourquoi j'ai gardé plus haut comme terme emblématique de cette pratique, distincte et de l'*epistëmë* et de la *techne*, le politique. J'aimerais citer à cet égard un mot d'Aristote au début de l'*Éthique à Nicomaque*: si l'on admet que toute activité, toute production, poursuit une fin, et si l'on trouve pour chaque métier une excellence qui en désigne l'exercice accompli, y a-t-il pour l'homme en tant que tel, – non pas le musicien, le pilote, mais l'homme tout court – une *fonction*, une *tâche* à remplir, qui permettrait de discerner les signes d'une vie accomplie? C'est cette question qui spécifie cette pratique relative aux mœurs, laquelle se ramifie en éthique et politique, à quoi s'ajoute le droit comme discipline distincte, et de l'éthique et de la politique. Mais le faisceau des pratiques relatives aux mœurs garde une consistance propre dans le tableau de la pluralité des pratiques: pratique théorique, technique, morale (au sens large des "mœurs"). L'idée de justice en constitue l'emblème par excellence.

Pourquoi me suis-je étendu sur cette question des mœurs et de la justice? Ce n'est pas seulement pour souligner la pluralité des pratiques et faire leur place aux pratiques non théoriques, mais pour préparer la discussion portant sur les interférences, chevauchements et conflits de frontières et de compétence mettant en question le statut de l'*homme*. Il est en effet le seul être qui relève de plusieurs, sinon de toutes, les pratiques: théorique, technique, morale, juridique et politique. Il est l'être du carrefour des pratiques.

III. *Le savoir sur l'homme*

Il n'y a pas eu de problème majeur tant qu'une frontière n'a pas été tracée entre une nature comprise comme animée et voisine de l'âme, et une âme elle-même empreinte de naturalité: c'est l'époque de la physique aristotélicienne et des éthiques naturelles. Cette frontière a été tracée à la fin de la Renaissance. Une certaine continuité entre la connaissance de la nature et celle de l'homme se trouve encore préservée dans la tradition du “droit naturel” au prix d'une redéfinition de la nature s'agissant de l'homme: c'est une nature qui comporte une *qualitas moralis*, pour emprunter le terme à Grotius dans *De jure belli ac pacis*: le sujet du droit resté inscrit dans la nature par le truchement de cette “qualité morale” (“attachée à la personne en vertu de quoi on peut légitimement avoir ou faire certaines choses”, *ibid.* I, 1, 4).

Le problème est devenu aigu dès lors que la nature est devenue l'objet d'une science fondée sur la seule observation et le calcul mathématique. C'est le sens de la révolution galiléenne et newtonienne: l'esprit humain reconnaît n'avoir pas accès au principe de la production de la nature par elle-même ou par un autre qu'elle-même. Il ne peut que recueillir les données naturelles et entreprendre de “sauver les phénomènes”. Ce n'est pas rien, tant est illimité le champ de l'observable et puissante la capacité de former des hypothèses, d'étendre et de remplacer les modèles, de varier la modélisation, d'inventer des procédures de vérification/falsification. Avec les phénomènes relatifs à l'homme, cet ascétisme de l'hypothèse, de la modélisation et de l'expérimentation est compensé par le fait que nous avons un accès partiel à la production de certains phénomènes observables, par la *réflexion*, portant sur ce que dans les pratiques autres que la pratique théorique, les techniques, les mœurs, on désigne du terme générique d'*action*. Dans le vaste champ d'activité des “mœurs”, l'homme se tient pour responsable de son action. Cela signifie qu'il peut remonter des effets observables de ses actions (et de ses passions) à l'intention qui leur donne sens et parfois aux actes spirituels créateurs de sens qui engendrent les intentions et leurs résultats observables. Ainsi l'action n'est pas donnée simplement à *voir*, comme tous les phénomènes de cette nature dont elle fait partie, elle est donnée à *comprendre* à partir des expressions qui sont à la fois les effets et les signes des intentions qui leur donnent sens et des actes créateurs de sens qui parfois les produisent. Il en résulte que la connaissance de l'homme ne se joue pas sur un seul plan, celui de l'observation et de l'explication; elle se déploie à l'interface de l'observation naturelle et de la compréhension réflexive. L'homme est à la fois un être observable, comme tout être de la nature dont il est une partie, et un être qui s'interprète lui-même (*Self-interpreting being*, pour parler comme Charles Taylor).

Cette affirmation d'un dualisme non plus ontologique, comme à l'époque des discussions portant sur l'union et de l'âme et du corps, mais épistémique, pourrait offrir une réponse de conciliation et de pacification à la question posée par le statut de l'homme dans le champ du savoir, si l'idéologie positiviste ne prétendait abolir la frontière entre les sciences de la nature et les sciences de l'homme et annexer les secondes aux premières. La philosophie, malheureusement, a répondu à ce défi par la simple juxtaposition d'une phénoménologie de l'homme incarné, sans souci d'articuler son discours sur le mode d'être au monde de cet être agissant et souffrant avec le discours scientifique.

Deux lieux conflictuels sont à cet égard à considérer en vue d'une vraie confrontation entre l'approche objective – naturaliste et l'approche réflexive: le domaine des sciences neuronales et celui des mutations génétiques et des sciences de l'hérédité issues de la théorie évolutionniste.

Je me bornerai à esquisser dans les deux cas les conditions d'une articulation raisonnée des deux discours sur l'homme.

Au plan des sciences neuronales, il est attendu du scientifique qu'il cherche au niveau cortical la corrélation entre des structures observables et des fonctions dont les structures sont la base, le support, ou comme on voudra dire. Le scientifique n'observe que des changements quantitatifs et qualitatifs, des hiérarchies toujours plus complexes de phénomènes observables; mais le sens de la fonction correspondant à la structure n'est compris que par le sujet parlant qui dit qu'il perçoit, qu'il imagine, qu'il se souvient. Ces déclarations verbales, jointes à des signes de comportement que l'homme partage pour une grande part avec les animaux supérieurs, viennent s'inscrire dans un type de discours où on ne parle pas de neurones, de synapses, etc... mais d'impressions, d'intentions, de dispositions, de désirs, d'idées, etc... À l'ancien dualisme ontologique des substances s'est substitué un dualisme des discours, un dualisme sémantique, si l'on peut dire, qui ne préjuge pas de la nature absolue de l'être-homme. Un corollaire intéressant de ce dualisme sémantique consiste en ceci qu'il est parlé différemment du corps, du même corps dans ces deux discours: il y a le corps objet dont le cerveau est la partie directrice avec sa merveilleuse architecture et le corps propre, ce corps qui est le seul à être mon corps, qui m'appartient, que je meus, que je souffre; et il y a mes organes, mes yeux "avec" quoi je vois, mes mains "avec" quoi je prends. Et c'est sur ce corps propre que s'édifie toute l'architecture de mes pouvoirs et de mes non-pouvoirs: pouvoir dire, agir, raconter, s'imputer à soi-même ses propres actions comme en étant le véritable auteur.

Se pose alors la question du rapport entre les deux discours, celui du neurologue et celui du phénomènologue. Et c'est ici que les discours se croisent sans jamais se dissoudre l'un dans l'autre. Le savant et le philosophe peuvent se mettre d'accord pour appeler le corps objet (et sa merveille, le cerveau), le "cela sans quoi nous ne penserions pas". Le scientifique peut continuer à professer un matérialisme de méthode, qui lui permet de travailler sans scrupule métaphysique: le philosophe parlera alors du cerveau en termes de condition d'exercice, de support, de substrat, de base; mais ce sont des mots "cache-misère". Il faut l'avouer, nous n'avons pas de troisième discours où nous saurions de quelque manière *ce* corps-cerveau et *mon* corps vif sont un seul et même être. Nous vérifions ici que nous n'avons pas d'accès à l'origine radicale de l'être que nous sommes. Faute de ce discours de l'origine, scientifiques et philosophes se borneront à chercher un ajustement toujours plus serré entre une science neuronale toujours plus experte en architecture matérielle et des descriptions phénoménologiques toujours plus près du vécu authentique.

C'est dans le même esprit que peuvent être traités les malentendus issus de l'extension à l'homme des théories évolutionnistes. D'un côté, aucune limite externe ne peut être imposée à l'hypothèse selon laquelle des variations aléatoires, des mutations, auraient été fixées, renforcées, en raison de leur aptitude à assurer la survie des espèces, dont la nôtre.

La philosophie – et pas seulement elle, mais les sciences sociales soucieuses de se démarquer de la biologie – ne se livreront pas à un combat perdu d'avance concernant les faits les mieux établis. Le philosophe se demandera comment il peut venir à la rencontre du point de vue naturaliste à partir d'une position où l'homme est déjà un être parlant et surtout un être *questionnant* concernant l'établissement de normes morales, sociales, juridiques, politiques. Alors que le scientifique suit l'ordre descendant des espèces et fait apparaître l'aspect contingent, aléatoire, improbable, de ce résultat que nous sommes de l'évolution, le philosophe-herméneute partira de l'auto-interprétation de sa situation intellectuelle, morale et spirituelle et remontera le cours de l'évolution à la rencontre des sources de la vie. Son point de départ avoué c'est la question morale elle même, donnée déjà là, surgissant dans une sorte d'auto-référentialité de principe. Une liberté unie à une norme, c'est ce que Kant appelait autonomie. L'autonomie une fois posée, auto-posée, il devient légitime de se demander comment elle a été préparée dans la nature animale. Le regard est alors rétrospectif, remontant la chaîne des mutations et des variations. Et ce regard croise le regard progressif, descendant le fleuve de la "descendance" de l'homme. Les deux regards se croisent en un point: la naissance d'un ordre symbolique dont les normes configurent l'humanité de l'homme. La confusion à éviter est alors entre deux sens du mot origine, au sens de dérivation génétique et au sens de fondation normative.

Là, comme dans le cas des sciences neuronales, la question restée ouverte est celle de l'articulation entre l'approche objective, naturaliste, et l'approche réflexive, herméneutique.

Mais dans les deux cas, et d'autres semblables, l'approche scientifique n'obéit qu'à l'injonction évoquée plus haut, par laquelle l'esprit de recherche se reconnaît guidé par le projet instaurateur de l'*epistémé.* Seul son rapport aux autres pratiques peut ouvrir devant lui un espace de perplexité.

DISCUSSION ON THE PAPER BY RICŒUR

ARBER: Merci beaucoup pour ces réflexions profondes qui vont nous servir certainement les prochains jours pour placer nos idées et réfléchir là-dessus ensemble. Mais je prends cette occasion déjà maintenant pour ouvrir une discussion d'abord au sujet de ce que nous venons d'entendre et puis si le temps nous le permet avant le déjeuner, peut-être pour y apporter encore quelques idées complémentaires. Je vois déjà Monsieur Singer, et puis Zichichi, Berti, dans cet ordre.

SINGER: Professeur Ricœur, merci beaucoup pour ces pensées très claires. Je vois un problème. Vous avez bien délimité les deux approches épistémiques de la perspective de la première personne qui est notre introspection, la source de connaissance dans les sciences humaines surtout, et l'approche de la troisième personne. Maybe I'll speak English, it's easier for me in science, and the third person perspective, which is the perspective of the natural sciences. Now, I can see very well that these two ways of describing reality can coexist peacefully for a while, but what are we going to do if – as it seems to occur at the moment – the third person perspective approach provides evidence that is in contradiction with the first person perspective? What are we going to do if, as it seems to happen at the moment, the evidence that is brought forth by the natural sciences, in particular neurobiology, contradicts in a flagrant way the evidence that we take from the first person perspective? Take the phenomenon of free will for example, where we have an irreconcilable contradiction between what neurobiology tells us and what we feel and what we think we know about ourselves. The same is true for the organisation of our brains. We feel very differently about the conditions of our neuronal substrates than what neurobiology tells us. And what are we going to do in such a situation where the two parallel systems are no longer compatible? How can we get around this problem? You didn't answer this question, I think.

RICŒUR: Yes: the logical gap between the assertion of free will and the logic of the creation of nature. Here I feel very close to Kant's cosmological antinomy; but we relieve this antimony thanks to the practices which imply that I am responsible for my actions, and to the kind of self-certainty which goes with the attestation that I am capable of doing what I am doing with the idea that I am responsible for it; that means that the scientist can go on with his approach to nature which I call in my paper 'matérialisme professionel'; but it is precisely because theory is itself a practice among the other practices that there is a right coming from the other practices not to impose its approach but to propose it as in competition with the presupposition of scientific knowledge. And so I don't think that we are able to bridge this logical gap, except if we were able to elaborate, as Leibniz tried to do, a treatise on the radical origin of everything. And if I had to express myself beyond what I wrote, I would say I am convinced that an intellectual interpretation of the narrative of creation provides us with the only reference to the radical production of the universe and of what I would call man as itself: the one that I am as, on the one hand, a part of nature, and, on the other hand, responsible for my own actions; the gap may be bridged not at the level of any of the concerned practices, but at the level of another kind of discourse which is to my mind poetico-mythical. But, then, I may be in discordance with those who believe more than I do in a radical ontology. So, it is rather a kind of confession that I am adding to my paper, in order to be frank with you.

ZICHICHI: Thank you, Mr. Chairman. J'aimerais remercier le Professeur Ricœur pour cette très stimulante série de pensées. But let me switch to English. I'll make just three remarks based on your three points. You spoke about verification and falsification, but the major steps in understanding nature, the greatest achievements of science, are due to totally unexpected discoveries. For example, radioactivity gave rise to the discovery of a new fundamental force of nature which has allowed the sun to go on for billions of years. The strange particles, in 1947, were totally unexpected, and allowed us to understand that nuclear physics is not a fundamental force, but a consequence of a more fundamental force, a real one, which is subnuclear physics. So, verification and falsification is not the motor of science, as many philosophers still go on telling us. However, history tells us that the exact definition of technology is the use of science. An example: for ten thousand years, only two inventions have guided all technological developments – the wheel and fire. Neither the wheel nor fire had ever been understood before Galilei. The wheel was understood, not discovered, by Galilei; fire by Einstein. An example of the technological use of science is given by the measurement of time. For ten thousand years, uncertainty in the measurement of time was a second per day with the meridian. Then Galilei invented the pendulum and discovered its laws. Now we speak about picoseconds, one thousandth of a billionth of a second. First science discovers something fundamental, and the applications follow at an exponential rate. So, the best definition of technology is 'use of science'.

Point number three: you've correctly quoted Kant, but the meaning of an experiment is not what Kant thought. We are not the masters of nature, as Kant claimed. The meaning of an experiment is to ask a question to the fellow who created the world. An example: after two hundred years of experiments in electricity, magnetism and optics, the mathematical synthesis came out, the Maxwell equations. Lorentz discovered that these equations implied that if time is real, space must be imaginary, and vice versa. For Kant, space and time had to be both real. If space and time were both real, light could not exist, and Dirac could not have discovered his equation which brought us to the discovery of anti-matter.

So, the real meaning of an experiment is to ask in a rigorous way a question to the fellow who created the world, and get from him the answer which no one had been able, for thousands of years, to imagine. So, if you allow me to reach a conclusion, I think that science is the discovery of the logic of nature, of a rigorous logic which we started to identify thanks to Galilei who based his method on mathematical rigor: ask a question not using words, but formulating in a rigorous way the question, and then searching for reproducibility in the experimental phenomena.

RICŒUR: I am not sure that we get rid of antinomies with the concept of time. The antinomy will return with the opposition between cosmological time and phenomenological time, because with cosmological time we have the pure succession of events and so on, without the reference to the present, the living present, and here I am very close to St. Augustine, for whom the present was the centre of perspective according to the *Confessions* referring to the three kinds of present: the present of the past as memory, the present of the future as expectation, and the present of the present as intuition. I think the experience of being responsible for anything within this time-structure cannot be derived from cosmological time.

BERTI: Oui, seulement une question, Monsieur Ricœur. Au début de votre exposé, vous avez caractérisé le projet de l'épistème, c'est-à-dire de la science comme une forme de vérité. Après, vous avez distingué l'approche scientifique, c'est-à-dire objective, naturaliste, de l'approche philosophique, réflexive, herméneutique. Alors ma question est: est-ce que vous croyez que même l'approche philosophique est une forme de vérité, aussi bien que l'approche scientifique et, dans ce cas, y a-t-il deux formes, deux espèces de vérité?

RICŒUR: Je répondrai en improvisant, si vous permettez, en français. Je proposerai l'idée d'une vision polysémique de la vérité. A cet égard, la vérité par observation de la nature, avec l'ascétisme sur lequel j'ai insisté de renoncer à tout ce qui ne serait pas nombre, figure, mouvement, délimite une sphère de la vérité qui oblige, et c'est celle à laquelle tout scientifique se conforme. Mais d'autre part on peut dire que dans le juste, comme requête fondamentale de la pratique, il y a une vérité en ce sens qu'il y a un *orthos logos* qui préside à cette forme de vérité. Alors, y a-t-il un niveau supérieur hiérarchique? Je dirais oui, moi, en employant avec le Père Stanislas Breton, l'idée de la fonction *méta*... qui me parait exprimée de la façon la plus radicale dans les *Dialogues métaphysiques* de Platon, dont le *Parménide* est vraiment le comble, mais aussi dans le livre *De la Métaphysique* d'Aristote qui définit les plusieurs acceptions de l'être. Et moi je dirai que, m'étant orienté dans la réflexion sur les pratiques, j'ai fait une sorte de pari sur l'une de ces acceptions du verbe être comme *dunamis* (puissance) et *energeia* (acte) couvrant toutes les formes analogiques de l'agir humain, et donc toutes les pratiques; la métaphysique occidentale a fait plutôt le choix de la définition de l'être par la puissance et l'acte; la substance a une productivité qui a été sous estimée, et peut-être masquée précisément par la version strictement substantialiste du verbe être. Mais cette discussion relève de ce que j'ai appelé la fonction *méta*, comme chez Platon et chez Aristote et son idée de la pluralité des dialogues métaphysiques de la série *Philèbe, Théétète, Sophiste, Parménide* constituerait peut-être le discours souverain.

WHITE: First of all, I think we all agree that this has been a very exciting presentation, and we'll probably be discussing it – I am sure – the entire day after we come back from lunch. Professor Singer was getting at it, but it seems to me that literally all of the statements from thought through observation, decision and so forth, do you agree that they have to be in a final analysis, it's the structure of the brain, whether you're talking about movement or observation, that is involved just as intimately with decision-making, contemplation and so forth. As a matter of fact, as you know, there is instrumentation now in the form of PET scanning, functional MRI, and so forth, where we can actually find the areas in the brain, still rather grossly, for even something like contemplation. These admittedly are measurements of brain neurochemistry or blood flow. But, I think even the most ethereal undertaking of what you've spoken of as spiritual, and I suppose some of us might think it would be perhaps more in terms of mind function, in the final analysis must be anchored in some way to the physical, the physics of the human brain.

RICŒUR: The last word is what you said concerns the cortical architecture of all human existence. This is the point of view from outside: but as soon as I speak responsibly of myself as being the authentic author of my acts I speak a quite different language. If you open a juridical text, you'll never meet the word 'neuron', 'synapse': this language is inappropriate, because it has another referent. And then I made an allusion in my paper to this plurality of sciences distinguished by their proximate referent; the proximate referent of cortical sciences is the brain; so for sciences the brain is an absolute reality, because it's an ultimate reference, but it's a reference for *that* approach. But for the ethical, juridical discourse we'll never use this language, we'll never meet the words belonging to these sciences; not only they are not relevant, but they will be, so to say, parasite words. So, each approach has its own basic language and its ultimate referent, but there is no referent of all referents, except the project of the instauration of the *epistème*, but scattered thanks to the plurality of what I called *thought events*, which choose a new basic referent for a new basic science. So, I don't see any overarching science which would be the science of sciences.

MITTELSTRASS: Let me also come back to what Professor Singer said at the beginning of our discussion concerning the two discourses on the nature of man. I mean, to make it short, if we start with a strict semantic dualism, two completely different discourses on the nature of man, I am afraid we are trapped in our own linguistic constructions. It leaves us without any solution, without any chance of a solution in that area. So, wouldn't it be better not to start with this kind of dualism, but with asking what philosophy, what anthropology can learn from the sciences, and of course also the other way round, what the sciences can learn from philosophy or from anthropology? That is to say, I strongly believe that in philosophy we have to take into account empirical facts given by the sciences, and perhaps in science we have to take into account, let me say, conceptual facts, and of course the philosophy of mind might be the discipline, might be the place in our modern discussions where these two areas, that is to say science and philosophy, meet; so I prefer another starting question. If we start with a dualism, we end with a dualism.

CULTURE AND SCIENCE

LOURDES ARIZPE

The concept of culture, in its current use, has been placed, in different periods and disciplines, *above* science, *in opposition* to science and *within* science. It is this polyvalence in meaning that makes 'culture' such a sensitive, valued yet sometimes contentious idea.

At the end of the 19th century, in the initial stages of scientific anthropological discovery, the term culture was to establish a basic epistemological distinction between natural events and human experience. Culture, in this very broad sense, was defined as 'everything that human beings have created'. This definition, *ipso facto* would include science, as well as all other belief systems and institutions of human society. Such a viewpoint locates culture *above* science, the latter being understood as the human activity that explains the natural world through a humanly intelligible discourse.

On the basis of this definition a heuristic opposition was established between 'nature and culture' which led to the classical demarcation that separated the natural sciences from the social sciences and humanities. It led to C.P. Snow's famous title to his book *The Two Cultures* referring precisely to the difficulties of bringing together the discourse of these two domains. In his book, published in the 1950s, he pointed at what seemed at the time a careening divergence between these two domains which made it difficult to advance towards an integrated, comprehensive understanding of a world made up of both natural and social phenomena.

Nature or Culture?

In the second half of the 20th century, however, the old debate of whether nature – understood basically as genetics – or culture determined human nature has been all but resolved. It has by examining the cases of the 'wolf children', that is, children who for some reason have grown up in the wild, isolated from all human contacts. It was seen that they could develop a few basic skills such as tool-making, refuge building and so on, and even a primary form of linguistic communication. However, they were unable to advance further in manual or conceptual sophistication. That is, they had lost what it was assumed they had initially, that is, genetically transmitted potentialities for acquiring knowledge, and developing manual skills and complex social abilities. Thus, the current accepted idea is that genetic inheritance provides specific possibilities for individual development which the cultural environment may either help develop to its highest degree or, on the contrary, stunt and underdevelop.

A more recent discovery which has confirmed such results are studies of the order of birth of siblings. For the sake of argument let us assume that siblings descended from one couple have exact or very similar genetic structures – granted, it is a momentous assumption – and hence, potentialities for personal development. Recent studies have shown that, even so, the psychological traits, specific skills, social and even political attitudes that each sibling develops may be very different. This has to do with the role that each sibling is assigned according to their birth order. This is why in many cultures there are different terminological concepts that differentiate siblings in this respect, for example 'primogeniture' in Indo-European cultures, or 'xocoyotl', the youngest son, in the Aztec culture.

The eldest son or daughter are expected to give continuity to family traditions, to be an example of respect, responsibility and emotional stability towards their younger siblings and so, in society they tend to be stable, conservative citizens and to reject change. The youngest sibling, in contrast, tends to be less disciplined, freer to explore emotional and imaginative experiences and so, in society, they tend to be artists and rebels.

Interestingly, a significant correlation has been found showing that 80% of gold medal Olympic athletes are first-born. Clearly, the physical investment of the mother in the first-born, assuming it is at its optimum, would give such children a greater physical endowment. But it is highly probably that, psychologically, the first-born may also benefit, if we may so presume, from the early harmonious stages of marriages.

Culture: Sparks in the Brain

Based on such evidence, one could say that nature, through genetic inheritance proposes many potentialities but it is the social and cultural environment which determines the degree to which such potentialities are realized. Clearly, the vibrancy and vitality of people's lives, barring disasters in the natural environment, will depend on how they interact with other people. This still holds even if the meta-physical is brought into the discussion. It would still mean that social relationships are decisive in allowing or not allowing people to achieve the development held as a promise in their genes or the spiritual fulfillment announced in belief systems. In other words, to paraphrase T.S. Eliot, between the physical and the metaphysical falls the social. Not, as the poet deemed it, as a shadow but as the 'lightness of being' that fulfills the promise of sustainability for the human world. For, as I have argued elsewhere, it is not the natural world that will ensure the sustainability of our world but rather, the social relationships that will lead people to care for the life-sustaining ecosystems of the planet.

It is fascinating to find how well this perspective fits in with the latest discoveries in neurology. As Professor Wolf Singer so clearly explained at the plenary session of the Pontifical Academy of Sciences, the more the layers of neurons in the cerebral cortex are able to connect in complex ways, as he expressed it, the greater the possibility humans have of developing higher consciousness. The intensity of connections between neurons is fuelled by the stimuli coming from outside the body. It must be clearly pointed out that, since tiny human beings are so vulnerable all such stimuli during their early years come from their immediate familial and social relationships. That is, the child, left on his/her own, or, to belabour the point, left in the wild, could produce very few stimuli for itself. On the contrary, a child surrounded by a great number of adults or children will receive countless opportunities of receiving and processing such stimuli. Granted that it is the quality of such stimuli rather than simply the number of them that makes a difference, any social scientist would affirm that *primary social interactions are responsible for producing the sparks in the brain that lead to full human development*. After that, a 'sparked' individual will be able to interact with the world in its full richness and mystery.

Culture as a heuristic tool for science

A different use of the concept of culture, that of constituting a heuristic tool for research, especially in anthropology and sociology, has placed culture within science. Culture was coined as a heuristic concept at the end of the 19th century, by Edward Tylor in the seminal book bearing that title. He proposed a 'holistic' definition of culture as a methodological instrument to be applied to societies understood as totalities. At that time he was in fact reacting to James Frazer's classic study, *The Golden Bough* in which he carefully selected beliefs, myths and rituals reported from many different societies, to piece together apparent regularities in the way in which human beings thought about the world and about themselves. As opposed to this view, cultures, Tylor insisted, should be analyzed as a coherent set of norms that human groups create to organize their social relationships and institutions.

Since that time, the concept of culture has gone through an evolution as rich as that of human phylogeny but in a speck of time. Already in 1948 Melville Herskovitz published a famous article listing more than 200 different definitions of the term culture. In ensuing years, through the work of Clifford Geertz, Umberto Eco, and the postmodernists, its definition has shifted from defining culture in terms of norms, to that of analyzing it in terms of meanings.

In the 1990s, however, the critiques of the concept of culture in anthropology piled up so high that in 1999 *Current Anthropology* thought it necessary to published an article by Christopher Brumann entitled 'Culture: Why a Successful Concept should not be discarded'.[1] Nonetheless, the term is still much in use in 'cultural studies', critical theory, the study of cultural diversity and pluralism, and, interestingly in the 'culture wars' in some countries, namely, the United States. Culture, then, is very much within science but, lately, brought into play in a very bellicose way.

This reflects what seems to be a paradox in the use of the concept of culture. While it is under interrogation and facing possible effacement in scientific discourse, 'culture' has emerged as the term to address many very different political and social issues in current world development. This is why, in this article, I have chosen to briefly describe the intrincate web of meanings and interests behind the use of this concept in current international debates on development.

Cultural Challenges in a Globalized World

The cultural challenges to humanity in a world in transition give the curious impression that they advance through contradiction. The more globalization spreads, the more fragmentation into particular cultures is on

[1] Brumann, Christopher. 1999. 'Culture: Why a Successful Concept should not be discarded' in *Current Anthropology*, Supplement, February 1999.

the rise. The more communications expand, the more individuals seem to live isolated lives. The more consumption for pleasure increases, the more people lose the meaning in their lives and turn towards drugs, alcohol, obesity, crime or Prozac. The more poverty increases, the more people dream of becoming media celebrities. The more democracy takes root, the less people seem to make sense of their political world and out of fear retrench into intolerant attitudes.

Are these temporary phenomena, a passing phase of maladjustments on the way to improved standards of living for all? Or will unprecedented levels of inequality portend a future of perennial conflicts? In any case, the deepening of several different kinds of impoverishment, other than economic, must also be given urgent attention.

In fighting against poverty international agencies and national governments are only beginning to understand the very grave consequences of social and cultural impoverishment. The monotonic encouragement of competition as the only and most desirable value is leading to the highest levels of economic inequality in the history of capitalism. In a world context of deregulation, it has fostered greater corruption in both the public and the private sectors, political clientelism and favoritism, discrimination against women and minorities and, most importantly, the destruction of the capacity to cooperate among all. This social impoverishment is very difficult to stem once distrust and violent competition are put into play. Police and military actions may stop the worst delinquent behavior but it will not root out the source of the frustration and hatred. They may, in fact, push violent behavior further towards terrorism.

Cultural impoverishment, however, is undeniably the loss that is most irreversible of all. Knowledge that has been accumulated for millennia by many, many peoples around the world, is being wiped out in a few years. Why is this diversity of cultural knowledge necessary in today's world? There is no doubt in my mind, as an anthropologist, that we need this vast reservoir of alternative knowledge to continue to find the best options for the future by exploring a diversity of solutions in every sphere.

Culture, science and society have always advanced by contrasting alternative ways of thinking and doing. Every aboriginal group survived in difficult ecosystems by evolving tools and ideas through trial and error. Every historical epoch presents humanity with unprecedented challenges it must overcome by trying out different strategies. In fact, the genius of the West has been its ability to systematize and to apply knowledge precisely through the experimental method, including other peoples' knowledge.

The term cultures, in the plural, in this restricted sense to refer to contemporary groups of bearers of given cultural traditions, acquires in my view a particular meaning. *My definition, in this sense, is that cultures are, simply, philosophies of life.*

As more and more of these millennia-old cultures become diluted, splintered through diverse forces of current globalization, since the eighties, the United Nations, UNESCO and many international organizations have taken up the challenge to mobilize world opinion towards a new vision of culture for international development.

Culture as the Soul of Development

As I explained in a recent paper for the World Bank on the 'Intellectual History of Culture and Development Institutions', based on the successful experience of the Marshall Plan in Europe, economists used the same economic development model in underdeveloped and decolonizing regions. This model has the implicit assumption that ethical, cultural, religious and social variables were unimportant. Since the sixties, however, studies have constantly shown a discrepancy between the expected results of economic policies and the actual results in their implementation, in the view of social scientists, precisely because such factors have been left out of the debate on development.

By the eighties, it was clear that the notion of development itself had to be broaden, as people realized that economic criteria alone could not provide a successful programme of governance, solidarity and well-being. The search for other criteria led the United Nations Development Program to elaborate a notion of *human development* as 'a process of enlarging people's choices'. It measures development in a broad array of capabilities, ranging from political, economic and social freedom to individual opportunities for being healthy, educated, productive, creative and enjoying self-respect and human rights. Culture is implied in this notion but it was not explicitly introduced. It was, however, increasing evoked by several other distinguished groups, such as the Brandt Commission, the South Commission, the World Commission on Environment and Development and the Commission on Global Governance. Building culture into the broader development strategies, as well as a more effective practical agenda, had to be the next step in rethinking development. In this context, the United Nations General Assembly passed a resolution to create the World Commission on Culture and Development.

This independent Commission was established jointly by UNESCO and the United Nations in December 1992. Chaired by Javier Pérez de Cuéllar, former Secretary-General of the United Nations, the Commission was composed of distinguished specialists from all parts of the world. Among its Honorary Members, were four Nobel Laureates. Between March 1993 and September 1995, the Commission held nine meetings in different regions. On each occasion, scholars, policy-makers, artists and NGO activists presented specific regional perspectives and concerns. These exchanges allowed the Commission to test its own questions and working hypotheses. It explored different lines of inquiry, consolidating some, abandoning others, and opening up paths not originally envisaged.

The first key message by the Commission is that development embraces not only access to goods and services, but also the opportunity to choose a full, satisfying, valuable and valued way of living together in society. Culture for its part, cannot be reduced – as is generally the case – to a subsidiary position as a mere promoter of economic growth. Its role is not to be the servant of material ends but the social basis of the ends themselves. In other words, culture is both a means to material progress, the end of development seen as the flourishing of human existence in all its forms and as a whole.

This is why the Commission was also convinced, and this is a second key idea, that issues of development cannot be divorced from questions of ethics. Views about employment, social policy, the distribution of income and wealth, people's participation, gender inequalities, the environment and much else inevitably are influenced by ethical values. What it is true of development is true with greater force of cultural issues. None of the important questions concerning culture and development could be addressed in an ethical vacuum. Values are always present, either implicitly or explicitly.

In its report, entitled *Our Creative Diversity*, the Commission placed at the head of its concerns the notion of a *global ethics* that needs to emerge from a worldwide quest for shared cultural values that can bring people together rather than drive them apart. It then explored the challenges of *cultural pluralism*, reaffirming a commitment to respect all cultures that have values of respect for human rights and for other cultures. It took up the challenge of stimulating human *creativity*, in order to inspire as well as empower people, in the arts, in the field of science and technology and in the practice of governance. It explored the cultural implications of the world *media* scene, focusing on whether the principles of diversity, competition, standards of decency and the balance between equity and efficiency, often applied *nationally*, can be applied *internationally*. The commission also addressed the cultural paradoxes of *gender*, as development transforms the relationships between men and women and globalization impacts both positively and negatively on women's rights. It was deeply concerned by the potential needs of *children and young people* and sought ways to bolster their aspiration to a world more attuned to multicultural values and to inter-cultural communication. It cast a fresh eye on the growing importance of *cultural heritage* as a social and economic resource and also built on the groundwork laid by the Brundtland Commission to explore the complex relationship between cultural diversity and bio-diversity, between cultural values and environmental sustainability. Finally, it set out a research agenda for interdisciplinary analysis of the key intersections between various aspects of culture and development issues.

Towards a new global ethics

The Commission described the profound need for new global cultural values. Our futures will be increasingly shaped by the awareness of interdependence among cultures and societies, thus making it is essential to built bridges between them and to promote cultural conviviality which I termed *convivencia*[2] through new socio-political agreements, negotiated in the innovative framework of a global ethics.

The role cultures may play in the search for a global ethics is complex and often widely misunderstood. Cultures are often regarded as unified systems of ideas and beliefs with sharply delineated boundaries, yet cultures have always overlapped. Basic ideas may, and do, recur in several cultures which have partly common roots, build on similar human experiences and have, in the course of history, often learned from each other. Cultures usually do not speak with one voice on religious, ethical, social or political matters and other aspects of people's lives. What the meaning of a particular idea or tradition may be and what conduct it may enjoin is always subject to interpretation. This applies with particular force to a world in rapid transformation. What a culture actually 'says' in a new context will be open to discussion and occasionally to profound disagreement even among its members.

Finally, cultures do not commonly form homogeneous units. Within what is conventionally considered a culture, numerous differences may exist along gender, class, religion, language, or other lines. At the same

[2] Arizpe Lourdes. 1998. 'Convivencia: the goal of conviviability' in *Unesco World Culture Report*, vol. 1:71.

time, ideas and clusters of beliefs may be shared by people of the same gender and of similar ethnic origin or class *across* cultural boundaries, serving as bases for solidarity and alliances between them.

What about recurrent themes that appear in nearly all cultural traditions? Could they serve as building blocks for a global ethics? The first such source, in the opinion of the Commission, is the idea of human vulnerability and the impulse to alleviate suffering wherever possible. This idea is found in the moral views of all cultures. Similarly, it is part of the fundamental moral teachings of each of the great traditions that one should treat others as one would want to be treated oneself. Some version of Kant's 'Golden Rule' is expressed in practically all cultures and faiths.

Many different sets of values would have to be brought to a common ground. It is not necessary to agree with all or give them equal weights but a minimum set of core beliefs would appear to be essential. This minimum set constitutes a point of departure, not a final destination, and the Commission believes that it is possible and greatly to be hoped, that this common ground will increase.

The Commission identified five ethical pillars: 1) Human rights and responsibilities, as the set of universal rights which establishes a standard against which international conduct can be judged, 2) Protection of minorities and vulnerable groups such as women and children, 3) Democracy and the elements of civil society whereby in the political arena, democratic processes should prevail so that people's needs and wishes are taken into account in determining how collective life is organized, 4) Equity within generations and between generations to ensure that all those living today are entitled to the basic necessities for a decent life and those who will come after us will inherit a world of equal or greater choices and opportunities, and finally, 5) Commitment to peaceful conflict resolution and fair negotiation.

Diverse culture, equal vulnerability

The search for a global ethic must come hand in hand, as the Commission on Culture and Development put forth, with respect for diversity. As stated in the Declaration on Cultural Diversity adopted in the 2001 UNESCO General Conference, diversity is '... the source of human capability of developing: we think by associating different images; we identify by contrasting ways of living; we elect by choosing from an array of options; we grow by rebuilding our confidence again and again through dialogue'.

In this new beginning, to cope with the momentous challenges of sustainability, governance and *convivencia* in a global era, we need cooperation on a world scale putting into play the creativity that can be summoned from all cultures and religions.

As explained in the Second World Culture Report 'it is no longer a matter of globalization allowing cultural diversity to continue to develop, it is cultural diversity as a condition without which globalization cannot continue...'.

Diversity must also include all the diverse sectors of societies, among them, women. Civilizations have been built by men and women, each with their respective and complementary contributions.

Scientists meeting at the World Science Organization Open Conference on the Challenges of a Changing Earth, in July 2001 in Amsterdam confirmed that global warming will have decisive impacts on the life of every inhabitant of the planet. Environmental global change thus creates an *equality in vulnerability* also deepened by increased interdependence in one single world economic system.

In *Crossing the Divide* it is pointed out that equality in vulnerability heightens the need for a broader, more political dialogue among cultures and civilizations. Thus, it stimulates dialogue. Because the real answer to equality in vulnerability, leading to equality of opportunity, is the adherence to accepted forms of common behaviour by more and more actors on the international scene. This requires, as stated in this report, '... an act of decision by each individual member of the international community, no matter how small... Perhaps what we are really talking about is no longer individual enemies for individual countries but a multifaceted enemy for all. The spreading of contagious disease, weapons of mass destruction, unrestricted dissemination of small weapons, poverty, all represent different faces of an "enemy" for the entire human race... If the enemy is common, it follows that fighting against it requires unanimity'.

Cultural Values in a Global Era: the Rainbow River

At present, globalization, telecommunications and telematics are changing the way in which people identify and perceive cultural values. People still have the tendency to think of the world as a 'mosaic of cultures' but this metaphor is no longer adapted to today's world. As mentioned above, cultures are no longer fixed, crystalized containers but have diasporic, planetary representations exchanged instantly around the world through the mass media and the Internet. As we stated in the second Unesco World Culture Report, the metaphor that best describes current cultural processes is that of a 'Rainbow River'.[3] We took Nelson Mandela's image when he referred to South Africa as a Rainbow Nation, and applied it to cultural diversity around the world. Cultural currents may mix or may be distinct for a while but they are all following, all changing, all exchanging, all the time.

To go back to the opening paragraph of this paper, as briefly outlined in this paper, the complex history of the relationship of science and culture – in the singular – and cultures – in the plural – explains the different ways in which they are being debated in our contemporary world. The ambiguities in the definition of culture and the implicit assumptions about culture in economic development models led to culturally blind rather than culturally sensitive development policies and programs and to generally well intentioned, yet frequently unsubstantial, institutional responses, both nationally and internationally. Given the problems of globalization, the main challenge for this new century, as stated in the first section of the 2001 World Culture Report, is to find strategies so that '...nations and the global community (may) prevent and remedy the deepening of inequality, especially along fault lines, new and old, that coincide with cultural diversity'.[4] Such a future will only be possible if science and culture work together to understand and to move the world.

[3] Unesco. 2001. *World Culture Report*. Paris: Unesco.

[4] Arizpe, Lourdes, Elizabeth Jelin, Mohan Rao and Paul Streeten. 2001. 'Cultural Diversity, Conflict and Pluralism' in *World Culture Report*, vol. 2. Paris: Unesco: 23.

DISCUSSION ON THE PAPER BY ARIZPE

RAO: As a sociologist, I thought you could help us clarify a thing that bothers me. I am going to refer to it tomorrow in my presentation. While the diversity of cultures and so on and related aspects are very, very important for this world according to me, science is doing exactly the opposite of that. The effect of science, including IT, globalisation, is to bring uniformity to everything. If anything, it destroys cultures, and has destroyed many language dialects in my own neighbourhood. I will refer to that tomorrow. They say science has nothing to do with this, that science is just discovery, innovation, and so on, but it is not so. Indirectly, science has a responsibility for all this. I do not know if you can say something about that.

ARIZPE: Yes, I would be glad to, because we have been going over the same question many times, especially in the commission. I would ask you: do Japan, the United States and France have the same culture? They don't. They even have different ways of living, different philosophies, different *savoir-faire*, and yet they all live within a capitalist world and within an international market. So, the question is not whether cultures and development are compatible, but how they can be made compatible, and there are ways. We do realise that there are some cultures that are extremely vulnerable, and these are the nomadic peoples, horticulturalists, and the hunters and gatherers, because their ecosystems are being destroyed by development or by the market or other forces, and there seems no way of stemming this destruction.

SINGER: I have two questions. The first relates to wolf children. I just wanted to know how good those studies are, and what the examples are. The second question refers to the dichotomy between science as one source of knowledge and culture or inborn knowledge or tradition as the other. Everybody would agree that one should not destroy the knowledge base that a population of farmers has on how to grow crops and things like that. Also, nobody would dispute that there is some intuitive knowledge that takes into account variables that cannot be consciously grasped and put together into a scientific theory because there are just too many of them or they are only known intuitively or through tradition, but don't you think we have an obligation to destroy false belief systems? In medicine, for example, there are the practices made through so-called 'overcome knowledge' which are extremely deleterious to the subjects, and I think there is an obligation for Western scientific medicine to go there and say, 'Look, this is not good for your patients because there is no ghost besieging them, they have a serious infection'. How about this distinction between the good and bad impact of science?

ARIZPE: As regards the studies of wolf children, there have been a number of them, except that the circumstances have always been rather difficult. Several of these cases occurred in the nineteenth century and there has never been a really rigorous scientific study of them because it is so rare for such children to survive. But the conclusion is clear from even these studies: there is a potentiality there that these children never developed. On the dichotomy between science and culture, this is an interesting question because many peasant societies, for example, have an extremely advanced and refined knowledge of plants and animals: ethno-botany, ethno-zoology. Now, are they false? Well, they are not false, you see, because they are based on certain principles that their cultures proclaimed as the most important. In anthropology, ethno-methodology has studied this: the principle of classification of some plants may be whether they are edible or not, and in that sense they open up other options for classification that the Linnean system does not possess. So, there is, I think, a valid ethno-science, but there may also be totally false beliefs linked to forms of social or religious or political control of societies, and that's an entirely more complex question.

ZICHICHI: I was very interested in your stimulating report. Your title was 'The Cultural Values of Science', and therefore I am forced to make this remark, because you said that scientific observations and discoveries depend on culture. If this were true, there would be many sciences, but if everything is science, nothing is science. There are many cultures, but only one science, because science is the logic of nature, and there are not two logics of nature, but only one. Since your lecture refers to a very important part of our conference, the cultural values of science, I am sorry to insist in making this remark: there is only one science and many cultures.

ARIZPE: I never said that scientific observations depend on culture. I just said that there was this very broad anthropological definition. I would not say that science depends on culture.

VICUÑA: A brief comment on this last remark – perhaps we can say that there are several ways to acquire knowledge: one of them is science.

ARIZPE: Yes, I think that would be a good way of putting it. However, I would also add that there may be different logical ways of understanding nature. Is that too heretical?

RAO: I would like to make one comment: while there are many cultures and one science, the approach to learning science has a tremendous cultural effect. A young child in a village in India or Bangladesh cannot learn science the same way as a city boy in Rome learns science. I think you should not just say there's one science and many cultures, It is not that simple, because culture has a tremendous effect on the way we appreciate nature. We wonder whether there is one nature. The way we understand it, the way we approach it, these are entirely different questions. I think that we should not oversimplify this matter.

ARIZPE: I would agree on that.

ŁOJASIEWICZ: You see, I would like to say, after the observation made by Professor Zichichi that there is only one logic of science, that we observe the world. I am somewhat close to the point of view of René Thom. There are many observations by which we try to describe some phenomena. There are many ways of describing them, many ways of doing this, and I don't know if we can speak in a very precise and clear way about what logic of science means. It may be very useful to explain what we mean by logic of science. It does not necessarily depend on culture; it may depend on culture, but we have many ways of seeing a phenomenon and describing it, even in a mathematical way, there are many different forms of mathematics, different forms of mathematics applied to describe a phenomenon. I am sorry, I am only a mathematician, I am not a physicist, but it seems to me that, as far as I have heard, and for example I connect here with the ideas of Thom, I do not understand what is meant by the view that there is only one logic of science.

ARIZPE: Could I just add that there might be one logic of science, but there might be other cultures that have observed things that are scientific in a different way because their needs push them to observe things that a city boy would not need to observe. So, what I mean is that the knowledge accumulated by other peoples can be added to science. Science could go into the molecular or chemical structure of something, but it has already been observed by an indigenous culture.

ZICHICHI: The chairman does not allow me to answer, but I can answer you in private. I totally disagree with you.

MENON: Mr. Chairman, I did not want to make any major comments here, but I thought that I would just tell you a little story about a question that one of the former members of this Academy, Abdus Salam, used to ask me. He said that when he looked at all the discoveries in mathematics and modern physics of recent times, he always found that, when the group theoretic approach was taken, the people who did it were Jewish in origin, and when he looked at approaches that were not group theoretic but analytical, they were non-Jewish. One doesn't know whether there is something in the tradition, in the way that children are brought up, which looks at groups and sets as being fundamental to thinking, which enable them therefore to make those discoveries later in life. We do not know about many such aspects; but I think much more study needs to be done on how your cultural setting enables you to look at things. That relates to the approach you take, not getting to a different science. Science, as we all agree, is an attempt at a description and understanding of nature. That cannot be different anywhere. There cannot be a science which is Indian science, or Chinese science, or Western science. But how does one arrive at that description and that understanding?

LÉNA: Thank you, Mr. Chairman. I just wanted to make two very quick points. One is that there is a relationship bridging science and culture, which is language, which of course is absolutely essential in education, and the fact that science, before being expressed in mathematical language, has to be expressed, especially in education, through layman language is a point where the relationship between culture and science occurs, and this should not be forgotten. My second point is quick, it has to do with your remark, Madam, about the ways of looking at things. Sun spots were observed in China with the naked eye almost two thousand years before they were observed by Galileo with a telescope: hence they could have been seen before in the West and were not! This has a direct consequence: had they been observed, then it would have been immediately discovered that the sun was rotating on itself.

ODHIAMBO: I just wanted to add a footnote to the question of the approach to scientific knowledge, and I want to give the example of disease. In African indigenous societies, and I am sure this applies to many other indigenous societies, disease is not simply parasitic, it is also the question of connectedness, family connectedness, society connectedness, community connectedness, and when you disrupt that connectedness you become sick, and therefore when you look at disease it is more complex than simply looking at the microbiology. That can be seen and it was very well illustrated by the work of Tom Lambo in Nigeria, who was able to solve psychiatric illnesses much more than anybody else. His first contact was to look at the community connectedness of the person who was sick and he did not try to bring in drugs until much later, and in most of the cases he solved matters without the use of any drugs at all through simply talking to the patient and resuscitating the broken community connectedness.

ARIZPE: I agree very much. The point is that if a person feels that a spell has been sent against him, he will die. But this not only happens in Africa. In the whole world why do people die of unrequited love?

CULTURAL ASPECTS OF THE THEORY OF MOLECULAR EVOLUTION

WERNER ARBER

Summary

Applications of scientific knowledge often refer to technological uses, but their impact on our world view can also be of great importance. Both of these kinds of applications have their cultural values. This view is here exemplified with recent developments in molecular genetics and evolution. Darwinian evolution resides on three pillars: genetic variation (or mutation), natural selection, and geographic and reproductive isolation. It is only since about 50 years that genetic information is known to be carried in DNA molecules. Molecular genetics and the theory of molecular evolution are the fruits of this knowledge. Molecular evolution is investigated by the comparison of genomic sequences and by the study of the molecular mechanisms generating genetic variations. Much of the available knowledge comes from microbial genetics. Genetic variation is brought about by a number of different specific mechanisms, which can be grouped into three different strategies, namely small local changes in the DNA sequences, rearrangement of DNA segments within the genome by recombinational processes, and the acquisition of foreign DNA by horizontal gene transfer. The three strategies to generate genetic variants have different qualities with regard to their contribution to the evolutionary progress. The available data clearly show the involvement both of gene products (acting as variation generators or as modulators of the frequency of genetic variation) and of non-genetic elements in the production of genetic variations. There is no real evidence that genetic variation would in general be a specific response to an identified need imposed by the environment that exerts natural selection. Rather, genetic variation is generally to some degree

aleatoric, and it is natural selection together with the availability of appropriate genetic variants which determines the direction(s) of biological evolution. In view of the activities of specific gene products to the benefit of biological evolution a dual nature of the genome becomes obvious. While many of its genes serve for the fulfillment of each individual life, others (the evolution genes) serve at the level of populations for the expansion of life, including the building up and replenishing of a rich biodiversity. The pertinence of this knowledge for our world view, as well as for the strategies of genetic research and its technological applications is discussed.

From fundamental scientific research to the application of its results

In this presentation I will focus attention to molecular genetics and more specifically to the mechanisms of molecular evolution. Upcoming knowledge on the genetic basis of biological activities and on their specific molecular mechanisms can serve us as guidance to apply that knowledge responsibly with the aim to facilitate the human life. This obviously enriches the patrimony of our civilization and represents thus cultural values. This kind of reflexion applies to many different fields of investigations in the natural sciences, so that the general conclusions regarding cultural values are of wide relevance.

Traditional research strategies in the biological sciences are largely observing and descriptive. In recent times experimental strategies of research are given increasing importance. They are often invasive, disturbing the system under study. For example, by knocking out the activity of a gene one can try to identify the biological function of that gene, by comparing the phenotype of an organism lacking the gene function with that of a genetically unaltered organism. Observing and invasive research strategies often differ in the kind and quality of their contributions to knowledge, they are largely complementary to each other. Applying different research strategies often involving trans- and interdisciplinary research is a good means to enrich our knowledge base. Since a knowledge base represents cultural values, these values increase with the increasing richness of the knowledge base.

Accumulated knowledge can lead to two kinds of applications. On the one hand, an application can be practical, often technological, and it is frequently invasive, causing some disturbance to the natural situation. Such practical applications may contribute to the shaping of the future, they may exert their influence on the longer-term development of things. On the other hand, the knowledge base is also an important source of our world view; novel knowledge can bring about changes in the generally accepted world view. Intrinsically, the world view represents philosophical, thus cultural values. The responsibility assumed by human beings is largely based on their validated world view. The latter can indeed provide guidance to society in the shaping of the future. This represents an important feedback of the world view to the ways and the intensity by which practical, technological applications of scientific knowledge are made. Similar reflections can apply to policy decisions such as on legal regulations that are related to available scientific knowledge, to the search for novel knowledge and to the practical application of such knowledge. It becomes more and more obvious that the principle of sustainability should govern the influence exerted by human activities on the natural environmental conditions. Therefore, the world view aspects of scientific knowledge deserve as much attention as the immediate utility attributed to technologically based applications of the scientific knowledge base. These considerations shall be illustrated in the following sections by the relevance of a deepened knowledge on the process of biological evolution for genetic research and biotechnology.

Quest for molecular mechanisms of biological evolution

The theory of Darwinian evolution resides on three pillars: genetic variation, natural selection and isolation. Genetic variation is brought about by a number of different mechanisms causing alterations in the genetic information of an organism. Genetic variants (or mutants) represent the driving force of biological evolution. In contrast, natural selection together with the range of available genetic variants guides biological evolution into specific directions. Geographic and reproductive isolations modulate the evolutionary process.

Biological evolution is a relatively slow, but steady process, in which once in a while an individual member of a population of organisms is hit by a mutational event. In ecosystems, mixed populations of different organisms and different variants thereof are steadily submitted to natural selection. Thereby, those organisms that succeed to cope best with the encountered living conditions have a selective advantage, so that they will at longer-term overgrow their competitors. This largely depends on the genetic setup.

We know that genetic information is encoded by linear sequences of nucleotides in filamentous DNA molecules. These sequences contain genes and intergenic regions. A gene typically contains an open reading frame that serves upon gene expression to instruct the manufacture of a specific gene product, which is often a protein with enzyme functions. The gene also contains expression control signals that serve to regulate the time and intensity of gene expression. The total genetic information present in each cell of an organism is called the genome.

In molecular genetics it has become a habit to call any alteration of the inherited nucleotide sequence a mutation. This contrasts with classical genetics in which the term mutation refers to an observed alteration of the phenotype, that results from the activities of the gene products. We will apply here the molecular genetic definition.

Spontaneous alterations in the nucleotide sequences are often attributed to errors upon DNA replication and to accidents occurring to the DNA. An alternative view, to be defended here, is to attribute mutagenesis to the common influence of particular gene products and of a number of non-genetic factors. Evidence for this interpretation can be expected from a deeper knowledge on the molecular mechanisms involved in the generation of genetic variants.

At present two approaches are available to explore the molecular mechanisms of genetic variation. One of these approaches is the systematic comparison of available nucleotide sequences of more or less closely related organisms. This strategy involving bioinformatic tools can be applied at the level of a gene for a specific function, at the level of a group of genes and also at the level of the genome. This can reveal single nucleotide changes, the reassortment of functional domains, as well as aspects of the genome organisation. Results obtained in such investigations can provide hints with regard to historical events that occurred to the ancestors of the compared organisms.

A more straightforward approach is the study of individual events generating genetic variants. Since these processes are both inefficient and generally not reproducible, their investigation is relatively difficult and has to be mostly indirect, by comparing the nucleotide sequences just before and after an event of mutagenesis.

Most of the data available so far on the generation of genetic variants at the molecular level come from microbial genetics, particularly from studies of bacterial and viral genomes. Bacteria are single-cellular organisms that propagate by cell division with typical generation times in the order of 30 minutes under optimal nutritional conditions. This facilitates population genetic approaches. Since the bacterial genome is haploid, spontaneously occurring mutations become phenotypically manifested rapidly.

These facts and the relatively small size of the microbial genome render studies of the molecular basis of genetic variation possible. From the available data it is clear that several different specific processes are at work, as will be discussed in more detail below.

It is a common observation made by many investigators that useful, beneficial mutations, are rather rare among the spontaneously generated DNA sequence alterations. More often, a mutation inhibits some life functions, thus providing a selective disadvantage (in extreme cases leading to lethality). Many other spontaneous DNA sequence alterations are without immediate influence on life processes. These are silent or neutral mutations. This situation is in line with the view that the spontaneous generation of DNA sequence alterations is in general not a specifically targeted answer to an identified need for adaptation of one or a few specific genes. In other words, there is no good evidence for a strict directedness of spontaneous mutagenesis.

Three major, natural strategies with different qualities contribute to the spontaneous formation of genetic variants

Referring to a more detailed outline given at the plenary session of our Academy in October 1996 (Arber, 1997), I can limit my presentation to an overview of the various molecular mechanisms that contribute each in its specific way to the generation of genetic variants. These conclusions are largely based on data obtained in microbial genetics, but they are likely to be generally valid also for higher organisms (Caporale, 1999).

Spontaneous genetic variation can be attributed to a number of mechanistically different events. These different mechanisms can be classified into three general strategies of genetic variation: local sequence change, DNA rearrangement within the genome and DNA acquisition. Each of these will be briefly characterized here.

The local sequence change brings about the substitution, deletion or insertion of a single or a few adjacent nucleotides. It can also result in a local scrambling of a few nucleotides. Several causes for such reactions have been identified, such as a limited chemical stability of nucleotides, a structural flexibility (tautomerism) of nucleotides implying alternative base pairing, other types of replication infidelities (e.g. replication slippage), as well as the effects of some chemical and physical, internal and environmental mutagens. The quality of local sequence changes resides primarily in their possibilities for a stepwise functional improvement of a gene and for the potential adaptation to alternative living conditions. In the long term, a series of subsequent local sequence changes can, in principle, also result in a novel gene function, but one can assume that this comes only to bear once the product of the genetic information in question becomes a substrate for natural selection. To a large extent, local sequence changes are initiated by non-genetic factors, mainly intrinsic properties of matter and responses to interactions of matter. However, various enzymatic repair systems have been developed by living organisms to limit the frequencies of local sequence changes and their detrimental consequences to relatively low levels ensuring a certain degree of genetic stability but still allowing for a low, evolutionarily useful frequency of mutagenesis.

Intragenomic DNA rearrangements generally affect DNA segments of variable length. These can undergo deletion, inversion, translocation to another site in the genome, duplication and higher amplification. These genomic changes are sometimes accompanied by additional local sequence changes at the junction sites. DNA rearrangements are often, or perhaps as a rule, brought about by the recombinogenic activities of specific gene products. We call these gene products variation generators. Generally, they work inefficiently and act on the DNA molecules at one of many different possible sites, so that the results of their reactions are not strictly reproducible; they are at most statistically reproducible. DNA rearrangements can bring about novel gene fusions (the fusion of a part of one gene with a part of another gene). This can in some cases result in a novel genetic activity. Alternatively, a DNA rearrangement can also fuse a given reading frame of a gene with a hitherto unrelated signal for the control of gene expression. In the case of the duplication of functional sequences, a duplicate copy can later serve as a substrate for further evolutionarily relevant events while the other copy can continue to exert its normal function.

In diploid eukaryotic organisms general (homologous) recombination between the paternal and the maternal genomes, as well as the meiotic assortment of chromosomes, are other well known sources of genetic variations.

The third strategy to generate genetic variations, DNA acquisiton, depends on the horizontal transfer of genetic information from a donor to a recipient organism. This process is well studied with bacteria where several different mechanisms contribute to the overall horizontal DNA transfer. The process occurs also in higher organisms where it is, however, less well explored than with bacteria. In the latter case, several factors have been identified to limit gene acquisition to low frequencies and to relatively short segments of DNA. This strategy of gene acquisition in small steps represents a sharing in successful developments made by other kinds of organisms. The process is relatively effective: in a single event of alteration of the genome the recipient organism can gain a fully functional activity which may by chance satisfy an upcoming need for adaptation to changing living conditions, such as in the sudden presence of an antibiotic.

In view of the occasional horizontal flux of genome segments, the classical evolutionary tree should be drawn with randomly placed horizontal connectors (Arber, 1991). Remember that, in general, relatively short genome segments become horizontally transferred to another organism, while in the vertical transmission of the hereditary information from generation to generation, the entire genome becomes transmitted to the progeny and steadily represents a target for genetic alteration by local sequence changes as well as by intragenomic DNA rearrangements.

The theory of molecular evolution postulates the generation of genetic variations to depend on the coordinated action of the products of specific evolution genes and of non-genetic elements

There is no doubt that a number of non-genetic factors contribute each in a relatively specific way to the production of genetic variants. As was already mentioned, this mutagenesis often depends on properties of matter such as a certain degree of chemical instability and of structural flexibility of biological molecules. In addition, random encounter also plays its role, such as in the interaction of an enzyme with its substrate, in the random choice of a recipient organism for horizontal gene transfer, or when a DNA segment is hit by a mutagen.

On the other side, increasingly strong evidence supports the interpretation that the products of a number of specific genes act primarily for the benefit of biological evolution. Some of these so-called evolution genes act as generators of genetic variations, while others act as modulators of the frequency of genetic variation. Examples for the latter activities are found among the already cited repair systems. The transposition of mobile genetic elements is a good example of a variation generator. The theory of molecular evolution also postulates that those evolution genes that are encountered today in living organisms had been fine-tuned for their specific activities in their own evolutionary development involving second order selection, a selection process acting at the level of populations (Arber, 2003a).

Dual nature of the genomic information

The genome is usually thought to contain genes with specific tasks to be carried out for the benefit of each individual organism. These are the housekeeping genes and genes of use under particular life conditions. The developmental genes ensuring in higher organisms the development from a fertilized egg to the adult organism can also be counted to this large class of genes of general relevance for each living being. They serve for the fulfillment of each particular life.

Until recently, evolutionary developments were generally assumed to depend on errors and accidents occurring to the DNA molecules. In view of evidence for enzyme activities of unique relevance for biological evolution, but dispensible for the individual life span extending from one generation to the next, the view of the existence of evolution genes in the genomes obtains increasing support. If this view is correct, the genomic information must be of a dual nature with regard to its purpose. Clearly, as was already said, many genes act for the benefit of the individuals. In contrast, evolution genes act for the benefit of an evolutionary development of the population, by serving as generators of occasional DNA sequence variations and as modulators of the frequencies of such variations. By doing so, they sometimes cause harm to an essential life function, if a novel mutation happens to provide a selective disadvantage. This has to do with the fact that genetic variation is, in general, a largely random event rather than a precise, directed response to an identified need. The duality discussed here can be seen as a consequence of the engagement of nature to care not only for the fulfillment of individual lives but also for the evolutionary expansion of life and hence, for the evolutionary installment and replenishment of a high diversity of life forms on our planet. It should be added to this discussion that the products of some genes are used for both purposes: for the benefit of the individuals and for the evolutionary development. Genes of this kind may have been evolutionarily fine-tuned to carry out both of their tasks properly.

Cultural values of the knowledge on mechanisms of molecular evolution

The involvement of products of specific evolution genes for the driving of biological evolution that insures a rich biodiversity implies a widely unexpected and surprising modification of our world view. Nature cares actively for the evolutionary expansion of life. Properties of matter and genetically determined mechanistic capacities of life itself are identified as coordinated driving forces of evolution. This represents an expansion of the Darwinian theory to the level of molecular processes and it strengthens the validity of this theory. The philosophical and hence cultural values of these conclusions are evident. Some of the aspects relating to an evolutionary, permanent creation were discussed in more detail elsewhere (Arber, 2003b), pleading for a reconciliation between, on the one hand, traditional wisdom such as the one transmitted in the Old Testament and, on the other hand, recently acquired scientific knowledge.

For several reasons the postulate of the presence in the genome of evolution genes and the knowledge on their ways of action also represent an enrichment for research on genomics and proteomics, as well as for the practical application of the results of these investigations in biotechnology. One aspect clearly illustrated by the enzymes generating genetic variations relates to the widely spread belief that genes encode strict programs for life processes. According to this view, primary gene products are thought to normally serve as enzymes in a sequence of events, the final output of which would be reproducible and therefore also predictable. In addition, the belief is quite widespread that enzymatic reactivities are always efficient. Evolutionarily relevant variation generators do not have these properties. Rather, they are inefficient and in the rare cases of their activities the output (which is a novel genetic variant) is not reproducible and not predictable from case to case. These aspects deserve due attention in the definition of the gene concept.

The knowledge on the three different basic natural strategies contributing to the generation of genetic variations forms a welcome basis for the evaluation of conjectural risks of genetic engineering, in particular in cases of deliberate release of a genetically modified organism (GMO). In genetic engineering, the genetic information is deliberately altered in a planned and thus *a priori* known way, e.g. by site-directed mutagenesis or by the horizontal transfer of a natural DNA sequence from one organism to another kind of organism. In all of these processes the investigator may apply, in principle, one or a combination of more than one of the described three natural strategies of genetic variation, i.e. local sequence change, intragenomic DNA rearrangement and horizontal gene transfer. Thereby, the quantity of involved base-pairs is, as a rule, in the same span as that observed in natural events of genetic variation. The use in genetic engineering of principally natural strategies which must have served in nature since a few billion years for promoting the evolutionary progress can at least suggest to us that conjectural, long-term risks of genetic engineering must be similar to those related to the natural evolutionary process. These considerations have been outlined in more detail in a contribution to a workshop held by our Academy in February 2001 (Arber, 2002). This is a good illustration for how the scientifically based world view can have its feedback on technological applications of scientific knowledge. Such feedback provides means to responsibly carry out technological applications as contributions to the sustainable shaping of the future for the benefit of Mankind.

REFERENCES

Arber, W. (1991) Elements in microbial evolution. *J. Mol. Evol.* 33, 4-12.

Arber, W. (1997) *The influence of genetic and environmental factors on biological evolution*. In: Plenary Session on the Origin and Early Evolution of Life (Part I). The Pontifical Academy of Sciences, Commentarii Vol. IV, N3, pp. 81-100.

Arber, W. (2002) *Molecular evolution: comparison of natural and engineered genetic variations*. In: The Challenges of Science. The Pontifical Academy of Sciences, Scripta Varia 103, pp. 90-101.

Arber, W. (2003a) Elements for a theory of molecular evolution. *Gene* (in press).

Arber, W. (2003b) *Traditional wisdom and recently acquired knowledge in biological evolution*. Proceedings of UNESCO Conference 'Science and the Quest for Meaning' (in press).

Caporale, L.H. (Ed.) (1999) *Molecular strategies in biological evolution*. Annals of the New York Academy of Sciences, Vol. 870.

DISCUSSION ON THE PAPER BY ARBER

MALDAMÉ: Professor Arber, could I ask you three short questions? The first refers to your slide, the evolutionary tree. What is the importance of this horizontal transfer in evolution? The second question is: in our genome we carry a lot of viral, genomic and bacterium particles. Could they have a role in evolution? And then there is my third question, which is probably difficult and always comes up in discussions. You see, I share your view, but I would like to hear more arguments from you. We have often been told that this is an error mutation. You say that it is not an accident. You say that it's natural law. What are your reasons for saying this?

ARBER: I will begin with your last question. I think it is important that we scientists should not always base our views on textbook interpretations of the available data. We have to have some flexibility. I have become more and more convinced of the major importance of biological evolution. I can therefore not consider that biological evolution could be driven by errors and accidents. Rather, we should look for functions that actively generate genetic variations. Transposable genetic elements are a good example, they exert no other function, as far as we know, than to produce occasionally novel genetic variations. As to the replication infidelities, they largely depend on properties of matter, such as a certain degree of structural flexibility and of chemical instability of nucleotides. These are intrinsic properties, not accidents.

In your first and second questions you asked about horizontal gene transfer involving, among other elements, viruses and in higher organisms sometimes even bacteria. The evolutionary role of these elements is well studied with bacterial populations. The horizontal gene transfer is in general a rare event. But if an acquired gene provides to the recipient an advantage, natural selection will not only maintain it, but also amplify selectively the novel hybrid. In this regard we learned a lot by observing the wide spreading of antibiotic resistance genes in bacterial populations due to the extensive use of highly selective antibiotics in human and veterinary medicine in the last sixty years. There is still less knowledge on the role played by horizontal gene transfer in higher organisms, where more relevant research is required. But it is known that some viruses can serve as natural gene vectors also in higher animals and thus in man. As to the general importance of horizontal gene transfer, this resides in its different quality as compared to the other natural strategies of generating genetic variants. In horizontal gene transfer an organism may have the chance to acquire from some other organism a genetic function which it had not possessed before. Such an acquisition is a one-step event. If these organisms would have to develop the same function itself, this would be a very laborious multistep process.

MALDAMÉ: I have a question. You reported at the end that genes' actions serve a purpose. What kind of purpose?

ARBER: I think the important purpose of many genes is to be seen in the fulfillment of individual lives. In contrast, evolution genes working at the level of populations provide means to produce and to replenish biodiversity.

By the way, the knowledge on molecular mechanisms of evolution can offer insights into the sense of life and the sense of death, although only in the context of the evolutionary development. We can compare naked DNA molecules with a closed library: nothing happens as long as there are no readers present. Any potential actions depend on the activities of readers. Reading of the genetic information on organisms is also the prerequisite for life manifestations. Remember that it is the life manifestations, not the DNA molecules, which are the substrate for natural selection. Active life has thus its clear evolutionary meaning. As to the evolutionary sense of death, remember that genetic variation is the driving force of biological evolution. Genetic variation depends on a steady renewal of the populations. Eternal lives could not satisfy this condition. In addition the space for living organisms in the biosphere is limited. The turnover of populations necessitates the death of individuals after having served for some time as substrates for natural selection.

SINGER: Prof. Arber, you gave us a very interesting and detailed description of molecular evolution where it can be studied. Would you agree with me that there has been no further evolution in human beings over the last 5,000 years because of a lack of selection pressure and because of a lack of inbreeding?

ARBER: I don't agree. I think we evolve steadily, like any other living organism, but in our short life span we cannot spot evolution so easily – this is not possible. Reading Genesis we can learn that the descendants of Adam and Eve (the products of creation) are not clones with identical properties. Each descendant has a specific character. I see in that description a traditional wisdom that within a species, all living beings are different from one another, and this is exactly the driving force of evolution. So I cannot say that we do not continue to evolve.

SINGER: Just a remark referring to your account of creation. Recently I talked to a Jewish priest who told me that in the original text of the Hebrew Old Testament there is a predecessor of Eve, Lilith. She was made out of clay at the same time as Adam, and they had equal rights. She was not part of man, she was no clone, but Adam could not cope with her because she was too self-determined. So he sent her away and she then lived with animals in the region of Jordan, but she had offspring.

JAKI: He should have told you that Lilith is in the Talmud and not in the Bible. That is the first thing. The second thing is that whenever a creationist claims that we have to take in a scientific, in a modern scientific sense that God created everything according to its kind, that is, each species separately, we should remind him that if you take one single phrase in the first chapter of Genesis in a scientific sense, then the basic rules of interpretation demand that you should take all the other statements in a scientific sense: then you have light coming before the sun, then you have plants coming before sunlight, and finally you may ask them: did the astronauts wear helmets to protect their heads when they went through the firmament?

ARBER: I agree with you that Genesis is not a strictly scientific text. I also became aware that plants were created before animals, and my interpretation is that this is in line with traditional knowledge. You know that animals eat plants, that's their food. You cannot create animals and then plants only the next day, because otherwise these created animals will die in the meantime. So, there is some logic in the sequence of events. And there is no mention of micro-organisms because human beings did not know at that time that there were microbes around.

VICUÑA: This may be a semantic problem, but I wonder if you can eliminate error as a source of evolution, because the enzymes that make

DNA, DNA polymerase, do make errors, otherwise they wouldn't have an additional activity that allows them to correct those errors. I mean, nucleotides are so similar to each other that I would imagine that an enzyme that is copying a template would make an error. They do the job so fast that they can make mistakes.

ARBER: The term error is a human interpretation of some unusual, often unexpected observation. In the case of DNA replication, we know several specific reasons for the incorporation of another nucleotide than the one expected from the sequence of the template strand. One of these reasons are tautomeric forms of nucleotides. These conformational variants are relatively rare and very shortliving. Most importantly for our discussion, they give rise to an altered base-pairing. This can result in a substitution mutation. To my mind, this is not an error and I call it a replication infidelity, which goes back to an intrinsic property of the molecules, their structural flexibility. Another source of base substitution is a certain degree of chemical instability of nucleotides.

As a matter of fact, these sources of mutagenesis were among the first to be known, and many textbooks on genetics and evolution generalize and propagate the idea that spontaneous mutations are base substitutions going back to errors in replication.

LÉNA: I am struck by a number of words that you have been using. Maybe it is only semantics, but maybe it is more. You have the words 'error', 'help', 'purpose', 'goal', 'use'. I wonder if this is not somewhat anthropomorphic and what Paul Ricœur would have to say on the use of those words to describe molecular biology?

ARBER: Well, you may have seen that my talk was actually trying to make a bridge between science and culture, and I used some words that could be more easily understood. What I gave was not a fully scientific talk, although I tried to give you some evidence for my ideas.

SCIENCE AND DREAM

PAUL GERMAIN

For many years, I have been impressed by the following statement. Let me quote it in French: 'L'homme, cet arrière-neveu de limace qui inventa le calcul intégral et rêva de justice'.

I am not sure I am able to give an English translation which can imply what is meant by this French statement. Let me try: 'Man, the distant cousin of the slug, who invented integral calculus and dreamed of justice'.

It is found in a book entitled *La vie et ses problèmes* by Jean Rostand, a biologist who was very interested in ethics, published in 1940 by Flammarion. The phrase was put by Jean Hamburger, a former President of the French Academy of Sciences, just below the title of his book *Un jour, un homme,* published by Flammarion in 1981. I also quoted it in my paper 'La science interpellée', published in *La Vie des Sciences* in 1990. I found that, with a few simple words, it gave a good definition of man.

Man, which means here the human society, who invented integral calculus and dreamed of justice. He is a product of biological evolution, the descendant of animal ancestors.

Integral calculus: it is a mathematical concept which has many useful applications in various sciences. Mathematics is the language of Nature. Here, integral calculus means science.

Then, humanity appears as the result of a double historical process: a passive one – evolution – and an active one, the creation by man of his surroundings. These two processes are governed by 'causality'. That means that each element is produced as an effect of a previous one by a rational progression.

The final part of the sentence concerns a dream, a vision, a feeling, an expectation. It says that man is unduly hopeful of a better world, a world of peace, of equity, of purity, a realm of fairdealing. Here the dream is oriented by a 'finality'. A scientific concept, a scientific statement are strongly established. They are always progressing. A dream, a vision are never certain, never permanent. They are fragile, delicate.

The purpose of this paper is to discuss if such a definition, which states that these two components, science and dream, are and must be present in what is man, is still always valid. I will present my comments in three points. The first one will recall the marvellous gifts of science to man. The second will briefly review the positions and attitudes of scientists about the dream. The last one deals with the new situation which is now encountered by the scientific community.

1. *The marvellous gifts of science to humanity*

Science provides models. In the most advanced disciplines, the models are theories. Starting from a few concepts or basic statements, they give the possibility to predict the properties of a large class of phenomena by a rational – often a mathematical – reasoning. For a given phenomenon, the results given by a theory have to be compared with those obtained by a direct experiment. The smaller are the differences, the better is the approximation given by the theory. Science is steadily improving the quality of the approximation and the domain of applicability of its models. What must be emphasized is the 'objectivity' of this knowledge. It means that it may be obtained by any scientist completely independently of his moral, religious, or political convictions. Then, science offers to people the vast domain of scientific knowledge which may be called 'the world of agreement', because any scientist, provided he applies the rules of a rational reasoning, reaches the same conclusion. This 'objectivity' is the main characteristic of a scientific model or theory which cannot be forgotten, as is often the case. As a consequence, it is not possible to derive from a scientific statement any moral or philosophical conclusion.

Science not only offers a large domain of the 'world of agreement' to those who want it, but also may offer every child an important contribution to the formation of his culture. This point is the theme of a recent book by my colleague Yves Quéré entitled *La science institutrice – Science as a primary-school teacher*. It explains and comments the successful operation 'La main à la pâte', launched with Georges Charpak and Pierre Léna, similar as far as I know to 'Hands on' in the United States. A child who receives such an education will never forget that science is a strong component of any culture and that it is an introduction to the 'world of agreement'.

Thanks to science we know now that the universe and life have a history. These facts were not known two centuries ago and have been revealed by science. They provide a deep understanding of our human situation. It is so important that some people are prepared to say that science is the motor of human history.

The applications of sciences are the source of significant improvements in techniques – and, more recently, of technology – which have produced significant wealth and staple commodities for the benefit of society. They give humanity the possibility of acting directly on its future.

The above remarks are sufficient to show the marvellous gifts of science to society.

2. *Scientists and the dream*

Scientists are, of course, aware of the gifts provided by sciences and their applications to humanity. The actions of sciences are going in the same direction. They are ever more powerful. It is certain that science is a strong component of the essence of man. In appearance at least, it is not the same for the dream: beliefs and feelings don't show a similar evolution. It is not then surprising if scientists have various opinions and show different behaviours in relation to about the dream.

To be brief, one may distinguish three main attitudes.

First, for some of them, the dream has no importance and therefore may be forgotten or even ignored in the progression of science and of its applications. Roughly speaking, they say that ethical considerations have not to be taken into account against innovations.

Second, others consider that, even if one cannot describe exactly the expectations and value of the dream, they are important for the development of humanity. But they think that they would be best achieved through the expansion of the scientific disciplines, especially by the emergence and the development of human and social sciences.

Finally, one finds the scientists who have no strong opinion about the possible dream of the society. As they don't know, they don't care about it. They consider that it is not their problem.

The reasons for these different choices among scientists are related to the source of the vitality of the scientific activity. One source lies in the personal feeling of scientists who, answering the question why they are scientists, say: for amusement, curiosity, pleasure, the satisfaction of discovering something new, to increase my knowledge, to participate in an activity which may give people a better life. Many scientists of the 19th century or of the first half of the 20th century had this kind of reaction. They thought that teaching science or working in science were favourable to the 'dream of justice'. They were the heirs of the scientists and of the philosophers of the time of Enlightenment, who had such confidence in science that they thought that the dream would be achieved by way of expansion of the scientific progress. That is the theme of a book by Ernest Renan, *L'avenir de la science*, who wrote: 'It is not an exaggeration to say that in science may be found the future of man. Science alone is able to tell him what is his fate and how he can reach his goal'. Let me quote also Jean Perrin, a Nobel Laureate, who wrote more than fifty years ago, in the book *La science et l'espérance*: 'The progress of science will increase and thought will continuously broaden. The wealth and the power of humans will increase. And then, by a miracle, Humanity will enter a new age. The public has a deep faith in science, a little confused, but deep. He expects that science will bring a liberation and will make possible for everybody access to the pure joys of Arts and Thought'. Of course, nobody would make such a declaration today. But such a hope has not completely disappeared. It remains in what may be called 'the ideal of being a scientist'.

However precious might be this source of vitality of science, it is probably not the most important for explaining its remarkable progress. One of my colleagues, Jacques Blamont, wrote a big book – 940 pages – called *Le chiffre et le Songe* devoted to what he called 'the political history of scientific discoveries'. For him, the wish for knowledge is not the essential factor of this progress. He thinks that 'man' is a force who wants to build tools to go to a real elsewhere which is not the future brought by religion or metaphysics, a new Earth, a new sea, towards space in the direction of the stars. The whole book is a deepening description of important achievements. His thesis is that they are the result of a triple conjugation. First the prince – that may be a king, a dictator, a man with great power – let us say: the 'motor' of the operation. Second, a scientific institution which may mobilize scientists and engineers who have to work together. And then a few great scientists who may have new ideas. Two conditions are necessary to guarantee success: the 'motor' must have a clear vision of the goal of the operation and must be able to collect a large amount of money. No big science without a lot of money; no money spent in a big scientific achievement without a clear vision of the goal. The methods to follow, the measures to use, however drastic they may be, are secondary.

Jacques Blamont's book gives many examples to illustrate these statements. Let us mention quickly two of them, the first from ancient times, the second a recent example. The first: the expansion of science due to the Ptolemes is astonishing. It was possible only thanks to the exploitation of the gold mines of Nubia in which thousands of people – slaves, war prisoners and Greek citizens – were working in appalling conditions. The second concerns the building in Germany during the last war of a large quantity of new arms, V1 and V2 rockets to be launched on England in order to try to avoid defeat. Thousands of people taken from prisoner of war camps or from concentration camps were working as modern slaves, victims subjected to horrible treatment. But this terrible enterprise was effectively, from the scientific and technical point of view, a highly significant step towards the conquest of Space and the leaders were fascinated by this goal, maybe more so than by the success of this new weapon. Most of the scientists and engineers working on such big operations did not agree with the treatment imposed on the workers.

In conclusion, looking at the opinions of scientists, one sees that in general there is no direct connexion between their attachment to science and their view about the dream of the society. Extreme positions may be found, some thinking that the dream will follow the progress of science, others that the dream should not be taken into account if it were to slow down the progress of scientific achievements. In this last case, which was exceptional, the dream could have been affected by the progress of science.

3. *Science and Society. A new situation today?*

In this last section, the aim is not to analyse the complex relations between sciences and societies. A few flashes only will be presented in order to see if the phrase I have chosen to comment on this paper is still relevant. Today refers to the few decades – 1 or 2 – before and after the starting point of the millennium.

Sciences today appear mainly through what is called 'technosciences', which are complex and elaborate assemblies of scientific and technical elements, results and methods, built up in order to produce special goods, machines or equipment. The above description of the system which produces scientific discoveries proposed by Jacques Blamont is appropriate to explain how technosciences may be implemented. Among the great variety of technosciences, three main kinds of 'motor' may be mentioned according to the type of goals they are looking for.

First: ‘the military motor’ whose goal is to strengthen political power – in general of a country – and to assure the safety of its citizens. It is a very important one for which many scientists and engineers are working. It has to support an army, a lot of officers and soldiers, and to give them the best arms they need. These equipments demand a large armaments industry. The budget devoted to these activities is very high. After the USSR collapsed, the possibility of a decrease in this large amount of investment was expected. But unfortunately that is not happening owing to recent events and especially the necessity to face the threat of terrorism.

Second is ‘the economic motor’. This too requires great numbers of scientists and engineers working in industrial enterprises and companies to produce goods and services. Some of them are highly important and very powerful. They need a lot of money. They are in general private and belong to the shareholders. If they are successful, the value of the share is high and the number of the shares may be increased.

The third: ‘the biomedical motor’ is more recent but its importance is steadily and rapidly increasing. Its principal technosciences belong either to pharmacology or to biotechnology. The first deal with chemistry for producing goods for living beings; the second are special technosciences using living materials or even living beings. One does find in this motor category, big companies working like classical companies with shareholders and patents, but also some laboratories. The latter may receive some public subsidies but also many gifts and donations of varying size, from people who are ready to help medical research to hasten the progress of discoveries for curing frequent and serious diseases like, for instance, cancer or Alzheimer.

The technosciences developed by these three motors receive big support and a lot of money from those able to take advantage of what they may offer, meaning people of the advanced countries and especially their rich citizens. These technosciences need to take up a large proportion of the whole of scientific activity, which causes a significant change between fundamental research devoted to knowledge and applications. Moreover the dream of society and also the public’s confidence in science may be affected by their development. Consequently, the relations between science and society may require serious attention.

The evolution of societies depends greatly on the development of communications which makes the world what is often called ‘a global village’. Everybody, everywhere, is aware of what happens in the rest of the world, and particularly so of all the modern facilities which are at the disposal of the people living in countries where they can take advantage of scientific and technical development for improving their individual cultural and social life. The people of the developing countries wish, of course, to be able to enjoy the same advantages for themselves and for their children. Their claim gives rise to worldwide meetings and demonstrations for expressing their expectations. Among these, the conferences organized by the United Nations on major issues of long-time global significance such as environment, population growth or social features including poverty deserve to be mentioned. Many academies of the world were invited to send contributions. A little later, an informal network of academies of sciences, the InterAcademy Panel on International Issues (IAP) was formed to facilitate further collaboration. IAP invited academies to develop their thoughts on the long-term quality of life of all people and also of the poor countries of the world which urgently require an increase in availability of consumption of some essential resources.

Important initiatives took place at the turning point of the century. First, ICSU and UNESCO organized the worldwide conference on Sciences and Societies in Budapest in June 1999, giving the opportunity to nearly 200 nations to express their views. The representatives of the developing countries told of how much they need and expect the help of Science in order to enable them to face their vital problems. Secondly, a year later, IAP called a meeting in Tokyo devoted to a preliminary study of the most important points science and technology might achieve in order to move the world globally to a sustainable way of life. It seems to me that the purposes of these initiatives are part of the new dream which may be proposed to 'man', to humanity. That is, to work in order to extend to all people of the world, in the long-term, the gifts which have so far been given to the citizens of the advanced countries – food, health, energy, education – and at the same time, the possibility of building and increasing their own capacity to participate in this action by developing their own level in science and in technology. It is an ideal of solidarity and equity. To make this dream a reality will obviously take a lot of time and strong convictions, in order to overcome the difficulties and the obstacles. It is clear, in particular, that the long-term improvement in the situation of the poor countries will not be possible without important change in the consumption patterns of the richer countries.

Since the Tokyo meeting this action has made a good start. IAP has the benefit of a good organization and now has eighty-five academies as members. A programme of four important topics has been adopted, including in particular Science education and Capacity building. Moreover, another working structure of fifteen academies, the InterAcademy Council (IAC), has been more recently created inside IAP, with the mission of carrying out studies and making reports for international organizations like the United Nations or the World Bank.

Conclusion

The statement recalled at the beginning of this paper which implies that science and dream must be present in man, that is in the human society, seems still to be valid, despite the fantastic changes and humanity's new conditions of life. But the relations of science and society inside this new complex man are modified. The gifts given by science, and in particular by technosciences, have to be understood and appreciated by the public and their dangers avoided. They must also be made available, at least in the long-term, to every nation of the world. It appears that in order to hope to achieve these difficult goals, the academies of sciences have a more important role than in the past. It is not surprising if one agrees with the statement of one former President of the French Académie des Sciences: an academy of sciences is the conscience of the scientific world, and, more than this, the scientific conscience of the world.

DISCUSSION ON THE PAPER BY GERMAIN

ZICHICHI: I enjoyed very much this fantastic contribution of optimism centred on science. We should do our best to transform these dreams into reality. I've only one point where I cannot say that I agree with what you said: where you say man is a product of biological evolution. Science is not the product of biological evolution, it's the incredible evolution of culture in terms of the logic of nature. The species that we belong to is not characterised by biological evolution; what distinguishes us from all other forms of living matter is not biological evolution, it's cultural evolution. How many millions of years would we have had to wait for our eyes to be able by biological evolution to see New York on television, and how many billion years would we have had to wait to fly at the speed of a jet? So, what distinguishes us is cultural evolution: language, logic and science.

GERMAIN: Of course, but I want to comment on a statement of Jean Rostand on man: 'l'homme, l'arrière petit-neveu de la limace'. I think this is a good way to tell people that if they are here it is because we have had a lot of years, as you say, with all the steps of evolution. I will not say that man is only this thing, but I said this as a comment to the sentence by Jean Rostand.

LE DOUARIN: I would like to make a small remark to Professor Germain. You emphasised that science and the progress of science now relies essentially upon large groups of people, big operations involving a lot of money and personnel. Don't you think that there is still room for small groups of individuals and perhaps even isolated individuals with very creative minds?

GERMAIN: First of all I don't say that all scientific progress is the work of techno-science, but a large part of it.

LE DOUARIN: You seem to say on page 7 that in the future the progress of science will be based on extremely large forces which is true, but perhaps this is not the only way to find new ways and new avenues.

GERMAIN: No, of course that's not my hope. I tried to give a description, and I can quote economists and sociologists who say that science has no importance, it is only techno-science which has the power to change the fate of humanity. And of course I'm very anxious to develop what I've called the ideal of being a scientist, I've repeated this view this morning, and you know that we in France, and I think in other countries as well, are noticing that not very many young people dedicate themselves to science. When they see the sort of style of some companies in the United States, they think that Europe will follow sooner or later. Of course an economy with big companies, even the biomedical, is very different from what they want. What they like is astronomy, astrophysics, mathematics and theoretical physics, because there is no application, no direct industrial application. The ideals of science may still be a source, a good source of what they dream. If the scientific community uses its tools, the IAP, the IAC, I'm pretty sure that young people will be persuaded to act. We have to be convinced of the future of science.

RICŒUR: Oui, je dois dire que je ne suis pas très heureux avec le mot rêve, dream, surtout que dans votre papier le complément de mon rêve a disparu, justice. Je n'ai plus jamais rencontré le mot justice. Alors, cette lacune fait que le mot rêve a perdu sa force, et avec lui le calcul intégral, puisque la totalité des projets scientifiques s'est trouvée absorbée et, si je peux dire, colonisée par trois facteurs de... comment dirais-je? Un véritable hold-up sur l'esprit scientifique, parce que les trois moteurs que vous avez cités, le moteur militaire, le moteur économique, le moteur biomédical, ce sont des rêves de puissance... Et donc la justice a disparu, ce qui peut-être impliquait que le mot rêve lui-même n'était pas adéquat, parce que ce qui manquait c'était le mot exigence, et là nous ne sommes plus dans le rêve, et nous sommes plus forts contre la captation des trois projets de puissance. Moi, j'ai l'impression d'avoir plus de respect pour la science que ce que vous en décrivez.

GERMAIN: Oui, ce que j'ai visé c'était une des formes actuelles du développement scientifique, pas seulement développement technique, mais une forme qui mobilise beaucoup d'hommes, beaucoup de scientifiques. Si nous nous plaignons de plus avoir assez d'étudiants qui font des sciences, si on regarde de plus près, comme je l'ai dit, l'astronomie, les sciences de l'idéal que j'ai cultivé toute ma vie ne souffrent pas. Quelles sont celles alors où il y a beaucoup de monde? C'est toutes les sciences techniques. C'est la physique, la physique pure, par exemple, qui a des difficultés. Monsieur Ricœur, je voudrais me défendre sur le rêve. Au début, j'ai dit ce que j'entendais: une vision, un sentiment, une attente, une espérance d'un meilleur monde, un monde de paix, d'équité, de pureté, un royaume de fraternité, voilà ce que j'entendais par le rêve... Je ne vais plus reprendre tout cela, mais pour moi quand je parle du rêve dans la suite c'est cela.

MENON: My comment is really not directed towards the speaker, but the Council and in particular the President of the Academy, because I agree with the concluding sentences of Professor Germain when he says that the Academies of Sciences have a more important role to play today than they did in the past. He says that one former President of the French Academy of Sciences has said: 'An Academy of Sciences is the conscience of the scientific world, and more than this, the scientific conscience of the world'. I agree with that, in which case we have to discuss in what way we can actually perform this task of being the scientific conscience of the world. It is hardly enough for us to discuss issues amongst ourselves. We've had many meetings of great value. Last time it was on education. Before that it was on science and development. We have discussed the question of genetically modified organisms and many such other issues. But, somehow, we have to get it across to society at large, to the world. There are many issues facing society today. The question of basic human needs and of meeting them, the question of the economic divide, the digital divide, aspects such as AIDS and many other diseases – one can list a whole range of them. I think it is important that as an Academy, and particularly the Council, for discussions in the Academy, should look at these issues from the viewpoint also of putting these across to society. This may not be the view of everyone. But if it is, how can we perform that role meaningfully?

GERMAIN: I'm sure you know about the IAP, InterAcademy Panel on international issues which started in Tokyo, May 2000. The two co-presidents are Yves Quéré and Edward Krieger. They now have ninety Academies, most of them from, of course, developing countries. They will have their next meeting in Madrid next year, and they have a programme with four topics: one is education, one is food, one is water, I don't remember exactly, health; four good topics. They are not very strong Academies, you know, most of them are recent; they meet and they can say what they want. The IAC has fifteen Academies or so, it was born after the IAP. It is an organisation which hopes to obtain studies and reports from the World Bank, from the United Nations, and the leading man of the IAC is the President of the US International Academy of Science, Bruce Alberts. I attended a meeting of this organisation last July in Paris, and it was about what they would like to do, we are a few people who agree, and Quéré has been very active. But we are few. I would like the world community to know about this organisation.

CABIBBO: I'll be brief. I think the question posed by Professor Menon is very relevant. We devoted a special meeting to that, which was a closed session where the Academicians discussed the future activities of the Academy. You certainly know that this Academy has nothing to be ashamed of in that respect. I mean, the Academy has always been very active on these subjects. So, if you have a specific proposal, we will be happy to implement it with enthusiasm. I should also point out that the Academy is a member of the InterAcademy Panel which was created to discuss these very interesting problems.

THE FACTS OF LIFE

CHRISTIAN DE DUVE

Introduction

The last fifty years have witnessed major advances in our understanding of the nature and history of life on Earth. The implications of these advances have yet to be incorporated into current philosophical and religious world-views, which are still largely pervaded by animist concepts that belong to an earlier age. The main points at issue are briefly reviewed in the present paper. A more comprehensive treatment of the subject is to be found in a recent book (de Duve, 2002).

FACTS AND THEORIES

In considering present-day knowledge, it is important to distinguish between facts and theories. The former may be viewed as incontrovertibly established, whereas the latter, even though they may be supported by all available evidence, remain open to discussion and possible dissent. In the summary that follows, I shall try to make this distinction, although the limit beyond which a theory becomes a fact is not always easy to define.

1. *Life Is One*

All living organisms, including bacteria, protists, plants, fungi, animals, and humans, descend from a single ancestral form, known as the *last universal common ancestor*, or *LUCA*. The kinship among all forms of life, long supported by their many structural and functional similarities, has now been proven beyond doubt by the sequence similarities among genes that perform the same function in different organisms. Hundreds of such cases are known.

Not only do the similarities prove descent from a single ancestral sequence. Even the differences are revealing, as they tend to be all the more numerous the greater the evolutionary distance separating the organisms that own the genes, thereby allowing the construction of molecular phylogenies.

2. *Life Is a Natural Process*

Here, again, the proofs are overwhelming. Thanks to recent advances in biochemistry, cell biology, and molecular biology, we have reached a stage where we may confidently state that we *understand* life. Admittedly, vast areas, in fields such as embryological development or the functioning of the brain, continue to pose challenging problems to research. Many details remain to be filled in. But the basic processes that support life, those that are common to all living organisms – metabolic pathways, biosynthetic mechanisms, energy transformations, genetic information transfers – can be explained in terms of molecular structures and reactions. This is so true that we can now manipulate life almost at will.

An important lesson to be derived from this newly-gained knowledge is that the age-old view of life as 'animated matter', which is still implicitly prevalent in much of current thought and discourse, is plainly wrong. There is no such thing as a nonmaterial 'vital force' or 'vital spirit' that somehow moves the molecular components of living organisms to behave the way they do. *Vitalism is no longer tenable.* Life is a normal manifestation of matter, entirely explainable in terms of physics and chemistry. Although solidly established scientifically, this fact has yet to become accepted knowledge by much of the general public.

3. *Life Is Ancient*

Alleged vestiges of bacterial life – including fossil traces of microorganisms, mineralized remains of large, complex, bacterial colonies, called stromatolites, and carbon deposits containing an excess of the light ^{12}C carbon isotope over the heavier ^{13}C, taken to be a signature of biological activity – have been discovered in a number of ancient geological sites, some as old as 3.5, or even 3.85 billion years. Doubts have recently been expressed about the authenticity of some of this evidence, putting into question the date of first appearance of life on Earth. This controversy is far from settled, but other, unquestioned signs of past life exist that go back well beyond 3.0 billion years. Furthermore, the organisms that have left such traces appear distinctly more advanced than the LUCA is likely to have been; and the LUCA itself must have been preceded by a string of more primitive organisms. Finally, the probability of finding preserved vestiges of past life in ancient rocks becomes increasingly small as the age of the rocks increases, and, with it, the likely destruction of these vestiges by metamorphic and other changes. For all these reasons, it seems probable that life is actually more ancient than the available evidence would seem to indicate. Its age could well exceed 3.5 billion years by an appreciable margin.

This age is to be compared with that of the Earth, which was born about 4.55 billion years ago. At that time, some 10 billion years after the Big Bang, the Earth condensed, together with the other planets of the solar system, within a disk of dust and gas whirling around a glowing core that was to become our Sun. Our nascent planet, battered by planetesimals, comets, and meteorites and convulsed by volcanic upheavals, remained unable to harbor life for at least 500 million years. Thus, life may have appeared on Earth almost as soon as the planet became physically able to bear it.

This possibility has led some workers to suggest that there would not have been enough time for life to arise locally, so it did not start on Earth but was brought to it from some extraterrestrial site by a comet, a meteorite, or some other means of transportation (even including a spaceship sent out by some distant civilization!). As will be seen, this argument rests on an erroneous estimate of the time needed for the emergence of life. Another piece of evidence put forward in favor of an extraterrestrial origin of life has been the discovery, which will be referred to later, that organic material is widespread in the Universe. However, it is now generally accepted that this material is of nonbiological origin. It thus seems reasonable to suppose that life originated on Earth. An advantage of this hypothesis for the purpose of research is that available geochemical data on the state of the early Earth help to narrow down the problem by defining the physical-chemical setting in which life may have originated.

The fact remains that an extraterrestrial origin of life cannot be discounted on the strength of present evidence. Neither can the possibility be ruled out that life originated in more than one site, for example on Mars or even on celestial bodies outside the solar system. As we shall see below, such eventualities are now generating considerable interest.

4. Life Arose Naturally

This is a theory, not a fact, as there is no direct proof that life did, or even can, arise naturally. But there is plenty of circumstantial evidence supporting such a possibility. Particularly convincing is the fact, stated above, that life is a natural process, entirely explainable without calling on the intervention of some 'vital spirit'. That such a process may itself arise naturally clearly appears as the most likely hypothesis. From the point of view of research, it is the only acceptable hypothesis. Scientific investigation requires the presupposition that its object be explainable.

A powerful argument in support of a natural origin of life has been provided in recent years by the spectroscopic exploration of outer space, the study of comets with the help of instruments borne by spacecraft, and, especially, the analysis of meteorites by means of all the techniques of modern chemistry. These investigations have revealed the astonishing fact that amino acids and other biological constituents form spontaneously in large amounts throughout the Universe. Thus, at least the building blocks of life are *natural products of cosmic chemistry*. The alternative hypothesis, sometimes formulated by the defenders of an extraterrestrial origin of Earth life, that living organisms are responsible for the synthesis of the detected compounds, is not considered tenable.

In the last forty years, numerous attempts have been made to reproduce in the laboratory some steps of the origin of life. Sparked by the historic experiments of Stanley Miller (1953), much of this effort has been directed towards the formation of small, organic building blocks of life. The finding, just mentioned, that such materials readily arise under natural conditions has lessened interest in this line of research. The main focus, nowadays, has shifted to the reactions whereby such building blocks could have assembled into more complex molecules, especially RNA, which, according to all that is known, probably played a crucial role in the early development of life.

So far, these efforts have met with limited success. But this is no reason for giving up. What may be needed is a change of approach, calling more on biochemistry than on organic chemistry in the design of experiments. Living cells show us at least one pathway whereby building blocks are combined into complex biological constituents by natural reactions. As I have pointed out elsewhere, there are good reasons to believe that the early chemistry that first produced life already prefigured some of the key processes by which life constructs itself in present-day organisms (de Duve, 2002).

The theory of a natural origin of life is far from being unanimously accepted. It is, of course, rejected and even violently combated by fundamentalists and creationists, who put greater store on a literal reading of the biblical account of Genesis than on scientific evidence and who, on this basis, negate not only the natural origin of life but even the existence of a

LUCA and the occurrence of biological evolution. Many less committed laypersons, some even highly educated, share the same attitude, not so much for religious reasons than because of the largely unconscious, ingrained vitalism that still pervades all that has to do with life. To this point must be added the powerful prejudice against 'spontaneous generation', popularized by what may well be the most celebrated experiment by Pasteur, who, incidentally, was a confirmed vitalist. This prejudice rests on a misapprehension. What Pasteur showed, and nobody will deny, is that microbes cannot arise spontaneously overnight in a sterile broth protected from aerial contamination. What origin-of-life research attempts to elucidate is a process of gradual 'complexification' that must have taken a considerable amount of time to give rise to the first primitive microbes.

In recent years, opposition to the notion of a natural origin of life has been voiced by a very small but vocal minority of scientifically trained persons who, while subscribing to the notion of a LUCA appearing *de novo* on Earth and evolving into present-day living organisms, claim that these phenomena could not possibly have taken place by purely natural processes, but required the intervention of some nonmaterial guiding entity that forced the raw materials of life to interact so as to produce the first living cells and also, as will be mentioned later, directed the further course of evolution (Behe, 1996; Dembski, 1998; Denton, 1998). Known under the name of 'intelligent design', this theory, which is close to vitalism, has been magnified much beyond its merits because of its alleged philosophical and theological implications. I shall come back to it when discussing evolution. Let me simply state now that serious flaws have been detected in the scientific arguments brought forward in its support.

The question of the origin of life deserves one additional comment: it is a *chemical* problem. What needs to be unravelled is the pathway, itself made of chemical reactions, between two kinds of chemistry: cosmic chemistry and biological chemistry. This fact entails two implications. First, the process must, for kinetic reasons, have been relatively *fast*. What is meant by this term is difficult to evaluate. My own estimate of the requisite time is anything from centuries to millennia, perhaps tens of millennia or even more, but certainly not tens or hundreds of millions of years, as was once believed by those who, for this reason, defended an extraterrestrial origin of life (see above). The fragility of many of the intermediates involved in the process precludes such very slow reactions.

A second consequence of the chemical nature of the processes responsible for the origin of life is that these processes must have been highly *deterministic* and reproducible. Like all chemical processes, they depended only on the physical-chemical conditions that prevailed where they happened, and they were therefore *bound to occur* under those conditions. This opinion is not shared by all scientists. On the contrary, the most widely held theory, for a long time, was that life arose as the outcome of highly improbable, chance events, so improbable that they are most unlikely to take place anywhere else, any time, and could very well not have happened on Earth either, were it not for the fantastic stroke of luck that made them possible. I shall discuss this theory later, in relation to the possible existence of extraterrestrial life. Let me just point out that its defenders unwittingly – and unwillingly – provided support to those who claim that life could not have arisen without the help of some special agency, or even an act of God. From a fantastic stroke of luck to a miracle, the mental step is short.

5. *The Theory of Evolution Is More than a Hypothesis*

In those words, Pope John-Paul II, addressing the Pontifical Academy of Sciences in a solemn session, on 22 October 1996, expressed the acceptance of biological evolution by the Church. Considering the implications of this statement, the evidence that convinced the Pontiff must be truly decisive. And so it is. Actually, the Pope's statement was overly cautious. Evolution is not a theory; it is a fact, implicit in the common descent of all living organisms and established with the same degree of certainty.

Thanks to the information provided by fossils and complemented by molecular phylogenies, we have a rough idea of the timing and manner in which evolution has proceeded. A schematic outline of its main steps is shown in Table 1. Bacteria were the sole representatives of life on Earth during more than one billion years. The first eukaryotes emerged around 2.2 billion years ago, probably as the outcome of a long evolutionary history of which no fossil trace has yet been found; they remained unicellular for more than another billion years. It is only after life had completed some three-fourths of its history on Earth that primitive multicellular plants, fungi, and animals first appeared, slowly giving rise to more complex forms. The animals, in particular, went through more than 99-hundredths of their own history before producing the last common ancestor of humans and their closest relatives, the chimpanzees. In the final hominization stage, *Homo sapiens sapiens*, our nearest forebear, appeared only about 200,000 years ago. In absolute terms, this is a huge expanse of time: 100 times the duration that has elapsed since the birth of Christ. In relative

Table 1. THE HISTORY OF LIFE

MILLION YEARS (approximate)	EVENT
-15,000	Big Bang
- 4,550	Birth of Solar System (Earth)
- 4,000	Earth Habitable
- 3,500	First Bacteria
- 2,200	First Eukaryotic Protists
- 1,000	First Plants and Fungi
- 600	First Invertebrates
- 500	First Fish
- 400	First Amphibians
- 350	First Reptiles
- 225	First Mammals
- 70	First Primates
- 6	Last Common Chimpanzee-Human Ancestor
- 0.2	Homo Sapiens
- 0.030	Cro-Magnon
- 0.002	Birth of Christ
0	Present
+ ???	End of Humankind ?
+ ???	? ? ? ? ?
+ 5,000	Explosion of Sun (Earth Uninhabitable)

terms, however, it is little more than one twenty-thousandth of the age of life on Earth, or the equivalent of the last half-hour in one entire year.

Two directions may be distinguished in the course of evolution. One, which I call *vertical*, proceeds in the direction of increasing *complexity*: from bacteria to eukaryotes; from unicellular protists to pluricellular plants, fungi, and animals; and, in each of these groups, from simple to increasingly complex organisms, with – at this point in time – the human species as summit in the animal line. At each level of complexity, *horizontal* evolution has produced a wide *diversity* of organisms, making up the rich array of species that compose each class.

6. *Natural Selection Is the Main Mechanism of Biological Evolution*

Modern molecular biology has provided powerful support, as well as a large amount of additional information, to the theory of natural selection first proposed by Charles Darwin. Many details of the theory are still being discussed, sometimes heatedly, among experts. But its main elements are largely undisputed.

To start with, there is *heredity*, the phenomenon whereby properties are transmitted from generation to generation. Known as an empirical observation by Darwin and his contemporaries, later quantified by Mendel in a manner that implied the existence of units of inheritance, or genes, this phenomenon is now understood in detailed molecular terms thanks to the discoveries of molecular biology.

Next, there is *variability*, which creates breaks in genetic continuity and allows the start of new evolutionary lines. The phenomena responsible for the breaks, called mutations, can now likewise be described in molecular terms and related to a number of physical, chemical, or biological causes acting in a manner that is well understood.

Finally, *natural selection* screens the mutant products of genetic variability according to their ability to survive and produce progeny under prevailing environmental conditions. In addition to being a logical necessity, natural selection has been seen in action, at least on the short term of human observation, in a number of instances. Resistance to toxic chemicals is a prominent example that has been documented in bacteria, protists, plants, and animals.

The most important information provided by modern biology is that the genetic changes responsible for evolutionary branchings are strictly *accidental* events, totally *devoid of intentionality*. Mosquitoes do not become resistant to DDT *in order to* escape from the toxic effect of the pesticide. Those rare individuals that *happen to be* resistant to DDT survive and proliferate in the presence of the chemical. All that is known of the mechanisms involved imposes this interpretation.

In simple terms, this understanding implies that each of the many forks that have, over almost four billion years, delineated the course of evolution, is the product of a *chance* genetic change that happened, again by *chance*, to take place in an environment conducive to the survival and proliferation of the mutant form. These facts are recognized by a vast majority of life scientists, even though there may be disagreements on certain details or side issues, such as the importance of neutral mutations, genetic drift, and the mechanisms of speciation, to cite only a few. Exceptions are the few defenders of 'intelligent design', already mentioned above, who claim that certain key steps in evolution, for example, the transformation of reptiles into birds, could not possibly have taken place by a strictly Darwinian mechanism and that some hidden agency must have guided the process according to a pre-set plan. The following quotation illustrates this viewpoint: 'It is hard not to be inclined to see an element of foresight in the evolution of the avian lung, which may well have developed in primitive birds before its full utility could be exploited' (Denton, 1998, p. 362). Note the terms 'foresight' and 'before', which are characteristic of this kind of thinking.

Intelligent design is but a new word for a theory known as 'finalism' (from Aristotle's final causes). Favored by a number of biologists of the nineteenth and early twentieth centuries, finalism slowly yielded to the convincing arguments of Darwinism and has now been abandoned, together with vitalism, in response to the advances of modern biology. Its present revival in the face of all the evidence against it is not scientifically justified, as has been abundantly shown (see: Miller, 1999; de Duve, 2002).

The theory of intelligent design would hardly be worth mentioning in a serious scientific context were it not for its amalgamation – consciously advocated by its supporters – with so-called 'spiritualist' philosophies, in opposition to the crass 'materialism' allegedly professed by scientists. Thus, intelligent design has become a rallying banner, enthusiastically hailed in some religious circles, for a number of philosophers, theologians, and creationists of one ilk or another, who emphasize that 'science does not explain everything', a statement, incidentally, few scientists would take issue with. Such confusion of some vaguely conceived animism with religion is unfortunate. It hardly helps the cause it is supposed to serve, which can only be weakened by identification with a dubious scientific theory. Among the many thinkers who have expressed themselves on this point, special mention deserves to be made of the late French philosopher Jean Guitton (1991) and the American biochemist Kenneth Miller (1999), both practicing Catholics.

Our understanding of the underlying mechanisms gives chance a central role in each of the many branchings that trace the course of evolution. According to most experts, this realization enforces the conclusion that evolution, including, in particular, the advent of humankind, has depended on such a large accumulation of fortuitous coincidences that its repetition anywhere, any time, cannot possibly be envisaged. In the words of Ernst Mayr, one of the most distinguished and respected representatives of the field, 'an evolutionist is impressed by the incredible improbability of intelligent life ever to have evolved' (Mayr, 1988). As will be seen, many have gone one step further and used this view as an argument for denying any significance to humankind.

Although seemingly inescapable, the conclusion reached by such scientists is not flawless (de Duve, 2002). Contrary to the intuitive perception sometimes evoked by the notion of randomness, chance does not necessarily exclude inevitability. All depends on the quantitative ratio between the number of *opportunities* provided for a given event to happen and the *probability* of the event's happening. Given enough opportunities, an event may be almost bound to take place – within limits of physical feasibility, of course – however improbable it may be.

This notion is highly relevant to evolution, which usually involves large numbers of individuals – millions, if not billions or more – competing for available resources, generation after generation, for up to millions of years. What this means in practice is that, in many cases, the genetic variants offered to natural selection cover the field of possibilities so extensively as to make the outcome almost predictable, given the environmental conditions that prevail. Witness in support of this affirmation the many cases of drug resistance already referred to – an almost unavoidable consequence, so it seems, of introducing a new drug into the environment – as well as many other remarkable instances of adaptation – mimicry is a good example – that have been marshalled in support of finalism in the past, and still are cited by the defenders of intelligent design today.

Allowing for a number of exceptions, the conclusion suggested by these considerations is that, in many cases, mutations are not the limiting factor of evolution, leaving the main role to the environment and its vagaries. It is important here to distinguish between horizontal and vertical evolution (see above). In horizontal evolution, which involves variations of the same body plan, environmental conditions play the leading role. Mimicry illustrates this point. Absent green leaves, no insect with leaf-like shape and color would be selected.

Things are different in vertical evolution, in which significant changes in body plan – from reptile to bird, for example – take place by way of intermediates that must all be viable and capable of successfully proliferating under prevailing conditions. The inner and outer constraints that narrow down the course of such pathways are stringent, and the role of chance is correspondingly reduced. In a number of instances, there are only one or very few courses for evolution to take, and the environment does no more than passively determine whether a course will or will not be taken.

Such considerations are relevant to the widely accepted view that so many chance events have been involved in evolution as to make it virtually impossible that a similar unfolding could ever happen elsewhere. This, no doubt, is true of many details of horizontal evolution, although, even here, one is impressed by many remarkable instances of convergent evolution (Conway Morris, 1998; Nevo, 1999). But when it comes to the main directions of vertical evolution, including the advent of humankind, the constraints may be such that, given appropriate conditions, similar directions may well be followed time and again, without the necessary assistance of a guiding agency.

7. *Earth Life Has up to Five Billion Years Left for Further Evolution*

Cosmologists tell us that the Sun will have exhausted its stores of energy in about 5.0 billion years, at which time it will expand into a red giant, enveloping the Earth in a fiery embrace and making the planet unfit for life. Other planetary catastrophes may extinguish life earlier, but probably not before 1.5 billion years, according to most estimates. Even this lower value is a truly enormous time, more than twice the evolutionary history of animals, 250 times the leap from chimpanzee to human, 200,000 times humankind's written historical record, some 20 million human lifetimes! The higher estimate allows life a future longer than the whole of its past.

What will happen in such huge expanses of time is obviously impossible to predict, or even to visualize. But some surmises based on past history are permissible. First, it is likely that life, which has survived so many planetary cataclysms, will persist in one form or another until the Earth becomes utterly uninhabitable. Next, it is safe to say that life will not remain at a standstill. Evolution, including our own, will continue, eventually leading to new forms that could be as different from present-day organisms as are sequoias from seaweeds or human beings from sponges. In particular, as will be mentioned below, if vertical evolution keeps proceeding in the direction of increasing complexity, beings with mental faculties much more highly developed than our own may well appear one day.

This, however, is only one scenario, inspired by past history. A much more dismal future could await life in general and humankind in particular. Evolution could regress, the biosphere could become poorer, humankind could disappear. The crucial factor here is that natural selection, although still operating, will no longer be solely in charge. Humankind now holds its future and that of life on Earth in its own hands. I shall come back to this point at the end of my essay.

8. *Life, Even Intelligence, May Be Widespread in the Cosmos*

This statement expresses a mere possibility, so far unsupported by any concrete evidence and long considered most unlikely by the majority. Opinions have changed. Many scientists now consider the existence of extraterrestrial life likely enough to justify great efforts and expenditures. A new discipline, named astrobiology, has formed around this topic. Explorations of Mars and other parts of the solar system aimed at uncovering signs of life have been carried out and more are planned. The search has extended to nearby stars, creating considerable excitement with the discovery of the first extra-solar planets. Even extraterrestrial intelligence is actively looked for by attempting to detect signals from any distant civilizations that may exist.

Although these efforts have not met with any success so far, the possibilities that inspire them appear plausible, perhaps even probable. In the preceding pages, I have defended the notion that life was bound to arise under the physical-chemical conditions that prevailed at the site of its birth. The main reason for this contention is that the processes involved were essentially chemical in nature and, therefore, highly deterministic and dependent only on existing conditions. A corollary of this view is that, if the same conditions obtain elsewhere in the Universe, life would likewise arise at that site and would have the same basic chemical properties that characterize life on Earth. With some 30 billion Sun-like stars in our Galaxy alone and about 100 billion galaxies in the Universe, the likelihood of the existence of other planets sufficiently similar to the

Earth to be capable of giving rise to life would seem to be very high. Most astronomers agree on this point.

Whereas the existence of extraterrestrial life is now considered likely by a majority of scientists, opinions are much less sanguine concerning the likelihood that life may evolve to produce intelligent, humanlike beings. As mentioned above, many evolutionists see this eventuality as most unlikely and view humankind as the unique product of an extremely improbable concatenation of chance events. It may be significant, in this respect, that the participants in the SETI project (Search for ExtraTerrestrial Intelligence) are mostly astronomers.

The biologists' skepticism may not be justified. As I hope to have shown, the well-established role of chance in evolution is restricted by two factors that are not always sufficiently appreciated. One is the richness of the mutational field presented to natural selection, with the result that the outcome under given environmental conditions often ends up limited to a small number of (optimized) possibilities. The other factor to be taken into account is the stringency of the inner and outer constraints that tend to channel evolution in the vertical direction whenever the opportunity arises. According to this line of reasoning, the emergence of humankind – and also, incidentally, that of beings of higher intelligence in the future – turns out to be a much less improbable event than is often maintained. That extraterrestrial life may evolve in a similar direction is also, by the same token, a realistic possibility.

THE HUMAN CONDITION

Our philosophies and religions, our social systems, our laws, our cultures, our civilizations, even our sciences and our cosmologies, are all traditionally centered on humanity. Terms such as human rights, human dignity, human freedom have acquired quasi-mystical status, under the unifying notion of *humanism*, which, from its literary origin in the Renaissance, has become the rallying concept of all human-centered reflections and activities. How could it be otherwise in a world where 'species-ism', the allegiance to one's species, has been deeply etched in by natural selection?

It has required modern science to shake the foundations of anthropocentrism. After relegating our abode to a speck of cosmic dust orbiting around one in one hundred billion stars, in one among one hundred billion galaxies, science has now shown that we are one out of millions of twigs that have branched from the tree of life on Earth over a span of some four billion years. This realization is only beginning to be felt by people outside scientific circles. Scientists disagree on its significance. In this essay, I focus on three aspects of humankind that I believe particularly deserve to be taken into account: transience, meaning, and responsibility.

1. *The Transience of Humankind*

This is probably the most revealing lesson of modern biology; it is also the most disturbing. For most of the existence of life on Earth, we were not around. We will most likely cease to be around long before life disappears from our planet. We are no more than a transient manifestation of life, a stage in its long evolution towards diversity and complexity, almost certainly *not the ultimate outcome* of this process.

Most likely, the road to humankind consisted of small increments – notably in brain size – without any sharp discontinuity. The perceived break between humans and their closest primate relatives is the artificial consequence of the lack of surviving missing links. The slow evolution of stone cultures over more than two million years illustrates this course in impressive fashion. It is only after the human species had acquired its characteristic modern features that cultural evolution started picking up, thanks perhaps to the acquisition of language, and went on proceeding at an ever increasing pace, up to the vertiginous rate we see today.

According to anthropologists, there has been no significant increase in the size of the human brain – and presumably in its associated mental capacities – during the last 50,000 years. An interesting question is whether such an increase will, or can, occur in the future. Whether it will occur may depend to some extent on our own interventions, as I shall mention below. Whether it can occur will only be known if it happens, but the possibility can hardly be ruled out on the strength of present knowledge.

It is illuminating, in this connection, to look from an historical perspective at the development of the human brain and the associated mental abilities. As already emphasized (Table 1), the last hominization steps have taken a remarkably short time relative to the preceding history of life on Earth and to its likely future. This fleeting period has been witness to an amazingly rapid increase in brain size, which, in just a few million years, has grown to three times the size it had taken one hundred times as long to reach before that. The cerebral cortex, the seat of consciousness, has expanded even more – more than four times – during that period. As illustrated by selected examples in Table 2, there has been a parallel expansion

Table 2. THE GROWTH OF MENTAL POWER

Cerebral Cortex (cm^2)	Performance Ability
500	Fishing Termites with Stick
1 000	Chipping Stone Tools
2 200	Sending Man to the Moon Nuclear Power, Supercomputers Genetic Engineering ----- Big Bang, Quarks, Relativity Natural Selection, Double Helix ----- Lascaux, Sistine Ceilings, Guernica Angkor Vat, Parthenon, Chartres Well-tempered Clavier, Ninth Symphony ----- Divina Commedia, Hamlet ----- Holy Bible, Discours de la Méthode
4 000	? ? ?

of mental performance, from the crude manifestations of purposeful intelligence shown by chimpanzees to the highest achievements of human culture. What if the cerebral cortex should expand even further? This question is unanswerable with our present brains. Beings better endowed mentally are as impossible for us to imagine as would have been Moses or Einstein, or even the humblest of illiterate humans, for Lucy, the young australopithecene female that roamed the Afar region, in East Africa, some 3.0 million years ago. What our minds do allow, however, is our raising the possibility and considering its implications.

Such a development need not necessarily take place in the human line. Humankind could disappear, and some other evolutionary line could take over and eventually lead to beings mentally superior to humans. There is certainly enough time for such a happening. All this is speculation, of course. I mention it simply to underline the fact that there is no objective reason to assume that humankind occupies some sort of evolutionary summit beyond which evolution in the direction of further complexity is impossible.

Another possibility that now deserves seriously to be taken into consideration is that other intelligent beings, some perhaps even mentally superior to us, may exist elsewhere in the Universe. Because of the immensities of cosmic times and distances, such beings may never come to be known to Earth humans. But their existence appears sufficiently plausible, if not probable, to be included as a possibility in any world-view.

What all this amounts to is that *humanism*, while continuing to rule our societies within the framework of human concerns, *must be dissociated from anthropocentrism*, the philosophical view that gives humankind a privileged position within some sort of cosmic blueprint designed around and for it. Whereas the former deserves to be maintained for obvious pragmatic reasons, the latter needs to be abandoned or, at least, amended by our philosophies and religions if they aim at universality. Admittedly, this necessary reappraisal will not be easy.

2. *The Meaning of Humankind*

In the eyes of many biologists, the reappraisal called for by science is drastic. It entails the recognition that there is no meaning whatsoever to humankind. We are no more than the accidental product of an enormous number of highly improbable chance events that could very well never have taken place, whether on Earth or anywhere else, and, therefore, are totally devoid of significance.

Propagated by persuasive advocates, this view has gained acceptance in scientific circles and, even, in part of the general public, as being the irrefutable message, however unpalatable, of modern biological knowledge. It has, in turn, evoked an anti-science backlash among the many who, for one reason or another, find the message exceptionable. The favor with which the 'intelligent design' theory has been received is partly attributable to this reaction. By making claims that contradict our most intimate convictions, it is contended, science disqualifies itself as a valid approach to the truth.

In my opinion, this conflict is unwarranted, largely because the popularized notion of the total contingency and, hence, meaninglessness of humankind rests on false scientific premises. As I have tried to make clear, there are solid scientific reasons to see the advent of humankind as much more probable than is generally believed, which, in turn, leads to the conclusion that we belong to a Universe in which the generation of intelligent beings is very likely, if not obligatory.

This notion has been defended by some cosmologists and physicists under the name of *anthropic principle*, which is based on a number of calculations showing that if any of the major cosmological constants had values only slightly different from what they are, our Universe would not have produced conditions compatible with the existence of life and mind. Hence the conclusion that we live in a Universe 'made for us'.

The calculations supporting the anthropic principle have not been challenged. But the defenders of cosmic contingency have disputed its significance on the grounds that our Universe could be just one in what the British astronomer Martin Rees (1998) has called a 'multiverse', a huge collection of universes with all kinds of different constants. As chance has it, so this interpretation goes, our Universe happens to have constants suitable for life and mind to arise and so has come to be known. But this, like biological evolution, is a pure matter of chance; it also is meaningless.

As I have explained elsewhere (de Duve, 2002), I do not accept this conclusion. Whatever the number of universes, ours remains, in my opinion, supremely significant. Life and, especially, the human mind, with all it has produced – the sciences, the arts, the philosophies, the religions, the social, political, and ethical systems, in short, all the fruits of civilization and humanism – are such remarkable manifestations that they can be but telling revelations of what I call 'Ultimate Reality'.

In this respect, I accept the premises of the anthropic principle, but not its name, which smacks too much of anthropocentrism. To the human-focused notion of a Universe 'made for us', I prefer the more neutral view that we live in a Universe conducive, by way of life, to the generation of increasingly powerful means of elucidating its secrets and apprehending its mystery. This, to me, is a *meaningful Universe*, even though I find myself unable, with my limited mental abilities, to grasp exactly what this meaning is. Perhaps, some day in the distant future, some beings may do better.

3. *The Responsibility of Humankind*

Even though humankind may be only a stage in an ongoing continuity, its advent represents a watershed. The two are not incompatible. Salamanders walk, fish don't; birds fly, reptiles don't. Yet a continuous chain of intermediates links the ones to the others. What distinguishes us radically from our primate cousins is our ability to *understand* the world and to *manipulate* it accordingly. Especially, it is the *moral responsibility* that goes with this ability.

This realization is recent. Up to a few decades ago, humans, at least those who are identified with the so-called higher civilizations, behaved as though they had been given the world for their indiscriminate enjoyment and exploitation. It is only recently that more far-seeing concerns have started to be voiced on the consequences of human interventions. In answer to these concerns, measures have begun to be taken or are contemplated, even though reluctantly, to protect the environment, avoid pollution, save the remaining forests, shield endangered species, preserve the ozone layer, decrease the emission of hothouse gases, in short to counteract the harmful effects of prior, unrestrained, human plundering of natural resources. Note that, except for a few true 'nature lovers', the motivation behind these concerns and measures is still largely anthropocentric. Only in the face of glaring and serious threats to human welfare or prosperity are restrictions recommended, enforced, and accepted. We still look at the world as our own but are moved to husband it better, the way we would our capital. Even here, however, self-interest stops too often at national boundaries for truly effective actions to be taken. One can only hope that global self-interest will prevail over narrow, local preoccupations before some of the damage inflicted on the environment by human activity reaches the point of no return.

Leaving these matters to the experts and decision makers, I wish to address a new and much more exacting challenge to human responsibility, occasioned by the developments of biotechnology. As of now, we already have the means to engineer life in many ways. The scope, precision, effectiveness, and ease of such interventions are increasing almost daily. Soon, we will be able to modify existing life forms and to create new ones almost at will, thus supplanting natural selection and replacing it by human intentionality, in the direction of evolution, including our own.

All over the world, voices have been raised in alarm at the prospects opened by these new capabilities. The sacredness of nature is invoked. All kinds of ethical safeguards, rules, and laws are clamored for. Powerful bodies, including many governments and the major religions, have demanded that some interventions, such as human cloning, be banned outright and that many others be severely restricted. The more aggressive environmental movements go so far as to resort to violent opposition.

In the face of all this turmoil, one must note first that there will be no going back. Biotechnology is here to stay and will inexorably move forward. Whatever restrictions are imposed, there will always be some exception to allow a new type of experimentation, be it only in a more permissive country. It is significant, in this respect, that the International Bioethics Committee created by UNESCO did not, in its 1997 'Universal Declaration on the Human Genome and Human Rights', proclaim the inviolability of the human genome, contrary to the desire of many of its members.

It must be noted next that the human impact on biological evolution is hardly new. For some 10,000 years, breeding and agriculture have modified animal and plant species to a point that their wild ancestors are hardly recognizable in their modern descendants. More recently, the advances of medicine have begun to change the human gene pool to a significant extent and not always for the better, since harmful genes are now given opportunities for spreading that they did not enjoy before. What has changed is that our means have become much more powerful and, especially, can be applied consciously and deliberately to much more specific and predictable ends.

Finally, we must admit that there is nothing intrinsically bad about trying to improve on nature. The argument that nature is sacred and should not be tampered with is scientifically invalid. 'Mother nature' exists only as a myth. She is neither wise nor benevolent; nor does she have any allegiance to the human species. Scorpions and the AIDS virus are as much objects of its solicitude as are butterflies and poets. Nature is governed entirely by natural selection according to an intricate network of influences that pit the conflicting interests of different organisms against each other (struggle for life) within the constraints imposed by their interdependence (ecosystems). Surely, to substitute *reason* for this blind interplay can hardly be condemned. In fact, such a takeover may be seen as part of the privilege – and burden – of being human.

The only serious problem raised by biotechnological developments is whether we, as humans, possess enough collective *wisdom* for the exercise of our newly gained mastery over the living world. This question is particularly acute as concerns the human applications of biotechnologies, especially at the germ-line level. The current opposition to a new form of *eugen-*

ics is probably justified in this respect. To give our fellow human beings the license to direct future human evolution may well appear to many like giving children a box of matches. Nevertheless, children do get hold of matches and a few even set fire to the house. The others eventually grow wiser and use the matches for good purposes. I have a suspicion that this is what will happen to directed human evolution. Probably, many egregious mistakes will be made. But, some day, our distant successors will put humankind on the right course and lead it on the way to more penetrating intelligence, finer sensibility, greater compassion, and, especially, deeper wisdom. If this does not happen, it will be up to natural selection to start a new, more successful line. There is plenty of time for that.

Final Comments

In this essay, I have endeavored, to the best of my ability and with as much objectivity as I can muster, to clarify, as much for my own benefit as for that of my readers, the manner in which recent scientific advances, especially in the field of biology, affect our perception of the human condition. Not altogether surprisingly, some of my conclusions are not readily reconciled with the traditional image of humankind one derives from the Bible and other sacred writings. It is not for me to decide how this discrepancy will be resolved. I can only, as a scientist, present the established facts, generally accepted theories, and likely surmises allowed by the present state of knowledge.

Acknowledgments

Neil Patterson has kindly given this paper his customary, critical, and constructive attention and helped me put it in final form. I thank him warmly for his valuable assistance.

REFERENCES

Behe, M. (1996) *Darwin's Black Box*, New York: The Free Press.

Conway Morris, S. (1998) *The Crucible of Creation*, Oxford University Press.

de Duve, C. (2002) *Life Evolving*, Oxford University Press. *À l'Écoute du Vivant*, Paris: Odile Jacob.

Dembski, W. (1998) *The Design Inference*, Cambridge University Press.

Denton, M. (1998) *Nature's Destiny. How the Laws of Biology Reveal Purpose in the Universe*, New York: The Free Press.

Guitton, J. (1991) *Dieu et la Science*, Paris: Grasset.

Miller, K. (1998) *Finding Darwin's God*, New York: Harper Collins.

Miller, S.L. (1953) A Production of Amino Acids under Possible Primitive Earth Conditions. *Science*, 117, 528-529.

Nevo, E. (1999) *Mosaic Evolution of Subterranean Mammals*, Oxford University Press.

Rees, M. (1998) *Before the Beginning*, Reading, M.A.: Perseus Books.

DISCUSSION ON THE PAPER BY DE DUVE

LE DOUARIN: Thank you very much for this very stimulating lecture, which is now open to discussion.

COYNE: Just a very direct question based on my ignorance of neurosciences. The emphasis upon the surface area of the cortex, rather than upon the chemical complexity of the content, is it just surface area of the cortex or is it the chemical complexity of what is contained?

DE DUVE: Largely the surface area. But it is not just the cortex. The whole brain has increased in complexity. The brain mass has increased three-fold during the last part of the hominization process; it is three times the mass of the brain of our nearest chimpanzee ancestor six million years ago. I mentioned the cortex, because it is believed to be the seat of consciousness.

COYNE: So the functional complexity of the human brain does not go linearly with the surface area of the cortex, or does it?

DE DUVE: I don't know about linearly. All I can say is that the surface area of the cortex has increased more (four-fold) than the brain mass (three-fold).

COYNE: You said that for the evolution of life certain chemical steps should be highly probable to evolve life. I would suggest that from evolved chemistry to life is probable, not necessarily highly probable.

DE DUVE: I didn't quite say that. My point was that because the origin of life depended on chemical steps and because chemistry depends on deterministic processes, the phenomena that led to life must have been highly probable under the conditions that existed at the time.

COYNE: Yes. And the other question is: you mentioned that for the first eukaryote to evolve on earth we assume that it took 25% of the life of the planet, 2.2 billion years out of 9 billion years.

DE DUVE: The first eukaryotes are believed to have arisen at least 2.2 billion years ago. With life starting about 3.5 billion years ago, perhaps earlier, this means that life may have gone through about one-third of its history before eukaryotes appeared. But all these figures are very rough approximates.

COYNE: So you say about 25% of the life of the planet. My question is: do you think that on other planets it could take much longer than 25%?

DE DUVE: Much longer.

COYNE: Yes, much longer. I mean, life is highly probable on other planets, provided that the first step is not long enough, is not too long.

DE DUVE: Life is probable.

BATTRO: Yes, thank you Professor, your paper was very interesting, but in my profession I do not deal with the double brain but with the half brain, and we can say that it is exactly more or less half the surface, but to test my students I say: in a normal brain we have 10^{12} neurons.

What is the half of 10^{12}? And this is a kind of trap, because mainly, or mostly, they say 10^{6}, which it is not. The half of the brain has an enormous number of neurons. Therefore my interest is: with this half brain some people are very intelligent and some even go to university. Perhaps the question is: what is the minimal architecture we need in order to be intelligent or human? This is a question we can deal with, and I am astonished every day, working with these kids or young men, how much they perform with only half a brain, and therefore I do not know really if we need so much brain to be human. Certainly not, because these persons are human, but what is the minimal architecture you need in order to prove Pythagoras's theorem? This is a scientific question, and I can say that at least half a brain is enough.

DE DUVE: Thank you, I think you are making a very interesting point. But we cannot discuss the details because I am not familiar with them. First of all, when you say half a brain, is it their left brain, their right brain, did they lose it by accident or did they have a complete brain to start with or what?

BATTRO: Normally this is a result of surgery.

DE DUVE: Surgery?

BATTRO: Surgery performed when they were young. They had both hemispheres but because of epilepsy or a tumor one was removed. Professor White is here and he did one of the first hemispherectomies.

DE DUVE: On a young man?

BATTRO: I know one young man who is 18, and he had his left language dominant hemisphere removed when he was 10, and now he is entering college, and we are astonished, it is like saying that the planets move in square orbits. We certainly imagine the plasticity of the brain, which is enormous. Therefore, this kind of experiment of nature shows that you can perform like a perfect, normal being in many cases with only half a brain. What is this brain power? Perhaps it is related not to sheer power but more to the architecture, the intricacies of that. Therefore, and in order to finish this, if we have 10^{12} neurons and you add all the neurons that are in the human species, it is around the Avogadro number. But this number is a very tiny part of all the animal neurons that are on earth today, and these other neurons could some day be transplanted into a human brain in order to provide new tissue for a disabled brain. Therefore I think the way evolution goes is that we can and we will introduce non-human neurons into the human brain. Well, this is not a wild idea; some people are trying to do that too.

DE DUVE: This becomes very technical, so I thank you for your comments. I will just say that half a human brain is not a chimpanzee brain, and what would a chimpanzee do with half a brain?

BATTRO: Well, they also do a lot.

CABIBBO: Well, I have two questions. One has to do just with the size of the brain. Perhaps it is not a question of brain size but really the invention of communication. Efficient communication and language were really a big bang for humanity, and maybe there is nothing comparable in the future, nothing much bigger than that. So, maybe you see that this has shown that we are not working with one brain but with Avogadro's number of neurons.

DE DUVE: The development of language was, of course, a very important step. Some workers believe that it was the development of language that inaugurated what is sometimes called the 'Great Leap Forward', the extraordinary acceleration of cultural evolution that started some 50,000 years ago.

CABIBBO: But language gave such an advantage, because it allowed sharing, conservation, storing, etc. That's one question. The other one I would like very much to examine from the point of view of the necessity of life, cosmic necessity. I think it is not necessary; for all that we know life could be very improbable, it just happens that we are here, I mean, we were lucky, so we cannot really know. Maybe a measure could be when we will be able to start exploring many other planets, or getting into communication with some of them, although it will not prove very much, because maybe these other planets have not waited enough, but it is a statistical thing, we don't know really. I know that my opinion is rather extreme, but even if it is highly improbable, quantum mechanics will make sure that at least in some branches of the quantum universe you do have life, so it's enough that it is possible.

ARBER: I very much appreciated your paper and largely agree with it. If I interpret your statement correctly, I can expect that sooner or later, on some other branches of the evolutionary tree, forms of higher intelligence will develop. Is that your idea too, i.e. not only humans can and will undergo a cultural development? And then the last statement said the future is in our hands. Are you going to cut off these other branches, or are you going to manipulate the human branch? You should tell us what is in our hands. What do you mean by 'the future is in our hands'?

DE DUVE: What I meant is that we now have the ability of knowingly and deliberately shaping the future of life on our planet, including our own future, in a totally unprecedented manner. Already now, the new technologies, especially their application to human beings, are raising many problems. And these problems are nothing against those that will confront coming generations. The increase in our brain power has given us science and the means to apply the discoveries of science. But it may not have given us enough wisdom to handle this power. We may do a lot of good, but also a lot of harm, including possibly causing our own disappearance. This is what I meant by saying that 'the future is in our hands'.

RICŒUR: Yes, my question is about your last sentence. The future, you say, is in our hands. Your whole discourse was the discourse of an observer; but the last sentence is heterogeneous to this discourse. Is it the case that we are responsible?

DE DUVE: Je ne vous comprends pas.

RICŒUR: Je disais que votre dernière phrase est hétérogène par rapport au reste de votre discours qui était celui d'un observateur, et votre dernière phrase, "le futur est dans nos mains", est d'un homme responsable. Vous êtes passé d'un discours descriptif à un discours de prescription, parce que le mot "nos", nos mains, our hands, nos, suppose la possession par un homme responsable de son action. Alors, votre dernière phrase ce n'est pas la conclusion, c'est un autre discours appartenant à une autre région de notre culture que la science.

DE DUVE: Je ne saisis pas la distinction philosophique. Lorsque je dis que l'avenir est dans nos mains, je me contente de faire une constatation. Je ne prescris en rien.

RICŒUR: Non, là il fallait dire le futur est dans ses mains à lui, l'homme dont on a parlé dans la description.

LE DOUARIN: Très bien. Merci pour cette mise au point.

LÉNA: My question is related to the point you made that chance does not exclude inevitability. If we assume, and I agree with you on the likelihood of life in many places in the universe, and possibly in an infinite number of places if the universe is flat, i.e. infinite, as it seems to be now, then the number of sites where life happened can be extremely great: you give a number of the order of 10^{15}, but it could be even higher, and then the occurrence of us is inevitable, is no longer a matter of chance, because almost all of the possible cases will be realised in this random process.

DE DUVE: I won't disagree with that.

JAKI: It seems to me that you take a too optimistic view about the great number of earth-like planets, and consequently on the very high probability of organic and intellectual life elsewhere outside our planetary system. Now, even from the purely biological viewpoint, the origin and development of life on earth heavily depends on the presence of a very strange body called the Moon around it, which is an exceedingly rare occurrence. Now, with respect to the intellectual development of life on earth, especially scientific development, it begins essentially with Greek astronomy, with Aristarchus, Eratosthenes and Ptolemy. For these people the presence of the Moon, a body of a given size, of a certain visual distance is absolutely indispensable for working out their geocentric hypothesis, and those hypotheses were absolutely indispensable for Copernicus; Copernicus was absolutely indispensable for Galileo, Galileo for Newton, and so forth. In other words, if we restrict our consideration of intellectual life on earth, we must conclude that the evolution of science is a most improbable phenomenon largely controlled by the presence of the Moon and we have a moon around the earth through an exceedingly rare glancing collision between the earth at a particular phase of its development and of an unknown body. Now, I am not sure whether you are familiar with the book *Rare Earth* published by two members of the National Academy of Science, which created quite a stir in the United States. Its conclusion is that life elsewhere in our whole galaxy is exceedingly unlikely. One of the authors is an astronomer, the other is a biologist, and they are very prominent people. They say that much of our galaxy is exceedingly hostile to life, and then in that book finally – which is about 330 pages long – there are three pages in which the earth, the bearing of the earth-moon system, is discussed. So, I'm very sorry, but I have to disagree with your optimism on strictly scientific grounds.

DE DUVE: I disagree with you. I have read a few books myself. You certainly know that other astronomers and cosmologists have a different view.

RAO: My first question was covered by him a few minutes ago, but I don't want to be too euphoric about this. You know, the number of human beings who actually use the surface area of their brains is very, very small, so what I wanted to observe is this. You've used probability in all your arguments. Even scientific discoveries have been made by a very small number of people even though the large population of human beings possesses this large surface of the brain. Therefore, having a greater surface doesn't mean more discoveries. I don't think it is a linear function. Second, you mentioned the environmental factors. Werner Arber also said how antibiotics destroyed so many... have made us resistant. Environmental factors and various factors that we are going to create now in this world may have a completely different effect on these happenings, including man becoming brainier and so on. I feel that we have to worry about the environment a bit more, not ignore the environment.

DE DUVE: As you know, this distinction has been made by many people. Relativity, natural selection, the double helix, or whatever was bound to be discovered some day. But the 'Wohltemperiertes Klavier' would never have been composed if Johan Sebastian Bach had not existed. So, there is a big difference between a scientific discovery, which is just finding something that is there to be found (if you don't find it, somebody else will), and a work of art, which is something irreplaceable. Something that depends on the unique brain connections that belonged to Bach, Shakespeare or Leonardo.

ZICHICHI: I would like to thank you for this impressive list of facts on the origin of life. However, I would like to ask you to add a detail, which could be an important fact; namely that if I give you billions of molecules having the same chemical composition, the same understanding that you correctly emphasise, no one would be able to transform this amount of inert molecules into living ones. Your series of impressive facts should have as a scientific consequence two basic points. Firstly, the reproducibility of phenomena. You said we understand the origin of life from the chemical point of view. You should add that nobody is able to transform any amount of inert matter into living matter. This is point number one. Point number two: no one is able to formulate in a mathematical way this impressive series of facts. After two hundred years of experiments in electricity, magnetism and optics, we end up with the Maxwell equation. Your very impressive list, which I appreciated very much, should have two concluding points: one, it lacks experimental reproducibility, i.e. no one is able to transform any amount of inert matter into living matter; second, no one is able to express in a mathematical form the synthesis of this very impressive set of facts. These facts bring me to the third point, which refers to life in the cosmos. The cosmos has existed for twenty billion years. In the cosmos there are, as you know, about a hundred billion galaxies, and each galaxy has on average a hundred billion stars. Our sun exists since just five billion years. There are fifteen billion years already gone for all other stars, billions of billions. Therefore, if life was so easy, why did not other fellows reach what we've been able to reach in ten thousand years, the number of years for our civilisation? These fellows of the cosmos should have been able to send us messages, because they are smarter than us: we are just very young, they are 15 billion years ahead of us. Where are they? They should exist in billions of forms. We have existed for only 5 billion years, but the cosmos has existed for 20 billion years: we have missed 15 billion years, and billions of billions of stars where a civilisation in ten thousand years should have produced an immense amount of smart guys able to communicate with us. You gave us a very fascinating presentation. Please add in your impressive list these three points in order to make the list complete and to ensure that everybody has the complete picture.

DE DUVE: You have said a lot, so it is difficult for me to answer all your questions or remarks. But let us start with the first one. I did not state that life arose naturally. I said this is my working hypothesis, consistent with what we know of the nature of life. It is true that nobody has so far been able to generate life in the laboratory. But, to me, this working hypothesis is the only one that can motivate research. You cannot try to understand something that you believe a priori to be unexplainable. Hundreds of investigators are presently occupied with the problem of the origin of life and have already obtained very interesting results.

As to why other civilisations, if they exist, have not tried to communicate with us, this question, as you know, was already asked by Fermi. There are many answers, including that the best proof of the existence of intelligent extraterrestrials is that they have *not* tried to communicate with us. But that is a joke. In actual fact, many efforts are being made to detect messages from extraterrestrial civilisations. In the United States, there is a special institute for this, the SETI Institute (Search for ExtraTerrestrial Intelligence). An enormous effort is also being devoted to the detection of extrasolar planets that might bear life and, perhaps, intelligence. Of course, astronomical distances are so enormous that the probability of such a search being successful is very small, even if the Universe should be teeming with life and intelligence.

LE DOUARIN: Thank you very much for these very optimistic conclusions. There is one pressing question, the last one, because we are late.

VICUÑA: I think it's clear that this was a very provocative and fascinating lecture. Statement number three: you said that life arose naturally by a large number of chemical, highly probable steps, and from that statement I would deduce that life arose several times on earth, but your first statement says that all living beings are descendants from a single ancestral form. Do you mean then that other forms of life are extinct? Why is it that all living beings descend from a single form if at the same time you say that life arose naturally by a large number of steps whereas according to the laws of chemistry that are deterministic you would expect that life would have arisen several times? That is one question.

DE DUVE: There are many possible answers to your question. It could be that conditions were right for life to start only in one place. Or that incipient life went through a selective bottleneck out of which the universal common ancestor emerged. And so on. My point was that life is a chemical process. When Professor Zichichi tells us that nobody is able to transform inert matter into living matter, that is of course not true. We and all other living organisms do exactly that.

VICUÑA: Dr. de Duve, I agree with you of course that life is explainable in terms of physics and chemistry; it has to be, and we cannot fill the gaps of our ignorance with, you know, religious beliefs or other types of knowledge. Our duty, as scientists, is to try to explain life as a natural phenomenon, irrespective of the type of faith that we may have. So, the question is: I suppose that we already have all the knowledge we need to define life, but why is it that there are so many definitions for life?

DE DUVE: This is because every definition emphasises one aspect, like the elephant in the story. My own definition of life is simple, even simplistic: life is what is common to all living beings. This is not a tautology, because it excludes many things from the definition of life. To be alive, one does not need a brain, or wings, or legs, or green leaves. One does not even need many cells. One does not need mitochondria. What remains is what is indispensable and common to all living beings. This is still quite a lot. If you look at my few remaining brain cells and at the colibacilli in my gut, you will find the same basic chemical components, the same core enzymes, the same central metabolic pathways, the same ATP, the same mechanisms for storing information in DNA, replicating the DNA, transcribing the DNA into RNA, translating the RNA into proteins, the same genetic code, and so on. That is what I call life.

MODERN COSMOLOGY AND LIFE'S MEANING

GEORGE V. COYNE, S.J.

Introduction

Modern cosmology, as well as ancient mythologies, cosmologies and cosmogonies, bear witness to the immense power which drives us humans in our continuous search for a deeper understanding of the universe and our place in it. They also bear witness to the insufficiency of our search for understanding, of the need for something or someone out there, beyond oneself. From time immemorial we have always sought this further understanding in a person with whom we could converse, someone who shared our capacity to love and be loved and our desire to understand and to accomplish.

Our attempts, therefore, to understand the universe have as much to say about ourselves as they do about the universe. In fact, in us the universe can reflect upon itself and from our reflections there grows the conviction that we are part of that upon which we are reflecting. As soon as we set out with the powerful instruments for telescopic observations, together with those of mathematics and physics, to understand the universe and our place in it, we are made aware that we are standing on the shoulders of giants and that the path which has led to what we know today has been, with respect to a human lifetime, a long and arduous one and that many have gone before us. But, in comparison to the age of the universe, it has really been quite a short trek. Let us review some of the important things we have learned about the universe during that trek.

The Universe of Modern Science

If we look in infrared light at the center of Orion we see boiling gas and dust. If we look even closer up we see incandescent regions buried in that gas and with the Hubble Space Telescope we see the fine separation of blue gas and red gas in the midst of a rather chaotic structure. The fact is that stars are being born in this gas. And where the hottest, most massive and, therefore, brightest stars are already born, they are irradiating the gas, and it is giving off hydrogen alpha radiation. In this way we can identify star birth regions.

The region of star birth in Orion is just a little part of our Milky Way. Our Milky Way, like most other spiral galaxies, measures 100,000 light years across and it contains about a hundred billion stars. It has several beautiful spiral arms and the sun is located in one of the outer arms, about 2/3 of the distance from the nucleus of our galaxy.

We have reconstructed the plane of our galaxy the Milky Way with a mosaic taken by an infrared satellite. We see myriads of stars but we also see dark areas where there are none or very few stars. It is precisely this dark stuff out of which stars are born. These dark areas are really veils of gas and dust hanging down and hiding the stars that are embedded in them.

How is a star born? It happens by the laws of physics. A cloud of gas and dust, containing about 100 to 1,000 times the mass of our sun, gets shocked by a supernova explosion or something similar and this causes an interplay between the magnetic and gravity field. The cloud begins to break up and chunks of the cloud begin to collapse. And as any gas collapses, it begins to heat up. In this case the mass is so great that the internal temperature reaches millions of degrees and thus turns on a thermonuclear furnace. A star is born. Thermonuclear energy is the source whereby a star radiates to the universe.

Stars also die. A star at the end of its life can no longer sustain a thermonuclear furnace and so it can no longer resist against gravity. It collapses for a final time, explodes and expels its outer atmosphere to the universe. This may happen nice and peacefully or it may happen in a violent cataclysmic explosion, called a supernova. The most famous of these is the Crab Nebula which has a pulsar at the middle as its dead star.

So stars are born and stars die. And as they die they spew leftover star matter out to the universe. The birth and death of stars is very important. If it were not happening, you and I would not be here. In order to get the chemical elements to make the human body, we had to have three generations of stars. A succeeding generation of stars is born out of the material that is spewed out by a previous generation. But now notice that the second generation of stars is born out of material that was made in a thermonuclear furnace. The star lived by converting hydrogen to helium, helium to carbon, and if it were massive enough, carbon to oxygen, to nitrogen, all the way up to iron. As a star lives, it converts the lighter elements into the heavier elements. That is the way we get carbon and silicon and the other elements to make human hair and toe nails and all of those things. To get the chemistry to make amoebas we had to have the stars regurgitating material to the universe.

Humans Come on Stage

Obviously this story of star birth and death is very important for us. Out of this whole process around one star, which we call the sun, a group of planets came to be, among them the little grain of sand we call the Earth. An amazing thing happened with that little grain of sand. We know it happened and we deal with it every day, but we should still pause to think about the amazing occurrence in the 16th and 17th centuries with the birth of modern science. We developed the capacity to put the universe in our heads. We do that by using mathematics and the laws of physics, of chemistry and of biology.

How is it that I can claim without hesitation, as I did above, that there are a hundred billion stars in our galaxy and that the galaxy is 100,000 light years across? I obviously could not go out there and measure those quantities directly. And yet I claim that those measurements are as accurate as the measure of my height and weight. I can have the same certainty because I have been able to use the laws of physics and mathematics and chemistry and biology to put a galaxy, the universe, in my head and work with it. Of course some measurements in cosmology are more certain than others, but we really are certain about the mass of our galaxy. Because it rotates we can use the law of gravity to measure the mass of the galaxy in the same way as I measure the mass of the earth and the other planets going about the sun. The law of gravity will give you the total mass of the galaxy.

The Questioning Human Brain

Once we developed this capacity to put the universe in our heads, we became passionately interested in asking all kinds of questions. I would like to ask a few. Did our planetary system come about by a miracle? Absolutely not. Although we do not know everything about how it came about, we know that it happened in conjunction with the formation of the sun. Gas and dust were left over from the birth of the sun, and this gas and dust had to form into a disk by the law of physics to conserve angular momentum. Once all of this mass is concentrated into a disk, there is a much greater chance that the particles of gas and dust will collide and, in some cases, stick together. And, just like the rolling snowball effect, planetesimals, about 100 kilometers in diameter, are built up through accretion and finally planets are accreted from the planetesimals. We do not know everything about this process, but we know enough about it to know that it did not happen by a miracle. It happened by ordinary physical and chemical processes.

So, a further question arises: Did what we have just described happen elsewhere? First of all we look at those nearby stars that we suspect may be something like the sun. We have detected thus far more than 100 planets about other stars due to the center of mass motion of the star. That is an indirect way but a very solid one of detecting planets. We detect a wobble in the star due to the fact that there is mass outside of it so that the center of mass of the system is not at the geometrical center of the star. Furthermore, with the Hubble Space Telescope we have discovered disks around very young stars. We know for certain that they are very young stars by their spectra. We call the disks proto planetary because we have indirect evidence that the first planets have begun to form in the inner regions of the disk. We are beginning to see about other stars the process that we think formed the planets about the sun.

Since we have the capacity to put the universe in our heads, a further question comes to us. Where did galaxies come from? Galaxies are the building blocks of the universe. Hubble Space Telescope has been able to photograph some of the most distant objects we have ever seen in the universe. They are at a distance of about ten billion light years from us. So we are seeing these objects as they were ten billion years ago.

We think that Hubble is seeing proto galaxies. We see, for instance, a case of two blobs which seem to be merging and perhaps building up a galaxy. However, this is very controversial. We are uncertain about galaxy formation, whether it is bottom up with small units that build into a galaxy, or top down with a big cloud that collapses to form a galaxy, and then the stars form within it. Nevertheless, when we compare distant galaxies to nearby galaxies, we see clear differences in the stellar populations. Galaxies as they are born and age go through an evolutionary process. Galaxies are participating in the expansion of the universe. When we look at them on a large scale we see that they are not distributed homogeneously. There are large empty spaces and many dense alignments.

Origins of Intelligent Life

How did we humans come to be in this evolving universe? It is quite clear that we do not know everything about this process. But it would be scientifically absurd to deny that the human brain is a result of a process of chemical complexification in an evolving universe. After the universe became rich in certain basic chemicals, those chemicals got together in successive steps to make ever more complex molecules.

Finally in some extraordinary chemical process the human brain came to be, the most complicated machine that we know. I should make it clear that, when I speak about the human brain as a machine, I am not excluding the spiritual dimension of the human being. I am simply prescinding from it and talking about the human brain as a biological, chemical mechanism, evolving out of the universe.

Did this happen by chance or by necessity in this evolving universe? The first thing to be said is that the problem is not formulated correctly. It is not just a question of chance or necessity because, first of all, it is both. Furthermore, there is a third element here that is very important. It is what I call 'opportunity'. What this means is that the universe is so prolific in offering the opportunity for the success of both chance and necessary processes that such a character of the universe must be included in the discussion. The universe is 15 billion years old, it contains about 100 billion galaxies each of which contains 100 billion stars of an immense variety.

We might illustrate what opportunity means in the following way. Einstein said that God does not play at dice. He was referring specifically to quantum mechanics, but it can be applied in general to his view of the universe. For him God made a universe to work according to established laws. This is referred to as a Newtonian Universe. It is like a clock that just keeps ticking away once you supply it energy. Today we might be permitted to challenge this point of view. We could claim that God does play at dice because he is certain to win. The point being made is that God made a universe that is so prolific with the possibilities for these processes to have success that we have to take the nature of the universe into consideration when we talk about how we came to be.

For 15 billion years the universe has been playing at the lottery. What do I mean by the lottery? When we speak about chance we mean that it is very unlikely that a certain event would happen. The 'very unlikely' can be calculated in mathematical terms. Such a calculation takes into account how big the universe is, how many stars there are, how many stars would have developed planets, etc. In other words, it is not just guesswork. There is a foundation in fact for making each successive calculation.

A good example of a chance event would be two very simple molecules wandering about in the universe. They happen to meet one another and, when they do, they would love to make a more complex molecule because that is the nature of these molecules. But the temperature and pressure conditions are such that the chemical bonding to make a more complex molecule cannot happen. So they wander off, but they or identical molecules meet billions and billions of times, trillions if you wish, in this universe, and finally they meet and the temperature and pressure conditions are correct. This could happen more easily around certain types of stars than other types of stars, so we can throw in all kinds of other factors.

The point is that from a strictly mathematical analysis of this, called the mathematics of nonlinear dynamics, one can say that as this process goes on and more complex molecules develop, there is more and more direction to this process. As the complexity increases, the future complexity becomes more and more predetermined. In such ways did the human brain come to be and it is still evolving.

Summary

It makes us dizzy to contemplate billions of years in the evolving universe and then to think that we are on a little planet orbiting a quite normal star, one of the 200 billion stars in the Milky Way. And the Milky Way is just one galaxy and not anything special among the billions of galaxies which populate the visible universe.

Cosmology today is ever more human; it stimulates, provokes, questions us in ways that drive us beyond science in the search for satisfaction, while at the same time scientific data furnish the stimuli. In this context the best cosmology, to its great merit, does not pretend nor presume to have the ultimate answers. It simply suggests and urges us on, well aware that not all is within its ken. Freedom to seek understanding and not dogmatism in what is understood characterize the best of cosmology. It is, in fact, a field where certainties lie always in the future; thus it is vital, dynamic and very demanding of those who seek to discover the secrets of the universe.

DISCUSSION ON THE PAPER BY COYNE

RAO: Professor Coyne, I don't think that the neural networks, or whatever those networks are, generate heat, as is the case in large integrated circuits. I do not know about thermal energy and the way it is released. Are you sure the situation is like that: as you increase the surface area you would expect heat to be generated? I just wonder, because it is important to know whether heat is generated because of our neural network functioning. I am not sure that this is known.

SINGER: The cooling problem is not the central problem of brain science. There is a very efficient way to cool down the brain by blood circulation, and there are much bigger brains than our brains, such as the elephant brain or the whale brain. What seems to limit brains ultimately is that the conduction time of the nerve fibre is finite and if you want to establish coherence in time you cannot go too far, otherwise you lose coherence, but there may be other reasons as well.

MURADIAN: I have a small, but I think important, remark about life in the universe, about the transformation of inorganic matter into organic matter. Let us suppose that the rate of the transformation, of the augmentation of humanity, human mass, is 1% per year, and that over the past five thousand years the mass of the earth has become a mass of humans. This is a historical time, not a cosmological time. Over these five thousand years all the mass of the universe will transform into organic or human mass. It seems that the arithmetic here is very simple. There is no doubt: it is Malthusian arithmetic. And what do you think will prevent such a catastrophe? The meaning of life is the transformation of inorganic matter into organic form, and we see that this transformation occurs in a very short time-scale. Is there a contradiction from the point of view of religion or science to this?

COYNE: If I have understood, I do not see any contradiction. Religion has nothing to say to the transformations to which you refer. From our scientific knowledge we know that there is a constant replenishment of inorganic materials to the universe through the process of stellar evolution. But, in my paper I did not address the percentage of living matter in the total matter of the universe. It must be very small. I assume, for instance, that life could not exist in, or even near, black holes of which the universe is abundant. Actually, I referred in my paper only to the distribution of living matter on the Earth, 98% in plants, 2% in animals.

LÉNA: Yes, this is more a comment than a question, and it's about strategies to look for life in the universe. You mentioned the SETI, the search for extraterrestrial intelligence with radio signals, which is one approach. This is a top to bottom approach: we search for the most elaborate forms of life that we know about through the detection of intelligent signals. Now, the other method is of course bottom up, namely looking for signs of life which are vegetation, for instance, or any other sign such as the presence of ozone around the terrestrial planet which in our view is related to organic chemistry and life production because of the balance of thermodynamic equilibrium. Now, both approaches are extremely interesting. The first one is a somewhat fishing approach, I mean, either you succeed, and you get a signal, or you get nothing and you know nothing. The other one seems to me more scientific in the sense that it can go gradually, you get an image and this is within reach. We know that, ten or fifteen years from now we will have images of the surface of planets such as the earth at distances of a few light-years, and then we can look on those for signs of changing vegetation with time, which is perhaps not as conclusive as the first approach, but it is less of a fishing approach. I think one has to have both. I suppose you agree with that point.

COYNE: Yes, I agree. I agree completely that there are two ways of doing this. The limitation today is that looking out from the Sun, there are only a few solar-like stars within a few thousand light years of the Sun. To look all the way across our galaxy is going to take two hundred thousand light years to send the signal and receive it back so the chances, if you put all the well-known statistics on the distribution of stars, the chances of getting an intelligent signal are minimal.

But the point is, it's a less scientific way to do it, but it would be an immense achievement if we received what could really be interpreted as an intelligent signal. There are all kinds of implications. I agree absolutely. Our observing technology is improving all the time. In the past decade we have discovered more than one hundred planets about other stars. We have also discovered planetary systems. Furthermore, we have discovered disks of matter about extra-solar stars which are very much like the disk of material about the Sun out of which our planetary system was formed. We are developing techniques to sample the chemical composition of extra-solar planets in an attempt to detect such constituents as oxygen, ozone, nitrogen, etc., possible signatures of life.

SINGER: I think I have to cut the discussion here. We could go on for long, talking about the possibility of extraterrestrial life and the limits of the universe and why we apply a Cartesian system in order to describe something which is probably not Cartesian, and so forth.

THE DIFFERENT PACES OF DEVELOPMENT OF SCIENCE AND CULTURE: THE CONSIDERATIONS OF A DEMOGRAPHER

BERNARDO M. COLOMBO

1. I am sorry, I am not familiar with cultural anthropology and I am afraid that something in my speech will sound amateurish. May I hope that, at least, my mistakes will not be too bad. As a way out, I will try to consider culture in the largest sense: including knowledge, customs and beliefs, ways of living, of expression and communication, going from legislation to stories and art, from books to databases and tools, and so on. In my opinion, in shaping a culture the level and content of knowledge comes first. But immediately, connected with it, and through evaluation of it, come decisions and behaviour. Behaviour means choices, and these imply free will and a certain amount of freedom. And it is linked to a strain towards targets.

This is obtained at the level of each individual person, with ensuing heterogeneity of subjects. Within a population, culture may be differently characterized by groups of people in some way connected and providing evidence of homogeneity under some aspects. By families, first of all. I think it has happened to each one of us to be uncertain on the phone whether we were speaking with the mother or the daughter, so indistinguishable was the tone of the answer and of the voice. And we have evidence of a sort of family lexicon. To be crude, blasphemy seems to belong to a family lexicon, transmitted through the male line. The relation between the level of education of the mother and the success of children at school has been repeatedly emphasized. And so on.

More usual is to associate the idea of a culture with that of a population by and large sharing it. But culture has many facets, and subgroups in a society are identified by particular features characterizing them. Divisions by town and country, level of education, employment status, etc., within a society are usual covariates considered in studies of differential demography. Certain characteristics qualify both subgroups within a country and populations across countries: language, race, religion are among them. They are factors of distinction as well as cohesion. I remember well what I heard in 1994, at the UN Conference on Population and Development in Cairo. A Muslim delegate of an intergovernmental organization was on stage at a plenary session, and I heard him proudly declare: ‘We are a billion and a half; in ten years we will be two billion’. A distinction in one of these characteristics is generally associated with divergences along other lines: from a demographic point of view, in behaviour in front of events and decisions concerning human life. But not necessarily everywhere in the same manner.

Characterizing elements like those just mentioned are enduring factors shaping a cultural trait. An Italian colleague had made an in-depth study of the history of fertility in Spain. He happened to show the results to a Spanish colleague. This colleague, expert in the history of the country, was astonished and explained that the obtained map of fertility levels by regions reproduced political divisions dating back to past centuries. May I mention a similar coincidence observed in another demographic field. I knew that Cameroon was, in Africa and in the world, the country with the highest rate of sterility. I happened to find a study mapping finely determined African regions with high sterility levels, with particular attention to Cameroon. This map allowed the identification of the trails followed by raids into the various zones. Not only did the slavers spoil indigenous populations of human capital, they also left behind as an added offence a diffusion of sexually transmitted diseases.

2. The influence of cultural traits on behaviour modelling demographic phenomena can be traced back to well before the heavy impact of modern science and technology. May I mention three examples.

In Europe, where the relevant documentation exists and can be exploited, seasonal trends of births have been ascertained. For a long time in the past, higher rates appeared to be reached in late winter and early spring, lower in autumn and early winter. The reverse was documented for some regions of the Southern hemisphere. This phenomenon was seen at every latitude. At the same latitude, instead, birth seasonality differed, at least somewhere, between town and country. Such observations led someone to hypothesize a behaviour, in the countryside, consistent with the intent of having available all human resources just in time for when work in agriculture most needed them.

On the other hand, man had proved unable to manage adequately the struggle against sickness in the case of large epidemics. Empirical observations during plague episodes had consistently taught the lesson of the risk of contagion. Therefore, when a notice came of an instance of infection in some place, the borders of a town were rapidly sealed, and the entrance of persons or products was admitted only under strict conditions. This terribly damaged the local economy, but was felt necessary. Moreover, diseased persons were isolated in *ad hoc* institutions, and their homes were closed and disinfected. Those populations did not know what science later found about invisible beings and rats and fleas carrying them around. These defeated guards at the entrances and interventions on isolated buildings.

Finally, following John Hajnal, imagine on a map a line going from St. Petersburg to Trieste dividing Europe into two parts. In the Western part, the age at marriage for both sexes and the percentage of population that never married at all had been for centuries, since the end of the Middle Ages up to that of the *ancien régime*, much higher than in the Eastern one. In a prevailingly rural economy, availability of exploitable land and laws of inheritance are supposed to have been major factors in shaping behaviour. This – by the way – allowed to rely on the valve of flexible nuptiality habits to repair the ravages of plague crises.

3. In any field a time lag appears between a new scientific or technological finding and the taking advantage of it by interested people for their specific purposes.

First of all, in scientific work itself. In my field, for instance, it was noticed that a leading journal of biostatistics hosted a paper making reference to Mendel's theory only in the late 20s. Locally, the attention to heredity centred around different aspects and approaches. Biases of schools were at work. In 1954, at the UN World Population Conference in Rome, a participant coming from Eastern Europe presented a paper about changes in population characteristics due to marriages and migratory movements. He stated that these changes were due to economic, social and political factors, not to genes: 'Simply because genes do not exist. They are a myth'.

Coming to an area in which I am personally involved, I mention the new horizons opened by the computer.

I was born too soon. I am not referring to my age, but to the circumstance that my classical preparation in statistics was done before the birth of the personal computer. The PC allowed new chapters in statistical methodology and in computational statistics to be opened. May I mention an exercise performed by a colleague with the students attending his lectures in statistics. A double set of issues of leading journals, one some thirty years old and one of the most recent years, was scanned. It was found that in statistical applications in the oldest journals about 10% of the papers appeared to use a Bayesian approach. At that time there was a great controversy between those accustomed to classical approaches and those relying on Bayesian procedures. In recent years said rate increased to 50%. Personally – owing to heavy engagements in activities outside research and teaching – I did not find time to catch up with developments in the two fields. My efforts proved sufficient to understand the substance and the limits of these developments. But I realize that, when I want to follow new lines of research opened by continuously updated techniques, I need collaboration.

Computers have shown possibilities and created problems also in other areas. I am referring to the so-called data mining. It consists in techniques of analizing data when they come in enormous amounts: contacts through cellphones, visits to websites, databases of administrative acts, etc. In a recent meeting I heard a speaker raising questions about the philosophy of the approach to an analysis of data. He praised, through those methods, the greater respect of real facts. The classical approach through models was thought to impose an unwarranted theoretical pattern to an unknown matter.

Considering again computers, they provide an example of advancement of science and technology in one area, computing, that generates questions to be solved in a quite different one. The software that makes the computer work is a typical example of an intangible good. How can it be evaluated and treated in national accounting and matrices? At the level of the cost of licences? But the same good can generate quite different values of outcomes with a change in applications. And what about when it arrives free of charge, as it happens with Linux or the functions and scripts of the R project? Great attention has started to be given in economic accounts to this kind of goods: like tourism, terribly damaged by a horrible event.

4. The last example shows how an innovation in one field might induce unintended consequences in another one. This reminds me of a debate made in this room less than four years ago. Some participants raised objections against the spread of genetically modified products in agriculture fearing that this could mean favouring a dominant corporate food system based on large farms and monocultures. To that were opposed the merits of a system of small farms, more productive on the whole, and 'multi-functional', acting also as a basis of a diffused culture and of political equilibri-

um. I certainly do not want to enter into this discussion, but I wish to underline one aspect of this ‘multi-function’ of an agricultural enterprise. I recall a statement made about half a century ago by Prasanta Chandra Mahalanobis, a top Indian statistician: ‘If you want to lower the birth rate in India – he said – you have to foster improvements in agricultural activities’. The idea was, I think, that rationalization in one important aspect of human life such as labour could favour rationalization in another important one such as reproductive behaviour.

This leads me to underline the links existing also between different components of demographic developments. They are strong, lasting and pervasive, so that a disturbance in one of them entails consequences in others. May I illustrate this point through an example.

Fig. 1 shows the relation, over an interval of about 40 years, between the sex ratio (surviving males over females) and age in 1970 in the populations of three countries: the United States, the German Federal Republic, the German Democratic Republic. In the population of the United States one notices the usual descending trend of the ratio with increasing age due to the higher mortality of males. In both German Republics in two distinct intervals a roughly constant level with advancing age is put in evidence. The second one, at the oldest ages, depends on outcomes of the First World War. The previous one, of the Second. In this last, the difference in the level of the ratio in the two German populations is due to selective migration from East to West in the postwar period before the building of the wall. These persisting imbalances in populations which at the end of the war were between, say, 20 and 40 years of age must have created constraints to nuptiality, thus lowering the birthrate. With it will change the rate of population increase, the age structure, the death rate. What I want to underline is that demographic developments may be characterized by a slow pace, but they are relentless. And I do not mention, now, the interaction with induced social and cultural changes and their feedback on the causing factors.

5. But let us now concentrate on the extraordinary social phenomenon named demographic transition by Frank Notestein and *révolution démographique* by Adolphe Landry. That is, the passage from a practically stationary population characterized by high birth and death rates to a similar situation in which both rates are low. This change was completed in the Western world in roughly one century and a half. Due to the more rapid decline in fertility, the size of the population in the countries of the region increased very much. I will avoid the boredom of figures and will not enter

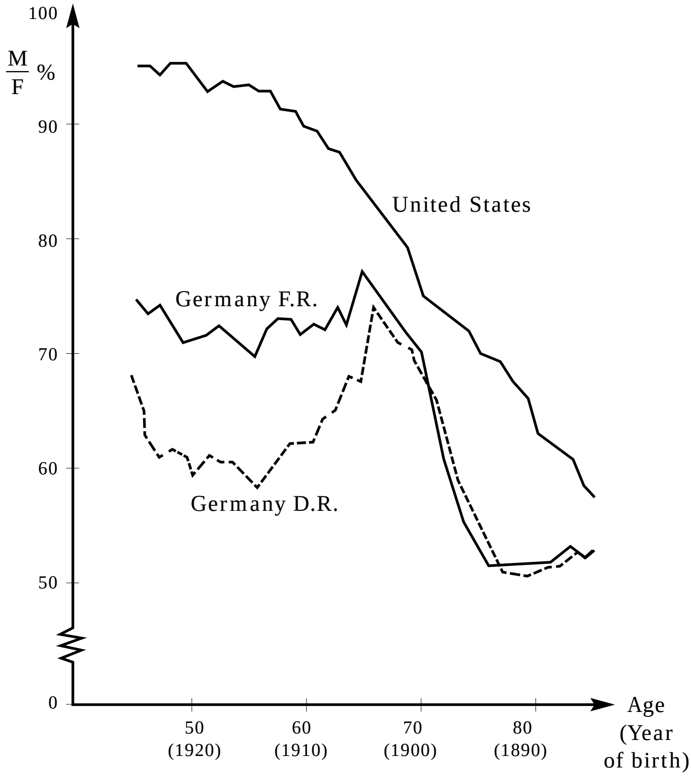


Fig. 1. Sex ratio by age, 1970.

into the debate on factors responsible for the decline of mortality. I will only mention a few of the several explanations advanced about the descending trend of fertility. Besides decreasing mortality, industrialization, education, urbanization, secularization, and so on have been underlined. But no generalization can be done. For each supposed causal factor, marked exceptions exist. Industrialization started first in England, well in advance of any important fertility decline. Compulsory schooling was adopted in Germany much before any perceptible shrinking of the birthrate. According to Ronald Freedman, the postwar baby boom disproved for the States the hypothesis on secularization.

Before the beginning of the change a limitation of births existed already in restricted circles: among members of the nobility and, in Italy, in some Jewish communities. The spreading of this behaviour within the general population definitely preceded any important contraction in mortality. It happened in the countryside, northwest of Paris, in France, decades before the revolution.

It has been suggested that this local behaviour may have been responsive to the supply of land. But it can be observed that France did not feel the need to take advantage of migration to the open territories of the New World. A French Canadian historical demography expert complained that in actual fact there had been a minimal flow of migrants from France to North America over a century and a half. French people, who were the first to settle on the St. Lawrence bay and the Mississipi delta, missed the opportunity to link the two original communities through facilities of rivers and lakes, giving by that another turn to historical developments. Throughout the nineteenth century fertility continued to decline in France more than anywhere else in Europe. Bertillon in 1895, seeing that the births in his country were half of the German ones, was frightened. He stated that he expected the outbreak of a war twenty years later.

I have mentioned these opinions in order to stress the importance of possible outcomes of demographic behaviour. But I immediately want to call attention to two basic points. In France, and anywhere else in Western Europe, the transition was not the consequence of any direct intervention of public authorities. It depended on decisions taken at the level of individual families. And this transition came to an end well before the discovery of the pill or of any other medical contraceptive. At the time of the world crisis of 1929-31, fertility in some countries had fallen down to about replacement level. The old valve of nuptiality was already exhausted. The change was due to traditional methods, coitus interruptus, abstinence, some rough condoms, and the like. And to induced abortion, presumably. I have never met reliable evaluations about its impact in past times. Folk methods may have been used, but I think that it is fair to suppose that it was a risky enterprise, apart from legal sanctions.

Given these facts, one might rightly ask which is the role played by advances in science. Before trying to give an answer to this question, let us glance briefly at what has been happening since the last war in developing countries.

6. From Jenner, to Koch and Pasteur, and to Fleming, to mention only some symbolic names, the art of medicine in a century and a half has

made extraordinary progress in every field, in prevention, diagnosis and therapy. Its great results were supported by improvements in living standards and in the organization of the public health system. All that scientific and technical knowledge was potentially available to any country at the end of the last world war. The enlarged possibilities of contacts with the developed world made possible in underprivileged regions the acquisition and spreading of knowledge, practices and products which had taken a long time to accumulate. But their application met with formidable obstacles. I do remember that I noticed, in a statistic of the WHO, that in a country there was a physician for every sixty thousand people. And I do not mention conditions of hygiene and undernutrition.

In spite of such severe limitations, the decline of mortality in the developing world has gone on much more rapidly than in the past in the more advanced regions. Certainly, a good deal more is needed to reach the levels obtained elsewhere, but the road is open, though with added hindrances. For instance, in sub-Saharan Africa, AIDS epidemics have caused the waste of much of the gains. But improved economic conditions, advances in educational resources and rearrangements in social organization will presumably allow the levels of control now prevailing in more affluent regions to be reached.

The better control of sickness and the lowering mortality meant enormous savings and advantages. For instance, it reduced the wastage of economic resources spent on bringing up babies who did not reach maturity. This fact increased human resources available in better health in productive lifetime. At the same time, it created conditions favourable to an increase in the already high fertility. More people survived to reproductive age, and were kept in good health through it. People then realized that it was no longer necessary to procreate many children to have a reasonable number of surviving ones at older ages. The contraction of the birth rate was the appropriate response to the new conditions.

At first, natality remained high, so that the rate of growth of the population steadily increased up to a level never reached in the past by any population. Later on, the fall in mortality was followed by a similar drastic drop in the birthrate. The main instruments used in this decline were no longer the traditional ones. New tools came to the forefront, all depending on new knowledge, products and abilities: pills, IUD, injectables, sterilization, in some cases induced abortion. Pressure from governments, in a variety of forms – even compulsory in some places – coupled with international urging have been moving rapidly in that direction. These external actions met with developments on the demand side of families facing new situations. But one point must be underlined. The fight against diseases and for survival is one-sided, and this simplifies choices and behaviour and makes it easier to foresee future developments. Procreation is a much more problematic area. Competing values and interests, at the level of involved couples, changing in time and meeting variable conditioning factors, led to heterogeneous behaviours, whose outcomes cannot be easily forecasted.

7. The last observation concerning uncertainties in evaluating facts and their developments in the demographic field has to be kept in mind when coming to an in-depth consideration about the timing of the adjustment of a cultural background. To this can be added that some events and realities are still puzzling and escape explanations. Take the sex ratio at birth – this pivot of our biological and social life – and its systematic variations between selected groups of newborns. After hundreds of proposed hypotheses, we might use an expression of Francis Bacon: 'What was a question once is a question still'. To take another example, it is hard to find the factors which determined the rise of the birthrate during the last war through 1945. From the States to Australia and New Zealand, through France and England and Wales, this happened in countries involved in the conflict and also in some – like Sweden and Switzerland – who were neutral but near the area of operations. And no demographer foresaw the baby boom up to the peak of 1960 in the States and of 1964 in Western Europe.

Dissection of a social phenomenon in an effort to identify clearly responsible factors is a difficult exercise, always in danger of falling in the fallacy of spurious correlations or of *post hoc ergo propter hoc* sequences.

We have seen that success in controlling mortality imposed as an unintended consequence a parallel containment of births. This happened, at different paces, in developed and developing regions. On the whole, as I have already had the opportunity to underline, mankind is now compelled to give up much of its potential fertility. The decline in mortality is in the forefront everywhere. Products, gadgets and techniques for checking fecundability play in general a minor role, simply more or less facilitating the itinerary towards a needed target. The variety of choices among societies and individuals reflect both cultural heterogeneity and consequences of external pressures on the supply side. Both take time in the expression of their weight.

8. In order to better clarify this question of timing in social adjustments, I choose a case study. For several years Italian fertility has been well below

replacement level. With 1.2 children per woman it is now at the lowest level in the world. It is well below replacement level. It is only about two thirds of that prevailing in France. What can be an explanation of such a difference?

In French society, the negative experiences of the past may have caused a sort of *revirement* in the general attitude. A new mood that, after the First World War and the great economic crisis, led to the approval in 1939 of the *Code de la famille* of the *Front Populaire*. This code included much more weighty measures in favour of families than those provided at about the same time in Italy. The demographic policy of the Fascist regime was very vociferous but substantially weak. I leave apart, naturally, the insults of antisemitism and the arrogant inconsistency of wanting at the same time more people and more space to lodge them. In recent decades in my country the baby boom has left space for a downward trend, in marriages first, and then in marital and general fertility. With the said 1.2 children per woman, we are far from the two children considered to be ideal for a family in answers given in several representative sample surveys. In my opinion this is a signal of social illness.

Some twenty years ago I had the opportunity to ascertain that, in France, public finance spent fifteen times more on family allowances than Italy. At that time, a French colleague found it strange that what in his country was considered social policy, in mine had the smell of fascist policy. Italian politicians were on the same line and did not care much about what was happening.

And what was happening – and still continues to prevail – was of the utmost importance for the life of the Italian population. Such a containment of births has had a strong impact on its age structure. The shrinking of the basis of the age pyramid will entail heavy population ageing. Italy, with Japan, already now, shows the fastest rate of ageing of the world.

This situation has consequences in many fields. In economic life, first. There is an increasing shortage of young adults in the labour force, that is of the more flexible and creative workers. In numbers, it is estimated that, to keep stable the proportion of the population in productive ages, hundreds of thousands of immigrants are needed every year. Sadly, while in the more industrialized regions of the North managers long for availability of labour force, in the South there continues to be severe unemployment, especially among young people. Persisting cultural resistances create obstacles to a better internal balance.

Provisions in the field of welfare also require a drastic rearrangement of activities and expenses. Some waste of resources is expected. Empty school buildings can be restructured for other services, but past spending to prepare teachers who are now out of work are lost. And it is probably not simple to convert a paediatrician into an expert of geriatrics. Certainly those who survive, say, at 65 years of age are nowadays on the average in better health than ever in the past. This makes it reasonable to postpone the age of retirement. However this solution plays against the prospects for the career of young people. There arises an intergenerational conflict of interests for which there are no easy solutions.

The most rapidly expanding segment of the population is that of the oldest old, say of people beyond 80. Among them, there is the highest proportion of persons who are not autonomous and self-sufficient: a proportion which is definitely higher, furthermore, among the poorest social classes. Most of the ensuing problems of help and assistance are now left in the hands and on the shoulders of families. This imposed onus is at the origin of much suffering especially for underprivileged units. This is a specific aspect of a more general problem. In fact, besides biological ageing, there is a social ageing ending in isolation and exclusion. Old people have lost much of their value as depositories of experiences and transmitters of knowledge. Their worst expectation is to live in solitude.

In Italy, the fraction of aged persons cared for in institutions is lower than in other similar societies. One may impute this deficiency to a lack of wisdom of politicians who failed to understand what was going on and came slowly and late to proper action. It is normal for politicians to look for immediately visible results of their intervention on today's problems. But a sense of solitude may be felt also in institutions. And most of the problems arising from isolation in a society are in the hands and under the responsibility of the behaviour of the people themselves. The contraction in the number of births impoverishes vertical family links – between children and parents and grandparents – which could provide better company and help for the aged. At the same time it offers less opportunity to enjoy horizontal ones through relatives, who are few in numbers, and live in similar conditions.

Other solutions have to be looked for to support and enrich the extended period of life, but the cultural accommodation of the society to the new conditions created by science and technology is going on only at a very slow pace. The inertia inherent in demographic movements facilitates forecasting future developments which society has to be prepared to meet. An urgent task, in my country, stimulating much attention and research.

9. In recent times, in several developing countries there has been both a decline in mortality and a drastic substantial drop in the birth rate. The considerations suggested by our case study might guide someone in imagining scenarios that could be happening in any of them. The experience in one instance certainly cannot simply be transferred, as it was realized, to another one. But the exercise could prove useful in illuminating the road of governance and of people. Failures might be unforgiving.

DISCUSSION ON THE PAPER BY COLOMBO

PAVAN: I would like you to tell us what you expect to have with the demographic stabilisation that will come in no more than fifty years, and how the thing will be solved, all these problems you are putting together now. And I would say that when you talk to young people and use a phrase of Dr. de Duve, 'your future is in your hands', I would say to young people, our future is in your hands. I would like to know what you think about this, what will happen with demografic stabilisation.

COLOMBO: I think that I underlined a disequilibrium. In demographic stabilisation there is a sort of equilibrium, and this will not be true in fifty years: in ten years or so there will be an almost stabilised situation. Certainly we wrongly mix the case of China, with its compulsory one-child family, with the cases of other countries which still have a high rate of increase. But I think the situation in Italy has not yet stabilised. In the future the population will stabilise.

PAVAN: Yes: but do you think that the problem will be solved by education of people or by medicine or other factors?

COLOMBO: I certainly think it is a problem of education, of personal education, of how to deal with their own problems.

PAVAN: Then we have to do a lot to achieve that.

COLOMBO: I think so.

RAO: I am glad that you ended up with education. I just want to bring some balance to this by referring to what is happening in most of the developing countries. In most developing countries, including India, the population is increasing among the very poor people. In fact, the poorest of the poor have very large families – they cannot afford that. Most of the children have to work to maintain the family. It is the rich, the educated, who have family planning, who have one or two children. So thus begins another imbalance, economic and otherwise. There are countries that find it difficult to maintain and support such people. At the same time, education is very important for the disadvantaged. It is a very serious problem in developing countries.

COLOMBO: May I give an answer? I quote what Professor Mahalanobis said, he was a top statistician, an Indian. He said: 'If you want to lower fertility in India you have to foster improvements in agriculture', probably because he thought that rationalisation in one important aspect of life, labour, could be transferred to rationalisation in another important aspect, procreation. It is a problem of education.

IACCARINO: Yes, only a question of terminology. You used the term 'fertility', whereas in other circles, such as UN circles, they use the term 'birthrate'. Did you use the term 'fertility' intentionally? Is it common among demographers?

COLOMBO: The word 'fecundity' is common among Italian demographers. It is translated from the French, not fertility. I changed the word to avoid boredom, but it is the same thing.

FROM WORLD VIEWS TO SCIENCE AND BACK

STANLEY L. JAKI

There are world views from which it is not possible to go to science. Such a world view is the one in which the many bubbles on the perspiring body of Brahma represent so many worlds that pop up randomly and in an infinite number through infinite space and time. I would not, however, be surprised if some scientists would take this world view for an anticipation of the multiverse theory, which in recent years has received the attention of leading newspapers. The latest case is the Tuesday, October 29, 2002 issue of *The New York Times,* where the headline of the Science Section declares: 'A New View of Our Universe: Only One of Many'. My reason for not being surprised is that the millions of years of world cycles as set forth in the Vedantas have repeatedly been taken as an anticipation of the vast phases of cosmic processes implied either in the Big Bang or in a cyclic cosmological model, such as that of an oscillating universe.

The article quoted many prominent astronomers in support of that idea of an infinite number of universes, but none of them cared to recall what Eddington succinctly stated in 1935: 'That queer quantity "infinity" is the very mischief, and no rational physicist should have anything to do with it'.[1] This statement is valid regardless of whether it comes from a great scientist or not. Infinity cannot be measured. Its introduction into science has always meant catastrophes. Unfortunately, a hundred years after Planck's great feat in 1900, its true significance is still to sink into broader scientific consciousness. With his feat Planck undermined the notion of physical infinity, although Planck himself failed to realize this, when he applied

[1] A.S. Eddington, *New Pathways in Science* (Cambridge: Cambridge University Press, 1935), p. 217.

finite series to account for the shape of black body radiation.[2] For as long as one tries to explain that shape with infinitesimal calculus, and not with the summation of discreet entities, there looms large what is called the infinity catastrophe in the ultraviolet region of black body radiation.

Another ancient world view from which it was impossible to advance to science was the combination of Confucian and Taoist world views. Joseph Needham of Cambridge offered a hollow rhetoric when he claimed that in ancient China the Taoists tried to move from a view of the world represented by a human body, to what Needham called the suppleness of the world lines of General Relativity.[3] Lately one of the most prominent experts of American constitutional law claimed that General Relativity justifies a supple interpretation of the laws, and indeed of any law. In plain language he meant to say, that one can twist and turn the law, provided one does it with sophistication. Such is the case whenever a non-scientist wraps his claims in profuse references to science, about which most in his audience know next to nothing. The legal expert was Laurence Tribe, professor at Harvard, who got a BS degree in physics before he entered Law School.[4] But I wonder whether a mere bachelor's degree in physics makes one an expert in General Relativity, which, incidentally, is the most rigid physical theory ever proposed. As Einstein himself warned, if only one of its predictions were to be contradicted by experiment, the whole theory would have to be abandoned.[5] In fact, any good physical theory is subject to this fate. Newton himself warned that if the orbits of the planets were not found to be re-entrant, his physics should be entirely recast. So much for some ancient world views that imply infinity or endless cycles for the universe.

Still another ancient world view, from which there was no advancing to science, was that of the ancient Egyptians. They viewed the world as the

[2] See my essay, 'Numbers Decide: or Planck's Constant and Some Constants of Philosophy', in J. Gonzalo (ed.), *Planck's Constant 1900-2000: An Academic Session at UAM, April 11, 2000* (Madrid. UEA Ediciones, 2000), pp. 108-134.

[3] In his *Science and Civilization in Ancient China* (Cambridge: University Press, 1954-), vol. II, pp. 146-51 and 425-29.

[4] See my article, 'Patterns versus Principles: The Pseudo-scientific Roots of Law's Debacle', *Notre Dame Law Review* (Fall 1993), pp. 135-57. Reprinted in my *Patterns or Principles and Other Essays* (Bryn Mawr MD: Intercollegiate Studies Institute, 1995), pp. 1-25.

[5] Einstein stated this in a public lecture he gave in Prague in 1920. See H. Steuwert (ed.), *Historical and Philosophical Perspectives of Science* (Minneapolis: University of Minnesota Press, 1970), p. 9.

combination of a horizontal male body, that of the deity Geb, which represents the earth, and, overarching it, the female body of the deity Nut, which represents the sky. A splendid picture of this is in the burial chambers of Rameses VI in the Valley of Kings. In this view the world is taken for a huge, all encompassing organism, a view dominating all ancient cultures and responsible in all of them for the invariable stillbirths of science. Stillbirths, because promising starts led to nowhere.[6] Such starts were, for instance, the marvelous technological feats of the Egyptians of old in technology. But they could not generalize plain arithmetic skills into general propositions.

Strange as this may seem, even the ancient Greeks are an illustration of this pattern of stillborn science. Ptolemaic astronomy, their scientifically best world, was not a world view at all. Apart from some phrases in its introduction, the *Almagest* of Ptolemy is a sheer geometrical formalism, which tells us nothing about the physical nature of the celestial sphere, of the stars and the planets, not even of the moon and of the earth, let alone of the force which moves all of them. There is some world view in Ptolemy's *Hypotyposes*, where he presents the planets as living beings, as a group of well drilled dancers or soldiers. As such, so Ptolemy claims, the planets do not bump into one another in going through their intricate paths. Neither Ptolemy, nor anyone in Late Antiquity or even later tried to go from the fantasies of the *Hypotyposes*, let alone from the astrological vagaries of Ptolemy's *Tetrabiblos*, to the science of the *Almagest*, a science of sheer geometrical formalism, which tells us nothing about the nature of the physical world.

The world view of the *Hypotyposes* harked back to the organismic world view which, after it had been proposed by Socrates in the *Phaedo*, reappeared briefly in the third part of Plato's *Timaeus*. The full working out of that world view, in which the world, at least in its sublunary part, is a huge digestive living organism, had to wait for Aristotle, who provided it in his *De Coelo* and *Meteorologica*. Within that world view everything under the moon's orb moves to achieve what is best for it, and the larger the mass or nature of a given body, the greater desire it has to move towards its natural place. From this it would follow that a mass a hundred times larger than another, would fall a hundred times faster and would reach the ground from the same height in a hundred times shorter time.

[6] For a detailed exposition of this view, see my *Science and Creation: From Eternal Cycles to an Oscillating Universe* (Edinburgh: Scottish Academic Press, 1974), chs. 1-6, that deal with six great ancient cultures.

Aristotle or the Aristotelians never drew that conclusion, for a reason which cannot really be fathomed. Perhaps it was an intellectual torpor on their part, or perhaps they recoiled from facing an obvious fallacy, which anyone could have exposed by standing on a chair, or on the edge of a roof. In all late Antiquity only Joannes Philoponus spoke up against the nonsensical nature of that Aristotelian law, but without referring to any experiment or citing any quantitative data.

Socrates chose that animistic view of the universe in reaction to the mechanistic world view of the Ionian *physikoi*. He read about that world view in a book to which Anaxagoras gave the title *On the Mind*. On reading it, Socrates first found that a mechanistic view seemed to explain everything, including the mind. But on reflection Socrates also found that it did not explain why beings such as humans, who had a mind, acted for a purpose, or for something which they thought was the best for them. Surely, Socrates argued, the mechanistic view did not explain why he had chosen not to accept the scheme of his friends, who bought off the jailkeeper so that Socrates might escape the hemlock waiting for him, although his limbs would have undoubtedly chosen to flee from prison.

Galileo did not face up to these questions as he tried to demolish the Aristotelian world view. Nor could he do so in terms of his own world view, a combination of Platonism and atomism. From Platonism Galileo developed the absurd idea that man's knowledge of quantities was as perfect as God's notion of them. From atomism he derived the view that secondary qualities such as taste and colors were mere subjective experiences and therefore not real.

It is not easy to trace the steps whereby the younger Galileo moved from the Aristotelian ideas of motion and mass toward a strictly geometrical formalism. Most likely he was at one point swayed by the power of numbers and geometrical figures in interpreting physical phenomena. The power itself has two aspects. One is the quantitative exactness, which only numbers have, the other is their full applicability wherever there are physical bodies.

Strangely, Galileo nowhere refers to the passage in the Book of Wisdom, according to which 'God disposed everything according to measure, number, and weight'. About that passage, E. Curtius, a Protestant historian of Medieval literature, stated half a century ago that it was the most often quoted biblical passage in that literature.[7] The passage may show Platonic

[7] E.R. Curtius, *European Literature and the Latin Middle Ages*, translated from the German by W.R. Trask (London: Routledge and Kegan Paul, 1953), p. 504.

influences as that Book was composed in Alexandria about 150 BC. But as the Book of Wisdom has always been part of the Catholic Canon of inspired books, Catholics like Galileo surely had to take it seriously. To what extent they did is another matter.

And this leads to that world view, which alone of all ancient world views came into a major interplay, indeed a conflict, with science. I mean the biblical world view. Within that view the world is merely a huge bedouin tent, with a floor, the earth, and a roof, the firmament. The sun, the moon, and the stars are mere decorations on that roof, the firmament, and the earth is a dish floating on waters which had no contours. Science could show no mercy to that world view.

There are quite a few who gloat over the primitiveness of the biblical world view. The late Fred Hoyle used to dismiss that view as 'the merest daub' compared with the world view of modern science.[8] Well, that world view was not even a daub when compared with the spherical world view of the Greeks.

Hoyle, who died a few years ago, should have known something about our modern scientific world view, but apparently he did not want to recognize it. He held that life on earth originated from spores that were carried from some other parts of our galaxy to the earth. He should have known that our galaxy is for the most part terribly hostile to life and therefore hardly any of those spores could have survived even a part of that long journey. The book *Rare Earth*, published two years ago by Peter Ward and Donald Brownlee, both members of the National Academy of Science, is a massive presentation of the evidence that there is little scientific ground to speculate about life, let alone intellectual life, as popping up everywhere in our galaxy. Even weaker, if possible, are the chances for life in galaxies which, unlike our galaxy, a perfect spiral, have very irregular shapes.

The world view within which life and intelligent life are ubiquitous in the universe has always been a dream, even though dressed up in science. And as it has been presented as science, it was demolished by science again and again.[9] The interesting thing is that the latest phase in that demolition has been overlooked for decades, as no attention was paid to warnings less massive than that large book, about the inevitability of that demolition. But some people in science never give up, as they promote their philosophical

[8] F. Hoyle, *The Nature of the Universe* (New York: Harper and Brothers, 1950), p. 138.

[9] See A.O. Lovejoy, *The Great Chain of Being: A Study of the History of an Idea* (1936; New York: Harper Torchbooks, 1960).

or ideological world views with profuse references to science. The protagonists of SETI (Search for Extraterrestrial Intelligence), who took part in our Plenary Meeting two years ago, have now begun to look for life which is not carbon based. Not only can they give no specifics about such a life, but they have recently hired an 'exotheologian'.[10] About a hundred and fifty years ago Moleschott and Vogt speculated about intelligent life based on phosphorus, but they stopped when it was found that the brains of geese were very rich in phosphorus. As is well known, in not a few languages geese are the epitome of stupidity. Ironically, the atomic number, 14, of silicon is just one less than that of phosphorus.

So much for the more general parts of the enterprise which is to go from world views to science. There are some specific and more profound parts as well. Profound because they are philosophical, although in some other sense very elementary. About half a century ago Karl Popper made popular a by then very old truth, that all science is cosmology.[11] This at least means that any decent scientific theory must lay a claim to universal validity, and no branch of science can be more universal in its intent than cosmology.

Cosmology, scientific or other, begins with a view of the cosmos or the world, or to use the felicitous German word, with a *Weltanschauung*. Now to have a world we must have things, unless one is a radical Platonist or a solipsist, or an advocate of an extreme form of the Copenhagen interpretation of quantum mechanics. According to that interpretation, one's mere thought is influencing one's observation, and indeed creates things, and indeed universes. These brave thinkers have still to explain why one's mere thought of a hundred dollar bill, or a bill of a hundred euros, does not produce one such entity. Tellingly those brave theorists have not yet approached with their ideas the World Bank, which certainly needs plenty of money.

All knowledge of a thing begins with the registering of its existence. Things are objects whose purpose is to object to the mind. Any philosophical or scientific system which begins with ideas instead of things puts the cart before the horse. This is so because only by means of things can ideas be conveyed to others.[12] This registering largely happens through siz-

[10] See D. Overbye, 'When it's Not Enough to Say "Take Me to Your Leader"', *The New York Times*, March 2, 2002, p. F1.

[11] K.R. Popper, *The Logic of Scientific Discovery* (1959; New York: Harper Torchbooks, 1968), p. 15.

[12] A basic theme and recurring argument in my *Means to Message: A Treatise on Truth* (Grand Rapids. MI: W.B. Eerdmans, 1999).

ing up the quantitative dimensions of a thing. Some people may be repelled by the fact that Aristotle had already pointed this out in his *Categories* (6b), but a truth may still be a truth even though proposed more than two thousand years ago. At any rate, in the same context Aristotle also stated that there is one category of words, those belonging to the category of quantities, about which the phrase 'more or less' cannot be predicated. These words are numbers. The number six cannot be more or less six. Numbers are rigid entities and they demand a rigid accounting.

This was the reason why the biblical world view came into conflict with science and was demolished by it. The point failed to be appraised in its true significance by Bellarmine, the most insightful defender of that view against Galileo. Insightful because Bellarmine hedged his bet by referring to the possibility of an eventual demonstration of the earth's motion. Two hundred and fifty years later Newman rallied to Bellarmine's defense when he wrote, in 1877, a new and very long introduction to a re-edition of a book of his he had first published as an Anglican concerning the interpretation of the Bible.[13] Believing as he did that the Bible stood for a divine revelation of utmost importance for man's ultimate purpose, Newman argued that the Church, or rather the Holy Office, was right in urging Galileo to hold his guns until he had convincing arguments that the earth did indeed move. As is well known the first such convincing argument came only two hundred years after Galileo. But, I am afraid to say, Newman, a great student of logic and of Aristotle's *Categories*, failed to consider a point, although Saint Augustine had already considered it.

Augustine readily conceded that, contrary to the biblical view of a flat earth, science had conclusively shown that the earth was spherical.[14] Augustine merely failed to say in some detail that what science showed about the earth was a set of measurements which are always quantitative. But Augustine made at least the general statement that if the human intellect established something convincingly about the physical world, the contrary statements of the Bible must be reinterpreted. There could only be one truth, Augustine argued, as long as God was one, and man was made in the image of God. But then Augustine came to the firmament, whose

[13] J.H. Newman, *The Via Media of the Anglican Church* (London: Longmans, Green and Co., 1897), vol. 1, p. lvi.

[14] He did so in his *De Genesi ad litteram* on which he worked for almost two decades. For a discussion, see my *Genesis 1 through the Ages* (2d rev. ed.; Royal Oak, Mich.: Real View Books, 1998), pp. 85-86.

existence, so he felt, the Bible stated emphatically. He also seemed to know that there were, even in Ptolemaic astronomy, serious reasons against supposing that the sky was a solid roof, a firmament. Still he felt that the Bible was to be vindicated about the firmament, and so he looked for a firmament. He claimed to have found it in the path of Saturn. From Ptolemaic astrology, that is from the *Tetrabiblos*, Augustine took Saturn for a cold body, which as such, he reasoned, had to produce a vapory layer in its wake. This vapory layer Augustine called the firmament.

Now Bellarmine and all the learned theologians he consulted, must have fully known of the futility of such an explanation. By its very futility it should have reminded them that great perils were in store if one took a stance on behalf of a proposition, say the immobility of the earth, which lent itself to quantitative determination. For against such a determination no authority, divine or human, could be invoked.

All this should make it clear that the quantitative determinations of science have a decisive impact on the validity of any world view. But the reverse of this is also true. Quantitative determinations have no say about anything except the quantitative aspects of things, let alone about realities that go beyond things, such as questions of free will, purpose, and the registering of existence itself. The meaning of the verb *is* cannot be evaluated in terms of grams, or centimeters, of fluid ounces.

It became a fashion to think that quantum mechanics justified speaking of free will. Eddington was one of the few, who within a year realized that the fashion was 'a plain nonsense'.[15] Just as pervasive has been the misconception that Darwinian evolution disposed of purpose. Well, if evolution is a purposeless process, why does it issue in beings, humans, who consciously can do nothing except for some purpose? And why is it that some evolutionists devote their whole life to the purpose of proving that there is no purpose?[16] Of course, those who claim that God created every species and for a purpose, must show that such is indeed what the Bible states.

As they take the phrase of Genesis 1, that God created all plants and animals 'according to their kind', to mean that He produced each kind with a special creation, they seem to forget that what is good for the gan-

[15] See A.S. Eddington, *The Philosophy of Physical Science* (London: Macmillan, 1939), p. 128, for his repudiation of what he had stated in his *The New Pathways of Science* (Cambridge: University Press, 1935), p. 88.

[16] He did so in his Vanuxem Lectures, *The Function of Reason* (Princeton: Princeton University Press, 1929), p. 12.

der is also good for the goose. If one takes one phrase of Genesis 1 for science, then all its other phrases can and should be taken for science. Then one comes up against the firmament, against light coming before the sun, against the sun's coming at the same time as the moon and the stars, and against the coming of the plants before sunlight is on hand. There is plenty of good reason to assume that God did not want to land man in a series of patent absurdities.

The consideration of these points should be a powerful motivation for looking at Genesis 1 not so much as a revealed world view, but rather as a view that merely illustrates some moral lesson along the Bible's typical line. The lesson is conveyed in the form of a parable about the importance of observing the sabbath rest. The author of that chapter presents God as a role model for doing within six days a work, the making of *all*, a point which remains valid regardless of whether one proposes that *all* in terms of a cosmic bedouin tent or in terms of Copernican, Newtonian, or Einsteinian cosmology.[17]

So much about the coming from world views to science and from the merciless impact of science on them. What has been said should make it clear that science is particularly effective in demolishing world views. And this was a conspicuous feature of science as it came into its own, mostly through the work of Newton. Now something about the other question or whether it is possible to go from science to the world view which lay in the mind of the scientist as he began his scientific work.

Let us take Newton. He certainly did not begin with a mechanistic world view, let alone with a mechanistic philosophy. There is nothing of that philosophy in the third book of the *Principia*, which is about the 'System of the World', that is, of the system of planets. Newton does not say in the *Principia*, or elsewhere, that the system in question is a clockwork. Twenty or so years later, when he began to increase the number of Queries attached to his *Opticks*, Newton spoke of various fluids, some of them quasi-spiritual effluvia, that may explain electrical attraction and repulsion. He never tried to give a mechanistic explanation of gravitation. The first such effort, in terms of differential pressure, came twenty years after Newton, through the speculations of George Le Sage.[18] In sum, there is nothing in Newton to support what later became celebrated as a mechanistic philosophy, and was presented as Newton's thought and as demon-

[17] See my *Genesis 1 through the Ages*, pp. 274-79.
[18] See my *The Relevance of Physics* (Chicago: University of Chicago Press, 1966), p. 77.

strated by Newton. This philosophy was largely the work of such amateurs in physics as Voltaire and others. Newton's world view or philosophy had always been a strange mixture in which, in its early phase at least, the ideas of the Cambridge Neoplatonists were prominent. But one would try to do the impossible if one were to reconstruct Cambridge Neoplatonism from the *Principia*, or even from the *Opticks*, or reconstruct any consistent philosophy or world view from any or both of those works. The best parts of the *Opticks* were experimental and mathematical, and almost entirely mathematical was the *Principia*. This is why Newton called it *Philosophiae naturalis principia mathematica*, so that it may be distinguished from Descartes' *Principes de la philosophie*, which was a heap of bad philosophy to support an even worse Cartesian science.[19]

It can never be pondered long and hard enough that the title of the *Principia* was a misnomer. There was no philosophy, no epistemology, no metaphysics in the *Principia*. There was not even nature, and certainly not the kind of nature which, as a living entity, is born, grows, dies, and experiences a rebirth, if it does at all. Had Faraday known more than elementary algebra, he could have found this out by reading the *Principia*, which he never read, and could have also found out that his philosophy of nature, full of vitalism, was a far cry from Newtonianism. But for all his vitalism, Faraday longed for mechanical models, and begged Maxwell to give him such models, which Maxwell found more and more improper to do, because he himself had to give up mechanical models as he developed his electromagnetic theory. Yet he stuck with his chief mechanical model, the ether. He calculated the resistivity of the ether, its coefficient of tension and the like. All those numerical data are in the article he wrote on the ether for the ninth edition of the Encyclopedia Britannica.

Such were some of the presuppositions of Heinrich Hertz, when after demonstrating the existence of electromagnetic waves, he decided to find out *what*, please note the word *what*, electromagnetism was. He did not ask *how* electromagnetism worked. He wanted to know what it was. And after years of reflection he felt he had no choice but to write: 'Maxwell's theory is Maxwell's system of equations'.[20] This meant that to take just the case of Maxwell, it was not possible to go from Maxwell's equations, to Maxwell's world view of physical reality, which was very mechanical, let alone to his

[19] See ch. 2, 'The Spell of Vortices', in my *Planets and Planetarians: A History of Theories of the Origin of Planetary Systems* (New York: J. Wiley, 1978).

[20] H. Hertz, *Electric Waves*, tr. D.E. Jones (London: Macmillan, 1893), p. 21.

much broader world view, which was quite spiritual in the supernatural sense. Yet, if Maxwell had not been a devoutly believing Christian, but a materialist or a Comtean positivist, it would have been just as impossible to work one's way from Maxwell's electromagnetic theory to any materialistic or positivistic world view, or *Weltanschauung*.

Positivism can, of course, be of two very different kinds. One is better known, the other is hardly known. And here I consider positivism only insofar as was it professed by prominent physicists, and only with respect to their science. Kirchhoff was a positivist physicist who claimed that only the positive data of physics constituted valid knowledge. And to his credit, he spoke of nothing else, at least in science. Of course, as a cavalry officer in the Franco-Prussian war, he had to admit that there was valid knowledge even outside science. Certainly in Kirchoff's collected works one would look in vain for Nature, for philosophy, for a world view. Quite different was the case in the positivism of Oswald and of Mach. They built a general sensationist philosophy on their positivist concept of science. To speak only of Mach, he finally espoused Buddhism as the only philosophy in tune with science.[21]

There was at that time only one notable physicist who, while strictly positivist in his science, warned against drawing metaphysical and/or countermetaphysical conclusions from science. He was Pierre Duhem, the founder of chemical thermodynamics.[22] But for the most part his warnings were almost completely ignored or even misconstrued. His book, *La théorie physique, son objet et sa structure*, or its English translation, *The Aim and Structure of Physical Theory*, is still the most penetrating study on this problem. But he also warned that nothing in physics, however effective, can be used against reasoning in that much wider field which is nowadays called the humanities. These, including philosophy, must stand on their own ground, or they become games in sheer equivocations. In that case they prove totally ineffective in coping with extravagant claims coming from the scientific side, such as the grand conclusion of Heisenberg's paper of March 1927, in which he first presented what he called the principle of indeterminism. In the conclusion of his paper he stated that because all experiments are subject to the laws of quantum

[21] See my *The Road of Science and the Ways to God* (Chicago: University of Chicago Press, 1978), pp.159-60.

[22] For details, see my *Uneasy Genius: The Life and Work of Pierre Duhem* (Dordrecht; Martinus Nijhoff, 1984).

mechanics and therefore to its uncertainty relation, which he had just derived, 'invalidity of the law of causality is definitively established (die Ungültigkeit des Kausalgesetzes [ist] definitiv festgestellt'). Few are aware of the fact that by then Heisenberg had rejected causality on entirely different grounds. He did so as a spirited supporter of the romantic ideology of the Jugendbewegung.[23] Should we therefore try to reconstruct that romanticism from the principle of indeterminacy? Should we see any rhyme and reason in expressions, such as 'passion-at-a-distance', of which more and more appear in writings about arcane interactions among fundamental particles?

Heisenberg would have been entitled only to conclude that as long as one used Planck's quantum and a non-commutative algebra, one had to conclude that it was not possible to make fully accurate measurements of physical interactions implying conjugate variables. He could not even prove that fully accurate measurements were absolutely impossible. And he certainly did not prove that the principle of causality did not exist. For even if causality was reduced to mechanistic causality, there was more to it than the idea of fully accurate measurements. And when causality was taken in its ontological sense, in relation to being and not being, then Heisenberg's conclusion amounted to a plain irresponsibility.

One could quote a number of prominent twentieth-century physicists who recognized that science in its most exact form was a mere set of calculations. Such a physicist was Feynman. Another was, and this may surprise many, Niels Bohr, the father, with Heisenberg, of the Copenhagen interpretation of quantum theory. All quantum physics, Bohr said, is a set of rules and nothing more.[24] In other words, insofar as quantum mechanics is science, it is not a world view, a philosophy of nature. And if quantum mechanics is turned into a world view, the sole support for this lies in the philosophy of the physicist who performs that turnover. The performance is all too often very shabby, in proof of a famous dictum of Einstein: 'The man of science is a poor philosopher'.[25] This does not mean that the scien-

[23] As well documented in P. Forman, 'Weimar Culture, Causality and Quantum Theory 1918-1927. Adaptation by German Physicists and Mathematicians to Hostile Intellectual Environment', *Historical Studies in Physical Science*, 3 (1971), pp. 1-115.

[24] N. Bohr, *Atomic Theory and the Description of Nature* (Cambridge: Cambridge University Press, 1934), p. 60.

[25] A. Einstein, 'Physics and Reality' (1936), in *Out of My Later Years* (New York: Philosophical Library, 1950), p. 59.

tist cannot be a very good philosopher, but if he is, the grounds for this must be philosophical.

Einstein was surely a poor philosopher when in the name of his science he denied the existence of free will.[26] It did not even dawn on him that unless his denial of free will was done freely, it could not constitute an argument. Nor did he, who spoke so much of human responsibility, realize the measure of his responsibility in that particular case. He denied free will in reply to a student who turned to him, as the greatest authority on earth, for advice on whether to believe in free will or not. Einstein failed to ponder that he constructed freely a four-dimensional cosmological manifold from which he could proceed only to the notion of a physical world in which there was no randomness, but no room either for any free act, including that of writing a letter.

So much for the hazards inherent in discussions of the cultural values of science as such values cannot make sense without a world view. A chief of such hazards is to run the risk of saying something equivalent to what Bohr once said, though in great confidence: 'One day the principle of complementarity will be taught as the only true religion'.[27] Anyone sharing that view has to explain how such religion can do what that word means to do as an act of *re-ligare*, or re-tie. But to what or to whom?

Philosophers can say even more startling things than some physicists. They seem to forget that when they say something which is about things and not about mere ideas, they all too often say something which is measurable. Then the scientist barges in, and rightly so. Hegel tried to escape this prospect by claiming that qualities control quantities. In reverse, this also meant – and both the Hegelian right and the Hegelian left kept saying this – that if one piles quantities upon quantities one ends up with qualities. In both cases the results for science were disastrous, to say nothing of other cultural disasters.

Contrary to Hegel, quantities remain in their splendid conceptual isolation. To a human mind which aims so desperately at a synthesis, this status of quantities may be a painful fact to consider. It may be a tiresome prospect to play always with two balls at the same time. In a higher world,

[26] Letter of April 11, 1946, to O. Juliusburger, in *Albert Einstein: The Human Side: New Glimpses from his Archives*, ed. H. Dukas and B. Hoffman (Princeton: Princeton University Press, 1979), p. 81.

[27] See *Niels Bohr: A Centenary Volume*, ed. A.P. French and P.J. Kennedy (Harvard University Press, 1985), p. 323.

such as the world of angels, let alone of God, it will be different. But here below, there is no way of reducing quantities to qualities and qualities to quantities. They form two sides of a coin, which cannot exist without having two sides. They form one reality, but the two sides cannot be integrated into one another if this means the fusing of the two into one. This is just another application of the memorable dictum about the tax coin.

Those for whom that dictum smacks of the supernatural world, may do well to ponder something about the natural world, in its totality, which is the universe. The universe is the greatest idea next to the idea of God, so Newman said in his *Idea of a University*,[28] easily the finest book ever written on higher education. I wish he had spoken not of idea but of reality, and in the interest of science. Science surely works with ideas, including the idea of the world, the universe, but the truth of any scientific conclusion must rest with empirical operation on the physically real. Now there is no scientific method that could assure an experimental, or observational proof of the physical universe, because there is no way of getting outside the universe in order to observe it. To have a rational certainty about the reality of the universe as the totality of consistently interacting things, one has to rely on a set of reasonings that are partly physical, partly metaphysical. I tried to work out that reasoning in my Liverpool University Lectures, under the title: *Is There a Universe?* In sum, one is driven back on the purely natural level too, to the image of a coin with two sides to it. Whereas the two sides are indispensable to one another, neither can be reduced to the other. Herein lies the source of all problems of any effort to go from world views to science and back and ascertain the cultural values of science.

On a much lower level it is the problem of a fish caught in a net which consists of ever smaller loops. Once the fish boldly swims into that net at its broad end, the farther it swims toward the narrow end, the less chance it has to retrace its steps to freedom. Let the wide left end of the net represent world views taken in a broad sense. The small right end of the net represents science in its quantitative exactness as well as narrowness. Just as the fish cannot move from the narrow end of the net back to the wide end, so it is with the man who goes from a world view to science and then in vain tries to retrace his track to that world view.

There is, however, a big difference. Although he must start with a world view, at the narrow end he can find science, but he cannot find there the

[28] J.H. Newman, *The Idea of a University* (8th ed.; London: Longmans, Green and Co., 1888), p. 462.

world or the universe. He finds at that narrow end only a set of quantities void of views taken in a broader sense. This is to be kept in mind in any discourse about the cultural values of science. In science there are no values in any cultural and ethical sense. Einstein himself recognized something of this when he said that he had not succeeded in deriving a drop of ethical value from his science.[29] There is no way of escaping the difference between quantities and qualities, or science and the humanities. They can come into conflict only when humanists state something which is quantitatively verifiable, and when scientists make statements that can have no quantitative verification. This conflict will fail to give uneasiness only to those who, while on this earth, try to play the angel.

[29] In an interview with P. Michelmore, *Einstein, Profile of the Man* (New York: Dodd. 1962), p. 251.

DISCUSSION ON THE PAPER BY JAKI

ZICHICHI: You've given a complete review of what mankind has thought from the beginning of civilisation up to now. Let me make a few comments. If we project into the real world all human thought before Galilei, the number of ideas that you've mentioned have zero projection on the real world. In other words, what was thought to be correct for ten thousand years about the logic of the world was all wrong. For example, you mentioned the atomic ideas of the Greeks. The basic atomic idea of Democritus has been proved by us to be incorrect for the following reason: up to 1975 it was imagined that if an object has a structure it must be broken, and this has been going on since the birth of civilisation up to 1975 when it was proved that the proton you and me are made of, and everything is made of protons, does not break, in spite of the fact that it has an innumerable number of objects (quarks, gluons, real and virtual) inside. Why? Because the forces acting inside the proton – no one had ever imagined this – are non-Abelian forces. This, in the history of human thought, had never been realised, and it's just an example of the projection of thought into the real world. You cited Maxwell, and Faraday who preceded Maxwell, and Einstein, but you did not cite Lorentz. The greatest conceptual consequence of the Maxwell equation is the complexity of space and time. As I mentioned yesterday, if space is real, time has to be imaginary and vice versa. This has tremendous consequences, which had never been imagined by any human being in the history of thinking. From this we are now at the point of formulating the theoretical structure of the super-world using mathematics. In other words, after Euclid we thought that space had three dimensions, three for space and one for time: total four. We are now convinced, following the development of science and therefore of the real world, that we have 43 dimensions, and this had never been imagined by anyone. So, I would like to convince you that progress in scientific thought started drastically with Galilei not because Galilei was thinking: 'This is how I imagine the world', but because he imparted to us the lesson that if you want to know the logic of nature you must perform experiments and interpret them in a rigorous mathematical form. This is how in four hundred years we could demonstrate that previous ideas were all wrong.

JAKI: First of all about the atomists, I did not talk about them at any length, but I never thought that the ancient atomists had anticipated modern atomic physics, partly because it radically differs from Democritus who claimed that atoms of all sizes must exist, even atoms of infinite size. You find this in Diels' *Pre-Socratic Fragments*. The other thing: you yourself said that with regard to space and time, first of all, long before Lorentz, Lobacevski, Gauss and Boyarin spoke of a four-dimensional manifold. You yourself said that whatever you think after that epoch-making discovery, of which man did not have thought before, you have to express it in mathematics, so you are saying exactly what I am saying. Ultimately it boils down to quantities, and that from quantities you do not get anything else, and this was your major dispute yesterday, the essence of your major dispute with Professor De Duve who spoke endlessly about philosophy, about purpose and some somersault in logic, namely chance that doesn't exhume to exclude inevitability: in Princeton any sophomore would be thrown out from the logic class if he came up with this idea. So, ultimately we have to live with quantities and with everything else, and this is the problem: we have to play with two balls all the time, and man is unwilling to live with this condition, man always wants to synthesise and to reduce everything to one single dimension, and this is the curse of reductionism, whether you call it scientific reductionism or any other kind of reductionism. It is a world view, a reductionist world view.

SHEA: Stanley, I want to thank you very much for demonstrating that wild speculation can be very stimulating. I'll make a very brief comment and ask a precise question. From the vantage point of an historian of science, one has to confess that the ideas that were thrown out were subsequently very influential, even if they were not modern science. The Atomists, for instance, deeply influenced Newton and his thinking, and Dalton also. Copernicus found the idea of the centrality of the sun in Hermes Trismegistus, so we cannot exclude that wild conjectures can be useful. This is my comment. My question is, since you insisted on the centrality of the notion of creation as being very important, could you say a few words about that precise point?

JAKI: Concerning your first comment, for which you did not ask a question, but I want to say something about it by way of a comment. All those wild ideas could be useful or utterly useless until somehow the core of those ideas was put in quantitative terms. Now, the second thing is this: the idea of creation. I have already lambasted the modern abuse of the word 'creation'. Too bad I did not bring here some clippings from *The New York Times* in which a most prominent cosmologist at MIT, Professor Guth and many others, claims that modern quantum cosmology enables him to create entire universes at least in theory, and he also said that for all we know our actual universe may have been created in a basement laboratory in another galaxy. Now, the only illuminating part of this statement is that he referred to a basement laboratory, which are usually very dark places.

Now, the idea of creation is absolutely fundamental because it allows us, assures us, that we must do *a posteriori* research. We cannot approach things on an *a priori* basis, and apriorism has been throughout the whole history of science the curse of the scientific enterprise. And also, that only in the Christian or Biblical or Catholic theological traditions you find this notion of the Creator who when He creates doesn't diminish. In all other forms of philosophic and religious traditions the first principle diminishes by producing something else out of itself. You see it in Plotinus and elsewhere, or in Spinoza. And if in this post-Christian or de-Christianising world we Christians or Catholics do not appreciate profoundly the importance of this greatest contribution of ours to world culture, then we can only blame ourselves.

SINGER: Thank you, Professor Jaki. I think we have reached our time, and it will remain difficult to know whether concepts precede theory or beliefs precede concepts or vice versa.

‘MUCH MORE IS REQUIRED’[1] SCIENCE EDUCATION IN THE 21st CENTURY: A CHALLENGE

PIERRE J. LÉNA

Introduction

Observing the many themes of Workshops or Sessions held over the last decades by the Pontifical Academy of Sciences, it is striking that none of them had directly dealt with *education* as a main title. This preoccupation was nevertheless present, especially in recent years and at the 2000 Jubilee Plenary Session, as shown in the vigorous summary of the 2000 Budapest *World Conference on Science* given by Werner Arber or the plea for responsibility given by André Blanc-Lapierre. With great foresight Ahmed Zewail, writing on the ‘*New world dis-order*’, and Paul Germain underlined the importance of *education in science* as a fundamental need of modern societies to achieve peace, justice and a sustainable development. In fact, the urgency to deal with this subject around the world has recently been demonstrated by an unprecedented number of Conferences,[2] which were called by

[1] John Paul II, *in* Letter to the Director of the Vatican Observatory, 1.6.1988.

[2] *World Conference on Science*, ICSU/UNESCO, Budapest 2000; *Transition of Sustainability in the 21st Century*, IAP, Tokyo 2000; *International Conference on Research Related to Science Education*, Monterrey, US-Mexico Foundation for Science, Monterrey 2001; ICSU/CCBS *Conference on Primary School Education on Mathematics and Natural Sciences*, Beijing 2001; ICSU/CCBS-IAP *Regional Conference on Science Education*, Kuala Lumpur 2001; *Science Education in the 21st Century: a Challenge*, Pontifical Academy of Sciences, Vatican City 2001; *Science Education*, Chilean Academy of Sciences, Santiago 2002; Regional ICSU (CCBS)/IAP *Conference on Science Education*, Rio de Janeiro 2002; *The Generation of Experimental Material & Learning Modules for Science Education,* IAP & Indian Academy of Sciences, New Delhi 2002.

Science Academies (*InterAcademy Panel* IAP or national Academies) or scientific bodies (mainly ICSU, through its *Committee for Capacity Building*). Education, not only of the future scientists but of all the children, has become a subject of intense attention from a number of prominent scientists and institutions: this is certainly a new development, where the creators and actors of science feel responsible to share it on a broad scale. Why is this concern emerging now? Is it only a lobby action of scientists, worried by the disinterest for science shown by students in developed countries? Or does it correspond to a deeper sense of urgency and justice?

It is quite obvious that the pace of development of the scientific and technological body of knowledge, its complexity, the *tour d'ivoire* in which many scientists live have left behind most of the inhabitants of the Earth, even those whose intellectual performances or cultural background would qualify for understanding what happens. To make things worse, the classical way by which the advances in knowledge used to percolate into the school, especially at primary and secondary levels, has become entirely unfit to the goal. For these two main reasons, sharing of scientific knowledge does no longer properly occur.

Was it appropriate of the Pontifical Academy of Sciences to move into this area, as its Statutes request this Academy *...to contribute to the exploration of moral, social and spiritual problems*? The Council so decided, and a Workshop was held during three days in November 2000, gathering thirteen Academicians and thirteen experts, to discuss *Science Education in the 21st Century: a Challenge*. The developed world was well represented, as were Latin America and India. China, Africa and the Islamic world were practically absent, which is unfortunate since preserving the cultural diversity of the world is an essential part of any education issue. The conclusions were published in the form of a Statement[3] later approved by the PAS Council.

I shall try in this summary to convey the spirit of the Workshop, which was fully published in 2001.[4] It essentially focused on primary and secondary education, leaving somewhat aside specialized and university training. There was a broad agreement on the importance of the subject, a number of encouraging plans or projects were reported, several difficult issues were identified and, before writing the final Statement, an enlightening discussion brought signs of hope.

[3] This Statement is reproduced at the end of this communication.

[4] 'The Challenges for Science: Education for the Twenty-First Century', *Scripta Varia* 104, Pontifical Academy of Sciences (2002).

Education in Science

At this point, it may be useful to clarify what is meant by *education in science* (science understood as the ensemble of disciplines dealing with nature, phenomena, and artifacts). During the last two decades, a strong emphasis was placed on scientific information of the general public through the mass media (press, television) and on informal science learning media (museums). But *information* is not *education*. Over these years, little attention was paid to the role and content of science education in the school systems, especially during the years of compulsory education, which in most countries extend over 8 to 9 years (primary and junior high school). No thorough reforms were undertaken. The subjects taught, the way they are taught, the teachers, training are more or less divorced from the living body of science in progress, of technology in action. To make things worse, the scientific community has remained outside this part of the education system, since it was often considered that the teaching at such elementary levels does neither require the sophisticated knowledge, which we develop and apply in our laboratories, nor the involvement of outstanding and respected scientists. It is only in the recent years that innovative initiatives have been taken.

The overall result is quite worrisome, as was repeatedly mentioned at the Workshop. In many countries, not necessarily developing ones, science is absent from primary schools (a 'good' example is France, where in 1995 science was taught in only 5% of the 350 000 classes). Too often, science lessons are made of accumulation of information, facts, results, formulae, lessons to be repeated by heart which make little sense for the child: Jonathan Osborne suggested that '*current practice is rather like introducing a young child to jigsaws by giving him bits of a one thousand piece puzzle and hoping he has enough to get the whole picture, rather than providing the simplified hundred pieces version*'. As an echo on the aim of the schools, Einstein quoted by Giuseppe Tognon: '*...the general ability to think and judge independently should ... take the first priority*'. Accumulation of mere facts, admiration of technological black boxes do not suffice to build up a critical mind, possessing the basic roots of scientific attitude towards the natural world, able to properly use rationality, to express himself with adequate words and arguments in order to deal with more abstract concepts, with causality, probability – a notion on which André Blanc-Lapierre used to insist – to discriminate between true, false, uncertain. It may seem odd but it is a fact, in many countries whether they are developed or not, that public policies or privately owned schools tend to undermine the importance and the role of science in education: this social trend probably reflects the increasing gap between science and the public and sometimes a suspicion, reflected by the politicians.

Going beyond this and quoting Erwin Schrödinger asserting that '*life is not merely made of science*', Stanley Jaki proposed a much deeper view on the goals that education in science should pursue, beyond the commonly accepted view that it is the art of imparting skills in computation or experimentation, a leisure to play with '*something that is technically sweet*' (Robert Oppenheimer).

At the beginning of the Workshop, a consensus was quickly established on the absolute need to develop these basic abilities for every child in the world, firstly to establish the technological and scientific basis of development, as strongly postulated and pointed out by Chintamani Rao. Quoting the latter, speaking on capacity building: '*I make this presentation with the fundamental faith that the mechanism to reduce global imbalance of development and to increase the stability of the world has to be based on knowledge*'. But the way is long, from the knowledge accumulated in laboratories or industries to sharing it through a school system, in order to achieve capacity building. Rafael Vicuña made an extensive and quantitative description of the poor capacities measured in the Chilean population, answering simple tests in reading comprehension.

Yves Quéré went further and pointed out, as M. Menon also did, that education is carrying values, not only knowledge: science is continuously educating us, decreasing our ignorance, addressing not only our intelligence but also our personal and social behavior, shaping our outlook of the world and even our character. Science teaches us values, which are fundamental for the intellectual and moral development of Man and of the societies: the idea of freedom, the virtue of humility and modesty, the spirit of research against the *more-or-less*, the *preconceived*, the *ready-to-wear* types of behavior, the ethical concern to deal with the applications of science. He recalled this universal Golden Rule '*Do not do unto others what you would not like them to do to you*', to be remembered in order to protect from technological harm the men of today and tomorrow. Again, this stresses the point that teaching science, even at an elementary level, goes far beyond learning the density of substances or the atomic weight of various elements.

There is an important issue, which the Workshop did not specifically address and which can not be decoupled from school education: lost in a world, urban and technological, which most people hardly decipher, all kinds of beliefs propose simple-minded explanations, leading sometimes to dramatic issues in the most radical sectarian movements. On its Internet front page, with the same seriousness and on equal footage, the French public-owned Telecom Company offers weather forecast, stock exchange access and... astrological predictions! It seems essential to constantly urge religious thinkers and leaders to educate properly on the nature of science, on the use of reason; to explore and properly integrate, no matter how difficult, the new areas of freedom opened by science (e.g. therapeutic use of stem cells, information technologies); to constantly re-think their message in terms which account for the progress of knowledge and are understandable within the new representations provided by science; to make sure the training of the clerical persons includes such preoccupations. Let me quote John Paul II: '*Il est illusoire de penser que la foi, face à une raison faible, puisse avoir une force plus grande: au contraire, elle tombe dans le grand danger d'être réduite à un mythe ou à une superstition*'.[5] During the last Plenary Session of this Academy, Ahmed Zewail made a similar plea, to avoid '*fanatical mix-ups of state laws and religious beliefs*' and to note the importance of knowledge, science and learning in the Quran as it is addressed to the Muslims, who are close to one billion in the world population. Placing truth, a virtue essential in science, at its right place becomes an essential objective in a world torn by simple-minded, oversimplified and dangerous views on truth: Jean-Michel Maldamé insisted to refute the idea that '*...science holds a monopoly on the truth*'.

I shall conclude this section by a warning, formulated by Giuseppe Tognon: '*If ...public opinion continues to consider scientific research as a means to an end, the scientist will continue to be viewed only as an economic entity...*'. Quoting Jorge Allende: '*For most people in Chile, science is something magical, complex and expensive that is done in the United States, Japan and Europe and that results in new gadgets or medicines that eventually appear in the stores in Santiago*'. One more reason to restore in schools a deep understanding of what is a free mind doing free science.

Hard points & Great hopes

The Workshop documented a picture of science education in the world which was rather grim: aside from the formation of an elite of exceptional quality, carrying out research mostly in developed countries (even with lim-

[5] *Fides et ratio*, Encyclical of Pope John Paul II, IV, 48 (1998).

itations of efficiency, as pointed out by Rudolf Mössbauer for Germany) and often through brain-drain (in 1999, 36% of Science & Engineering Ph.D.s in United States were given to non-citizens, while the foreign-born Ph.D.s represent 30% of the total academic employment of doctoral scientist and engineers in this country[6]), the percolation of modern science into the cultures through schools is poor or often absent. On the other hand, a number of remarkable and recent initiatives were reported, which seem to indicate a potential for deep transformations, where the science community is called to play a novel and major role.

Two main related factors were identified: the first dealing with the goals assigned to science education and the pedagogy implemented to reach these goals, the second with the quality of teachers, considered as an absolute requirement for any sustainable transformation.

It would be too long to summarize here the deep analysis carried by Jorge Allende, Richard Gregory, Stanley Jaki or Jonathan Osborne on the entirely outdated and inefficient pedagogy used today to convey the nature of science and scientific knowledge to children and teenagers. Characterized by an accumulation of unrelated facts, a lack of historical context and of experimental approaches, a dogmatic teaching without the exercise of the proof or the virtue of error analysis, a knowledge broken into disciplines and hiding the unity of science, the fundamentals of scientific method and the beauty or power of its results, this teaching has little meaning to children and teenagers: '*La science, cela n'a rien à voir avec la vie*!' (a French pupil) or '*It does not mean anything to me. I am never going to use that. It's never going to come to anything, it's just boring*!' (Quoted by J. Osborne).

Fighting this, and referring to many analyses carried out on *How people learn*?,[7] a novel conception of basic education in science has emerged in recent years, and was beautifully demonstrated at the Workshop, including a practical laboratory working session proposed by Douglas Lapp. Under various names (*Hands-on* or better *Inquiry* science in United States, *La main à la pâte* in France, *Mao na massa* in Brazil, *Zuò zhong xue* in China) the same concept is proposed and implemented, in some cases in a limited number of schools (Mexico, China, Brazil), or inspiring broader reforms in

[6] National Science Foundation, *Science & Engineering Indicators 2002*, http://www.nsf.gov/sbe/srs/seind02.

[7] *How people learn?* National Research Council, National Academy of Sciences, Washington, D.C. (1999).

other countries (United States, France) and rapidly spreading. As pointed out by R. Gregory, *Hands-on* science is not a new idea, since Francis Bacon described it in his unfinished bool *New Atlantis* (1626).[8]

The central idea is to cause children to participate in the discovery of natural objects and phenomena, to bring them into contact with the latter in their reality directly through observation and experimentation, to stimulate their imagination, to broaden their mind and to improve in this process their command of language. On a subject proposed by the teacher, a child asks a question and immediately, instead of giving the answer, the teacher throws the question back to the class: through observation, hypothesis, arguments, experiments, writing and drawing, children practice the dialectic of reasoning and experiment which is at the heart of research and science. The questions, instead of the answers, become the focus of a learning process which indeed must ultimately lead to answers. Through this process, three fundamental points are to be progressively carried to the pupils, along the way of their progression in the curriculum: the marvels of the world, sensible or hidden, are understandable by the human intelligence seeking answers to the questions, as these are not the product of magic or remote characters; this understanding, which we call science, gives us an incredible power to act on the world, to build machines, and we call this technology; science and technology are the products of a long and endless human history, made of errors and flashes of genius, of patience and team efforts.

Although no large-scale assessment of these innovative programs could be presented at the Workshop, they at least produce happy and lively classes, encounter broad support wherever they are put in practice, and it is already proven that their impact is especially impressive on children with difficulties ('street children' in Mexico City with Guillermo Fernandez, *Réseaux d'éducation prioritaire* in France with Georges Charpak, Chicago slums with Leon Lederman). They seem to achieve the goal Rudolf Mössbauer was assigning to education: '*...Help children and youth to preserve their joy of life, their curiosity and their concern for one another*'.

Two important questions place this old method into new perspectives. The first is the role and use of the computer: should it take a significant place in science education? When? How? *Hands-on* approaches insist on the contact of the child with the real world, since he should first perceive it with his own senses rather than through artifacts or scientific instruments. Antonio Battro made a strong point in dismissing the classical (and too

[8] Bacon, Francis (1620) *New Atlantis*. Oxford: O.U.P. (1915).

easy?) opposition between real and virtual: '*Many human activities can be projected in two dimensions, real and virtual*'. For him, '*...the neural plasticity is expanded by the help of a computer ... new digital tasks require new digital skills and the exercise of new patterns of brain activation. This opens a new field in education which may be called neuroeducation*'. To comfort this thesis, a fascinating experiment carried by R. Pawar in the streets of Indian cities was recently reported at the TWAS General Assembly:[9] children are given computers without any instructions, and seem to learn quickly their use teaching it to adults. M. Menon underlined also the potential impact of information technologies, stressing the need to conceive and produce on large scales a one hundred dollar PC, with a simple operating system, battery driven, for operation in Brazil, India, Africa.

Related to this issue is the whole understanding of the learning process, as explored today by cognitive sciences. In particular, Stanley Jaki stressed the underestimated role of memory training. The development of cognitive sciences was barely addressed at the Workshop, and would deserve further confrontation of ideas. The importance of emotion in the learning process of children has too often been underestimated, and may become a fundamental factor in societies where children and families are submitted to drastic social changes, as in China with the current policy of the single child.[10] The concept of a child with a 'virgin brain', to be filled by knowledge, had already been contradicted by the studies of Piaget and Wittowski. More recently, cognitive studies carried on babies[11] have shown the incredible plasticity of newborns to put in action a number of cognitive schemes, which are typical of scientists at work: the scientist, as the music composer or the painter, is a person who by good fortune has not lost his childhood abilities, as many of us know!

Finally, another very interesting point was raised by Mambillikalathil Menon: his plea for the diversity of cultures was expressed as a wish to maintain the diversity of languages, hence to explore possibilities for a 'universal networking language' (UNL), which may become possible with proper machine translation and may have a strong impact in spreading innovative pedagogical tools.

[9] R. Pawar, *Digital divide: problems and opportunities*, at Third World Academy of Sciences 8th General Conference, New Delhi, 19-23 Oct. 2002.

[10] Wei Yu, *Cultivate the emotion competency of our children*, OECD, 2002.

[11] Alison Gopnik et al., *The Scientist in the Crib: What Early Learning Tells Us About the Mind*, Harper, 2001.

Implementing new teaching methods depends on curricula and standards, which may quite easily be modified (such a global change just occurred in France in 2002 for the primary school, following the *La main à la pâte* effort). But this is nothing without the teachers, a point that has been the focus of many exchanges at the Workshop. Restoring their social status, improving their salaries is one aspect. Providing equipment is another: 70% of Indian schools do not have libraries or laboratory facilities; in Brazil, only 26% of secondary rural schools do have a science laboratory, and 7% of the primary urban schools. One should not overstate this problem: an excellent science lesson can be done with very little and cheap equipment, or even only with the natural phenomena available in the school surroundings, as long as the teacher is prepared to exploit the opportunities. The Workshop did not consider extensively, as it probably should have, the economics of school development and the competition between private and public sector in what becomes in some countries a profitable market. An analysis of the World Bank education policies, as often suggested in recent Conferences on science education, may at some stage become useful.

But the central point is teacher training, in order for the teacher to understand what the science is, how it evolves and how it ought to be taught. In many countries, teacher training is too often full of elaborate considerations on theoretical pedagogy without application to real cases: Jorge Allende mentioned the case of Chile where '*...this training is done in Education Faculties or Teacher's Colleges ... which do not have groups doing scientific research*'. The same is true in France, where primary school teacher training in science, already slim, has been cut by a factor of two in 2001 and is practiced with little or no contact with active scientists. To reverse this, there is one simple and powerful idea: to put the teacher in the same questioning and inquiry process that will be later proposed to children. This makes them realize and understand the mental process at work, and is better than feeding them with a formal knowledge, to be later re-injected to children. Stanley Jaki went even further, saying that '*the science of education* [which organizes teacher training] *resembles ever more closely a machine devised to produce illiterates in ever larger numbers*'.

Modifying the teacher's views and tools to transform education in science is such a radical revolution that it may only occur if the scientific community gets involved and supports the transformation. In fact, every new program mentioned above and detailed at the Workshop has been conceived, supported in front of governments and implemented, including teacher training, by scientists, often prominent ones, and with the support of the Academies (Brazil, China, France, Mexico, United States). In countries with weak Academies, or without, implementation could only succeed with external help (Morocco, Vietnam). Along with their prestige, which is useful to convince governments, and their numerous ties with the grass-root scientific community in their home country and across the world, the permanence of the Academies offers a significant, even decisive advantage when dealing with educational issues, where the time constant of changes has to be measured in decades rather in the usual 'political' time constants of a few years. A remarkable example was presented by Celso Pinto de Melo, who in Brazil is devising a national program devoted to the creation of *Centers of reference in science education*, initially focused on secondary education, providing a regional space of continuous re-training of science (and mathematics) teachers. Another example was developed by Rafael Vicuña for Chile, pleading for an integrated community between science teachers and scientists, a very ambitious goal given today's fractures. It is significant to observe that many Academies, as well as their common body the *InterAcademy Panel* (IAP), are putting education in science as one of their forefront programs for the years to come.

The production of pedagogical resources at the appropriate scale is a challenge, for which no one yet has provided convincing solutions. But our times are granted a formidable tool, if properly used: *the Internet*. Although many schools, areas or even countries do not yet have an easy access to the Web for their teachers at decent transmission rates, this situation is rapidly changing (in 2001, 23% of rural Brazilian primary schools have a computer laboratory, 20% of French primary school teachers are connected to the Web and use it). Regarding science education, the Internet has several virtues: *a/* it allows teachers to exchange their experiences, and problems; *b/* it allows a broad dissemination of successful class protocols, lists of equipment; *c/* it allows a direct link between teachers and scientists, for questions and answers bridging the ever increasing gap between the ones who create the knowledge and the ones who teach it; *d/* it allows to connect schools across the whole planet to undertake cooperative work, contributing to forge the idea of science universality.[12] A convincing demonstration

[12] An interesting example of this is the Eratosthenes network of schools, built for measuring the radius of the Earth with the old method of Eratosthenes: it simply requires to measure simultaneoulsy in two schools the length of a pole shadow at local noon, and to know their kilometric distance in latitude. Results are spectacular (http://www.inrp.fr/lamap/eratosthenes). *Hands-on astronomy* could be practiced the same way.

is offered by the French *La main à la pâte* site open in 1998, which I presented at the Workshop (50 000 connections a month), or its counterpart in Chinese at Nanjing, open in 2001 (similar audience), or in Portuguese for Brazil.[13] Again, none of this could have occurred, been funded and accepted by the official public school systems without the support and the explicit responsibility of prominent scientific authorities.

Of special importance is the difficult task to select then convey the essentials of the new knowledge to teachers, in order to make it percolate in the schools. It is a pity to observe the formidable accumulation of facts, often irrelevant or impossible to understand, that are present in textbooks for secondary schools. Only active scientists, working closely with teachers, can discriminate in this flood of information, which is finally dis-informing the pupils. Georges Coyne, for instance, made the point that modern cosmology is a remarkable resource for elementary school education, leading children to understand that '*we have all been made in heaven*' and broadening their view point, in order for them to become acutely aware of mankind's interdependence with the environment and the Universe.

Conclusion

The Workshop Statement, which in February 2002 was approved by the PAS Council, summarized the thorough concern of the participants in front of a problem of immense magnitude and a formidable task: these cannot be brushed aside by the scientific community and entirely left to the 'classical' actors of education policies, although the scale of solutions does require Government actions. The scientists, who are often privileged in the resources they are granted, encounter here a moral obligation of justice, as said Yves Quéré quoting *The good Samaritan*.

As teachers are at the heart of the required changes, every effort should be made to help them change their view of science and their pedagogy: partnership or rather companionship (as extensively implemented by *La main à la pâte* in France); personal encounters with scientists and science activities at a simple level, far from the spectacular but often too remote 'shows of science' given by television; restoration of their trust in themselves to teach science; research activities to tie progress in cognitive sciences to actual teaching of science.

[13] In France: http://www.inrp.fr/lamap. In China: http://www.handsbrain.com. In Brazil: (http://ciencia.eciencia.pe.gov.br/).

I have always been impressed by the impact the *International Center for Theoretical Physics*, founded by Abdus Salam in Trieste, had and still has on the scientific development of many countries, by systematically organizing the contacts between prominent scientists and post-doctoral students. I wonder if this model could not be adapted to the needs of science education. We have repetitively observed how teachers, initially feeling incompetent to teach science in primary schools, have been transformed, have gained self-confidence and later achieved beautiful lessons, once they were exposed to convincing classes, given proper resources and scientists' companionship. On the model of ICTP, could *Regional Centers* be implemented where education leaders or teachers visiting for short periods (a few weeks) would meet high reputation scientists involved in education, practice *Hands-on* science, discover resources and get moral support to become later advocates of change?

At the Workshop, several participants supported the idea to have a well documented website to circulate information, country by country, on these issues. ICSU and IAP have agreed on this goal, have funded it and an International Website on science education,[14] in primary schools to begin with, will open in January 2003.

If I may conclude with a personal touch, it strikes me that education in science has to achieve a delicate balance between the universality of science, which is one of its fundamental characteristics and values, and the character of education, which must be deeply rooted in a particular culture, especially through language. Modern globalization, linked to technology, tends to a uniformity, which many resent as negative. By placing science in historical and cultural perspective, by inspiring education in local contexts, scientists have a great role to play.

* * *

[14] The temporary address of this site, built for ICSU and IAP under a contract with the Académie des sciences in France, is: http://www.icsu.org/ccbs/teaching-science. For information contact: jasmin@inrp.fr .

THE WORKSHOP STATEMENT

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 economical 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 their 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.

DISCUSSION ON THE PAPER BY LÉNA

BATTRO: I want to share with you that we are doing a nice experiment now with our students of education at Harvard. I proposed to them, graduate students and doctoral candidates, to design an exhibit at the Museum of Science in Boston about the classes I'm giving to them. Instead of writing a paper, an assignment, I invited them to produce an exhibit of one of the main themes, and they've chosen to design an exhibit on chronobiology, and the way our brain sleeps or is awake. I can tell you that they are very excited to do that instead of writing an assignment.

ARBER: When I was a child we were taught at the level which we could identify with our senses, the eye, smelling and so on. We were stimulated to go into the field and to look at plants ourselves and make discoveries, and it worked beautifully. I do realise that in the last fifty or more years research has gone through micro- into nanoscales both in life sciences and in physics. At these scales it is very difficult for non-initiated people to understand and to accomplish an experimental approach. So, this was missing in your report. I think we have there a major natural barrier of scale. Children still like to look through the optical microscope, that's fine, but if it goes lower down, we just lose them, and I have a hard time telling them how at the level of filamentous DNA molecules the things proceed. One should really give serious thoughts on how to teach at that level and incorporate it with the macroscale views in order to get the message through.

LÉNA: I cannot agree more with what you say and should have insisted more on those first steps where perception and the use of their senses by children is absolutely essential to bring them in contact with reality. One can then build upon this to reach the next steps, which are more remote, deal with very small or very large scales, and with more abstract concepts.

IACCARINO: Many years ago children had to study much less in all fields of knowledge compared to now, and today one of the things that has changed is the number of hours that children are required to stay at school or study at home, and we perhaps do not appreciate enough this change. For example, the hyperactive children syndrome, which is a problem today, was non-existent one hundred years ago. Have you discussed these types of problems?

LÉNA: Not specifically, but your remark reminds me of the comment made again and again on the need for revolution, because science teaching is in many circumstances made up of an accumulation, a superposition of layers of successive science which ultimately hide the substance of science. It's more an accumulation of facts than an attitude toward the world and conveying the fact that it's possible to understand it, and therefore the revolution is probably to rethink the whole process and avoid this accumulation which leads to confusion in the children's minds.

JAKI: Dr. Goldwin, the Director of the NASA programme in the United States, gave a speech, a nationally publicised speech about the problem of recruiting engineers to further the cause of space exploration, and he gave the following data: between 1965 and 1970 or 1969, that is the time of the moon landing, NASA had to recruit a total of sixty thousand electrical engineers. At that time twenty-four thousand Americans graduated with a BS in electrical engineering. In 1989, according to his data, the number was down to fourteen thousand. In 1994 the number was down to ten thousand, and I am sure that today the number is not more than eight thousand per year. At the same time, in 1965 the number of those who graduated from American Colleges with a BS, a Bachelor of Science degree in park and recreational services was zero. In 1989 their number was five thousand, in 1994 their number was equal to the number of those who graduated in electrical engineering, that is ten thousand, and today, in 2000, the number of those who graduated in park and recreational services and get a Bachelor of Science degree exceeds by a few thousands the number of those who graduate in electrical engineering. I merely hope that the shock of September 11, 2001 will be very effective, and I think that similar reversals in the numbers could be quoted from other western nations as well.

PAVAN: I would like to inform you that at the University of Campinas in Brazil a group under the leadership of Prof. Octavio Henrique Pavan developed a new system of teaching at high school level through a kind of game in which not only the student would learn but the professors must be updated in relation to the subject matter of their area.

LÉNA: Thank you for this comment, Professor Pavan. One thing which is repeatedly said at those conferences and that we observe in classes in France is the fear that teachers have of questions when dealing with science. They feel they have to give answers, and answers in science are too complicated, so they avoid the complete theme rather than moving into a field so uncomfortable for them that entering the question without being sure of the answer becomes dangerous. So, I would say that one of our goals should be to restore the culture of questions.

NEW SCIENTIFIC PARADIGMS AND CHANGING NOTIONS OF THE SACRED

JEAN-MICHEL MALDAMÉ

It may seem surprising to mention religious language in relation to natural sciences. As a matter of fact, the great contests about the relationship between faith and science which have been carried out these last few years, dealt with the questions of the beginning of the world, the origin of life and the origin of man. They are still going on, about questions raised by technological advances, regarding the status of the human embryo, regarding genetic engineering, or the protection of the environment. In such context, spiritual questions seem to be of secondary interest; but they are not. This is why I suggest that we pay attention to questions which, in all likelihood, will be at the very heart of the debates of this century which is just beginning – and which are related to what is commonly called spirituality. Is spirituality a value of science?

It is in relation to this religious concern, that we can measure the present change of attitude. If the immediate object of Science is to master the ways and means towards a distinct improvement of life – like going ever farther and faster, a better protection against climatic or environmental aggressions, better food, a better-performing health service, more comfortable homes and a more rational organisation of traffic in our cities – our reflexion addresses the justification of such an aspiration. Indeed, a number of significant changes have accompanied the progress of scientific knowledge.

1. Spiritual Concerns and Rationalism

The foundation of science has long rested with the confidence which men placed in Reason. Their trust is based on the philosophy which supports what we call classical science. It began in the 17th century and boomed in the 19th century. It has been taught in schools throughout the 20th century and is strongly going on today.

1.1. According to this philosophy, science is founded on laws made rigorous through the language of mathematics. Such a language enables us to anticipate future occurrences: astronomy allows us to foresee various phenomenons that take place in the universe; like solar or lunar eclipses and other astral occurrences, or – in the more immediate context of daily life – like the setting up of calendars, improving the functioning of machines, developing means of communications, etc. All this was made possible through an increasingly efficient management of space, time and organic matter.

1.2. In this global view of life, Reason must always be able to claim victory over Chaos and cope with the Unexpected. It relies upon a deterministic paradigm, voiced by the mathematician named Laplace.

There are cultural values of science. Reason is indeed an eminent quality of intelligence, at the service of Truth. Its practice has a moral dimension: rectitude, and a logical dimension: intellectual rigour. Reason has always insisted on being 'pure Reason' – a specifically human faculty which must keep away from all sorts of contaminations, like prejudices, emotions and other passions involving soul or body. Clear Reason insists on being the sovereign good. This is why it has criticised all forms of religious language, as being guilty of emotional attitudes and because it has surrendered to the authority of Tradition. But such an attitude does not go without a spiritual dimension: that of an ideal of transparency and purity.

1.3. In spite of these criticisms of religious thought, this kind of rationalism allowed some sort of spiritual attitude: that of clarity, linked to the demands made by objectivity. Subjectivity, or personal idiosyncrasies must give way to the demands of Truth, which by its very nature, has to be the same for all. It is an attitude of exacting disinterestedness.

Thus, within European culture, a specific spiritual dimension has developed, ideally implying total freedom of mind, through the independence of Reason and a critical attitude towards prejudices. Concurrently with the success of Science, a spirituality has emerged, promoting intellectual work and calling for keener intellectual perceptions and a more complete ascendency over the body.

Besides, classical science is also linked to a sharp consciousness of the limits of reason. It is thus in full compliance with a certain attitude of renunciation, which is at the very heart of the mystical experience. Reason reflects on itself: it is fully aware of the fact that it does not know much. Such is the predicament of the Christian, who prays and lives in the perpetual awareness of the difficulty of meeting the absolute of God, whose transcendence is overwhelmingly present.

So, it is possible to say that is a spirituality linked to the exercise of reason, in its classical form of objectivity, logical line of thought, and disinterestedness. The French tradition has several representatives of this sort of spirituality. Among the philosophers are Paul Valéry and the philosopher Alain. But also the Christian philosopher Simone Weil belongs to that tradition.

But this way of seeing things was shattered by the emergence of a new science in the twentieth century. Is it a denial of Reason? Or a turn-back to the past and a way to go out of scientific methodology? If it is the realisation that its exercise was more flexible than the rationalists had first imagined, it is also a danger to go in philosophical and religious monism. So we have to be careful. I limit my enquiry to Physics and to some theological research.

2. A new Approach to Nature

The emergence of quantum mechanics, at the beginning of the 20th century, came as a surprise to those who had been accustomed to the vision of classical science.[1] A long time elapsed before this new theory could be conveyed in concatenating words.[2] Although research is still going on, one must not believe that quantum theory can better explain a number of phys-

[1] In 1889, Max Planck introduced the notion of discontinued energy exchanges between organic matter and the earth's radiation. In 1905, Einstein explained that photoelectric effects were caused by the ejection of atomic electrons.

[2] Louis de Broglie was the first to attribute undulatory properties to electrons. Since then, progress has gone on endlessly. First, on a purely theoretical level, a mathematical formulation called 'undulatory mechanics' (to use E. Schrödinger's expression) or 'matrix mechanics' (according to W. Heisenberg) came into existence. Then, on an experimental level, the knowledge of the elements constituting the nucleus of the atom has improved. Lastly, quantum mechanics have kept being verified through technical innovations, like laser technology, which is now of current use, superconductivity, or optoelectronics.

ical phenomenons. Not only such phenomenons as take place in particle accelerators, but also those which take place in stars (neutron stars, quasars, and even black holes), thus serving as a basis for cosmology, which offers a global explanation of the Universe.

This new language has resulted in making physics look like an enigma to those who had been trained in classical physics – and even for some of them like an opening to mystery. This has also resulted in a new set of references for scientists. Traditional mechanics had grounded its basic elements on the most systematic rationalism. As the new mechanics could not follow suit, some founders of the new science felt the need to inscribe the results of their researches into a global vision of nature, which was quite different from the current one. In order to do so, they drew on a tradition which can be described as 'mystical', in so far as the word refers to realities which diverge from what classical physics, influenced by determinism, consider as 'reasonable'. Several examples of this can be mentioned, depending on the various aspects of the new physics used by the authors to sustain their argument: indetermination, logics, participation and symbolism. It is necessary to examine that topics, before giving a critical judgment.

2.1. *Indetermination*

The first thing which gave rise to mystical considerations, was the breaking away from determinism. This is a well-known fact. Everyone has heard about Heisenberg's uncertainty principle. The inequality it has brought to light shows that one cannot expect to locate particles in space, and time, or determine its energy, with absolute accuracy. This inequality does show that the language of new physics is no longer determinist, but based on statistics. Resorting here to calculation of probability has nothing to do with the limits of human knowledge: it intrinsically belongs to the phenomenon under scrutiny.

Faced with this new perspective, Arthur Eddington's reaction was significant. He recorded the decline of determinism in new physics with delight, in his *The Nature of the Physical World*.[3] The book opens with a first chapter on 'the failure of classical physics'. He then enters the discussion of the great concepts of physics, like time, gravitation, quantum, and questions of method, like causal relations, the future, the place of man in the

[3] *The Nature of the Physical World*, AMS Press, reprint ed., 1995.

Universe (or more precisely, the conditions of life in the biosphere). The book ends with a chapter on 'Science and mysticism'. In his conclusion, after raising the question of abstract knowledge, he writes:

> As a conclusion to the arguments produced by modern science, it may perhaps be possible to say that religion became an acceptable option for scientific minds from 1927 onwards [...] If the view is confirmed that 1927 witnessed the final elimination of strict causality by Heisenberg, Bohr, Born and others – then that year will certainly remain as one of the most important landmarks in the history of scientific thought.

Freedom seemed to be ruled out, within the framework of physics ruled by the determinist pattern, where everything followed everything out of absolute necessity. The unpredictable nature of fundamentals removes this difficulty. Certain authors think that human freedom fits into the neuronal function governed by quantum indetermination. Karl Popper or John Eccles see in the indeterminate comportment of particles the ontological foundation of freedom.[4]

2.2. *Another Logic: Paradoxes and Dialectics*

The second aspect of spiritual developments is linked to the paradoxical nature of the languages of new physics. Since the tenets of new physics could be verified at the experimental level and were coherent at the level of mathematical expression, the logic that presided over classical mechanics was called into question – in particular the Aristotelian principle of the third party or third man-argument.

This theme appears in Niels Bohr's thought, whose coat of arms, following the Yin and the Yang signs, carried the Latin motto *Contraria sunt complementa*. Through this, Bohr revived the thought categories of the Renaissance theologian Nicolas de Cues, the Romantics and some implications of Hegel's thoughts.

The notion of paradox thus found itself elevated to a paradigmatic level within the framework of a certain logic – a logic which had no longer anything to do with the framework of classical thought and through which the mystics gained renewed acceptance. In a spiritualist context, B. Nicolescu coined the neologism 'trialectic' to express the

[4] John Eccles, *How the Self controls its Brain*, Springer-Verlag, Berlin/New York, 1994.

notion of going beyond classical logic and to challenge the logical principle of the third party argument.[5] His intention was thus to go beyond materialism through a form or dialectics that do not only apply to the level of matter. In order to achieve this, he introduced the ontological notion of 'level of reality'. The fundamental antagonisms that are found in physics are overcome and lead to a superior reality. Like, for instance, the theological discourse. Thierry Magnin has not failed to explore this spiritualist opening, reading Christian Mystery and discussing the classical Christian assertions in terms of dialectic opposition as 'complementary in contradiction'.[6]

2.3. *Philosophy of the Spirit*

Another aspect of the convergence of the language of new physics and the language of mystical experience is illustrated by the fact that in quantum mechanics, observation is interactive, since no one can observe anything at a primary level without modifying what is observed.

The philosophy that follows postulates that one should give up the concept of objectivity which classical physics claimed to be fundamental to truth. It interprets the interactive process of measurement by saying that the observer can no longer claim to be neutral: he is involved in the process as a 'participant'.

> The most important thing about quantum mechanics is that it has done away with the concept of an external world, seen as a distinct area located 'out there' by an observer standing behind a ten-foot thick glass window. Even in order to examine an object as minuscule as an electron, the observer must break through the glass window. He must reach out to it. He must set up his measuring instruments. It is up to him to decide whether he is going to observe a position or a 'moment'. In any case, he cannot measure both at the same time. Besides, the operation modifies the condition of the electron. The Universe won't be quite the same afterwards. In order to describe what has taken place, one must replace the old

[5] Bassarab Nicolescu, *Nous, la particule et le monde*, Paris, 2002.

[6] Thierry Magnin, *Entre Science et Religion*, Monaco: Edition du Rocher, 1998. He reads the Christian Mystery in this light and discusses the classical Christian assertions in terms of dialectic opposition as complementary in contradiction.

> word 'observer' by the new one: 'participant'. Strangely enough, the Universe is a universe of participation.[7]

The word 'participation' is understood in the sense it has in mystical communion. It is referred to in many works. The Tao of Physics by F. Capra is the best-known one; the book betrays the author's concern to find in modern physics patterns identical to those found in Tao mysticism. F. Capra speaks of physics and mysticism as converging experiences. The latter one is an experience of the whole world; a cosmic experience.

A number of Christian authors consider the formal aspect of quantum mechanics as one of the main characteristics of human consciousness. The very heart of reality then becomes consciousness. This is the thesis defended by Jean Guitton following the publication of a book by the brothers Bodganov which was greatly successful. For them, quantum mechanics negate materialism:

> The fundamental distinction between matter and spirit has been changed deeply and in a non-reversible way. Hence a new philosophical concept which we have called 'metarealism'; for the first time, we have made materialism compatible with spiritualism, we have reconciled realism and idealism.[8]

2.4. *Symbolic language*

Another link between science and mysticism has been suggested by the works of another pioneer of new physics, Wolfgang Pauli. His concern for spirituality originated in his interest in the success of abstract formalism. He found a first convergence of scientific language with religious language in the Cabala, noticeable for its formulation of equivalences between numbers and letters. He tried a unifying approach to the problem. In order to show how those conceptual registers were related, he decided to turn to Jung's archetypes.

[7] John A. Wheeler, *The Physicist's Conception of Nature*, quoted by Michael Talbot, *op. cit.*, p. 27.

[8] Dieu et la Science: Vers un Métaréalisme, Paris: Gresset, 1991. The book was reviewed in *La Recherche*, n° 237, Nov. 1991, Vol. 22, pp. 1350-1352. The review was made by François Russo, Elisabeth Giacobino, Serge Reynaud and Antoine Danchin. The book was denounced as a fraud by the scientist, the theologian and the epistemologist. It deserves to be mentioned here only because of the sociological phenomenon which was revealed by its success.

A long correspondence with the psychoanalyst who had specialised in symbols led him to explore the fundamental aspects of the psyche. He established a link between physical experiences and psychological experiences. Reality being composed of two parts – one psychological, and the other one physical, the two approaches should meet in a unifying vision. The reference to Jung is overwhelmingly present among circles interested in finding unifying links between science and mysticism.[9]

At the end of this brief account, one must acknowledge that the issues raised by the relationship between science and religion have changed, since scientists establish converging links between scientific language and spiritual language. The updating of traditional perspectives has led theologians to address a number of its requirements; it has in the first place helped them to do away with a certain form of rationalism, inherent to classical theology. Such an evolution can be found among several theologians who must now be rapidly discussed: they are facing up to the challenges posed by the altered vision of the scientific world – which does not have only happy outcomes.

3. Effects on Christian Theology

One initial critical remark is necessary. The themes developed by scientists are not so original as they may appear. They belong to a tradition which has always been part of western civilisation. Often, the circuitous approach to the problem through oriental religions is an artifice used to get back to religious currents which belong to western culture. The convergence between new physics and mysticism goes back to the tradition which acknowledges an immanent rationality in the world, or – to use the old vocabulary – a *logos* or a *pneuma*. A long theological debate has been conducted among the Fathers, bearing on the interpretation of these words.[10] Today, theologians who echo the above mentioned convergence are reviving the fundamentals of Christian theology. So if I quote some theologians, it is not my personal approach of the creation.

[9] The correspondence between Wolfgang Pauli and Gustav Jung has been translated and published in Paris Albin Michel, 2000.

[10] See G. Verbecke, *L'Evolution de la doctrine du Pneuma du Stoicisme à Saint Augustin*, Paris, 1945.

3.1. *Science considered as a Spiritual Quest*

A first echo of the new approach is perceived in the way in which certain theologians accept to consider science as an adventure of the spirit, more than an adventure of reason – as a spiritual experience, in the full meaning of the word. Alexander Ganoczy witnesses such an attitude in a huge theological work. In particular, in a synthesis where he defends the forms of religious thought which refer to science in explicit relation to the mystical process: *Suche nach Gott auf den Wegen, der Natur, Theologie, Mystik, Naturwissenschaften – einer kritischer Versuch*.[11]

He notes that the main leaders of modern science are no longer filled with the positivist or rationalistic spirit. The Themes of mysticism are present in their minds. He then devotes an important part of his reflexion to the way in which a spiritual experience is encouraged, like Hinduism, Taoism, Zen Buddhism and Christian mysticism, as illustrated by the tradition of German mystics (Hildegard von Bingen, and the Flemish Dominican from the Rhineland. A. Ganoczy examines the spiritual attitude of the scientist). He finds it illustrated in one of Einstein's texts about the religious mind:

> The most beautiful experience we can have, is about the mystery of life. It is the primordial feeling in which all art and all true science originate. When one doesn't have such an experience, when one is no longer able to wonder at life, it is as if one were dead, as if the light in our eyes had gone out. The experience of the mystery even mixed with awe has given rise to religion. The little we know about an inscrutable reality – the manifestations of the truest reason and of the utmost beauty, which are accessible to human reason only in their most primitive forms – such knowledge and such an intuition nurture the true religious experience.[12]

While approving of such an attitude, A. Ganoczy looks at it with a critical eye. He is well aware that one cannot upgrade from a romantic vision of nature to the Christian vision, unless one is ready to go beyond pantheism.

> To conclude, I would put forward that it is possible to perceive a certain similarity between Einstein's actual or (alleged) pantheism – and Christian theology. I have in mind what he says about the

[11] Düsseldorf, Patmos Verlag, 1992.

[12] Quoted from Albert Einstein, *Mein Weitbild*, 1930. On that topics, see Max Jammer, *Einstein and Religion*, Princeton University Press, 1999.

> 'inscrutable' or the 'mysterious', which arouse in the scientist a religious attitude in front of the cosmos and which are constitutive elements of science (*op. cit.* p. 65).

3.2. *The Value of Mystical Language*

If religious feelings are part of the scientific approach, it follows that the mystical language is more than any other kind of language apt to account for it. A. Ganoczy's approach is a justification of the mystical language as a help to understand nature.

For him, the language of mysticism which is present in sciences is that of the spirit, which is above that of reason. He is very close to the kind of theology which interprets the passage in the Bible about Man having been 'made in God's image' in a way that is not limited by reasoning, or by the Cartesian project of making Man into 'the master and owner of nature'.

If it is through his spirit that Man-Adam is the image of God, then the conquests of science are 'divine works'. Biblical monotheism comes to terms with the demands of other religions – including 'the religion of science'.

As a matter of fact, the believer gets involved in the adventure of science in a fuller and better way than others:

> He who follows Christ Jesus and allows his Spirit to inspire his own motivations, cannot ignore nature, or divide it into two parts, as does the dualistic approach. But he does not have, either, to bury himself in the bosom of Mother-Nature, or wish he could dissolve into it in some sort of mystical trance, as though an adult being could crawl back into the original womb. In a Christ-centred perspective, or from a pneumatologic point of view, he is called upon to exercise his responsibilities towards nature, which for him is God's creation (*op. cit.*, p. 330).

The acknowledged confluence of terms used in quantum physics and the experiences described within those traditions, calls for a critical reflexion on the concept of Nature (with a capital N) – thus going back to the themes of Romanticism. Nature is endowed with a great power for renewing itself; it is a creative force, in fundamental physics as well as in biology.

3.3. *The Action of the Holy Ghost*

A third form of theological renewal, in connexion with the new science, can be seen in the way in which the Christian language introduces the theme of Trinity, in order to take into account the demands of a reference to the spirit or The Spirit. This theme is found in J. Moltmann who, in *Gott in die Schöpfung*,[13] proposes a theology which takes the dimension of science into account. He breaks away from rationalistic dogma and in a way, through the themes of ecology, joins the romantic tradition.[14]

J. Moltmann's theology insists on the Trinitarian dimension of the creative act, in which the Holy Ghost has a specific role. Through its very nature, the Holy Ghost affords the possibility of making the themes of transcendence agree with those of immanence, and of distancing oneself from deism (too much marked by rationalism) and from determinism (too close to the mechanistic pattern). Theology, thus, acknowledges the immanence of God in his creation:

> An ecological treatise of creation implies a new reflection on God. It will no longer center on the distinction between God and the world, but on the knowledge of God's presence in the world and the presence of the world in God (p. 27).

In order to develop his new theological approach, J. Moltmann challenges the notion of essential causality, dear to the determinist approach, which implies a long-distance of essential domination. J. Moltmann proposes a theology based on immanence, which makes sense at the interactive level, already discussed:

> The creation of the world is different from the causation of the world. If, by virtue of his Spirit, the Creator is himself present in the creation, then his relationship with the creation must be thought of as a complex network of unilateral, multilateral and reciprocal relationships. In such a network, 'to create', 'to retain', 'to maintain' and 'to accomplish' do indeed refer to the major unilateral relationships, but 'to inhabit', 'to sympathise', 'to participate', 'to accompany', 'to suffer', 'to rejoice' and 'to glorify' are reciprocal relationships, which represent a cosmic community of life between God, the Spirit and all his creatures (p. 29).

Such a theology of creation of the world extends into an anthropological vision, where the spirit of man and the Spirit of God are in communion,

[13] München, Chr. Kaiser Verlag, 1985.

[14] See John Jedley Brooke, *Science and Religion*, Some Historical Perspectives, Cambridge: Cambridge University Press, 1991; see also the acts of a symposium edited by Andrew Cunningham & Nicolas Jardine, *Romanticism and the Sciences*, Cambridge, Cambridge University Press, 1990.

non only under the species of grace, but also under the species of nature. The notion of conscience is the privileged locus for such an exchange, which can be understood from the viewpoint of the new patterns given by science:

> Such a conception of God within the creation in the form of creation in the Spirit makes it possible for one to consider creation and evolution no longer as contradictory concepts, but complementary ones. There is a creation of evolution, because evolution cannot be explained of its own; there is an evolution of creation, because the creation of the world is oriented towards the kingdom of glory and for that very reason, transcends itself in time. The concept of evolution must be that very reason, transcends itself in time. The concept of evolution must be understood as the fundamental concept of self-motion of the divine Spirit in creation (p. 33).

As one can see, the novelties of the scientific language have been introduced into the very heart of the divine mystery. Non only the approach to creation, but to God himself, at the most inward part of his being. Coming back ten years later to this new approach, J. Moltmann confirmed it:

> The Trinitarian God does not only face his creation, but enters it through his eternal Spirit, penetrates all things and communes with the creation by inhabiting it. Hence follows a new conception of the relationship between all things, which is no longer a mechanistic one.[15]

J. Moltmann's developments are not centered on these notions, but he utilizes them freely. Clearly, the language of science as based on the unpredictable and randomness is accepted by the theological discourse, even when it is not in direct touch with the sciences of nature.

Many more authors could be quoted from. As far as the activities of this Academy are concerned, the authors mentioned should suffice to outline the main lines of the subject.

4. Taking seriously the Contingent Nature of the World

Another dimension of the theological reflexion rests with the contingent nature of the world, which is now being addressed and taken seriously. It is a part of the new vision of the world, where scientists no longer talk of pre-

[15] Der Geist des Lebens. Eine ganzheitliche Pneumatologie, Gütersloh, Chr. Kaiser Verlag, 1991.

cision or lack of precision, but of determination or indetermination. What now lies in the foreground of all scientific debates, is the notion of contingence, which has a philosophical dimension. Contingence does not only mean fragility; in accordance with the new scientific vision, contingence appears as a possible way towards new approaches. This last point has been taken by theologians anxious to connect the natural order with the supernatural order and to give the latter precedence over the former.

Lutheran theologian G. Siegwalt has developments in that direction.[16] He devotes two volumes to the theology of creation in a huge dogmatic synthesis. For him, 'the doctrine of soteriology is the key to cosmology' (p. 57). The very close link between soteriology and creation is one of the most important aspect of this study, which gives to the word creation a specific theological meaning, based on the conviction that 'revelation [...] throws light on reality' (p. 175) because on the one hand it makes one look in the direction of a new creation (p. 117) and on the other hand, it gives the humanity of Christ a privileged place to express the meaning of the whole cosmology.

The fact that modern science has broken away from rationalistic determinism appears to him to be an opportunity to be seized, in order to give the Christian discourse its full dimension, without reducing it. The reduction of the vision of the world entailed by positivism is thus avoided. The breaking away from determinism makes it possible to liberate the spirit from materialism and G. Siegwalt can make room for the world of the Spirit. Theology insists on the meaning of the word creativity, which conveys the notion of the ability given by God to his creatures to find fulfilment. This gift is actual.

The author's prudent approach makes it clear that there can indeed be converging patterns between theology and the vision of the sciences of nature. A number of concepts can help bridge the gap between both disciplines – both regarded as ways to access reality.

Conclusion

To close this attempt at putting these theological questions in perspective, I would like to give my personal point of view on the subject – very shortly to respect the time allowed for my speech.

[16] Gérard Siegwalt, *Dogmatique pour la catholicité évangélique,* t. III, *Cosmologie Theologique*; vol. 1: *Sciences et Philosophies de la nature,* t. 2: *Théologie de la création,* Paris, éd. du Cerf, 2001.

1. In the first place, I am delighted to see that open-mindedness has prevailed over the rationalists' narrow attitude. But this doesn't go without some ambiguity. Particularly on two points, about which I have personal reservations. Fundamentally, the perspective offered tends to revive certain forms of monism. It seems to me that it is important to keep up fighting pantheism.

On the other hand, the new physics tend to encourage the merging of the language of mystical theology with that of science, as though they were identical: this is a confusing issue, because the difference between modern science and theology must be strictly maintained.

2. One thing can help ward off such the danger: the concept of incarnation (it is usually mentioned by theologians who are anxious to manifest the specificity of their faith in Christ). The word is used in its strict meaning by Christian theology in order to convey what happened to the Word of God, the *Logos*, the Eternal Son of God, who could not under any circumstance be identified as a force of nature.

Incarnation is not the emergence of a latent process in the evolution of the Cosmos. It is a breaking away from the old, a real innovation. The word implies that the otherness of God should be acknowledged. The transcendence of the Word of God is not abolished. The theme of incarnation emphasizes God's transcendence and the freedom of his acts. The Christian faith acknowledges the otherness of God. It is not repealed by the acknowledgement of his coming through incarnation.

3. This is why the attitude of science which is founded on otherness agrees with such an acknowledgement. Scientists do not seek to hold a religious communion with reality. They observe it, in order to understand it better, which means that they keep a distance from it and remain critical towards personal emotional attitudes. Such an attitude agrees with the attitude of Christian prayer.

As a Catholic theologian, I think we have to stay somewhat vigilant on this point. Vigilance does not run counter to the scientific spirit, quite to the contrary, it is a way of showing respect for its exacting fundamental demands.

DISCUSSION ON THE PAPER BY MALDAMÉ

SINGER: When I made my remark to say something, I was very much afraid that you were actually pursuing the point of view that was pursued by the people you were citing, namely that religion would now try to reconcile contradictions between the scientific procedures and belief systems by trying to explain the unexplainable by the unexplainable, like taking quantum physics in order to solve the mind-body problem. Now I see that you don't do this, and I am very happy that you didn't do this, because it's my firm belief that these two systems are orthogonal, and that theology or belief systems would not do what they should do if they tried to reconcile what is knowable through scientific approaches with what they know through their internal belief systems, *Offenbarung* in German, or *révélation* in French. This is what esoterism does, and I think it's a disaster, and there are many physicists, and I deplore this very much, who supply arguments to the esoterists to make their systems scientifically sound. So, a scientific foundation of the belief system would be a disaster, because believing starts beyond the rational explanation that science can give. But, as an example of how dangerous this can be, I may refer to our conviction as cultural beings that we are free in our will and in our self-determinism. This was certainly in conflict with the positivistic mechanistic world view of the nineteenth century, and is of course not resolved by quantum physics at all, because it simply replaces firm deterministic causality by a probabilistic process. But if our brain processes depend on probabilistic processes, then hazard plays the game, and not freedom. One replaces determinism by hazard, which is not a gain at all. This is just one example of the many pitfalls that one runs into if one tries to take scientific advances as they have been put forward in quantum physics to explain other mysteries. Quantum physics probably doesn't apply very much to the brain, because it's a warm, big system. This warning was written down before you came to your end, so I apologise, I just wanted to repeat that point because I consider it important.

GERMAIN: Yes, thank you. I think that is not a convergence between science and religious discourses. Je vais dire en français. Il faut séparer les deux languages, et si ils se rencontrent c'est dans une médiation philosophique, mais pas scientifique.

MALDAMÉ: The topic is: the frontier between science and belief; the more science can explain things like ontogeny or evolution, the less there is a need for belief systems to fill these gaps, so they can start to work beyond those frontiers and what happens is a continuous moving out of these frontiers beyond which belief systems are necessary, so there is a rephrasing, but it's not an incorporation.

SINGER: Yes, yes, I think so.

GERMAIN: Merci, Monsieur le Président. Je dois avouer que cette communication me cause un certain malaise. Je suis d'accord avec la conclusion, mais alors je me demande pourquoi le développement, qu'est-ce que le Père Maldamé souhaite nous faire comprendre, à nous Académie des Sciences, qu'est-ce que ça nous apporte? En particulier, pour parler d'une chose que je connais bien, vous avez cité le livre de Guitton en disant effectivement qu'il a eu un succès considérable. Bon, mais j'ai eu trois quarts d'heure de discussion avec Jean Guitton, c'est un livre terrible. Quand je discutais avec Jean Guitton, au bout d'un moment je lui ai dit: "Mais, cher Monsieur Guitton, où avez-vous pris votre image de la science?", et il m'a parlé de Platon, Aristote, Saint Thomas d'Aquin et puis Bergson, et encore de Maritain, Maritain que j'aime bien mais quand-même moins quand il raconte des choses sur la science. On pourrait discuter tout ce que vous avez dit, mais en conclusion, si j'ai bien compris la discussion avec le Professeur Singer, vous arrivez à un problème qui pour moi est central qui est l'unité de l'esprit, l'unité de l'esprit quand on est à la fois chrétien, vivant sa foi aussi profondément qu'on peut, et puis scientifique, mais on ne va pas discuter de l'unité de l'esprit à l'Académie des Sciences, ça me paraît déplacé. Je voulais simplement remarquer que j'ai éprouvé un certain malaise en tant que membre de l'Académie Pontificale des Sciences, et en tant que chrétien. La conclusion, alors là je me retrouve avec un certain nombre de choses, aussi bien avec par exemple des mots de Menon, et ce que vous dites pour la spiritualité du chrétien que je suis, cela c'est très intéressant, mais comment voulez vous que ce qui est intéressant pour moi puisse servir à la majorité de nos confrères qui sont là, comme moi d'ailleurs, pour parler de la science avec la société.

MALDAMÉ: J'ai fait état d'un certain nombre de publications dont le livre de Jean Guitton; je suis d'accord avec vous qu'il ne vaut rien au plan scientifique, mais ce livre a eu un très grand succès. Nous sommes attentifs à l'image de la science. C'est par rapport à cela qu'il me semblait qu'il était important d'être vigilants. Avec ce livre, on sort d'un certain rationalisme fermé, mais en même temps la manière d'en sortir est une confusion. Tel était le but de mon intervention, puisqu'on parle des valeurs de la science: montrer qu'il y a les valeurs de la raison, qui s'accordent avec une certaine dimension spirituelle. Jusqu'ici il y avait le désintéressement, l'objectivité, mais on a introduit au cours des derniers décennies de nouvelles valeurs spirituelles; il me semble important d'en faire une évaluation et que ceci fait partie, me semble-t-il, des travaux d'une assemblée comme la nôtre. J'ai cité bien des auteurs mais, comme vous l'avez bien compris par ma conclusion, ce n'est pas pour les approuver.

ZICHICHI: I would like to support your conclusion. Vous dites la différence entre science moderne et théologie doit être strictement maintenue. In fact, science is the most rigorous way of studying the immanent part of our existential sphere, while theology is the rigorous study of the transcendental part of our existential sphere. I'm sorry about my poor English. I can speak physics in English, but philosophy is different. However, it is very important to emphasise, and I agree with Professor Germain when he says he has difficulties, that the difference must be maintained despite the fact that great physicists like Pauli and others have tried to study the connection of the two spheres.

I think that the great mystery of our existence is exactly there: there are two spheres, one is transcendental; the other is immanentistic. Science is there, even if you speak about the new symbols, the new mathematics, the new rigorous strategy to understand the immanentistic sphere. Still whatever we do must in the end produce reproducible results, while the transcendental part is completely different, the two spheres are different. If you confuse the two spheres, sooner or later you reach the conclusion that science should prove the existence of God. This science can never do, because God is not science only, He is everything. When, in five billion years, the sun will stop burning – by the way, the sun will not explode, it has been said that it will explode but the sun expands, it does not explode, it's too light to become an explosive star, this has been said on other occasions, not by you – and will come where we are, the transcendental sphere of our existence will 100% be there. This is why we must keep the two spheres completely separated. You emphasise the extremely important point that we should not be influenced by great physicists when they speak about the transcendental part of our existence; they are not theologians. We must keep the two components strictly independent and try to see what conclusions we can draw. The fascinating aspect of our existence lies in exactly the fact that the two spheres are independent, and each one has its own laws. I repeat: in five billion years the immanentistic component of our existence will be completely different. The transcendental one will not be.

JAKI: Well, first a very brief remark. You quoted Eddington, 1927 (the year when Heisenberg proposed his indeterminacy principle), that religion for the first time became respectable for a rationalist individual or rational man. But you see, Eddington withdrew his statement, so here is a very factual defect of your presentation. And there are others, but I do not want to list those because we've not enough time. Then, for over two pages in your English text you speak about Moltmann and Siegwald, two theologians, but you never raise the question, you never investigate what is the scientific training of these theologians, and I strongly doubt the statements of anyone about science who doesn't have a serious training in science. Duhem, Pierre Duhem, whom you know well, already stated this one hundred years ago, and it fell upon deaf ears among Catholic theologians. Now, I would like to bet my bottom dollar that neither Moltmann nor Siegwald has as much as a Bachelor of Science in any of the hard sciences. Finally, and this is a very serious remark, excuse me, you are a dear friend, but my feeling was that if I ignore the last three lines of your presentation as a Catholic theologian and so forth, I think I am not entitled to conclude in an unambiguous way that the author of this paper was a Catholic theologian, let alone a priest, let alone a Son of Saint Dominique. One more thing from which your paper would have greatly profited, and this has already been indicated by Professor Zichichi, if you had paid attention to what Einstein said: 'When you deal with scientists, ignore what they write and what they say, and watch carefully what they do'.

MALDAMÉ: I have nothing to say about Moltmann and Siegwald, they are theologians, and they are well known as theologians.

JAKI: The question is their training in science, because they talk profusely about science, and this is what bothers me.

DE DUVE: J'ai écouté le Père Maldamé avec énormément d'intérêt. Je suis un petit peu déçu de constater que, comme la plupart des philosophes qui se penchent sur les relations entre philosophie et science, il établit pratiquement une équivalence entre le mot "science" et le mot "physique". Quand il parle d'une nouvelle vision de la nature, il nous parle de la vision de la nature qui nous a été donnée par Planck, par Heisenberg, par les physiciens. Or, je ne vais par répéter ce que j'ai dit hier, mais je crois que la biologie est aujourd'hui devenue beaucoup plus importante que la physique dans le message, je dirais, philosophique qu'elle nous transmet.

MALDAMÉ: Oui, je suis d'accord avec vous. Dans mon intention première je voulais aborder la question de la biologie, par le biais de la contingence, mais les limites du papier ont fait que je n'ai pas abordé la question. Mais je suis tout à fait d'accord avec vous; il y a eu un glissement au cours des dernières années qui fait que la science fondamentale pour notre vision du monde est passée de la physique à la biologie. Donc, j'avais l'intention de faire un peu la même chose, de relever la même équivoque à propos de l'affirmation bien connue que "la vie est sacrée", qui donne la même confusion.

MITTELSTRASS: Just a very short remark on your introductory remarks on reason and rationalism: I think you said that reason always insisted on being pure reason. This is certainly true, at least in a Kantian tradition, but did it always insist on being purely rationalistic? Blaise Pascal may pass as an example, but what we call non-rationalistic or even mystic could also be something like the incognito of reason, so pure reason and rationality is not necessarily the same, and I don't think that it has been the same in the history of science and philosophy.

MALDAMÉ: Yes, there a lot of things to be said about reason. I think that when I speak of pure reason I am thinking of Kant, and I think there is a lot of influence of Kantian philosophy on university work in France and in Europe. Personally, I think that there is no opposition in Pascal between science and reason, no systematic opposition, but factual opposition, and the movement of the Pensées of Pascal, is to use some physical or scientific concept in his apologetics. But it's another problem. But you are right, I can't say everything about reason. I taught in the university tradition, and the Kantian influence that was very strong in France.

CABIBBO: We now tend to consider Jung as a sort of mystic. Maybe at that time people saw him as a scientist, and maybe also Paoli would consider him as such. I mean, Jung and Freud were considered scientists in the past. I don't know what would be the present evaluation on the scientific standing of their doctrines.

THE MORAL SUBSTANCE OF SCIENCE

JÜRGEN MITTELSTRASS

Science and morals form an ancient topic. Plato and Aristotle had already connected the idea of science with that of morals – in the notion of what the Greeks called a good life, which had to have both a theoretical and a practical form. A theoretical life (βίος θεωρητικός) and a practical life (βίος πρακτικός) go hand in hand. When a practical life lacks a theoretical element it cannot recognise itself (*homo sapiens* without *sapientia*). And when science lacks a moral orientation, that is to say an orientation towards the good life, it remains senseless (a tool without an end). In such cases, a rational culture in which praxis is guided by theoretical considerations, that is to say in which praxis understands itself as being reflected, and in which theory is related both to practice and to life, could not come into being.

This idea of the interrelation of science and morals seems to have got lost along the long roads followed by science and ethics, and along the long road of reflection about science and morals. At least since Max Weber, the idea has taken hold that science is value-free, and that science is formed according to rules differing from those of morals. Conversely, many think that morality has no need of science, in that it is something radically different from scientific rationality. On the side of the sciences, there is also the view that this rationality of the sciences, above all of the exact and empirical sciences, constitutes the whole of rationality. It then follows by definition that any points of view which seek to constrain scientific practice, whether by reference to 'practical' or normative considerations, are in fact unauthorised points of view, or indeed ones damaging to science.

But this point of view is itself too radical, for it overlooks the fact that science is not value-free, as the Greeks had pointed out already, and that it rather has a moral substance. This will be taken up in the following under the rubrics 'Science as Idea', 'The Measure of Progress' and 'Ethos in the Sciences'.

1. *Science as Idea*

As a rule, the concept of scientific rationality refers to a particular *form of knowledge* and its production, that is to say to theories, methods and the special criteria of rationality to which theories and methods are subjected. Among these criteria, whose fulfilment represents a condition on knowledge- and truth-claims, are, for instance, the reproducibility and controllability of scientific results and procedures, the linguistic and conceptual clarity of scientific representations, the intersubjectivity and testability of scientific results and procedures, as well as methods of justification. If such criteria are abrogated, science loses its claim to objectivity and truth, so that science and opinion become indistinguishable. But this is only one meaning of the concept of science, although it is, from the scientific point of view, the most important one.

A second meaning of the concept of science is given by the fact that science is also a *social organization*, that is, the particular social form in which science is realised as a special form of knowledge formation. Here, we speak of science as an *institution*, for instance the university. The formation of science stands under particular socially defined conditions, among which we may include the pedagogical and research responsibilities of the university. Science becomes visible as an institution, even if only symbolically, when one thinks of the invocation of truth and of the spirit which earlier adorned the portals of our universities.

But the concept of science is still not exhausted by this second, institutional meaning. There is a third one extending beyond those of its theoretical and institutional characters. This can be illustrated in connection with the above-mentioned criteria of rationality. These criteria cannot be restricted to purely methodological aspects, especially if, following the sociologist of science Merton,[1] we add to them such criteria as disinterestedness, truthfulness, and organized scepticism, that is, the general invocation to criticise. On the contrary, these criteria connect scientific rationality to a *moral form*. With regard to this moral form, science is not only methodically enlightened rationality or a means to differentiate and stabilize the social organization of consumption and the satisfaction of needs, but it is also an *idea* that relates to the second nature of Man, i.e. his epistemic or rational nature, or, even more, a *form of life*.

[1] R.K. Merton, *Social Theory and Social Structure*, New York and London, 2nd ed., 1968, pp. 604-615.

This third meaning, which transcends everything methodological or theoretical and everything institutional, was once the essential meaning of science. Greek philosophy, to which we owe the theory-form of knowledge, spoke expressly of the *bios theoretikos*, the theoretical life, and not of theories that, in the sense familiar today, make up the contents of textbooks. *Theoria*, according to Aristotle, is a general orientation with regard to life; theory in this sense – not in the sense of our textbook concept – is one of the highest forms of practice.[2] The scientific or epistemological subject and the 'civic' subject are still one here, and therefore the truth-orientation of science cannot be played off against its social relevance and vice versa. With *theoria* as a form of life, truth also becomes a form of life, that is, according to the distinctions I have introduced, it belongs not to the methodological but to the moral form, and thus to the idea of science. In this sense both the work of Man on his rational nature and truth are moral. How does this express itself in actual scientific and social developments? Is what I have called 'the idea of science' also actual?

2. *The Measure of Progress*

Another fact that seems to speak against my suggestion that science has a moral substance, and that scientific rationality orients our life is the progress made by science, and in consequence by technology. For science seems to go where it wills. Furthermore, scientific and technical developments are inter-dependent. Progress in the one drives progress in the other, and vice versa. Progress in science and technology is, at its essence, *immeasurable*, excessive, or to put it differently: if there is an internal measure of science and technology, then it is that they exceed all measure. For measure means definition, or limitation, whereas scientific and technical rationality define themselves precisely through the provisional character of what limits they may have.

Still, that is not all that one can say. If scientific (and technical) progress has no internal measure, a measure which could of course be a moral one, then this means nothing more than that the limits of progress are self-imposed limits, and thus that the measure of progress can only be a self-imposed measure. The idea that the world, that nature itself has limits that cannot be surpassed by the scientific understanding, and that progress also

[2] *Eth. Nic.* K7.1177a12ff.

has a measure that delimits it from inside, does not in fact make sense. It is an idea that can be disproved at any time on both historical and systematic grounds. Thus the boundaries of progress do not lie at those points where they are evidently impassable, but rather where they *should* lie, in other words where Man decides that he may not proceed further. Self-imposed limits in this sense are *moral* or *ethical* boundaries. The same is true from the point of view of measurement. If there is a measure of progress, then it is not a 'natural' measure, but an ethical one. For it assumes an answer to the question concerning which forms of progress Man wants, and which he does not, that is to say which forms can be justified by ethical norms and which cannot. At least regarding his ethical nature, Man remains the *measure of all things*, just insofar as he resists assimilation by the world – not only in moral and political matters, but also in scientific and technical ones. And this is an idea that has attached to the concept of science from the very beginning, that is to say from its foundations in Greek thought.

Generally speaking, ethical problems in research and in science, problems concerning the consequences of scientific praxis and progress, are problems of *practical* reason, not of theoretical or technical reason. By this it is meant that in rational or technical cultures, the rational or technical understanding is not in a position to solve the problem of justified progress, or to respond to the demand for an orienting form of knowledge that goes beyond knowledge as a form of mastery. Already Max Weber claimed that 'All natural sciences give us answers to the question: What should we do, *if* we want to master life technically? *Whether* we want to master it technically, and whether that indeed makes sense – they leave such questions unanswered, or they assume [the answers] in pursuing their ends'.[3] Answering such questions is not the responsibility of science from Weber's point of view. But this just makes the problem concerning a form of practical reason that guides action, thus of a justified progress, all the more troublesome. Science has acknowledged this itself, and has indeed regretted the weakness of practical reason. As Albert Einstein observed in 1948: 'The tragedy of modern Man lies in the fact that he has created for himself existential conditions that are beyond the capacities given him by his phylogenetic history'.[4] Put otherwise, the drives of the subcortical structures are

[3] M. Weber, *Gesammelte Aufsätze zur Wissenschaftslehre*, ed. J. Winckelmann, Tübingen, 3rd ed., 1968, pp. 599f.

[4] A. Einstein, *Über den Frieden: Weltordnung oder Weltuntergang?*, ed. O. Nathan/H. Norden, Bern 1975, p. 494.

stronger than the cortical control. One might well ask in this situation whether science, in its freedom of research, still bears responsibility for what it does and what it affects.

Freedom and responsibility are difficult concepts not just in the context of science and research. They are among those that everyone has on their lips and some in their hearts as well, even if they do little more with these concepts than to apply them rhetorically. We know that freedom of research or freedom of science is written into the programme of the enlightenment and into many modern constitutions, that research and development serve social purposes, and that responsibility is one of the virtues of a citizen in a democratic society. But it remains difficult to state more precisely what responsible freedom of research or science *are*, and where they begin and where they end.

In the case of science, the problem begins already with the fact that freedom of research or science means on the one hand freedom of the *scientist* and on the other hand freedom of the *institution* of science. The restriction of the one freedom is often justified by the claims of the other: Since the institution of science is losing its freedom increasingly to the state – so say the scientists – the personal freedom of the scientists must be all the more unrestricted. Since the freedom of the scientist is claimed and exercised without restriction – so say the governmental administrators – there must be regulatory influence of the state on institutional affairs. This seems to mean that it is no longer possible to take both the freedom of the scientist and the freedom of the institution of science together. Wherever the one is exercised without restriction, the other must accordingly be limited.

But this surely involves a misunderstanding, one which indeed occurs whenever one fails to make an adequate distinction between freedom and arbitrariness. Often the social good of the freedom of science deteriorates into mere whims on the part of the scientific actors, namely the right to do what they like. Concepts like justification and (social) responsibility seem in the minds of many scientists to belong to the vocabulary of the unfree. But this is mistaken. Freedom, rightly understood, is always *responsible* freedom, otherwise it is arbitrariness. Consequently, both freedoms, the freedom of the scientist and the freedom of the institution go together. Freedom of science understood as a boundless subjective freedom of the scientist is unacceptable from the point of view of science because the old Humboldtian ideal of research in 'solitude and freedom' cannot be demarcated effectively enough against misunderstandings of unbounded scientific subjectivity. Even genius, which in scientific affairs is not nearly so common as scientists like to think, does not justify expansion without limit. This holds in science as well.

So much for the concept of freedom of research. The concept of responsibility with regard to this freedom still remains to be discussed. In fact, wherever a claim is made to freedom of research or science, this freedom must be related to structures of responsibility. This leads us then to ethical or moral arguments. What I mean is again that the usual distinction between science as a particular form of knowledge formation and science as an institution is not exhaustive. This has been made clear by norms which, serving as criteria of scientific rationality, are above all practical, as opposed to theoretical, in kind. They are aimed at superseding mere subjectivity. Scientific states of affairs are strictly speaking *inter-* or *trans-subjective* states. Not in the sense that scientific subjects disappear, but in that they are distinguished by a morally determined generality of scientific norms such as those mentioned. Those who do not subordinate their work to these norms, which are not purely methodological norms, not only overstep the bounds of scientific rationality, but they also overlook the normative lines that connect scientific work with the life-world. Science has not only a *knowledge*-task but also an *orientation*-task. It has a cultural meaning.

3. *Ethos in the Sciences*

In this context, the notion of a scientific ethics is a popular topic of conversation these days. It is supposed to counter the suspicion that not all is well with the ethical bonds that once held between science and society. One hears more and more talk in connection with the sciences about arrogance and immoderation, indeed even about treachery in the ranks. Science's supposedly divine nature has evidently given way to quite human urges.

On the other hand, there is much evidence that the expectations directed towards an 'ethics of the sciences' and to its realisation are too great. It may even be that the call for such an ethics may lead us in the wrong direction, at least in so far as one thinks of an ethics of the sciences as a special ethics *for scientists*. There cannot be such a thing, for the simple reason that an ethics is always an ethics of the *citizen*. It cannot be divided along social lines, that is to say in a scientific ethics which is the ethics of the scientists, and a non-scientific ethics, which is the standard ethics of society as a whole. And the same holds for morals. There are, strictly speaking, no closed ethical or moral worlds, in each of which a single ethics or set of morals holds sway.

This objection is directed not only at the exaggerated hopes for an ethics of the sciences, but also at the idea that the scientist has more responsibilities than the average citizen. A scientist does of course have a special responsibility, which derives from the essential uncontrollability of scientific knowledge by extra-scientific knowledge, as well as from the dependence of modern society on the special competence of the scientific understanding. However, this special responsibility does not translate into a special ethics. What is needed is rather a better *ethos*, as for instance has long been the case with the socially realised professional ethos of physicians. All rules, all norms which one might like to prescribe to the practice of science in order to strengthen the responsibility of science and of scientific rationality, are superfluous once we have such an ethos of the scientist and once it is in fact observed. Of course that it is in fact often not observed is obvious enough. But that doesn't mean that an ethics of the sciences has failed, or that it must be improved, but rather that the norms of general, civic ethics, were violated, and the ethos of the scientist was violated by base personal motives. I suspect that there is little more that can be said about the ethics of the sciences, except perhaps that the attention of science as an institution towards the observance of the scientist's ethos should be more strongly enforced in the future.

As an example of this sort of institutional attention we might take a so-called 'code of conduct' published in 1998 by the German Physical Society (DPG). Here we may read that 'Every member is also a member of the community of scientists, and shares in their special responsibility towards coming generations. The members support the development of science. At the same time, they acknowledge and respect the fundamental principle that holds for all science in all countries, namely that of honesty towards oneself and others. The DPG condemns scientific misconduct and disapproves both of fraud in science and of the deliberate misuse of science'.[5] Clearly enough, notions deriving from a general civic ethics are being translated onto science and the special circumstances of scientific practice. These rules do not constitute an ethics of the sciences in a distinct sense.

Rules such as these, which science imposes upon itself in order to tie its freedom to some ethical measure, sound like rules of reparation. They hint dimly at some forgotten scientific ethos which conceived of science as an idea and a form of life. Indeed, the ethos of science has today lost much of

[5] 'Verhaltenskodex für DPG-Mitglieder', *Physikalische Blätter* 54 (1998), No. 5, p. 398.

its effectiveness, and thus also its subjects. However, to the extent to which it has become unrecognisable, it has also lost sight of society and its relation to science. The crisis of confidence that has grasped hold of science is also an ethical crisis, a crisis of a scientific ethos. Thus it is of utmost importance to overcome this crisis that science is itself responsible for.

In this connection I would like to draw your attention to three arguments, which on the one hand explain why it has come to a crisis of confidence both with and within the sciences, while at the same time making clear what must be kept in mind in the future.[6] Among the causes of this crisis of confidence is first of all an increasing 'scientific incompetence' on the part of society, of which science is of course a part, by which I mean the inability to understand the production of scientific knowledge. A second cause is the 'desymbolisation' of science, which has not led to 'emancipatory progress', but rather to a loss of 'ethical self-consciousness'. Third, there has been increased competitive pressure, that is to say an uncritical importation of the market model into the practice of science. Here it is largely a question of reversing this trend whenever possible by appeal to the forms of (social) interaction that are specific to the sciences, and which speak against using an economic paradigm, or indeed using a 'professional code' of 'institutional procedures'.

These are indeed essential factors in questions of confidence and ethics, and yet, in the final analysis, it is a matter of most importance to bring back a scientific ethos to scientific consciousness. We understand under the notion of an ethos an orientation towards largely implicit, and implicitly observed rules, which are conceived as holding self-evidently both for individual and social actions. Whether we conceive of these rules as the simple rules of conduct to which one usually holds (rules of etiquette), or whether they are rules to be evaluated morally or ethically, such as maxims – in both cases it is a matter of implicit knowledge. And this knowledge demands being followed practically rather than being theoretically mastered.

The connection between an ethos, morals and ethics would then be the following. Ethics is a critical theory of morals, which is above all concerned with regulating institutional morals that are often in conflict with one another. That is to say with regulating socially implanted systems of rules of action and goals by evaluating them and deciding among them by

[6] C.F. Gethmann, 'Die Krise des Wissenschaftsethos: Wissenschaftsethische Überlegungen', in: *Ethos der Forschung / Ethics of Research (Ringberg-Symposium Oktober 1999)*, Munich 2000, pp. 38f.

providing the arguments that permit decisions. These arguments must in consequence be generally valid, and so the corresponding ethics must itself be *universal*. This means in turn that it makes universal claims of validity, and that it must be in a position to ground these claims. Kant's ethics provides an example of such a universal ethics. An ethos is, on the other hand, a part of morality, and thus of a universal morality when the latter is characterised by a universal ethics. Here, an ethos relates to a universal conception of ethics, that is to say it 'represents' the latter's claims to validity, or indeed it realises them.

And just this is the case with science. For science is the expression of universal claims to validity, and this both in the sense of being a special form of knowledge formation, that is to say of the scientific formation of knowledge, as well as in the sense of being a scientific ethos, which is also the moral form of science, as I stressed in my opening discussion. The orientation towards truth typical of the one of these follows the orientation towards truthfulness of the second. That is to say, quite simply, that *truth* determines the scientific form of knowledge, whereas *truthfulness* determines the moral form of science, which as a result belongs to the form of life of the scientist, to his ethos.

Our task for the future is thus to make these connections explicit in the practice of science, and to ensure that we act in accordance with that explicit knowledge. For if this cannot be achieved, then the crisis of confidence into which science has fallen – deservedly and undeservedly – will continue. This will in turn threaten not only the foundations of science, but also the foundations of rational cultures in general, that is to say of modern society. The question concerning the ethics and the ethos of science is therefore not merely a question concerning the future of science, but also one concerning the future of our society, concerning that of our culture.

DISCUSSION ON THE PAPER BY MITTELSTRASS

ZICHICHI: Professor Mittelstrass has raised a very crucial point which is at present extremely interesting for the future of science: the responsibility of science. If science is the study of the logic of nature, in so far as you study the logic of nature, you should do whatever you want to understand nature as quickly as possible. It is not an accident that in four hundred years we've understood far more than anybody else did during the previous ten thousand years. So, we must clearly distinguish science from technology. Science has only one responsibility: to prove that it is worth being as we are. We are the only type of living species able to understand nature; there is only one such species. This is the one we belong to. We can reach this conclusion thanks to science, which is only for man, never against.

Technology, however, can be for and against man. Professor Menon raised a very delicate point which was also raised in previous days about Rasetti. I totally disagree with those who agree with Rasetti, because as it happens I was young enough not be involved in any of these dramatic suicide attempts of Europe, but not too old, in such a way that I could meet practically all the members of the Manhattan Project. They were terrified by the fact that the Hitler project for the nuclear fission bomb would arrive first. So, they were morally justified in doing what they did. Who knew what was going on in the Nazi project which had started three years earlier? A great advantage. So, I think that when we speak about technology we should be more linked to the historical events. Our fathers of the Manhattan project tried to help humanity not to be the slave of a crazy man, a criminal like Hitler. So, with regard to the Manhattan Project, I've great respect for those people who had the courage to commit their brains to being as successful as possible.

The technology for man cannot be judged just on the basis of some *a priori* definition. And I have personal experience on the topic. Once I was involved in an experiment, and in order to prove something it was necessary to devise a system to invent a gadget which was ten times more powerful in time measurements than all previous gadgets. Professor Weisskopf, who was the Director General of CERN, decided not to patent this invention. Then it was used for military purposes. Am I responsible for this? No. I was trying to see if nature obeys some logic, because at that time there was a big crisis, nuclear anti-matter was not found by other experiments at the level of 1 part in 10 to the 7, and we found it at 1 part in 10 to the 8. So, even the technological inventions which later have military implications are not the responsibility of the poor guys in their lab trying to understand the logic of nature and being generous in not patenting anything.

The topic that you've discussed is extremely relevant today, and therefore I would urge you to convince as many people as you can about the fact that science is the study of the logic of nature, and has no implication whatsoever. Technology can be for man and against man, but even the technology which could appear at first instance to be a responsibility with a negative sign can turn out to be in fact the other way round.

BERTI: I'll try to defend Max Weber's conception of science a bit as well, because it is true that Weber said that science is a free value, but he also conceived science as a form of life, as a profession, as, in German, a *Beruf*, and this implies a set of ethics and some rules, and when he said that science is a free value he meant, I suppose, that the judgements given by science are not judgements of value, but judgements of fact, they are descriptions of the facts, of a reality, and in this sense I think that they are free from values.

MITTELSTRASS: I think I agree. It was not my intention to attack Weber at that point, but what I wanted to say is that Weber was not only talking about science in the strict sense – he was also talking about the social sciences and the humanities, so, talking about value-free procedures and results is not enough. This cannot mean that science has no contact with the realm of responsibilities and values, with culture in general. I don't know whether the distinction he made between science, its procedures, its results and society using these results is a clear distinction. I have my doubts. But this was not an attack on Weber but the hint that this cannot be the last word – the statement that science is value-free.

SINGER: I'll try to be brief. I think the Manhattan example is a poor example, because the main scientific discoveries had been made. It was an engineering problem; the Manhattan Project was an application problem. What I would like to have your opinion on is whether one can't also formulate the necessity of science more positively, seeing it as a moral obligation, because if humanity decides to interact with its biotope and its future, then I think it follows that there is a moral obligation to try to know as much as possible before one acts. So, science becomes not only a necessity, it also becomes a moral obligation. We are condemned to know if we want to act with responsibility, and therefore there must be unrestrained search for knowledge. Application is something else.

MITTELSTRASS: I agree. I mean, mankind wouldn't have a future if we didn't invest in science, in research. What I wanted to stress is exactly that science also in this respect is not only a means, it's also a purpose in itself.

CABIBBO: I wanted to say something more about Rasetti. I think his choice was correct, but maybe also the opposite choice of other people was correct. I think he gave an example of peacefulness. Of course he also had a particular problem because he was an Italian citizen in the United States, in Canada and, although he didn't like Fascism, he probably didn't want to work on a weapon which could be used against Italy, perhaps that was part of the problem. Finally, I recall the fact that when he came back to Rome in the early 70s he helped develop a very practical, in the end, gadget to measure the density of plasmas, ionized gases, which could have applications outside the peculiar scientific investigation that he was interested in. I think he had no problem with that. So, in the case of Prof. Zichichi, I recall that he invented this chronotron to measure the muon lifetime. I mean it's unavoidable that what science does will be used by someone else later on, but it's a wider problem. To do nothing because of the dangers of this fact would be to do no science at all.

RECONNECTING SCIENCE WITH THE POWER OF SILENCE

THOMAS R. ODHIAMBO

The three epochal revolutions that have involved the dominant societies of the world in the last four centuries – the Industrial Revolution from the early seventeenth century, the Electronic Age from mid-twentieth century, and now the prevailing Information Age – have catapulted the human family into new configurations in unprecedented ways never foreseen before. In each case, scientific discoveries, momentous technological innovations, and singular entrepreneurial talent have come together to re-direct human endeavour along paths rarely trodden before. The Industrial Revolution led to the emergence of massive industrial labour concentrating in large factory towns and cities, thus abandoning the countryside to commercial chemically-oriented industrialized agriculture, and the wanton rape of the biosphere for self-interest, profit-making business. The Electronic Revolution led to the emergence of a burgeoning consumer society, and the uncovering of a global entertainment, popular culture. The Information Revolution is currently characterized by borderlessness, the creation of new employment patterns, and the phenomenon of the flexible working place and frame.

For 10,000 years, farming dominated society. This has changed dramatically other than the tropical developing countries of the world, the share of the farm sector to the gross domestic product of the industrialized countries is currently down to a mere 17%, where 90 years ago it was a dominant 70%, and the farm population is now tiny. Manufacturing is today going through the same diminishing scenario. The Information Age is on the ascendancy: for instance, information-dense products, such as education and healthcare, have five to six times the relative purchasing power that manufactured goods once commanded half-a-century ago [1].

The contemporary world is facing a seismic challenge in how to manage modern technology. The latter has today reached the capability to measure actual chemical events at the atomic level in femtoseconds and is, at the same time, treating life as a tradeable commodity. The globalized marketplace has substituted the *consumer* for the *citizen*, and is fast consigning the concept of citizenship to the container of fading, old-fashioned human sociology. The crucial question is whether there exists at this juncture of human evolution a will and an intention to govern and manage the scientific endeavour of discovery and innovation within a God-centered environment of universal truth and wisdom, of honesty and peace.

The contemporary scene seems to depict the process of scientific discovery and technological innovation as a mindless robot having no morality computer chip to guide its actions vitally important in the societal arena. Indeed, a 1998 survey by the University of Georgia showed that the great majority of scientists in the United States (93% to be exact) are either atheists or agnostics; whereas, for years, Gallup polls have shown that over 90% of ordinary Americans profess a belief in God [2]. The conclusion is dramatically clear: that the scientific community, by the manner in which they do things scientific, have by and large taken a different path to that taken by the great majority of humanity in the search for their wellbeing and wellness.

This situation, prevalent in the scientific community, is not a surprise. It is becoming clear, through social science research that through our assumptions, the topics we select, and especially through our choice of questions, we largely create the world we subsequently discover. We seem to live, each one of us, in our various worlds that our enquiries create. Thus, humans evolve in the direction of what they most persistently and genuinely ask questions about. Questions, in this sense, do more than gather information: the questions that we, as a group, ask consistently focus attention and direct energy toward that focus, thereby structuring what we subsequently find. What we find becomes the new starting point for our conversation and dialogue. And the results then constitute a platform from which we make sense of the world around us, narrate and imagine, speculate and theorize, and then create our future together emotionally, conceptually, and spiritually. As it happens, scientific enquiry in its modern practice over the last few centuries, through its conceptual scientific methodology of observation, study, and experimentation, has strictly limited itself by design to investigate and interrogate only those issues that can be validated by observation, that can be measured, and that can be counted. This material-centered path to knowledge is extraordinarily successful; but it is constricting, and shuts out questions that go beyond the material realm.

It is clear, then, that science as we know it at present, progresses only, first, through the acute use of the entire sensory capabilities of the human being – observing, counting, and measuring – and, second, by the use of reason and the human being's capacity to analyze the collected data in relation to a hypothesis as to how things work in this physical dimension. Thus, *science* is about revealed genius, and talent, and skills; it is about connectedness, and about knowing what is current and gone before; it is about endeavouring to know about the unchartered waters of the yet-to-be-known; and it is about understanding this novel aspect in relation to what we had conceived as our framework understanding. On the other hand, *spirit* is about worthiness – about revealed wisdom and knowledge, about righteousness; it is about connectedness and sharing, about forgiveness and love; it is about knowing God. The two, science and spirit, are not mutually exclusive, as *both deal with truth and knowledge*, and *both depend on connectedness and sharing* as their foundational underpinnings. The two, however, differ in a seemingly irreconcileable way by the current scientific methodology, which insists on the validation of scientific knowledge that is testable by objective observation and experimentation.

Yet, we need to understand that the great majority of the world's people do not consider themselves merely as material, physical beings, responding to material exigencies and physical circumstances, and coming to know the world only through their physical senses and reasoning. This majority view themselves as spiritual beings, with the soul, the intellect, and the mind constituting the very basic essence of their life and being. In this view, then, the physical body and its physical apparatus (including the brain and its nervous and sensory systems) constitute the spiritual essence's crucial embodiment for the physical manifestation of the outputs of the non-physical, essentially spiritual activities of the soul, the intellect, and the mind. *Intuition*, *revelation*, and *non-physical vision* then become a significant channel for instant knowing and comprehensive understanding. Thus, this great majority of the world population is as much concerned with spiritual and moral wellness as with material wellbeing [3].

The scientist, in consequence, neglects this visionary, revelatory, and intuitive source of knowing and understanding at his own peril. Indeed, one can state almost categorically that what singularly defines the human experience is this transcendental component of the gathering mechanism for human knowledge and wisdom. It is what unlocks the creative capacities within human consciousness and, therefore, undergirds human self-dignity [4].

The apparent dichotomy between the rational (mostly science) and the sacred (largely spirit), and between reason and faith, is artificial. Reason and faith are complementary tools: they enable society to apprehend truth – a more comprehensive, all-dimensional truth. Science and spirit mobilize, into their own particular sectoral operations, both reason and faith. What the human world now needs is a new complementarity in human knowledge and in the perpetual search for truth and wisdom – an innovative new synthesis that draws upon both the scientific method for knowing and understanding and the explicit acknowledgment of instantaneously knowing and understanding accomplished by way of intuition, revelation, and non-physical vision as we design our experiments and scientific observations, or as we explore the underlying purposes in our lives and in our society. The contemporary dominance of a material-centered worldview is an impoverished view of a more abundant holistic reality, which encompasses the spiritual and the transcendent as well.

The operations of science are predicated on predicted observation, induction, the elaboration of a hypothesis, the employment of reasoning, and the testing of predictions based on the hypothesis. These same elements are also present in the operations of spirituality, except they operate in different configurations and at a different level of rigour. On the other hand, science too is built on elements of faith, especially faith in the regular order of nature, and the capability of the human mind to explain the workings of this natural order – even if that order is self-organizing. Consequently, science and spirit are truly complementary sources of knowledge and understanding – and both need to be interrogated for a more wholesome, comprehensive corpus of knowledge and wisdom.

The question arises as to how we can manage and make sense out of the estimated 60,000 thoughts that we experience each normal day of our lives.

The Nature of Silence

When one turns from the external world of a myriad sensory inputs arising from the entire sensory apparatus comprising sight, hearing, smelling, tasting, and feeling, and the equally myriad brain functions of managing and manipulating these enormous sensory inputs every millisecond of our being alive and awake, and instead turns inward into our own psyche, one then opens up the mind space of inner thoughts and human consciousness. This is a different realm, an often unused dimension – an inner space for silence and contemplation – which can only be attained by totally quietening down the outer tumult of sensory inputs, and their receipt and manipulation by the brain. This inner quietitude, this silence of the mind, is the opening key to the soul, and its connectedness to God.

The attainment of deep silence in our inner being requires a great deal of practice. But when accomplished, it opens up a whole new dimension to one's being – that of our foundational transcendental nature, that of being at peace with ourselves, and that of knowing that our true power and wisdom comes, at its most basic, from our soul-ness. Indeed, the capacity to introspect is the hallmark of human consciousness – and therefore of the most primary element of human nature. It is in this light that reconnecting science to this capacity to introspect – this deep silence which is the fundamental result of conscious introspection – becomes our responsibility as scientists, to evoke in order to be transcendentally powerful in our day-to-day work as scientists. It has been the selfsame message of many spiritual teachers across the millennia, as Jesus encapsulated this message of power so dramatically in these words [5]:

> Then Jesus told him [the congenitally blind man he had just healed], 'I have come into the world to give sight to those who are spiritually blind and to show those who think they see that they are blind'. The Pharisees who were standing there asked, 'Are you saying we are blind?' 'If you were blind, you would not be guilty', Jesus replied. 'But your guilt remains because you claim to know what you are doing'.

This inner spiritual authority, this deep silence, provides the accomplished introspector with the power for decision-making and self-knowledge, because of its direct connectedness to God. The introspector no longer has to rely solely on the externally-sourced information derived from the sensory panoply. It is no wonder that when the famous nineteenth-century physicist of electromagnetism fame, James Clerk Maxwell, lay in bed in Scotland terminally ill in 1879, the Reverend Professor E.J.E. Hort who went to see him quoted Maxwell as making this profound statement [6].

> What is done by what I call myself is, I feel, done by something greater than myself in me.

Maxwell had 'constructed major bridges to the future, but could only speculate about the nature of the land that lay beyond' – and he knew it and savoured it in his death-bed statement [6].

Or savour this legend of the genre of evening camp-fires, about Friedrich August von Kekule, a German chemist who in 1805 was puzzling over the structure of a newly discovered compound which contained six carbon atoms and six hydrogen atoms in a manner that it still respected the conventional rules of chemical bonding. The answer, so the story goes, came in a dream, as he was dozing in front of the fire. He saw a vision, of two intertwined serpents biting each other's tails. He promptly awoke; and realized that the novel molecule – what later became known as *benzene* – was a hexagon, with alternating single and double bonds. It is this quality silence, of being alone with one's inner space of spirit, that often leads to leaps of imagination, of innovation, and of discovery. Giant steps in scientific advancement are so replete with these stories of vision, of revelation, of intuition, that the scientific community must now transparently take it as a faithful way of leading to truth, to knowledge, and to wisdom – but by further subjecting such flashes of genius to experimentation and rationalization.

Our manifest problems are within – the way we have neglected the mind and the intellect, and the way we have forgotten that our fundamental selves are in reality constituted in the soul. All of these three entities (soul, intellect, and mind) are singular; and they are what characterizes human uniqueness in the universe. Our theories of evolution and genetic inheritance deal with the physical body; they have not as yet confronted the living reality of the mind, the intellect, and the soul – because we have not yet conceived how to scientifically study the spiritual, transcendental essences of our existence and life. The physical study of the body, and the heart, and the brain – the speculation and thorough investigation of which has occupied human attention for the last 6,000 years or so – is the easy part of our coming to know the physical part of ourselves. The hard part should now be the next stage of knowing ourselves – the understanding of the mind, the intellect, and the soul – all devoid of physical reality, and without a physical locus. How to make a study of these non-physical realities is a major question to settle first. But what is abundantly clear is that the conventional scientific methodology will not do it. For a start, it is impossible to be an objective observer of the three essences outside of our own mind, intellect, and soul: self-examination and self-observation will necessary be part of the study platform. A second concern is whether to sever, for the sake of research, the overarching connectedness of the three essences with the three homologues in other human beings, and the three essences' connectedness with God.

And, third, there is the concern of whether we can fashion a reference point – a sort of benchmark – for this study, or whether we are looking for another special relativity in the investigation of these transcendental elements. These are all momentous uncertainties; and we need to settle them, as we seek deeper into understanding ourselves, our innate connectedness with ourselves, and our relationship with the springwell of knowledge and wisdom.

We are currently wallowing in the Information Age, fueled by the incredible advances in digital information and communication technologies, as well as the epochal progress in bioinformatics through the unraveling of the human genome and its impact on the unraveling of the genetic information written into the genomes of other living non-human beings. But when we start to engage in the serious study of the three transcendental elements of humanness, employing new tools well beyond the 400-year-old scientific methodology, then we will truly be knocking on the door of a new epoch – *the Age of the Mind*. We will thus be transiting well outside the contemporary Information Age, and other earlier Ages (Agrarian, Industrial, Electronic) which were all dominated by the overwhelming reality of materiality and physicality. Then, human beings can truly characterize themselves as not what we are physically, but in what we think, what we imagine, and what we create.

Thought is central to the concept of culture. Frantz Fanon in his book, *The Wretched of the Earth*, has said it very well, avoiding to make a national culture congruent with a national folklore [7]:

> A national culture is the whole body of efforts made by a people in the sphere of thought to describe, justify and praise the action through which that people has created itself and keeps itself in existence. (Page 88).

The scientific practitioners cannot continue to artificially keep science and spirit separate in opposing domains. The search for the knowledge and understanding of nature, including the universe, must now reach beyond the physical reality into the transcendental reality, by adopting a new path that goes outside the strictly conventional scientific methodology. The scientific methodology has served us extraordinarily well in the last three centuries; but it is now beginning to stultify itself into a dogma.

This search for a novel methodology is a daunting assignment. We, daring scientists, can only say with the Reverend Martin Luther King, 'I have a dream…'.

FURTHER READING

1. Drucker, P. (2001) 'The next society'. *The Economist* 361 (8246): 3-5.
2. Center for Science, Policy, and Outcomes (2002) 'Living with the genie: Friction and fulmination'. *Static* 1(1): 3.
3. Cooperrider, C. and F.J. Barrett (2002) 'An exploration of the spiritual heart of human science enquiry'. *Reflections* (The SoL Journal) 3 (3): 56-62.
4. Institute for Studies in Global Prosperity (2000) 'Science, religion and development: Some initial considerations'. *One Country* 12 (3): 2-3, 15.
5. The Catholic Living Bible (1976) John 9:39-41. Wheaton, Illinois, USA: Tyndale House Publishers, Inc.
6. Seitz, Z.F. (2001) James Clerk Maxwell (1831-1879); Member of APS 1875. *Proc. Amer. Philos. Society* 145 (1): 1-44.
7. Fanon, F. (1978) *The Wretched of The Earth*. London: Penguin Books.

DISCUSSION ON THE PAPER BY ODHIAMBO

LÉNA: I just have one question for you. Could you give one example of any field of science where you would imagine this change that you are proposing?

ODHIAMBO: As far as my immediate concerns are involved, one is what is life. We as biologists are studying living things. We are not really studying life. We don't know what life is. I think that we have to characterise what we really mean by life, that's one. Another is, I think, quantum mechanics, that whole field is where you can really begin to have an interface between the physicality of what we normally observe and talk about as scientists and the essences that I've been talking about. But there may be many more, and I am willing to discuss them.

TOWARDS A CULTURE OF SCIENTIFIC EXCELLENCE IN THE SOUTH

MOHAMED H.A. HASSAN

It is indeed an honour and a pleasure to be here today to speak before such a distinguished group of scientists and scholars. The Pontifical Academy of Sciences is a unique institution bringing together the world's most eminent scientists and scholars – here at the spiritual centre of Christianity – to examine some of the world's most critical social and moral issues. One rarely has an opportunity to examine such deep and complex problems in such a serene, yet rarefied, atmosphere. For this I am deeply grateful.

The theme of this plenary session – 'The Cultural Values of Science' – has assumed even greater import in light of the events of the past year. The rise of religious extremism in a number of countries represents not only a challenge to these countries but to the entire world – threatening to create an enduring barrier to the prospects for global peace and harmony. At the same time, unprecedented advances in science and technology – first in physics and, more recently, in biology and chemistry – have drawn science and cultural values closer together in a difficult but enlightened debate over fundamental principles concerning nothing less than the meaning and sanctity of life. No genetic scientist can blithely ignore the ethical dilemmas posed by biotechnology, just as no religious authority can turn a blind eye to the potential for healing that this technology could bring to hundreds of thousands – indeed millions – of people suffering from such chronic, often debilitating, diseases as diabetes and malaria.

These are some of the reasons that the topic of my presentation, 'Towards a Culture of Scientific Excellence in the South', is such a critical yet complex issue for all of us. It is a topic that poses far-reaching ethical and cultural concerns. It is topic that has become more, not less, critical with each passing day. It is a topic that sheds revealing light on practical issues that extend well beyond intellectual fora like this one. And it is a topic that carries important implications shaping the real lives of people throughout the world, especially in the developing countries. After all, I am sure that we all agree the developing world will not break out of its unending cycle of poverty and material deprivation unless it embraces a culture of excellence in science and technology.

The truth is scientific innovation and traditional cultural values must be considered partners, not adversaries, in the South's quest for a better future. Unless common ground is found between the world of spirituality and the world of science, countries throughout the South will continue to be marginalized.

For the developing world, the search for common ground is not simply a matter of intellectual curiosity and debate; it is a matter of survival and material well-being.

While some fanatics have led others to believe that religion and science are at odds with one another, history tells us there need be no contradiction between religious fervour and scientific excellence. Embracing one does not lead to a rejection of the other. There are numerous examples of eras when science and religious beliefs stood as twin beacons of understanding, intensifying the light that was cast on God, nature and the place of human beings within the order of the universe. Let me cite two times and two places both very different from one another. One that occurred a thousand years ago and is now largely forgotten (at least until recently); the other unfolding as I speak. Both serve as primary examples of successful marriages between dedication to religious values and the pursuit of scientific excellence that served not just their societies but the entire world as vital, reinforcing sources of change, which at their best brought all of us closer together.

The first example comes from the Islamic world.

More than a thousand years ago at the height of global influence, the Islamic world represented the most dynamic force on earth, spreading its influence throughout north Africa, east Asia and southern Europe. It was a world marked not only by conquest but also by fine art and literature, respect for the glories of Greek and Roman antiquities, breathtaking architecture and design, and an unquenchable thirst for knowledge that found expression in an extraordinary range of learning, research and teaching. Indeed it was a time when virtually all of the world's greatest names in philosophy and science came from the Islamic world, including:

– Al-Khwarazmi (780-850) whose book on mathematics gave birth to the word ‘algebra’ and whose accomplishments are commemorated today in the name of one of the most fundamental tools of mathematics, ‘algorithm’.

– Followed by El-Farabi (878-950), a philosopher second only to Aristotle in the Islamic world in terms of the respect and influence that he exerted on thought and culture.

– Followed by ibn-Sina (980-1037), the renowned medical doctor and researcher who is known in the West as Avicenna; and

– Followed by Omar Khayyam (1048-1122), the ingenious mathematician and poet.

Religion and science did indeed occupy common ground during this golden age of Islamic culture working in an atmosphere of mutual respect that allowed the faithful to express their fidelity to religious teachings while fervently embracing a culture of scientific excellence.

The second example comes from the present situation in the developed world.

Today, most surveys indicate that people in the United States are among the most religious people in the developed world, wilfully embracing the power of faith expressed in Christianity, Judaism, Islam, and other forms of spiritual expression. Whether the question relates to a personal belief in the existence of God, or the number of times one attends a house of worship each month, or whether God plays a direct and tangible role in a person’s daily life, Americans have consistently shown themselves to be more closely affiliated with deeply rooted religious principles than their contemporaries in Europe.

At the same time, there is no doubt that the United States is the most advanced scientific and technological power on earth unmatched in the breadth of its scientific knowledge and, perhaps more importantly, in its ability to transform that knowledge into products and services that continually improve the lives of its people. In fact, the United States’ ability to develop and harness science and technology represents its most distinguishing characteristic – a primary factor that separates the United States even from its closest cultural brethren in Europe.

While important to recognize, it is not sufficient simply to assert that history shows religious fervour and scientific excellence need not be contradictory – and leave it at that. Other factors come into play when examining the deep spirituality and broad material success of Islamic society a thousand years ago and U.S. society today.

First, both societies displayed remarkable tolerance for those who did not share the dominant religious attitudes. Early Islamic society welcomed those of all religions, including Christians and Jews, into their communities, often allowing them to live and prosper in peace and harmony within the prevailing Islamic culture. And I don't need to tell you that an unflinching tolerance for varied cultures and religions is one of the hallmarks of contemporary society in the United States, where those of all faiths and creeds are welcome. Indeed some observers cite this open attitude as one of the U.S.'s most important competitive advantages in today's globalized world. That advantage may have been put at risk by the security measures that have been taken in the aftermath of the terrorist attacks on 11 September. If these measures remain in place and prove an enduring insult and burden to targeted communities and foreign visitors, the U.S. may begin to lose one of its greatest assets.

Second, both Islamic society in the distant past and U.S. society today have had the good fortune to be shaped largely by social and political systems that encouraged and supported the pursuit of scientific knowledge. These systems helped to reinforce prevailing cultural attitudes and, in the process, helped to nurture and sustain a mindset that allowed each society – each culture – to progress while still maintaining a heartfelt allegiance to traditional values. As a result, each moved ahead by warmly embracing the future without coldly abandoning the past.

Third, both Islamic society of a thousand years ago and U.S. society of today accepted science as an integral part of their cultures. This lesson is particularly important for today's Islamic societies to understand and appreciate because all-too-often science is seen by Islamic extremists as a Western and Northern phenomenon alien to their own sensibilities and values. Nothing, in fact, could be farther from truth. Civilization began in what is now the Third World, including the Islamic world and, as we have seen, science flourished there at a time when Europe found itself lost in the dark ages.

Equally important, traditional knowledge continued to play a critical role in 'developing countries' – long after their ability to pursue cutting-edge scientific inquiries had been compromised by political and social conflicts and a host of other forces – some self-inflicted, others created by factors beyond the society's control and influence.

Traditional knowledge, acquired and tested over centuries of time, is now proving increasingly important as we try to tailor our global concerns for economic and social well-being to a myriad of local circumstances. Respect for such knowledge, in fact, could provide an entryway for re-establishing a culture of scientific excellence in the developing world while simultaneously giving today's universities and research institutions valuable time-tested information and techniques for examining some of the world's most difficult health and environmental problems.

Where does all this leave us? More specifically, what lessons can be learned from these experiences of past and present for institutions such as the Third World Academy of Sciences (TWAS), which is dedicated to building scientific capacity and promoting scientific excellence in the developing world?

I am pleased to note that these institutions include the Pontifical Academy of Sciences, which, as many of you know, was instrumental in facilitating the founding of TWAS nearly 20 years ago. Your Academy, in fact, provided the forum where the idea of creating an academy for Third World scientists was first discussed in 1981. TWAS was born two years later. I am also pleased to note that 24 members of your Academy – nearly one third of its membership – are also members of TWAS.

In this spirit, I think it is important for all of us to recognize – as the founding president of TWAS and member of your Academy, Pakistani-born, Abdus Salam often said – 'science is the cultural heritage of all humankind'. No culture has a monopoly on science and technology. And all cultures have a great deal to learn from exchanging experiences and knowledge concerning the wonders of the natural world and the benefits of science and technology.

I think it is also important for us to recognize, particularly for those of us concerned about the relationship between cultural values and science, that great civilizations have often flourished when the two – traditional cultural values and contemporary science – were being sincerely embraced and cherished by their leaders and citizenry.

Given all this, what practical steps should the developing world take to ensure and maintain a culture of scientific excellence? Put another way, what factors could help the South knit scientific excellence into the fabric of its cultures in ways that would enable traditional values and science to be threaded together in a pleasing harmonious pattern?

Let us first acknowledge that the task is not an easy one. Here are some snapshots that reveal the depth of the challenge.

– The South is home to 80 percent of humanity but produces just 10 percent of the articles published in international peer-reviewed journals.

– Since the Nobel prize was initiated over a century ago, only three scientists who have conducted research in the developing world have been awarded science's most coveted prize: C.V. Raman in India; Bernardo Houssay in Argentina; and Luis F. Leloir in Argentina.

– Israel, which has only four million people, publishes more research papers in science and technology in international peer-reviewed journals than the entire 57 countries belonging to the Organization of Islamic Conference (OIC), with a total population of nearly 1 billion.

Yet, we should not be discouraged by the challenges we face. Several countries – notably, Brazil, China, India, Mexico and South Korea – have planted seeds for scientific excellence that are not only bearing fruit today but have enriched these nations to the point where these seeds are now likely to regenerate and grow even stronger in the years ahead. These countries and several others have expressed strong desire and commitment to engage in South-South cooperation programmes in education and research that aim at helping less privileged countries to develop their capacities.

Such experiences – along with more effective strategies for North-South cooperation – suggest that the road to scientific excellence in the developing world may no longer be marked by wrong turns and dead ends.

In fact, we know what it takes to succeed and we now have examples of how to get there:

– First, we need to provide – not just for one year or two, but year-after-year – generous research and travel grants based on competition and a peer review system that does not rely on nepotism or seniority in the selection process. Here the efforts of such organizations as TWAS and the African Academy of Sciences to provide competitive research grants in a variety of fields bodes well for the future of science in many places throughout the developing world. Such programmes, however, need substantial additional funding if we are to build and sustain a critical mass of world-class scientists in every country of the South.

– Second, we need to develop sustainable institutions of excellence that can attract, train and retain scientific talent. Here the work of the Third World Network of Scientific Organizations (TWNSO) may prove particularly significant. TWNSO, which operates under the administrative umbrella of TWAS in Trieste, first identified and then involved institutions of high standing in the South in the building of networks dedicated to addressing real-life concerns in the developing world. To date, TWNSO has launched networks in indigenous and medicinal plants, dryland biodiversity, water management and, most recently, renewable energy. These networks closely track the critical problems – water, energy, health, agriculture and biodiversity – that UN Secretary-General Kofi Annan recently cited as a framework for action in events leading to the Johannesburg summit on sustainable development held earlier this year.

– Third, we need to nurture an environment that fosters cooperation between leading organizations that support the pursuit of excellence in science and technology. Here the initiatives of the InterAcademy Panel for International Issues (IAP), also located in Trieste and operating under the administrative umbrella of TWAS, to bolster merit-based national science academies in the South and North could help transform a vastly under-utilized source of scientific expertise into a strong and effective voice for science-based decision-making.

– Fourth, we also need to devote sufficient resources to the problems of least developed countries whose scientific communities have become increasingly isolated and marginalized in recent years. Here's where TWAS's recent programme to recognize and support the best research groups in the LDCs could prove to be a critical strategy for developing and sustaining scientific excellence under difficult conditions. The programme offers grants of up to US$30,000 a year for three years to research groups in universities and research institutions.

– And, fifth, scientists need to communicate, in an atmosphere marked by mutual respect and understanding, with the keepers of other forms of knowledge – notably, practitioners of traditional knowledge in health, the environment and natural resources. Here TWAS's call for greater interaction with indigenous sources of knowledge, as outlined in its most recent strategic plan, could help bridge the divide between two reputable sources of knowledge – melding the universality of modern science with the localism of traditional knowledge in ways that serve both these noble pursuits.

We must also devise effective strategies for conveying the benefits of scientific excellence to our political leaders. This means putting science to work to solve practical problems. Not only will such a strategy clearly convey the value of science to the larger public, but it will also put scientific endeavours more closely in line with a society's cultural and social values. This also means giving scientists the opportunity to provide objective and credible advice to governments on issues of local, national and international concern. Here again national science academies, if given the know-how and training, can play a pivotal role.

In all these endeavours, we must never lose sight of the fact that promoting a culture of scientific excellence generates benefits beyond a society's material well-being – that, in effect, a culture of scientific excellence is a boon to the entire culture. Through opportunities to interact with individuals associated with educational and research systems beyond one's national borders, science, in a broader sense, promotes greater understanding of the cultural values of different societies. This interaction, in turn, enriches and transforms cultural attitudes and customs.

These are some of the experiences, lessons and observations that the developing world – and I should add the developed world – should heed in their desire to protect traditional cultural values while finding lasting peace with the material benefits that only science and technology can bring.

In the spirit and purpose that guides the Pontifical Academy of Sciences, the Third World Academy of Sciences, and all other institutions that share our vision, let us all pray and reason together that – at this critical juncture of history, marked by increasing cross-cultural suspicions and hostilities – we can create a successful pathway, through science, to a new level of global understanding.

Thank you.

DISCUSSION ON THE PAPER BY HASSAN

MENON: May I just make just one remark, Mr. Chairman? Dr. Hassan is now the moving spirit behind the Third World Academy of Sciences. Its President is sitting here right next to me, Prof. C.N.R. Rao. The Academy should know that the Pontifical Academy was the birthplace of the Third World Academy of Sciences. I was showing Dr. Hassan and Prof. C.N.R. Rao, along with my founder fellow colleague Tom Odhiambo, the places down below where we used to have breakfast and lunch in the old days where the discussions took place among scientists from the Third World who belong to the Pontifical Academy which gave birth to the Third World Academy of Sciences. I think this was a major accomplishment of this Academy for developing science in the Third World, for which the Pontifical Academy can take the credit.

SCIENCE AS A CULTURE: A CRITICAL APPRECIATION

CHINTAMANI N.R. RAO

Scientists have generally stood for certain principles that have provided traditions which go far beyond geographical boundaries. Scientists of the world do indeed constitute a supranational sub-culture and have evolved a value system of great relevance to society. Important qualities such as integrity, honesty and search for truth are taken as essential elements in the science sub-culture. Science also allows for aesthetics and has a place for beauty in science itself. What is not often understood, however, is the need for science in society or in one's life, other than for utilitarian purposes. Clearly, science also has a place in society just as poetry and philosophy.

In spite of the great virtues of science and the positive impact of science on human beings at large, it is important that we are conscious of how science is being practiced at the working level and how it may develop undesirable traits over a period of time. Such introspection and alertness are necessary to preserve the culture of science and science itself in the long run. The decreasing enthusiasm for science and the low priority it receives in the value system in many societies and amongst the younger generation makes it imperative to examine certain features that have emerged over the recent past. I shall attempt to examine some of these issues briefly.

The very rigour of science often results in parochialism and narrow loyalties, which can promote undesirable ways of communicating with one another even within the scientific community. It is not only divisions such as physics, chemistry and biology that dominate our functioning, but further subdivisions. For examples, in physics it is particle physics versus condensed matter physics. In chemistry, it is worse. It is just not organic, inorganic, physical etc., but people define themselves even more narrowly (e.g. molecular biophysical chemist). But, science is interdisciplinary, and science is one and universal. Such narrow sub-divisions have seriously affected the teaching of science. This is specially true of chemistry. This has gone to the extent that many well-trained chemists find it difficult to teach a general chemistry course to beginning college students. They would rather teach specialized courses. We practice science in an interdisciplinary fashion. We carry out much of our research with an interdisciplinary approach, but we teach science on the basis of disciplines. We have to examine how this indisciplinary aspect comes into teaching. In many countries, curricula have become so rigid that a physics student has no way of learning biology or vice versa. A medical doctor does not learn basic science after high school.

'Fundamental' study is the general explanation or excuse given by most of us who carry out basic research. Under the façade of fundamental study, there is a tendency amongst many of us not to constructively scrutinize established styles of research. People find it convenient to classify science as basic (or fundamental) and applied. I find this to be counter productive. As far as I am concerned, there is science that has already been applied and science that is yet to be applied. Furthermore, the quality of mind required for applied work is by no means inferior to that required for basic research. Such distinctions may come in the way of creativity and encourage routine research. This may also render science less exciting.

There is a tendency amongst some scientists to claim that science can explain everything, including many of the human feelings and emotions such as love and faith. This has given rise to a new form of arrogance. Such arrogance may not be conducive to a meaningful way of life and to a purposeful practice of science.

Science has given birth to a language which tends to be antiseptic. Scholarly articles are accepted for publication only if a certain type of impersonal language is used. For example, one cannot write a paper where one states, 'I took the sample in a tube and heated it and then while cooling, I added x to it'. Instead one writes, 'the sample was taken in a tube and heated, and x added to it while cooling'. Is this necessary? Or, is this good? Is passive voice best for science? After all, much of the science is an expression of personal ideas, dreams and accomplishments.

While we use passive voice in writing, many of us have become much too selfish in the practice of science. Excessive industrial consultancy and commercial interests affect the way science is practiced. Rivalry, monetary benefits and the like have had a dominating influence on many scientists. Recognition and rewards (at all cost) become the priority and the pleasure of discovery is lost in this process. Such things change the value system in science.

Highly restrictive practices in the sharing of data and information go against the spirit of science. We have to carefully navigate in the present day scenario to ensure that knowledge is created basically for the benefit of humankind.

While promoting science culture, it is important to give due attention to the existing cultures in the world. These cultures have survived for centuries and have created languages, traditions and a variety of other important treasures of humankind. It is possible that as the science culture spreads, it may favour a common language which may slowly wipe out the importance of many important languages and cultures that exist today. Looking at the performance of human beings in the last century, we see that many important cultures, as exemplified by those of many tribes in Asia and Africa, have been wiped out. Many of the dialects and languages have been disappearing. I personally know of some of the languages and cultures in India wiped out in recent years. This may happen more during the next century even to some of the major languages and cultures of the world which may gradually lose their identity. This would be very unfortunate because the very diversity of this world is what makes it interesting and exciting. We have the responsibility to protect cultural diversity and traditional knowledge of various countries. At this juncture, I must point out that the cross-cultural effects play a role in teaching science in the villages of Asia or Africa. We have to examine the importance of cross-cultural effects in science education and in the spreading of the culture of science.

I cannot help feeling at this stage of my life that there is something called bad science as opposed to good science. A typical scenario that creates bad science is one where a scientist carries out a programme of research knowing fully that the results will be used to harm other human beings. The case of Haber is an example of a scientist who did great science (synthesis of ammonia) which saved humankind from hunger and also bad science (mustard gas) which killed many innocent lives. Cloning humans is, to me, an eminent example of bad science and yet it is being pursued. Bad science destroys the image of science and will contribute to the negative aspects of the science culture. Should we pursue any kind of science and at any cost? Some people may feel that cloning or making a killing chemical may be technology and not science, thus wash off the responsibility of science and scientists. I do not, however, subscribe to such puritanical views. As far as I am concerned, human cloning or synthesis of chemicals for warfare is also pursued by well-trained scientists.

When we think of science of the future, we have to be concerned as to how the culture of science will develop and influence the future of mankind. In order to protect and preserve the good features of the science culture, scientists would have to bear social and moral responsibility for situations arising from scientific pursuit. While scientists undoubtedly will continue to be interested in the discovery of new knowledge, it is important that science involves the minds and hearts of the peoples of the world and includes a component that leads to enlightenment. The culture of science could indeed help to make the practice of science a spiritual experience under favourable circumstances.

I believe that in this century, we should evolve practices that bring about major changes in our science culture which in turn would improve human condition and transform human society for the better. This would require a change in our attitudes to the poor, and those from the third world. The third world, consisting of a majority of the world's population is still suffering from illiteracy, poverty, disease and the absence of basic needs such as safe drinking water. The third world is yet to benefit from the scientific knowledge that has accrued in the world. We should do everything possible to spread scientific temper and knowledge amongst all the peoples of the world. In order to accomplish this, the main stream of science has to flow everywhere creating new channels and tributaries. Such a river of knowledge can only be created by the involvement of enlightened scientists in science education and human development. This will require humility, generosity and human concern on the part of all concerned scientists.

DISCUSSION ON THE PAPER BY RAO

VICUÑA: Before I comment on Dr. Rao's talk, I would like to say to Professor Zichichi that sometimes it's not so easy to differentiate between science and technology. I used to think the way you do, but now you see scientists that are in favour of doing research with embryos to manipulate them and to extract cells from them to do research, and they use words that don't mean exactly what they should mean, for example, they don't want to call it 'human cloning', they say 'nuclear transfer', and they say that the embryo is not a human being or a human entity just to be able to extract cells from them and do research that may have a very nice or useful purpose in the future, but the end doesn't justify the means, and that is research, it's not technology, that would be science. And when Dolly was cloned people were very concerned about cloning humans and I participated in so many debates in Chile and elsewhere saying: 'Don't worry, we scientists are pursuing the truth and we'll do what we have to do, but other people may use this knowledge in a bad way, but that is not our fault'. And you see now scientists that are doing research in a way that at least I don't approve and not everybody approves, and I would say that of scientific research. You may respond to that later, but I would like to comment on Dr. Rao's talk, and I think I share with him most of the concerns he has expressed about the way science is being conducted today, and I think that that's due to the fact that until recently science was a more idealistic activity, and was conducted by few people who followed a vocation, but science today for most people, especially for young people, is another way of making a living, you see, it has become a profession, a less idealistic activity perhaps than it used to be, so it is more competitive, there is more selfishness and it has become more massive than before, and I think that is the explanation.

IACCARINO: Professor Rao mentioned human cloning. I wish to make a comment. In UNESCO we prepared the Declaration on the Human Genome. It has been approved by the governments of all states, including the Vatican. This declaration includes a paragraph on the prohibition of human cloning. I assume, and this is a question, that the Vatican approved the declaration after consulting the Pontifical Academy.

CABIBBO: No, we were not involved in that. I think it's important, however, to distinguish between ethical behaviour in research and the aim of the research. So, for example the use of embryos for purely scientific research is an ethical problem and it's certainly a serious problem, but there are other problems, such as mustard gas, which are completely different, maybe worse. Anyhow, they are two different problems, it's not that because you are only looking for truth you are automatically ethical. There may be bad things that you can do while looking for truth.

MENON: Mr. Chairman, I agree with my friend Professor Zichichi that science has first of all to be regarded as a creative activity through which one is trying to explore for the truth, to try to understand nature, to explain how nature behaves, and to do all of this on a quantitative experimental basis. But I would like to point out another angle to Professor Zichichi. He is a television star, and he interacts with governments at various levels. To some extent I've done the same, at least interacting with governments, and I know how politicians and administrators look at these things. I would like to read out to you from Professor Léna's talk this morning in which he says, quoting Jorge Allende, a very distinguished biologist from Chile, who said: 'For most people in Chile science is something magical, complex and expensive, that is done in the United States, Japan and Europe, that results in new gadgets or medicines that eventually appear in the stores of Santiago'. We must recognize that this is not the image of science that I just outlined. If you are a mathematician and do pure mathematics, number theory and the like, you can say it's the purest of all activities, and it is not harming anybody, but public perception is equally important, and nobody, no society today accepts a definition where science is looked at in this particular way. We all know of the interaction and the symbiotic and synergistic relationship between science, technology, applied science and what it has led to, and this is what society sees. You may say that science has nothing to do with the ozone hole, nothing to do with DDT, nothing to do with the thalidomide disaster and so on, but in the public image it has. CFCs are highly inert: they have a long lifetime; and therefore, as far as scientists were concerned, they were considered totally safe; that was the promise made. But when they finally went into the stratosphere they interacted, and we found that they were capable of producing the ozone hole for reasons that we now understand. There are many instances like this. The fact is that public perception, how people look at all this, is even more important than our semantic definitions of what science is. This is the first point.

My second point is this. I remember Professor Singer said that the Manhattan Project was an engineering project, and so we should not regard it as science. One can say that it was purely a technology project because it was making an object, an object called the atomic bomb. But if you read the list of people who worked on the Manhattan Project they were the greatest scientists you had around, Robert Oppenheimer, Enrico Fermi, Louis Alvarez, John Cockcroft, Hans Bethe, Ernest Lawrence, Rudolph Peierls, Richard Feynman – a who's who of science. There were many unsolved questions which had to be dealt with before you could make something so completely new at that point in time. It needed knowledge then unknown and understanding of how Nature behaved. Therefore, we must accept that in many areas there is a significant overlap of science and technology, and we have to be very careful to understand how the public perceives it. We cannot escape responsibility by saying, 'Look, as far as we are concerned, this is science, this is what we are doing, therefore we are totally clear'. The American philosopher Herbert Marcuse has written, 'When the most abstract achievement of mathematics and physics satisfy so adequately the needs of IBM and the Atomic Energy Commission, it is time to ask whether such applicability is not inherent in the concepts of science itself'.

The other point that I want to make, if I may take a few minutes, Mr. Chairman, is on a completely different topic. It concerns the very important point that Professor C.N.R. Rao made about culture and language. We have to recognise that, in this particular meeting, we are talking about the cultural aspects of science. The title is 'The Cultural Values of Science'. Certainly science has a cultural value, since it is related to values such as creativity, curiosity, beauty and truth. If you ask how science flowered and grew exponentially over the last few hundred years, it is essentially because there were conditions in society which favoured it, and which allowed it to develop that way. Therefore we cannot separate science from society as a separate independent activity.

In society we are dealing with its culture, not with a monolithic culture but with diverse cultures. Professor Arber talked about biodiversity; similarly there is cultural diversity in the world which has also evolved over time. And there is a strong relationship between language and culture. We are aware of the fact that what distinguishes human beings from the rest of the animal kingdom is their ability to communicate, their ability for social interaction, and with it of absorbing what is in the surroundings. And therefore we can ask ourselves, how did all these languages grow? We've heard the very brilliant lecture by Professor Werner Arber sitting in front, on the whole question of evolution from the Darwinian stage right up to molecular evolution through which we broadly understand, the horizontal spread, the vertical spread and so on. We still don't understand how languages developed. There are of course theories on how they grew from initial stages, but what is certain is that language has a great deal which relates to the surroundings. That is why words emerge which relate to what you see: relating to the desert, the tundra, the mountains, the icy continents, the forests, and so on and so forth, for those who live in these. Many languages and concepts have arisen from their surroundings, tradition and history, for which there are no corresponding expressions in any other language. This is all part of the diversity that humanity has inherited over a long time period: cultural diversity and linguistic diversity.

Now, if you look at the situation on the ground, you find that actually the total number of languages, and I have a list here, is about three thousand in the world, of which at least 38 are spoken by more than ten million people each. There are ten languages which are spoken by more than a hundred million people. Now we are in the age of information technology, and it is very young; the Internet and www in its present operational form with widespread IT ramifications in society, are just ten years old. What is happening is that the bulk of the knowledge base of the world, in the form in which it can be actually largely accessed is in English or a few other languages of the Western world, and that is where everybody searches. This is going to create a situation of tremendous imbalance, of Western, indeed English predominance, with everything in English; this will have a major impact if you take a longer time horizon. I know Dr. Lourdes Arizpe answered Professor Rao's question yesterday when she said: 'Look at the fact that you have America, the United States, you have Europe, France, and you have Japan, and they still, in spite of IT and so on, have preserved their cultural differences'. But I would like to state that this is only in a time period of a few years that the IT age in the form of the Internet and www has been in existence; if you take a much longer period its impact could be greater, as you focus entirely on accessing knowledge, and people will have to do that in the knowledge-based economy and society of the future. What impact this will have on human psychology cannot be forecast as it involves brain development, cognitive and group psychology. Those who are out of it are totally left out. The digital divide could be the most defining divide of the future, if we are not careful, and we'll have to look into it.

If you look at English today, it relates to about 320 million people in the world. Just two languages that I can name in India and Bangladesh, Hindi and Bengali, have more related population than English, and yet nobody knows them here. Therefore this dominance and its impact on the cultural diversity of the world is something that should concern science. That's why Professor Léna referred to comments that I had made in the education study group last year about the need for scientific efforts and technological breakthroughs relating to a seamless transition from one language to another, which is now possible for a large part of the work involved in access to scientific knowledge.

So, I thought I should mention that we should not, when we only talk of the cultural value of science, forget the rest of cultural diversity that characterises the societies of the world; or what is going to happen to this in the future as we proceed along with scientific developments converted to technologies in the IT area, and their impact; this is similar to what is happening to biodiversity as a result of human greed, and that is again something we cannot afford to lose; as Professor Werner Arber has told us, that is something which we cannot reproduce, which has arisen out of a process of evolution over a long time period in ways which we are not competent or capable of generating; it is not that we can't make an individual transformation, but on the other hand to do that on the scale as nature has done is something which is unlikely to take place.

So we ought to be cautious of how we move in these areas, and ensure that what we do ensures that the ill effects don't take over.

ZICHICHI: Professor Rao has made an encyclopaedic review of the three basic achievements of the human intellect which are, and remain, indeed, language, logic and science. It is our duty to let people clearly understand what the implications are for each of these three pillars of our intellectual achievements. Let me give an example: a couple of years ago the President of the most powerful country in the world, the United States, signed a cheque for 20 billion dollars for a project which is technology but which was presented as science, and crossed out another project which was also presented as science and indeed was real science. The decision-making people need to have clear ideas. The image of science is due to us, not to anybody else. If we go on confusing technology and science, then we'll suffer from this. Cloning is genetic engineering, it's technology, it's not science.

You mentioned Fermi, Oppenheimer, Wigner, the great scientists of the twentieth century involved in the Manhattan Project. Why? Because the moments were tragic, and therefore if you want to select people to implement the project you cannot use a poet, but if Dante was able not only to write the 'Divina Commedia' but also to invent an instrument, you cannot say that language and technology are the same thing, because the same person can play the violin and then engage himself in some other activity in science. So, the distinction between science and technology is absolutely profound, and I'm very grateful to this great Pope, who has made this distinction clear to everybody: the use of science is no longer science. We cannot confuse technology with science, because as a result true science will suffer. For example, you mentioned my public activity in Italy. Why do I do this? Because we live in a democratic country and if you want to have influence you must speak to people. It is not enough to speak to decision-makers. You must show that people follow you, and people in Italy follow me. They make this vital separation between science and technology. There was a sort of analysis made by a British group of people and they realised that Italy is the first country in the world where science and technology are clearly defined. People don't confuse science and technology. It is in our interest, in the interest of science, of true science, to make this distinction.

If we go on confusing bad science, good science, technology, language and logic, then how can a decision-maker, who hardly understands the difference between chemistry and physics, make a decision? So, it is our responsibility to make clear the distinction between pure science and technology. I invite my friend Professor Menon to help us in making a big step in India to make all Indian people clearly distinguish between science and technology.

RAO: Who cannot agree with Professor Zichichi? We all agree. Among scientists I think this is a very good argument, and I always defend science outside and say, 'Look, don't confuse science with technology'. I've been doing that all my life, and there is nothing new in what he says. The unfortunate thing is that there are cross terms. It is not that science is pure, technology is pure: there are not two compartments. There is a tremendous interaction. For example, discovering a new compound, which is a better nerve gas, is science, there is no technology in that. So, you cannot say: 'Oh, it is pure technology'. Similarly, many things I talked about today deal with interaction of science and society. You cannot say scientists are not responsible because the destruction of a language has nothing to do with science. Yes, sure, except that the way we are practising science and bringing new technology – there is a responsibility to see that the societies we live in do not experience the disappearance of languages and cultures, because they are all trying to follow the science culture and the technology culture. So, we can't say sciences are so pure they have nothing to do with technology. In fact, where Zichichi is wrong is that some of the science I do today, in two months may become technology. There are certain areas for example in nanoscience that I do, some become technology within a year, within six months, so it is very difficult to say where science ends and technology begins. So much purity, I do not approve of.

LÉNA: I would simply like to point out that a distinction between science and technology may be looked at at a theoretical level, but has also to be looked at at a practical level. I have the good fortune to work in an area of science – astrophysics – which has little applications, but is critically dependant on technology to build new instruments, discover through new observations. Is this lack of immediate applications the reason of the great favour astronomy always enjoys with the public?

On a practical level, everybody understands who decides which science ought to be done: the scientist. But who decides for the technology? It is unclear for the public: the industry leaders? The politicians? While clearly a given technology is related to science, and scientists are always proud to show their discoveries have applications. In practice and to many, science appears hard to distinguish from its applications.

CABIBBO: I wanted to propose that we close at this point, because we still have two talks to hear. If I am allowed, however, to comment, I always remember the story of the mad cow disease, which was somehow counted as one of the bad effects of science, when it was due clearly to someone else. I mean scientists discovered the thing, warned against its danger but their warnings were not heard.

RAO: Professor Cabibbo, I don't know if you remember, but in the beginning of the talk I did say that these are the issues where the Academy should be really worried. We are in fact really not just scientists.

As Professor Zichichi said, our relations with society are intense. I think we should spend much more time on these issues, and come out with maybe our own guidelines and whatever we want to. I don't know if it helps anybody, but certainly it's not a bad thing to look at these issues. We really should have more discussion.

ON THE PREDICTABILITY OF CRIME WAVES IN MEGACITIES – EXTENDED SUMMARY

V.I. KEILIS-BOROK,[1, 2] D.J. GASCON,[3] A.A. SOLOVIEV,[1]
M.D. INTRILIGATOR,[4] R. PICHARDO,[5] F.E. WINBERG[1]

We continue here the series of studies in the predictability of critical phenomena i.e. abrupt overall changes ('crises') in complex systems. That problem is particularly challenging in the absence of fundamental equations governing the systems' behavior. The prediction of critical phenomena is important both for a fundamental understanding of the systems under consideration and for crisis preparedness and control. Such is the usual twofold goal of prediction research. The critical phenomenon considered in this study is a sharp and lasting rise of the homicide rate. Qualitatively, this phenomenon is illustrated in Fig. 1; and we call it by the acronym *SHS*, for 'Start of the Homicide Surge'.

This study integrates the professional expertise of the police officers and of the scientists studying complex systems.

The problem

Our goal is to develop a method for predicting the surge of homicides by monitoring the relevant observed indicators. We hope to recognize the 'premonitory' patterns formed by such indicators when an *SHS* approach-

[1] International Institute of Earthquake Prediction Theory and Mathematical Geophysics, Russian Academy of Sciences.
[2] Institute of Geophysics and Planetary Physics, University of California, Los Angeles, USA.
[3] Assistant Chief (ret), Los Angeles Police Department, USA.
[4] Department of Economics, University of California, Los Angeles, USA.
[5] Crime Analysis Section, Los Angeles Police Department, USA.

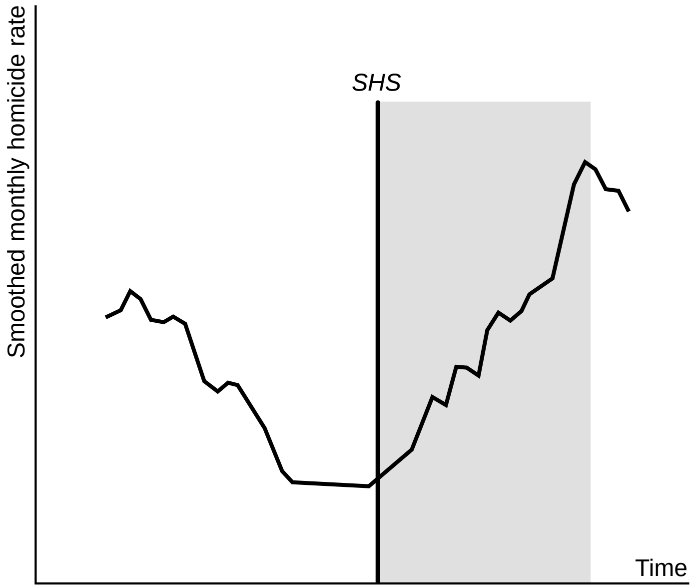


Figure 1. Target of prediction: schematic definition. The vertical line shows the target (the start of the homicides surge, or 'SHS'). Gray bar marks the whole period of the homicide surge.

es. In terms of pattern recognition we look for an algorithm that solves the following problem.

Given the time series of certain relevant indicators prior to a moment of time t, *to predict* whether an episode of *SHS* will or will not occur during the subsequent time period $(t, t+\tau)$. If the prediction is 'yes', this period will be the 'period of alarm', The possible outcomes of such a prediction are illustrated in Fig. 2.

The probabilistic component of this prediction is represented by the estimated probabilities of errors – both false alarms on one side and failures to predict on the other. That probabilistic component is inevitable, since we consider a highly complex non-stationary process using imprecise crime statistics. Moreover, the predictability of a chaotic system is, in principle, limited.

Such 'yes or no' prediction of specific extraordinary phenomena is different from predictions in a more traditional sense – extrapolation of a process in time, which is better supported by classical theory.

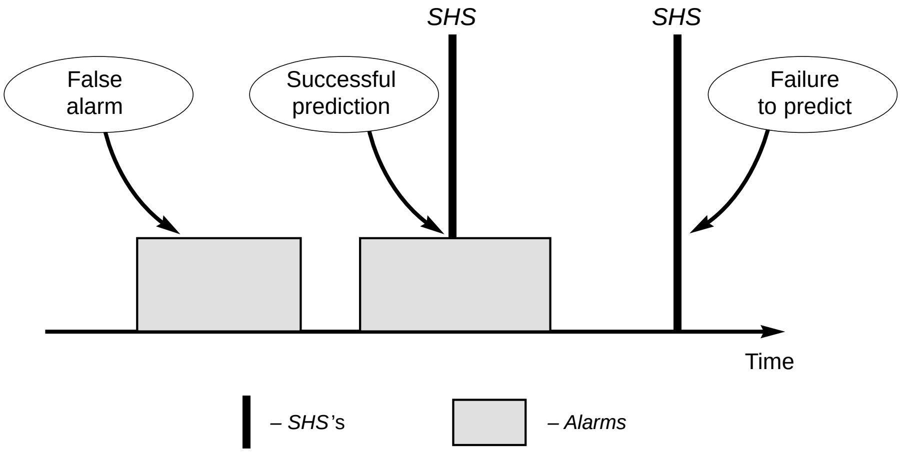


Figure 2. Possible outcomes of prediction.

Methodology

Our methodology is *pattern recognition of infrequent events* – a methodology developed by the artificial intelligence school of I.M. Gelfand [6, 18] for the analysis of infrequent phenomena of highly complex origin. It has been successfully applied in many problems of natural [6, 14, 18] and socio-economic [10-12] sciences, helping to overcome the complexity of phenomena under consideration and the chronic imperfection of observations. A distinctive feature of this methodology is a robust analysis that provides 'a clear look at the whole', which is imperative in a study of complex system [7-9]. This methodology is, in a way, akin to exploratory data analysis, as developed by the school of J. Tukey [22].

We also take advantage of mathematical modeling of critical phenomena in complex systems [1, 5, 13, 14, 19-21, 23, 24].

The data

Among a multitude of relevant indicators we consider, in this initial analysis, monthly rates of homicides and lesser crimes, including assaults, burglaries, and robberies (see Table 1). These data are taken from [3, 4].

TABLE 1. CRIME RATES CONSIDERED

Homicides	Robberies	Assaults	Burglaries
• All	• All • With firearms • With knife or cutting instruments • With other dangerous weapons • Strong-arm robberies*	• All* • With firearms • With knife or cutting instrument • With other dangerous weapon* • Aggravated injury Assaults*	• Unlawful Not Forcible Entry • Attempted Forcible Entry *

* Analyzed in sensitivity tests only.

Our findings can be summed up as follows:

1. We have found that the upward turn of the homicide rate is preceded within 11 months by a specific pattern of the crime statistics: *both burglaries and assaults simultaneously escalate, while robberies and homicides decline*. Both changes, the escalation and the decline, are not monotonic, but rather occur sporadically, each lasting some 2-6 months.

2. Based on this pattern we have formulated a *prediction algorithm*, giving it a robust and unambiguous definition. Its performance is illustrated in Fig. 3. Data for 1975-1993 have been used for developing the algorithm. It was then applied as is to the data for 1993-2002.

It is noteworthy that the performance of the algorithm did not change through all the years, when Los Angeles has witnessed many changes relevant to crime. This stability is due to the robustness of the algorithm and it is achieved at a price, in that the time of a homicide surge can be predicted with only limited accuracy.

Fig. 4 shows in more detail the case history of prediction of the last homicide surge one that continued for more than two years. We see that the algorithm gave a warning about this rise as early as December 1999.

3. *Sensitivity tests* [11, 17] demonstrated that these predictions are stable to variations in the adjustable elements of the algorithm. The algorithm is self-adapting to average crime statistics, so that we could test it by *application to independent ('out of sample') data* not used in its

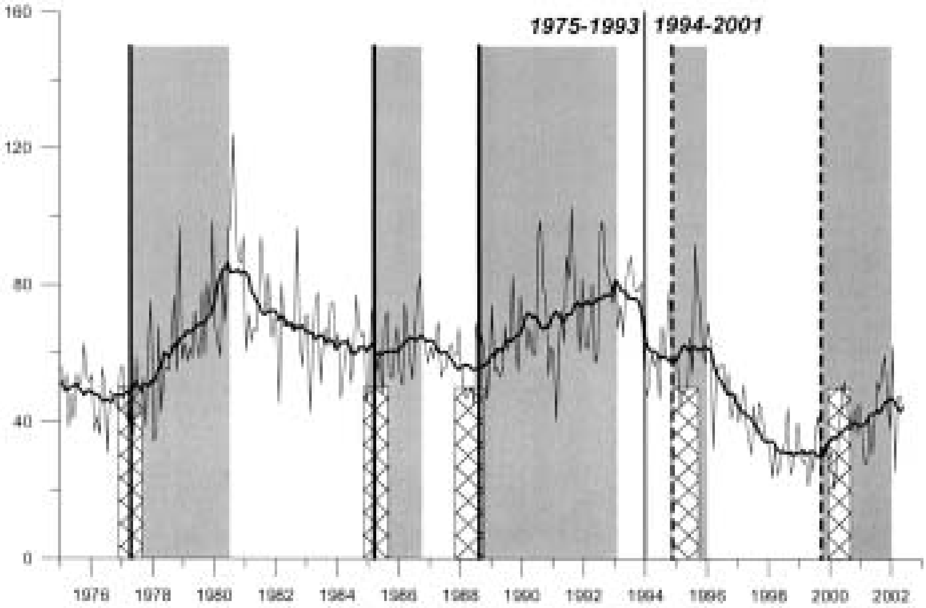


Figure 3. Performance of prediction algorithm through 1975-2002.
The thin curve shows total monthly rates of homicides in Los Angeles city, per 3,000,000 inhabitants. The thick curve shows the same rates with seasonal variations smoothed away. The vertical lines show the targets of prediction – upward turns of the smoothed homicide rate; while the solid and dashed lines show the turns that occurred before and after 1993. Gray bars are the periods when the rate of homicides remained high. Checkered bars are the alarms declared by the hypothetical prediction algorithm

development; The results of that test are also encouraging; however, as always, the algorithm remains hypothetical until it is validated by advance prediction.

4. Closer to the surge of homicides, the robberies also turn from decline to rise. This indicates the *possibility of a second approximation to prediction*, with more precise (about twofold shorter) alarms.

What did we learn about crime dynamics?

The existing qualitative portrayals of crime escalation are complemented here by a quantitatively defined set of precursors to homicide surges. The same set emerges before each surge through the time period under

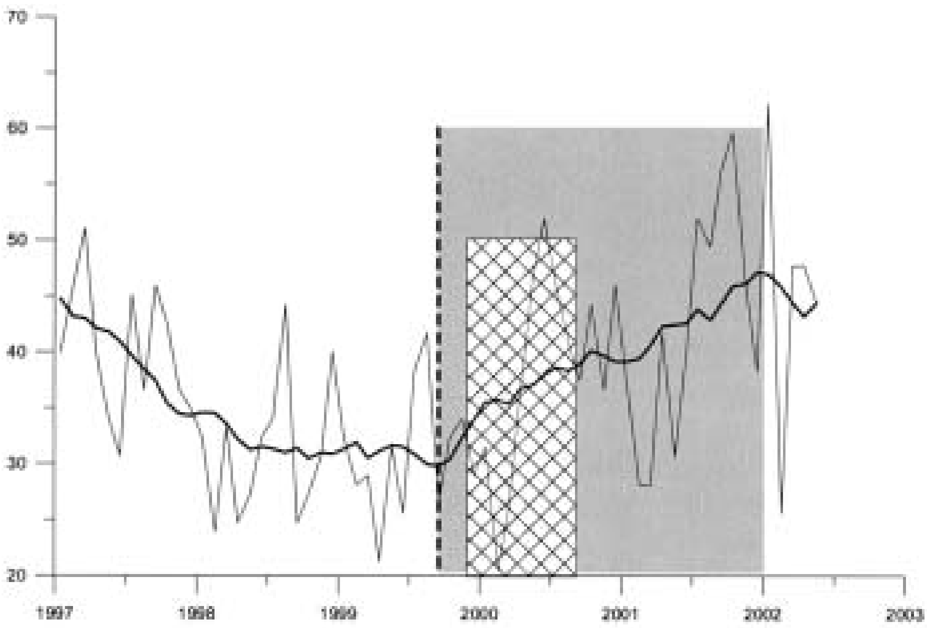


Fig. 4. Prediction of the last rise of the homicide rate: a case history. Notations are the same, as in Fig. 3.

consideration. We give a quantitative definition of this phenomenon that has been extended to a prediction algorithm.

It was unexpected that the premonitory pattern of indicators includes a *decline* of robberies, simultaneous with the rise of other crimes considered. That possibly might be explained by the rising influence of the gangs, temporarily suppressing 'unorganised' crimes.

The prediction described here is complementary to cause-and-effect fundamental analysis. The cause that triggered a specific homicide surge is usually known, at least in retrospect. This might be, for example, a rise in drug use, a rise in unemployment, etc. Our 'yes or no' algorithm captures the symptoms of *an unstable situation* when such a cause would trigger a homicide surge.

Relevance to the science of chaos

Our findings are in accord with the following ‘universal’ features of many chaotic or complex systems.

1) The permanent background activity (‘static’) of the system tends to rise before a fast major change, one that represents a ‘critical transition’.

2) That rise, and the other premonitory changes of the static, are not monotonic, but are realized sporadically, in a sequence of relatively short intermittent changes.

The ‘universal’ models of hierarchical complex systems, such as those developed in theoretical physics and non-linear dynamics, exhibit both of these features. They are also observed in a variety of real-world systems, including the seismically active Earth’s crust, the economics of recession, the labor market, elections, etc.

In terms of complexity the episodes of *SHS* might be regarded as critical transitions, and the changes taking place in the ‘lesser crimes’ – as static. The universality of the features of complexity is limited and cannot be taken for granted in studying any specific system. Nevertheless, it is worth exploring in crime dynamics using other known types of premonitory patterns [14, 23, 24].

Perspective

Altogether, the above findings provide heuristic constraints for the theoretical modeling of crime dynamics. They also enhance our capability to anticipate the possible future homicide surges. It is encouraging for further research that we used here only a small part of the relevant and available data. Among these are other types of ‘lesser’ crime [2] and economic and demographic indicators [16]. Decisive validation of our findings requires experimentation in *advance prediction*, for which this study sets up a base.

Acknowledgements

We are grateful to Dr. Robert Mehlman and Professor Wellford Wilms (University of California, Los Angeles) for valuable comments; and to Marina Dmitrenko and Tatiana Prokhorova (International Institute of Earthquake Prediction Theory and Mathematical Geophysics, Russian Academy of Sciences), and Cecile Coronel (Los Angeles Police Department) for the difficult work in data collection and preprocessing.

This study was made possible by the 21st Century Collaborative Activity Award for Studying Complex Systems, granted by the James S. McDonnell Foundation.

REFERENCES

1. Allègre, C.J., P. Shebalin, J.-L. Le Mouel, and C. Narteau (1998). 'Energetic balance in scaling organization of fracture tectonics'. *Phys. Earth and Planet. Inter.*, 106: 139-153.
2. Bursik, R.J., Jr., H.G. Grasmick, and M.B. Chamlin (1990). 'The effect of longitudional arrest patterns on the development of robbery trends at the neighborhood level'. *Criminology*, 28(3): 431-450.
3. Carlson, S.M. (1998). Uniform Crime Reports: Monthly Weapon-specific Crime and Arrest Time Series, 1975-1993 (National, State, and 12-City Data). ICPSR 6792, Inter-university Consortium for Political and Social Research, P.O. Box 1248, Ann Arbor, Michigan 48106.
4. Data sources: National Archive of Criminal Justice Data (NACJD), 1975-1993 (http://www.icpsr.umich.edu/NACJD/index.html). Data bank of the Los Angeles Police Department (LAPD Information Technology Division), 1990-2002.
5. Gabrielov, A., I. Zaliapin, W.I. Newman, and V.I. Keilis-Borok (2000). 'Colliding cascades model for earthquake prediction'. *Geophys. J. Int.*, 143, 2: 427-437.
6. Gelfand, I., V. Keilis-Borok, L. Knopoff, F. Press, E. Rantsman, I. Rotwain, and A. Sadovsky (1976). 'Pattern recognition applied to earthquake epicenters in California'. *Phys. Earth Planet. Inter.*, 11: 227–283.
7. Gell-Mann, M. (1994). *The Quark and the Jaguar: Adventures in the Simple and the Complex*. W.H. Freeman and Company, New York.
8. Gunderson, L.H., and C.S. Holling (eds.) (2002). *Panarchy: Understanding Transformations in Human and Natural Systems*. Island Press, Washington, DC, 507 pp.
9. Holland, J.H. (1995). *Hidden Order: How Adaptation Builds Complexity*. Addison-Wesley, Reading, Mass.
10. Keilis-Borok, V.I., and A.J. Lichtman (1993). 'The Self-Organization of American Society in Presidential and Senatorial Elections'. In Yu. A. Kravtsov (Ed.), *Limits of Predictability*, Springer-Verlag: 223–238.
11. Keilis-Borok,V., J.H. Stock, A. Soloviev, and P. Mikhalev (2000). 'Pre-recession pattern of six economic indicators in the USA'. *Journal of Forecasting*, 19, 1: 65-80.

12. Keilis-Borok, V.I., A.A. Soloviev, C.B. Allègre, A.N. Sobolevskii, and M.D. Intriligator (2003). 'Patterns of macroeconomic indicators preceding the unemployment rise in Western Europe and the USA'. Submitted to *Advances in Complex Systems*.
13. Keilis-Borok, V.I. (2002). 'Earthquake prediction: State-of-the-art and emerging possibilities'. *Ann. Rev. Earth Planet Sci.*, 30: 1-33.
14. Keilis-Borok, V.I., and A.A. Soloviev (eds.) (2003). *Nonlinear Dynamics of the Lithosphere and Earthquake Prediction*. Springer Ser. Synerg., Springer-Verlag, Berlin-Heidelberg, 337 pp.
15. Lichtman, A., and V.I. Keilis-Borok (1989). 'Aggregate-level analysis and prediction of midterm senatorial elections in the United States', 1974-1986. *Proc. Natl. Acad. Sci. USA*, 86: 10176-10180, December 1989, Political Sciences.
16. Messner, S.F. (1983). 'Regional differences in the economic correlates of the urban homicide rate'. *Criminology*, 21(4): 477-488.
17. Molchan, G.M. (1997). 'Earthquake prediction as a decision-making problem'. *Pure Appl. Geophys.*, 149: 233-237.
18. Press, F., and C. Allen (1995). 'Patterns of seismic release in Southern California region'. *J. Geophys. Res.*, 100: 6421 –6430.
19. Rundle, B.J., D.L. Turcotte, and W. Klein, eds. (2000). *Geocomplexity and the Physics of Earthquakes*. Am. Geophys. Union, Washington, DC.
20. Shnirman, M.G., and E.M. Blanter (1998). 'Self-organized criticality in a mixed hierarchical system'. *Phys. Rev. Letters*, 81: 5445-5448.
21. Sornette, D. (2000). *Critical Phenomena in Natural Sciences. Chaos, Fractals, Self-organization and Disorder: Concepts & Tools*. Springer Ser. Synerg., Springer-Verlag, Berlin-Heidelberg, 432 pp.
22. Tukey, J.W. (1977). *Exploratory data analysis. Addison-Wesley Series in Behavioral Science: Quantitative Methods*. Addison-Wesley, Reading, Mass.
23. Yamashita, T., and L. Knopoff (1992). 'Model for intermediate-term precursory clustering of earthquakes'. *J. Geophys. Res.*, 97: 19873-19879.
24. Zaliapin, I., V. Keilis-Borok, and M. Ghil (2003). 'A Boolean delay model of colliding cascades'. 'II: Prediction of critical transitions'. To appear in *J. Stat. Phys.*, 110.

DISCUSSION ON THE PAPER BY KEILIS-BOROK

ZICHICHI: Is the full line your mathematical predictions?

PIETRONERO: I have worked a bit with Volodya on earthquakes, using similar methods. The issue is very fascinating and rather complex. I would put it in the following framework: all the scaling and universality are for asymptotic time and space, so you have a distribution which eventually refers to infinite space and infinite time. Now, this is not good for prediction, but it's usually the target of theoreticians like myself. This means that with a renormalization group you predict nothing, I mean, in terms of what is useful, such as earthquakes. You predict other things for physics. Now, the issue that Volodya raises, and of course by which I have been fascinated, is: can you do something like the opposite? Can you forget about asymptotia and go into finite time and finite space predictions? This is essentially the opposite of what physicists have been doing. So we've been disoriented, because that's not the usual approach, and recently we've tried to invent methods which may also be good for small time-scales. That's what they have been doing for many years. So, I would say this is a new frontier of complexity in which one does not look at the asymptotic but at the opposite, at short time, at short space, and I think this is where the frontier is.

ZICHICHI: But the data represented by the grey pieces are supposed to be in agreement with the predicted derivative. This does not seem to be the case.

PIETRONERO: I think Volodya should answer.

KEILIS-BOROK: Prediction is aimed at increase of time derivatives. And you see that the smoothed (thick) curves change their trend upwards at some moment within each gray area. Generally speaking, increased derivative may still be negative, but actually the trend only flattened once, and went up in other cases.

ZICHICHI: You are predicting with your mathematics the behaviour of the function. In one case it goes up, in the other case it goes down. This is not a prediction, it's a contradiction.

KEILIS-BOROK: We predict the sharp upward bend of the smoothed function (the thick curve). The function first goes down, then it turns upward. If the turn is strong enough it goes up, otherwise it becomes nearly horizontal. It could be horizontal first then climb upwards. To predict specific realization of that bend would be the next approximation, I can describe it in 15 minutes.

ZICHICHI: No, no, I just want to know if what you show is your prediction. You should only say yes or no.

KEILIS-BOROK: We do not predict derivative of the function (the drop or the rise). We predict when the derivative will quickly rise. Next questions are how long will last the new trend, and how steep it will be, we are doing this piece by piece.

ZICHICHI: Take the grey line, then the function goes down. If this is your prediction, the same function cannot go up.

KEILIS-BOROK: It can go up after it was going down. We predict the time of the change.

ZICHICHI: You cannot have a mathematical model which goes up and down at the same time. The disagreement is between the model and the data.

KEILIS-BOROK: There is no disagreement – the function goes up and down not at the same time. It goes first down then it goes up or horizontally, that change is what the model predicts. But it does not predict how the rise of derivative will be realized; these are major unsolved problems.

HASSAN: Can I just ask you: I know that you've developed a model for predicting earthquakes in the same region. Some time ago I remember you explained it to us in Trieste. Can you tell us whether that graph that you developed for earthquake prediction is rather similar to what you have presented here? What is the correlation between them?

KEILIS-BOROK: Yes, prediction is based on evolution of background activity of a complex system prior to a critical transition. Scenarios of that evolution are partly universal for different systems; but partly they are system-specific. In case of homicides static consist of the rates of lesser crimes. Before a homicide surge some rates rise and some drop; police experts with whom we worked explain that by impact of intruding organized crime. In case of earthquakes the static we studied consists of small earthquakes, and their rate grows before a strong one. So, you are right – a certain similarity exists.

SZCZEKLIK: Professor Keilis-Borok. Predicting or prognosing was always considered part of an important medical skill, and about ten years ago, an attempt was made to introduce so-called expert systems into medicine using computers which were supposed to give right prognoses. They didn't work very well, didn't become much of use. Has there been some progress in this field very recently?

KEILIS-BOROK: The key to developing expert system is collaboration of mathematicians with the experts in the field, medicine in your case. A mathematician cannot take the data from a physician and put them through pattern recognition algorithm; neither a physician can do the opposite. There is a culture of interaction with experts for such purposes, not widely known, but not really new. About 30 years ago Gelfand's school developed a very successful expert system for predicting the outcome of operations on the brain. You might recollect T.S. Eliot: 'Where is our wisdom, lost in knowledge? Where is our knowledge, lost in information?'.

THE IMPACT OF NEUROSCIENCE ON CULTURE

WOLF J. SINGER

The natural sciences share numerous features with human activities that are commonly addressed as cultural. The essence of science is to explore the world around us and ourselves with rational tools. In the center of scientific endeavours is the search for regularities in nature and the formulation of rules. This then permits the construction of predictive models and thereby the foundation of novel views on our conditions. At their roots scientific activities do not differ from those in art, literature and philosophy as the creative process is likely to rely on very similar cognitive functions. The directly perceived world as it is conveyed by our unprotected senses is extended by descriptions of newly uncovered relations, by the formulation of rules, by metaphorical descriptions, and by the creation of artefacts: useful tools in the case of science, metaphorical descriptions of our conditions in the case of art and literature, and rational constructs in the case of philosophy. As all other cultural activities, science changes our view of the world and of ourselves.

Among the various scientific disciplines neuroscience is the one that has with all likelihood the strongest impact on our self-understanding because it explores the organ that is constitutive for the specific qualities of human beings. It is the organ that determines our cognitive abilities and endows us with a mental and spiritual domain.

Before exploring in more detail the consequences of neurobiological discoveries for our self-understanding it is necessary to raise awareness for an important epistemic caveat. In case of brain research, the explanandum and the explanans are identical. A cognitive system, our brain, uses its perceptual and analytical tools in order to describe itself. It is unknown whether this process can converge to a comprehensive description or whether it is susceptible to infinite regress. Another and closely related epistemic problem is that we can only discover what we can imagine, we can only know about us and our conditions what our cognitive abilities allow us to perceive and analyse. Evidence indicates, however, that our cognitive abilities must be confined because our brain is the product of an evolutionary process that has probably not been optimised to bring forth a cognitive system that is endowed with the capacity to perceive and imagine all the dimensions that lie behind the phenomena to which we have access.

It has surely not been the goal of evolution to bring forth a cognitive system that is capable of accessing absolute truth in the Kantian sense. Rather, nervous systems have been optimised by selection pressure to arrive at fast, well adapted, and hence usually pragmatic solutions to real-world problems, problems that organisms are confronted with that occupy a narrow range within the large dimensions spanned by the reality that we know of. Living organisms typically have dimensions in the range between micrometers and meters and hence have adapted to the dynamics that govern interactions among objects at this scale. Accordingly, our sense organs are tuned to decode signals from the environment only within a very narrow range.

Numerous examples of perceptual illusions document that our cognitive systems are not optimised to decode signals from the environment as they would be decoded by a physical measurement device and that our way to categorise phenomena is highly idiosyncratic. The perceived colour of an object is only loosely correlated with the wavelength of the light reflected from a coloured surface but depends essentially on comparison with the spectral composition of light reflected from adjacent surfaces. Electromagnetic waves are perceived as light within a narrow spectral range. If the wavelength exceeds the visible range we perceive the radiation as heat. Likewise, low frequency mechanical waves are perceived as vibrations and higher frequency waves as sounds. Also, the way in which we make inferences and construct predictive models orients itself on the typical dynamics that dominate interactions among objects that have our dimensions. This is probably one of the reasons why classical physics has preceded quantum physics.

Another result of evolutionary adaptation is our inclination to assume linearity when formulating predictive models about the dynamics of our environment. We have difficulties to imagine non-linear processes – and there is a good reason for this. As it is difficult and in the long run impossible to predict the trajectories of highly non-linear dynamic systems there was no evolutionary pressure to develop an intuitive understanding of such dynamics. Hence, our cognitive abilities have been optimised to analyse those processes which permit good predictions on future trajectories, and these are processes with linear dynamics.

Can these restrictions and idiosyncrasies of our cognitive functions be overcome by reasoning? The fact that we became aware of these restrictions and of the sometimes illusionary nature of our perceptions proves that reasoning and the design of physical tools can compensate for some of the deficiencies of our cognition. Likewise, the ability to find mathematical tools for the treatment of non-linear dynamic processes and for the description of interactions in the quantum world documents that we can extend our imagination by tools based on reasoning. However, the neuronal substrate that endows us with the ability to reason is the same as that which underlies our perceptual abilities. It is the cerebral cortex. The regions of the cerebral cortex that support reasoning are not different from those that mediate our perceptions and they owe their properties to the same evolutionary process. Hence, it needs to be considered that our reasoning is also constrained by the same evolutionary demands that shaped our perceptual systems. It is likely, therefore, that the nature of our reasoning is also idiosyncratic and optimised according to rather pragmatic evolutionary criteria.

Perhaps it is these deficiencies of our cognitive abilities which are at the basis of the incompatibilities among the various description systems that mankind has developed about itself and the embedding world. The most blatant of these incompatibilities are apparent in the descriptions that we derive from introspection on the one hand and from scientific analysis of our conditions on the other. The self-model that we have derived from our first person perspective is by and large incompatible with the descriptions that we derive from a third person perspective on which our scientific inquiries are based. We experience ourselves as self-determined autonomous agents that are endowed with free will, with a mental and a spiritual dimension, and it is our intuition that processes in this mental domain precede and dominate the physical processes that underlie our actions. However, when we analyse our conditions from the scientific third person perspective, we are forced to view ourselves as organisms that own their existence to a continuous evolutionary processes, the rules of which can be formulated within physico-chemical description systems. Likewise, it appears to us that we can describe in the same terms the ontogeny of human beings from the egg to the adult organism. Although this process is exceedingly complex we seem to be able to understand it as a self-organising process that will eventually be describable within the description systems of the natural sciences.

Obviously, human beings are distinct from animals because they have a cultural dimension. However, this dimension, too, appears to us as a product of evolution, as a product of the constructive and creative cognitive interactions among beings who are endowed with brains that have the abilities to create mental, cultural and spiritual dimensions. Among these abilities are our capacity to develop a theory of mind – to imagine what goes on in the brain of the respective other when he/she is exposed to a particular condition – the ability to develop a symbolic language system, and the capacity to form meta-representations of one's own brain states, i.e. to be aware of one's perceptions, thoughts and actions. An analysis of the neuronal prerequisites for the evolution of human culture is another and fascinating endeavour of contemporary anthropology and cannot be dealt with in the frame of this contribution. Rather, an attempt will be made to explore to which extent the incompatibilities between first person and third person perspectives can be resolved on the basis of currently available knowledge about the relations between brain functions and behaviour.

We seem to have no difficulties to understand the behaviour of animals as an emergent property of the neuronal interactions in their nervous systems. Also, we seem to have no problem with the concept that the emergent behaviour is described in a different description system as the neuronal processes which generate this behaviour. We are used to the fact that the emergent properties of complex systems are not identical with the components whose interactions generate these properties although they are fully determined by the component interactions. However, we seem to encounter insurmountable problems when this notion is generalised to higher brain functions that are specific for human beings. These functions comprise our abilities to perceive, to decide, to imagine, to plan, and to execute intentional acts, and above all, our capacity to be aware of all these functions. This is the more surprising as we have indisputable evidence that all of these higher cognitive functions are emergent properties of the neuronal interactions in the brain. Partly, this evidence comes from investigations of the relation between brain functions and behaviour in animals. Many of the cognitive abilities listed above can also be identified in higher mammals, and here direct correlations can be established with the underlying neuronal processes. Similarly compelling evidence for such substrate-function relations has also been obtained for the human brain with the help of non-invasive imaging techniques that allow measurements of neuronal activity while human subjects perform cognitive tasks. These studies establish close correlations between the activation of particular brain regions and both cognitive and executive functions. It is now possible to specify which brain regions become active when human subjects imagine perceptual objects, when they direct attention to particular contents, when they plan to execute a particular action, when they reason, when they have particular emotions, and when they are subject to self-generated delusions such as occur for example during hallucinations or déjà-vu experiences.

Comparative studies of the brains of different species have also provided indisputable evidence that the higher cognitive functions that we consider to be specific for human beings are the result of a continuous increase in the complexity of the nervous system that has been achieved during evolution. We see no events in the evolution of the brain that would justify identification of ontological discontinuities, neither at the structural nor at the functional level. Progress in molecular biology and physiology leaves no doubt that the properties of nerve cells have changed only little from their first appearance in molluscs until their implementation in the cerebral cortex of primates. All the mechanisms of signal transduction within cells as well as between cells are conserved. Also, since the appearance of the vertebrate brain, the basic organisation of the nervous system has remained unchanged. The only major change is the steady increase of the surface of the cerebral cortex and of the volume of related structures such as the basal ganglia and the cerebellum. Remarkable in this context is the fact that the new areas of the cerebral cortex, that have been added in the course of evolution, have exactly the same intrinsic organisation as the phylogenetically older areas. Since the computational algorithms realised by neuronal networks depend exclusively on the functional architecture of the respective network, it can be inferred that the more recently implemented cortical areas operate according to exactly the same principles as the older regions. This forces the conclusion that the emergence of higher cognitive functions is solely due to the iteration of self-similar computational operations. Considering the embedding of the newly developed cortical areas it is of importance to note that these are receiving their input mainly from the already existing areas rather than from the sensory periphery. Likewise, their output is not directly connected to effector organs but to phylogenetically older cortical areas which have executive functions. Thus, the newly added cortical areas receive already pre-processed information and appear to treat this information in very much the same way as the older areas process the information that arrives from the sense organs. The hypothesis is that this iteration of self-similar computational operations leads to the generation of ever more abstract and symbolic descriptions. Because the newly added areas are also massively and reciprocally interconnected with each other, the higher order descriptions realised by these areas are also no longer confined by boundaries between the different sensory modalities. This is the structural basis for our ability to generate abstract, modality-independent representations of contents. On the one hand, such an organisation is probably at the basis of our ability to develop a language based on abstract symbols, on the other hand it can probably account for the generation of meta-representations which allow the brain to run a protocol of its own internal processes. At least intuitively it appears plausible that such an iteration of self-similar representational processes enables highly evolved brains to subject part of their own functions to cognitive processes, and hence become aware of their own perceptual and executive acts.

In a highly simplified way one could say that the phylogenetically more recent cortical areas look on the already existing areas that are directly connected with the sensory and motor periphery as these look at the outer world. Thus, brain processes become themselves the subject of cognitive operations. This could be the organisational basis of a function that is sometimes addressed as the 'inner eye'. However, this simplistic view leaves one with the unresolved problem of who then looks at the representations of these internal processes, interprets them in a coherent way, reaches decisions, and executes adapted responses.

The classical view has been that there ought to be a convergence center somewhere in the brain where all the available information converges and is available at the same time so that coherent interpretations of the world become possible. This would be the place where decisions are reached, plans formulated, actions coordinated, and finally it would have to be the place where the self articulates itself.

Neurobiological evidence indicates that this intuition is wrong. The brain presents itself as a highly distributed system in which a large number of computational operations occur simultaneously. There is no evidence whatsoever for the existence of a coordinating center at the top of the processing hierarchy. This suggests that the neuronal substrates of a percept, of a decision, of an action plan, and of a motor program, are specific spatio-temporal patterns of widely distributed neuronal responses. The same must be true for the meta-representations that contain the contents of phenomenal awareness, the consciously experienced qualia. Therefore, it is a major challenge of contemporary neuroscience to identify the binding mechanisms that coordinate the distributed activities into functionally coherent assemblies. A mechanism is required that defines from moment to moment which neuronal responses need to be related to each other, and read-out processes are required which are capable of identifying distributed dynamic states as representing particular contents.

Much of our recent work in the laboratory in Frankfurt has been devoted to the identification of putative binding mechanisms and to decipher the nature of the distributed code. Our hypothesis is that temporal coherence, i.e. the synchronisation of oscillatory responses, serves as signature of relatedness that binds together in a context-dependent and highly dynamic way the responses of large numbers of spatially distributed neurones. This is not the place to present and discuss the results of the related experimental work. However, the essential concepts and findings have been summarised in several recent review publications that are listed at the end of this chapter.

In essence, the search for binding mechanisms in distributed processing is accomplished by recording simultaneously from very large numbers of neurones, analysing temporal relations in these high-dimensional time series and then trying to relate specific correlation patterns to perceptual and/or motor performance. The evidence that has been obtained so far is fully compatible with the notion that representations consist of highly complex and dynamic spatio-temporal patterns of neuronal activity that emerge from a self-organising process that assures very precise temporal coordination of the discharge sequences of individual neurones. Thus, it appears as if representations of contents in the cerebral cortex are best described as distributed dynamical states that are configurated by the temporally structured activity of very large numbers of neurones in ever changing constellations.

We are still far from fully understanding the self-organising processes that structure these distributed and dynamic codes, nor do we understand how these dynamic states are identified by the brain as a consistent result of computational operations and how they are distinguished from spurious constellations. Accordingly, we are also far from understanding how these states can give rise to subjective experiences, emotions, and last but not least to consciousness. What is required now is the development of analytical tools for the investigation and characterisation of consistent patterns in these highly complex non-linear, non-stationary dynamics.

At present, it appears as if we knew enough about the components of the brain, the nerve cells, and about the way in which they can interact with each other in order to solve these problems. It is unlikely that we shall have to postulate hitherto undiscovered mechanisms of signal transduction, or that we shall have to include phenomena of non-classical interactions such as occur in the quantum world. The reason for this prediction is that we have no difficulties to fully explain the behaviour of simple organisms by what we know at present about the organisation of their nervous system. As our brain differs from the simple systems only because of dramatically increased complexity it must be assumed that our specific abilities result from the phase transitions that occur in complex non-linear systems and lead to the emergence of new qualities.

If this prediction is correct, we shall eventually arrive at a comprehensive description of brain states that correspond to particular behaviours including mental states associated with perception, decision making, planning, and consciousness. We shall then be able to establish a causal relation between a particular brain state and a particular subjective experience, and this is probably as far as we can get. However, if this prediction holds it necessarily implies that also our subjective experience of having decided something on the basis of subconsciously and consciously represented variables is itself a consequence of dynamic brain processes that preceded this experience. This challenges our intuition that our mental activities including our will to perform particular actions are causing neuronal states rather than being a consequence of them. A particular neuronal state that corresponds to a decision, or an intention, or a judgement is of course not fully determined by preceding states because the brain, like any other dynamical system, is subject to noise. Hence, transitions from one state to the next are not fully determined but follow probabilistic rules. However, this does not counter the notion that our experience or awareness of having decided something is the consequence of neuronal states that preceded this awareness and lead to it. This conclusion seems logically unavoidable but it is entirely incompatible with our traditional notion of free will that is so deeply routed in our culture. This notion assumes a strict dichotomy between the mental and the material world and poses that the mental processes are autonomous and the cause of material processes rather than their consequences. In our case the mental decision to act would have to initiate the neuronal activities that are required to translate the decision into action. In the light of modern neurobiological evidence this concept of mental causation of material processes is untenable, and we therefore have to arrive at a new self-model that reconciles our intuition to be an autonomous agent with our knowledge about our brains. Necessarily, such a synthetic attempt will have far reaching consequences on our self-understanding, on our concepts of responsibility and guilt, and our educational systems. Thus, knowledge provided by neurobiological research will inevitably have a massive impact on dimensions that we consider as genuinely cultural. Science, therefore, needs to be considered as an integral part of cultural activities.

BIBLIOGRAPHY

Singer, W. (1993) Synchronization of cortical activity and its putative role in information processing and learning. *Ann. Rev. Physiol.* 55:349-374.

Singer, W. (1995) Development and plasticity of cortical processing architectures. *Science* 270:758-764.

Singer, W., and C.M. Gray (1995) Visual feature integration and the temporal correlation hypothesis. *Annu. Rev. Neurosci.* 18:555-586.

Singer, W. (1999) Neuronal synchrony: a versatile code for the definition of relations? *Neuron* 24:49-65.

Singer, W. (2000) *Phenomenal awareness and consciousness from a neurobiological perspective.* In T. Metzinger (ed) Neural Correlates of Consciousness. Cambridge, Ma: MIT Press, pp. 121-137.

Engel, A.K., and W. Singer (2001) Temporal binding and the neural correlates of sensory awareness. *Trends in Cogn. Sci.* 5(1):16-25.

Engel, A.K., P. Fries, and W. Singer (2001) Dynamic predictions: oscillations and synchrony in top-down processing. *Nature Rev. Neurosci.* 2:704-716.

DISCUSSION ON THE PAPER BY SINGER

ZICHICHI: Professor Singer, in your very interesting and provocative report you emphasised a very important point, oculus imagination, saying that there is nothing that can go beyond our imagination. This is unfortunately not true for the following reason: our oculus imagination fails to imagine what science discovers in the logic of nature. I will give you only two examples. Example number one: no one before 1905 had been able to imagine the existence of a real world, we call it 'space-like'. Our world is 'time-like'; time dominates. This took two hundred years of experiments in electromagnetism to be discovered. Now something more recent. Up to 1947, no one could imagine the existence of the third column of our building blocks. We are made of three columns (the world, including galaxies and everything, including you and me), and four fundamental forces in nature. No one could imagine the existence of the second column up to 1947, and no one could imagine the existence of the third column up to 1960, so oculus imagination has only one distinct feature compared to all other brains which you listed in your evolution picture. Our brain is the only one that is able to understand nature's imagination. Our imagination is very small compared to the imagination of nature.

SINGER: I cannot disagree more. The examples you gave were examples where, due to instrumentation and calculus, you discover new qualities of nature, you get answers to questions that you've asked, because you could imagine these questions.

ZICHICHI: This is not true. The greatest steps in science come from the totally unexpected and unthinkable. I gave you two examples. Let me give a third one. The fundamental force of nature discovered by Fermi, the so-called 'weak force' which controls the nuclear fire of our sun and all the stars. No one could imagine the existence of such a fundamental force of nature. It took fifty years to understand the weak forces, so...

SINGER: I think we should discuss it in private, but it depends on what you understand by understanding and imagining. It just says, and I think this is an inevitable conclusion, that there must be limits to our cognition, because our cognitive tool is the product of an evolutionary process. It would be very, very surprising if there were no limits to the ability of our brains to understand. What do we know? We don't even know the limits. I think the only thing we can safely say is that there must be limits. Now, I called them limits of imagination, you may call them limits of cognition or whatever, let's do this privately.

WHITE: Professor Singer, as you know those humble surgeons like myself that have to operate on this incredible organ you've been discussing, using many of the techniques that you use in your studies to locate centres of function and to avoid areas of importance, and yet we remove large sections of the human brain as you well know, and particularly of the cortex, and so the question I am asking is, why is it that these patients so often recover so very, very well at a mental level and many of them, of course, do not? Is a redundancy built into the system of which you're speaking, is a repair built into the system, or is it that we are still not capable of measuring these people who in some way or other have had, you know, significant brain damage?

SINGER: It doesn't seem as if there were redundancy in the sense that there are areas that are not used and then come into play once you need them, because any lesion always causes deficits. The brain uses itself fully, but it's extremely plastic and it can use strategies to compensate for lost functions, unfortunately, only to some extent. Think about stroke and the inability to recover.

CARDINAL MARTINI: Thank you very much for this fascinating presentation. I have two questions. Maybe you said this, but through the limits of my understanding I could not exactly catch the point. My first question: is it evident that, in our mind, affections, emotions count much more than perceptions and insights? You gave examples of perceptions. But some authors, I am thinking of Gerard Roth, think that emotions are what count, and that what we think are decisions from insights and reasoning are really emotions. Is there any evidence of that? And then the second question: from what you showed, one may think that the system is always working, able to work at the same capacity. How is this reconcilable with the fact that we not only fall asleep, but after ten minutes of attention it goes down, and then it comes again. Is there any evidence in the system for this?

SINGER: One can show very well the state changes which are associated with attention, drowsiness and sleep. Sleep seems to be a very important active process of rearranging conditions in the brain in order to stabilise memories and keep the homeostasis in order, dreaming as well. Now, concerning emotions, it is certainly true that what gets into consciousness is only those contents to which attention is directed, and the emotional background that is permanently changing in the brain biases the focus of attention towards certain contents. When you are hungry, you are much more likely to perceive a bakery shop or to be more sensitive to the smell of food than when you are not hungry, or even feeling bad. So, what we are focusing on is very much determined by these ongoing emotional drives. They control attention, and attention then controls what's coming into consciousness, because most of the factors that determine our actions are unconscious motives that we have no handle on.

THE ART AND SCIENCE OF MEDICINE

ANDREW SZCZEKLIK

As we grow older and we cross the shadow line, we begin to wonder what is the profession which has consumed our life. Between August and September 1957 Pablo Picasso closed the door of his studio and faced the challenge of Las Meniñas of Velázquez. He changed the vertical format to the horizontal and opened the great window. Then in a boundless game of imagination he metamorphosed the figures. The principal focus of Picasso's attention was a little girl, the Infanta Margarita. Picasso devoted 14 studies exclusively to her, decomposing and composing her, trying to get her essence, to break to the heart of the matter (Fig.1). Now, if we try to get in a

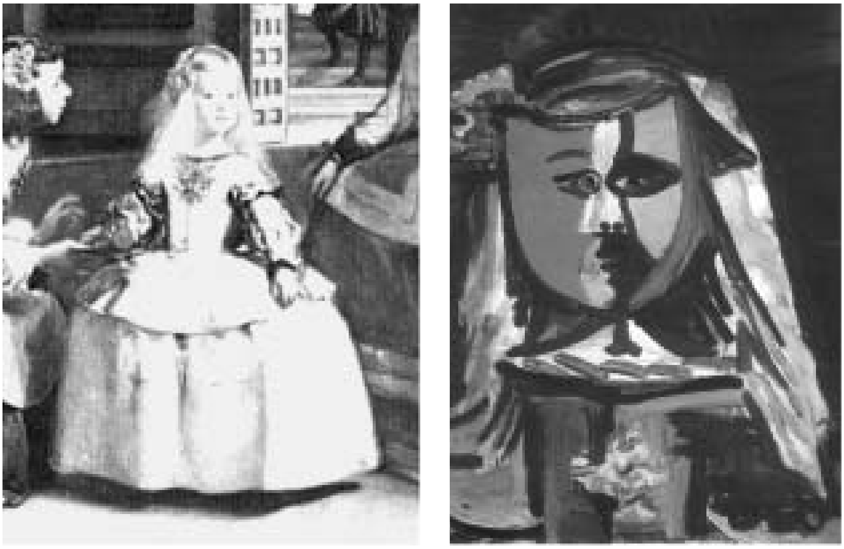


Fig. 1. The Infanta Margarita by Velázquez (left) and Picasso (right).

similar way to the essence of medicine we might end up with the head of the Infanta Margarita split in half, exemplifying the two faces of medicine: art and science (Fig. 2). Do they, indeed, represent two entirely different categories of being, between which there can be no easy discursive account? Or is this split rather artificial?

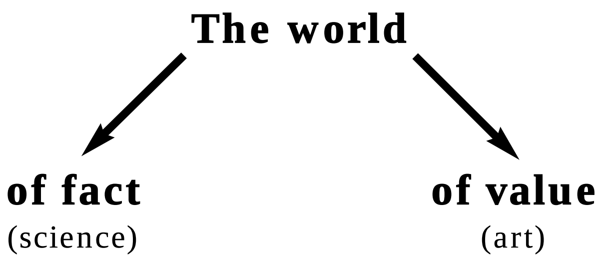


Fig. 2. Is the split between culture and science real or artificial?

Medicine and art emerged from the same source, i.e. magic, characterized by the omnipotent power of the word. It was the word, that if pronounced properly, could expel the disease or cause it, bring rain or drought, disclose the future, or bring back the dead relatives. The pre-modern medicine set great store by a highly personal clinical relationship between the doctor and the patient and emphasized the personal experience in diagnosing and treating the individual case as the royal road to successful healing. A radical transformation of medicine occurred over the last century with medicine becoming a specialized, high-tech endeavor with ever increasing aspiration to become science, or at best a science-based art.

* * *

Hippocrates considered medicine techne. Plato called it art. The Hippocratic physicians identified the healing power of nature [1]. Doctors, they taught, are merely nature’s servants. They took their diagnosis and therapeutic cues from what they could observe at the bedside – patients suffering from acute illness often are pale, jaundiced or flushed, they sweat, vomit, cough up phlegm or blood, develop pustules or rashes. The Hippocratics interpreted these signs and symptoms as evidence that the body is a marvelous mechanism with a natural capacity to restore the humoral balance which determines health. Pythagoreans conceived the idea that medicine leads to katharsis of the body, while music results in katharsis (purification) of the soul. Since Aristotle the meaning of the word katharsis [2] became an enigma in art and a source of endless disputes over millennia.

* * *

We owe to the ancient Greek mythology, this 'most thoughtful vision of the tissue reflecting our existence' [3]. Socrates thought that we enter the mythical when we enter the realm of risk, and myth is the enchantment we generate in ourselves in such moments. It is a spell the soul casts on itself [4]. In the early times, Greeks believed, things were not imprisoned in one form, they could change, metamorphose. Ancient Greeks were fascinated by this phenomenon which they called polymorphism. Thus, Zeus would transform himself into a white bull to carry away Europa, or into a swan in burning necessity in front of Leda. And at the very last moment when Daphne was to be caught by Apollo, leaves started to grow from her fingers and she turned out into a laurel tree (Fig. 3).

Fig. 3. Apollo and Daphne by Giovanni Lorenzo Bernini (1622-1625). Galleria Borghese, Roma.

Polymorphisms are widespread in the human genome [5]. There are a number of ways to categorize them. When classified according to the mechanism, point mutations – that is, a change in a single DNA letter (the base) in the sequence – are most common. Such substitution in one letter of DNA is called single nucleotide polymorphism (SNP) (Fig. 4). It may lead to an alternative amino acid, because of the way it changes the three-base sequence, or codon, that codes for an amino acid. In the genetic code of man (DNA), one letter (nucleotide) per one thousand is replaced by another, giving rise to SNPs. Every day scientists are discovering new SNPs; their number is now over 2 millions. In terms of functional effects most SNPs are silent, their role is negligible, but sometimes they might be responsible for appearance of a particular trait predisposing to a disease [6-8]. (Fig. 5). Long stretches of DNA with a distinctive pattern of SNPs are called haplotypes. Successive haplotypes can combine in many different ways. Last November the U.S. National Institute of Health announced [9] that it has garnered the $ 100 million necessary to construct a so-called haplotype map (the HapMap). A popular theory is that haplotypes could mean the difference between health and

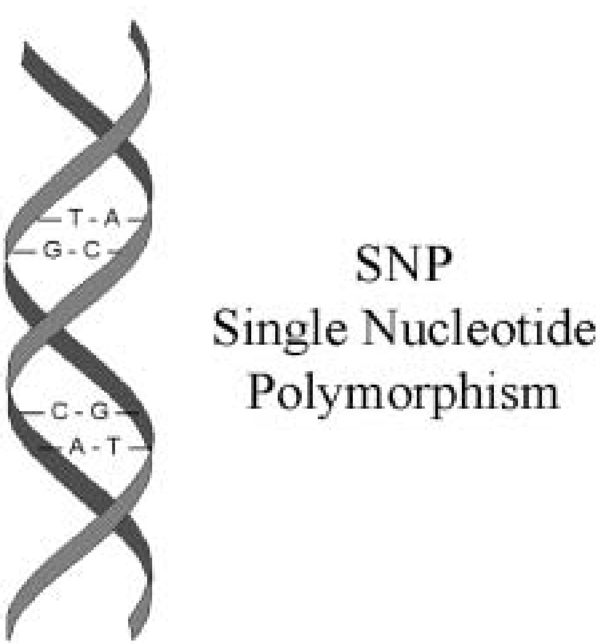


Fig. 4. The change of one nucleotide for another in a four-letter genetic code (A,C,G,T) constitutes the most common polymorphism (SNP) in human DNA.

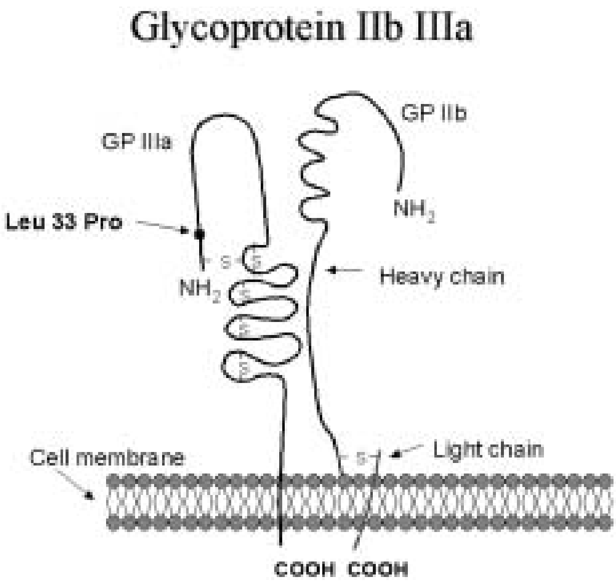


Fig. 5. A substitution of one nucleotide by another in the gene coding of the molecule of glycoprotein IIb/IIIa leads to change of one amino acid (leucine for proline) in the functional region on the surface of blood platelets. Such variant molecules are present in about 25% of Europeans and Americans; they facilitate blood clotting and, in consequence, predispose to heart attack and stroke.

ailments ranging from cancer to diabetes. If Zeus were to look at us today he would smile seeing how we find deep in ourselves polymorphisms which millennia ago were supposed to be the feature of gods.

* * *

Science and technology have become the new religion. They are looked upon as the origin of all sorts of freedom and all sorts of material goods. There is growing belief that medical science will ultimately take away all the ills of the world. Is science, indeed, able to answer the questions we might pose about the world? It is essential to realize not only the exceptional power of science, but also its limitations [10]. First, there is the limiting fact that quantum theory, our best scientific theory thus far, involves the inherent uncertainty associated with any measurement of a physical system. Then comes the self-referential fact that the very tools we use to probe nature are themselves part of nature. And finally, and most importantly, there is science's inherent inability to cope with anything unique, sometimes labeled 'origin problems' [11].

Science is just one of several ways of searching for truth. Truths of science stand beside the revealed truths of religion, the persuasive truths of humanities and the demonstrable truths of mathematics. And there are also 'magical truths' [10], complementary to science, associated with the non-material, human forces in the world, such as poetry, music and the fine arts.

* * *

Medicine's commitment to the patient is being challenged by external forces within our societies. Changes in the healthcare delivery systems in countries throughout the industrialized world threaten the values of professionalism [12]. Business ideology infiltrated healthcare when costs spiraled and governments reconsidered their long-standing commitment to the welfare states. The conditions of medical practice are tempting physicians to abandon their commitment to the primacy of patient welfare. 'Mediocricity became the benchmark for running a health service. Priorities shifted. Quality was eroded by a concern for quantity (...) Morale collapsed, cynicisms became commonplace'. These are very strong words. They come from the editor-in-chief of the prestigious *The Lancet* [13].

But medicine is governed by the ethos, not a balance sheet. Market forces, societal pressures, and administrative exigencies must not compromise the fundamental issue of patient welfare. Physicians both in Europe and in the USA have very recently developed a set of principles to which all medical professionals can and should aspire [14]. It reaffirms the fundamental and universal principles and values of medicinal profession and provides a new insight into medicine as both an art and science.

* * *

Medicine throughout most of its recorded history must be seen more as an art than science. It was only recently that radical transformation of medicine put it on a scientific path on search for truth. Let us then ask: What is truth? 'Truth is the moving army of metaphors' answers F. Nietzsche [15]. If that statement about truth is true, then science meets art and medicine finds its place in this encounter.

REFERENCES

1. Bynum, W.F., 'Nature's helping hand'. *Nature* 2001; 114:21.
2. Szczeklik, A., *Katharsis*. Znak. Kraków, 2002.
3. Brodsky, J., Preface to *The Marriage of Cadmus and Harmony* by R. Calasso Vintage, London, 1994.
4. Calasso, R., *The Marriage of Cadmus and Harmony*. Vintage, London 1994; p.278
5. Guttmacher, A.E. and Collins, F.S., 'Genomic Medicine. A Primer'. *New Engl J Med* 2002; 347:1512-21
6. Sanak, M., Simon, H.-U., Szczeklik, A., 'Leukotriene C_4 synthase promoter polymorphism and risk of aspirin-induced asthma'. *Lancet* 1997; 350:1599-600.
7. Szczeklik, A., Musiał, J., Undas, A., *Reasons for resistance to aspirin in cardiovascular disease*. Circulation 2002;106:181e-182e.
8. Undas, A., Sydor, W.J., Brummel, K., Musiał, J., Mann, K.G., Szczeklik, A., 'Aspirin alters the cardioprotective effects of the factor XIII Va 134 Leu polymorphism'. *Circulation* 2003; 107:17-20.
9. Conzin, H., 'HapMap launched with pledges of $100 million'. *Science* 2002; 298:941-942.
10. Ridley, B.K., *On science*. Routledge. London and New York, 2001 p. 34
11. Casti, J., 'The world of testable truths'. *Nature* 2001, 414:254.
12. Editorial: 'Just how tainted has medicine become?'. *Lancet* 2002; 359:1167.
13. Horton, R., 'The doctor's role in advocacy'. *Lancet* 2002; 358:458.
14. 'Medical Professionalism in New Millennium: A Physician Charter'. *Ann Internal Med* 2002; 136:243-253.
15. Nietzsche, F., in: R. Calasso, *Literature and Gods*. New York 2001, A. Knopf, p. 184.

DISCUSSION ON THE PAPER BY SZCZEKLIK

MENON: Thank you very much, Professor Szczeklik, for that illuminating talk which ended on a very high note concerning ethics and morals and human behaviour. Now, could I have just two brief questions? We do not have time for a long discussion. The questions will have to be brief. Professor Jaki.

JAKI: Your last remark, a quotation from Nietzsche about truth being an army of metaphors...

SZCZEKLIK: A marching army.

JAKI: A marching army. Is that statement a metaphor itself?

SZCZEKLIK: That probably will lead us to metascience.

JAKI: It is not.

SZCZEKLIK: In a way it is, in a way, you are right. I just like this definition, but this will open a long discussion: what really is truth?

MENON: That sort of comment would have to be discussed personally because it's like discussing poetry, if I may say so. Is there another question for Dr. Szczeklik? We have had a very illuminating lecture; there is really no question. There are a lot of questions one could ask, but we are limited by time, and the President has given me strict instructions on that matter. Thank you very much, the session is closed.

THE HOW AND WHY OF OUR ORIGINS

WILLIAM R. SHEA

The cosmos is about the smallest hole that a man can hide his head in.
(G.K. Chesterton)

What is Man, that Thou art mindful of him?
(Psalm 8, 4)

Human beings need creation stories. Cultures are defined, at least in part, by their common creation myths, stories that answer important questions about how things came to be and how meaning is to be found within the existing order.[1] 'How did we get here?' is a scientific question. 'Why are we here?' is a religious one. Human beings raise both types of question but the relation between the first and the second has not always been obvious. One of the most remarkable insights of the late twentieth century has perhaps made this relation clearer, and I will come to this in a moment. But first a word about the book of *Genesis*.

How the Bible Puts It

When an account of the origins of the universe was first offered in *Genesis* it was intended to provide a religious insight – mind you a genuine insight not a mere emotional response – into the ultimate truth about the world and our place in it. This insight had to be couched in the language

[1] Karl W. Giberson and Donald A. Yerxa, *Species of Origins: America's Search for a Creation Story*. Lanham, Maryland: Rowman and Littlefied, 2002. The present essay owes much to this remarkable book.

and culture of the people to whom it was communicated. So the author of *Genesis* adapted the cosmological science of his day to convey a message that transcended the particular scientific culture of his time but remained deeply imbedded in it. Essential to the story is that God cares for the world he created and that he is responsible for human life.

This story of creation does not fit our current knowledge about the origins of the cosmos and the evolution of life. Yet, the essential (I would venture to say unalterable) truth of creation has to be conveyed to a modern audience. This is not a question of changing the doctrine but of communicating the original insight in a new context.

God did not give us the Bible to satisfy our curiosity about nature. He gave us another book for that, the one described in Psalm 19,1: 'The heavens declare the glory of God; the skies proclaim the work of his hands'. In the sixteenth century, Cardinal Baronio, who was an acquaintance of Galileo, put it this way, 'The Bible teaches us how to go to Heaven, not how the heavens go'.[2] But what if the two books disagree? What strategies can be used to settle their difference? Are certain disciplines in a privileged position to adjudicate between knowledge claims or are all on equal grounds? Other contributors to this meeting have raised some of these issues, I will limit myself to asking: Is a post-modern creation myth possible?

'*We Are Stardust, We Are Golden*'

In their celebration of Woodstock in the 1970s, four young singers, Crosby, Stills, Nash and Young sang, 'We are stardust; We are Golden; We are Billion year old carbon'. Described as the anthem of the baby boomers, and unique among pop songs, the Woodstock lyrics communicate one of the most remarkable scientific insights of the late twentieth century: human beings, and indeed all life forms on planet earth, and even the earth itself, are stardust. It is now well understood that the atoms that compose the earth were once in the interior of a star. This star exploded some 15 billion years ago, strewing its spent fuel – stardust – into an enormous spherical cloud. Our solar system, comprising the sun, planets, and billions of smaller bodies from moons to asteroids, developed from this cloud as gravity slowly reassembled the stardust. Then, one such planetary body happened

[2] Quoted by Galileo in his *Letter to the Grand Duchess Christina* of 1615 (in the national edition of Galileo's *Opere*, edited by A. Favaro, Florence: Barbèra, 1890-1909, vol. 5, p. 319).

to be just the right distance from this star so that water would be in liquid form, a coincidence that made life possible.[3]

We are, in a profound and puzzling sense, stardust. Every atom of every element in your body, except for hydrogen, was actually *manufactured* inside stars. Stars are made of hydrogen and helium. A young star has no carbon, oxygen, nitrogen, iron or phosphorous. These so-called heavy elements are fused in the star from supplies of primordial hydrogen dating from the early moments of the Big Bang. The production of stardust takes place through stellar fusion, one of nature's most remarkable processes. Stars are gigantic nuclear reactors that run with surprising smoothness. The unimaginably great tendency of the star to explode under the outward pressure of its ongoing nuclear explosion is delicately balanced by gravity, pulling everything into place. This perfectly balanced stellar tug of war provides a stable environment where a star like our sun can shine consistently for ten billion years, providing steady illumination for planets like earth, and for a long enough time for life to emerge, develop, evolve, and write songs about the process.

Stars were not there from the beginning. In the early universe, there were only subatomic particles that were pushed outward by the Big Bang whose considerable energy worked to separate these particles and prevent their collecting together. Gravity did its best to stop the expansion of the universe and crunch everything back together into one gigantic ball. It failed to halt the expansion but succeeded in gathering most of the material in the universe into the structures that we know as stars, galaxies, galactic clusters, and the like.

Thus begins the modern scientific story of creation, told in brief outline, with most chapters left out, and no conclusion. What is of particular interest is that the existence of human beings is tied to the physical properties of this early universe. Some of the key structural features of the Universe turn out to be prerequisites for the emergence of life, and this has given rise to a renewed and fascinating discussion about our origins. At the heart of this reappraisal is the recognition that certain properties of the Universe are far from obvious, in the sense that they are brute facts and cannot, at least for the time being, be explained by our theories. These include: (1) the expansion energy of the Big Bang; (2) the precise

[3] See John Gribbin, *Stardust*. London: Penguin, 2000, and the excellent discussion in Karl W. Giberson, 'The Anthropic Principle: A Postmodern Creation Myth', *Journal of Interdisciplinary Studies* 9 (1997), pp. 63-89.

value of the gravitational constant, which gives us stars and planets; (3) the delicate balance between gravity, electromagnetism, and the strong nuclear force, which gives a hydrogen-dominated universe and provides for an abundance of stellar fuel in long-lived stars; (4) the precise details of the nuclei of helium, beryllium, and carbon, which makes the production of carbon unusually efficient and thus facilitates the biochemistry of life; (5) the relative masses of the neutron, proton, and electron, which make for stable long-lived atoms capable of participating in a variety of chemical reactions.

Let us glance for a moment at physical constants, for example, the charge of the electron is 1.6×10^{-19} coulombs, the strength of gravity is $6.67259 \times 10^{-11}\ m^3kg^{-1}sec^{-2}$, the mass of the proton is $1.6726231 \times 10^{-27}$ kg, and Planck's constant is 6.626075×10^{-34}. These values have been measured with great accuracy but they cannot be deduced from any mathematical theory. There is no discernible reason why they have these particular values, and not some others. But although they do not have to be as they are, we know that if they were otherwise, we would not be here. They play a basic role in the structure of the universe and make possible the chemistry of life.[4]

Whether there are planets like ours elsewhere in the Universe is a matter of conjecture, but what is certain is that the particular location of our Earth is not 'average'. To be a mere 8 light-minutes from a star is most unusual; typical distances are measured in light-years. Yet only those rare locations near a star like our Sun are suitable for life. All the vast elsewhere is hostile to life. Carl Sagan put it eloquently when he wrote:

> Our universe is *almost* incompatible with life – or at least what we understand as necessary for life: Even if every star in a hundred billion galaxies had an Earthlike planet, without heroic technological measures life could prosper in only about 10^{-37} the volume of the Universe. For clarity, let us write it out: only 0.0000000000000000000000000000000000001 of our universe is hospitable to life. Thirty-six zeros before the one. The rest is cold, radiation riddled black vacuum.[5]

[4] See John D. Barrow, *The Constants of Nature*. London: Jonathan Cape, 2002.

[5] Carl Sagan, *Pale Blue Dot: A Vision of the Human Future*. New York: Random House, 1994, p. 34.

Strange Coincidences

> *'Any coincidence', said Miss Marple to herself, 'is always worth noticing. You can throw it away later if it is only a coincidence'.*
> (Agatha Christie)

The average temperature of the Universe is 3 degrees Kelvin, namely 470 degrees below zero on the Celsius scale. In other words, if we were to choose a point at random in the Universe, it is overwhelmingly probable that we would find the temperature to be minus 470°C, much too cold for there to be any question of life. The very few exceptions to this numbing cold are mainly the stars whose inside temperature reaches millions of degrees. Water is necessary for life, but a place where it can be found in the liquid state, rather than as a gas or a solid, can only be at an exceptionally specific and rare distance from a star. The Earth is at one of those rare places.

The density of the Earth is also far from average, for the Universe is mostly empty space. A typical location in the Universe has about 6 atoms per cubic meter. This is about as crowded as a peppercorn in a volume the size of the Earth. A cubic meter of Earth, by contrast, contains about 10^{37} atoms. In addition to the unusual density and our location in space, the composition of our planet is also exceptional. The Universe contains about 96% hydrogen, 4% helium, and negligible amounts of the other 100 or so elements in the periodic table. There is only an insignificant percentage of elements like carbon, oxygen, and nitrogen, zinc and iron. But on Earth, the life-sustaining atmosphere contains vast quantities of oxygen, nitrogen and carbon dioxide, life-giving molecules that on the scale of the Universe are far more rare than gold on the scale of the Earth.

The probability of finding life on earth is ludicrously small, and when something is so improbable, it is sensible to ask why. Allow me two homely illustrations to illustrate how we normally behave when we are faced with very unusual coincidences.

Example 1: Near Escape

Terrorists have captured you and you are facing a firing squad. Twelve expert marksmen aim their rifles at you, and as you open one eye to get your last glimpse of the sun, you hear them pull their triggers on the command to execute. You close your one opened eye; the hammers in the rifles click against a backdrop of utter silence. You shudder ... and nothing happens. All twelve of the rifles have misfired. Paralysed from dread you slump to the ground, wondering why you are still here. 'Thank God', you whisper as you pass out.

When you regain consciousness you begin to ponder your strange fate. How could twelve new rifles, operated by twelve expert marksmen, all simultaneously misfire? You recall the feeble 'thank God' that passed from your lips before you lost consciousness, but now you are beginning to wonder. Your present circumstance is the result of twelve remarkable 'coincidences'. But you don't really believe in coincidence. And you can't quite bring yourself to believe that God himself put his finger on the hammers of all those rifles and made them misfire. So you lie awake in your cell, staring at the ceiling, asking yourself what really happened.[6]

Example 2: The Lottery Ticket

My second illustration is even simpler. Suppose that the Chancellor of the Pontifical Academy of Sciences and the nine members of his staff all buy one ticket apiece in the national Italian lottery. All ten of them win prizes on the drawing, and no one else wins anything. Now it is not at all remarkable that there were ten winners; the history of the lottery could reveal that ten winners is normal. But that these ten winners should all be members of the staff of the Pontifical Academy of Sciences is not normal. The odds are vanishingly small that this could be the case. This situation seems so improbable that some sort of investigation would certainly be launched.

Now in the universe *we* have won the lottery. The number selected by each of the forces is *our* number. As far as we know *homo sapiens* has won all the prizes. So we come back to our original question: How can we 'explain' this remarkable constellation of circumstances? It is clear that there is *something* to explain for scientists cannot help being curious about these 'anthropic' coincidences.[7]

[6] See Karl Giberson, 'The Finely Tuned Universe: Handiwork of God or Scientific Mystery?' *Christian Scholar Review* XXII (1992), p. 187.

[7] I shall use the expression 'anthropic coincidence' although the more common one is 'anthropic principle' introduced in 1974 by Brandon Carter (Brandon Carter, 'Large Number Coincidences and the Anthropic Principle in Cosmology' in M.S. Longair (ed.), *Confrontation of Cosmological Theory with Astronomical Data*. Boston: Reidel, 1974, pp. 291-298. A detailed discussion can be found in John D. Barrow and Frank J. Tippler, *The Anthropic Principle*. Oxford University Press, 1986.

For the sake of this argument, and to provide additional insight into what is at stake, let us briefly examine one of the striking coincidences – the strength of the so-called 'strong force'. The strong force is the force that operates between the elementary particles known as 'quarks' binding them together into familiar particles like protons and neutrons. At about one millionth of a second after the moment of the Big Bang, during the brief epoch when quarks existed as particles, the strong force began to bind them together in trios to make larger particles like protons. While the strong force was strong enough to bind the quarks together inside individual protons, it was not strong enough to bind quarks from *different* protons together. Thus it was, for the most part, unable to bind protons to each other. The 'coagulating' of quarks stopped at the formation of single protons, rather than continuing until all the quarks were bound together into one giant mega-proton.

Furthermore, as soon as individual protons were formed, the electromagnetic force, which causes protons to repel each other, kept the protons away from one another, further discouraging runaway coagulation. Now the strong force is very precisely balanced. If it were a little bit stronger, then it would have continued to coagulate protons into ever larger nuclei, perhaps combining all of the protons in the early universe into a mega-particle; if it were a little bit weaker it would have been unable to make protons from quarks in the first place. These single protons, of course, are the hydrogen that is so essential to everything in the universe – essential as the fuel by which the stars shine, essential as the water by which we live.

The very existence of a sun that can make us warm, and water that can make us cool, depends on the precise strength of the strong force. It if were ever so slightly different, we could not exist. It has a certain value – 10^{41} times as strong as gravity, 10^{39} times as strong as electromagnetism. Why does it have *this* value, and not one of the others – one of the infinity that are incompatible with the development of life? And why is its value so carefully balanced with the values of the other forces? There would appear to be some fine-tuning here, and it is difficult to understand how there can be fine-tuning without someone doing the tuning.

This argument, which I wish to examine in some detail, turns on the precise meaning given to the phrase 'difficult to understand'. What is it that is 'difficult to understand' and what does it mean to "understand" in this context?

Variations on a Cosmic Theme

When physicists consider what an alternate hypothetical universe might be like, one of the things that they like to do is change the strengths of the force ever so slightly and see what differences that makes in the resultant universe that would evolve through the interaction of those modified forces. The astonishing result of these speculations about alternate universes is the discovery that almost *any* change in the precise values of the four forces – gravity, weak nuclear, electromagnetic, strong nuclear – results in a universe that is inhabitable. And, in many cases, the values must be 'finely tuned' to within one part in a million, a billion, or even a trillion, of their present values. Otherwise, no participants at the plenary session of the Pontifical Academy of Sciences or anywhere else for that matter.

It is obvious, however, that the values of the physical forces must have *some* value. And the values that they have individually are no more remarkable than any of the values that they don't have. Of course, the values must be such as to allow us to be here, since it is clear that we *are* here. All this is obvious. What is remarkable, however, is the large number of precisely determined, yet apparently *unrelated*, things in the universe that are, so far we understand at present, related to each other *only through their relevance to us,* as creatures who eventually evolve in this 'finely tuned universe'.

God of the Gaps

From the evidence available can we take the next step and say that the universe is designed? In the early history of science it was common, almost universal, to attribute to God those parts of the explanation that could not be provided by science. At various times in history God was moving planets, altering animal forms, blotting out the sun at midday, and so on. Even in the 'scientifically sophisticated' nineteenth century God was designing the eye, originating life, defining absolute space, etc. The conclusion that God designed the universe is not a new argument. In his widely read *Natural Theology; or Evidences of the Existence and Attributes of the Deity,* William Paley argued that anyone who examines the precision and intricacy of design of a watch is forced to conclude 'that there must have existed, at some time, and at some place or other, an artificer or artificers, who formed it for the purpose which we find it actually to answer; who comprehended its construction and designed its use'.[8]

Whether or not God can be used to fill gaps in our understanding of the universe is not a trivial question (surely God must make *some* difference in the physical world!) but it is manifestly clear that invoking God as an *explanation* is begging the scientific question entirely. It is nothing more than an admission of ignorance. We propose to 'understand' something that is very complex by attributing it to some other thing that is more complex. It must be admitted that we cannot know something about God in a narrow scientific sense (How can He move? How fast? How far? What is his source of energy? etc.) So when we propose to *explain* some empirical problem, like anthropic coincidences or the design of the eye, by invoking God, we have not provided a 'scientific explanation' at all. As Karl Giberson has pointed out, the only way that God can serve as a meaningful 'explanation' for something like the anthropic coincidences is within the context of a larger metaphysical scheme of which God is already a part.[9] If God is already *assumed on independent* grounds, then he can perhaps be invoked to 'explain' other elements in the metaphysical scheme. This is why the argument seemed so natural prior to the Enlightenment when virtually everyone believed in the existence of God. But the epistemological criteria for metaphysics are so different from those employed in science that this effectively changes the rules in midstream. When we are searching for explanations that meet the more restrictive epistemological criteria of science, it is precisely here that the God of the Gaps is not what we want.

Possible Scientific Explanations of the Anthropic Principle

Furthermore, before concluding that the anthropic coincidences offer material for a new creation myth, we must be aware that there are a number of possibilities *within* (or at the edge of) science that should be considered even if they may have to be dismissed for giving rise to more problems than they can solve. I shall mention three:

[8] William Paley, *Natural Theology; or Evidences of the Existence and Attributes of the Deity*. London: Mason, 1817, p. 7. The work was first published in 1802.

[9] Karl Giberson, 'The Finely Tuned Universe: Handiwork of God or Scientific Mystery?' *Christian Scholar Review* XXII (1992), p. 192.

1) *Big Bang Recycling*. The current Big Bang could be followed by a Big Contraction and then another Big Bang, *ad infinitum*. The scientific information to assess this theory is not yet available but, given time, this cycling of the universe may appear no more curious than the cycling of the seasons. If the Big Bang does recycle, then it is possible, or even probable, that certain physical parameters might be 'reset' in some way at each new beginning, when the entire universe is squeezed through the eye of the needle of creation. This 'resetting' of the initial conditions would obviously influence the outcome each time. We live during a cycle when the physical parameters have the values necessary for life. Next time around life may not make it. The time after that, the universe may teem with life, far more varied than we observe at present.

2) *Multiple Universes*. Prior to the development of modern cosmology it was proposed that we could 'understand' quantum mechanics better if we supposed that quantum measurements resulted in bifurcations of the universe. This is highly speculative but we cannot at this time rule out the possibility that multiple universes might provide an 'explanation' for anthropic coincidences. In any event, the invocation of a deity to explain these coincidences is hardly an 'ontological bargain'.

3) *Inflationary Cosmology*. Certain modifications to the Big Bang suggest that our visible universe might be just one of many embedded in a much larger meta-universe. On this view our visible universe is a bubble that inflated shortly after the beginning and had some of its particular physical parameters adjusted by that inflation. According to this 'inflationary cosmology', there may be other such bubbles in the meta-universe, but ours has the right values for life.

All three of these explanations have in common that there may be many different universes, and that we happen to be in one that is 'finely tuned for life'. In this way they can be said to 'account' for the anthropic coincidences although there is no direct scientific evidence at present for any of these other universes. Their existence can only be postulated as a logical consequence of a scientific theory that is accepted for other reasons. Thus, we cannot claim that we believe in these alternative universes for *scientific* reasons but rather for reasons that we consider epistemologically more pleasing, namely because they follow from theories that are mathematically more elegant and seem less paradoxical. It is largely a matter of one's metaphysical beliefs whether these alternative universes are considered more satisfactory.

An Open Quest

In a somewhat different vein, some leading theoretical physicists have argued that we live in a 'symbiotic' or 'participatory' universe; that our presence (in the form of our consciousness) is necessary to 'collapse the wave function of the universe', which is quantum mechanical jargon for 'bring potentiality into actuality'. It is in the nature of consciousness (whose description and interaction with matter is still extraordinarily mysterious) that it can only collapse wave functions that are compatible with its existence. It is well known in quantum mechanics that things can exist in hybrid superposition states for long periods of time and then be distilled into one of the constituent components through observation by a conscious observer, such observations apparently affecting not merely the present *but also the past history of the object under observations.* The universe, in this view, needs consciousness to select from among its various latent potentialities one actual universe – one real buzzing, whirring, cosmic machine. And consciousness, without apology, selected that one which was compatible with its own existence. We think, therefore, the universe is.

I would still wish to argue, however, that God is responsible in an *ultimate metaphysical* sense for anthropic coincidences, just as I would argue that the laws of nature do not *govern* the universe but rather only *describe* it. In the worldview of the scientist who is a Christian, gravity still finds its ultimate origins in God, even though He is not personally 'pushing' on the planets.

Who is the God of the Anthropic Principle?

We must therefore exercise caution in using anthropic coincidences to tell a creation story.[10] A God so posited would be a god who is constrained – either by choice or of necessity – to operate within a very restrictive evolutionary framework. Why was the world so structured that *homo sapiens* could evolve when it would have been possible to created human beings according to the traditional formula? It would seem that a God looking for dust of the earth to fashion people could just create this dust. Why did He have it evolve in the furnace of a star, distributed into space and finally recycled by gravity? We can marvel at the fact but we cannot fully account for His intentions.

[10] See Ernan McMullin, 'Indifference Principle and Anthropic Principle in Cosmology'. *Studies in History and Philosophy of Science* 24 (1993), pp. 359-389.

Conclusion

It is certainly true that anthropic coincidences are a fascinating topic. They have sparked a renewed interest in the history of our origins, and they have started the scientific community thinking seriously about the larger context of their work.[11] Both science and religion seek creation myths, stories that give our lives meaning. From the highly theological Near Eastern creation stories of the Gilgamesh epic and the Hebrew bible to modern accounts that use mathematics and physics, every creation story is pregnant with a particular worldview. Although it may be too early to draft a new creation myth to clarify and mitigate the exhilarating, challenging, and terrifying patterns of life and death, it is fair to say that there is room for a fruitful dialogue between science and religion. History and the findings of social science confirm that human society must agree on fundamental issues if it is to cohere and endure. The creation story that underpins the larger structures of meaning is certainly a central element in this agreement. Contemporary society doe not share a common notion about how things came to be but the time may come when it will. We cannot be indifferent to the fact that the world appeared and to the meaning of its appearance.

[11] In 1951 already, in an address to the Pontifical Academy of Science entitled, 'On the Proofs of the Existence of God in the Light of Modern Natural Science', Pope Pius XII described the expansion of the universe as a strong indication that the world was created at some specified moment in the past.

DISCUSSION ON THE PAPER BY SHEA

LÉNA: Thank you, Mr. Chairman. You gave a very inspiring paper and addressed many questions which are essential, especially everything connected with the value of numbers, but there is one point where I would like to bring – I don't know if you agree – a word of caution. It's about reasoning about probabilities, because what we have is one single case of life realisation, and then we try to evaluate the probability of that by multiplying extremely small numbers like the one you've shown, by extremely large numbers, the number of possible occurrences in the universe, and on those two numbers we have no real scientific evidence. We don't know exactly what's the likelihood in the probability sense of the happening of life through the process of evolution, molecular evolution, and we begin to have very little evidence on the likelihood of habitable conditions in the universe, not to speak of the maybe not so impossible areas in interstellar space, because some of them are very well protected from radiation and aggression.

SHEA: Well, I wouldn't quite put it like that, but it is important to recollect that very small numbers times very large numbers can give about anything. I should perhaps have developed an argument along the remarkable relations between these universal constants. But I was trying to address a general problem. I believe that calling onto God to explain the origin of universe is using a methodology that is not inside science as we practice it. Why? Because the way we do science is very simple, we ask: how big, how fast, what is the mass. These are questions we cannot ask of God. In the seventeenth century, with Galileo, Newton, Descartes, Leibniz, it would have just been surprising to say: my science leads to a mere indication, not a proof, that God exists. That would have seemed absurd. Since the Enlightenment, things have changed, but we need these metaphors. Rival accounts to the one I've given exist. In the cultural context in which we live we find mainly either atheists or agnostics, who object to a singularity. I prefer living in a context that is closer to the seventeenth century. Newton would have said: 'I know from other grounds that God exists; my science cannot be in opposition to my beliefs'.

This doesn't mean that science and religion are convergent, but for me they are consonant. My assumption is the following: science deals with the real world, so does theology.

CABIBBO: Certainly, this is a very interesting argument. Of course it is not something you can prove, unfortunately, so we remain in doubt. In other words, if the appearance of life has only a low probability, as low as you like, then the so-called anthropic principle is perfect: since we are here discussing it we hit it, we were lucky and we are in that particular universe. So, if it is only a question of probability, the argument is not convincing. If the constants of nature are fixed, and that is the only value that we have, it's not a question of probability, it's a question of absolute, then the argument becomes strong, but you cannot prove that it is so, I mean, at least not now.

SHEA: I don't say that we can prove the existence of God with this argument. I'm simply saying that modern science is consonant with religious beliefs. The way you have answered right now talking about probability embodies cultural values about how you feel about probability. So, if you say to me: 'I don't want singularity in the universe', then…

CABIBBO: No, no, I don't say that, I say that probability is a possibility; that there are many universes is quite possible.

SHEA: Absolutely.

CABIBBO: So, if there are many universes, even if it is very improbable that in one of them life exists, the fact that we are discussing it means that in this particular universe life exists. It's not a question of probability. We probably will not be able to know. Maybe when string theory is fully developed we'll know whether at least in that theory it is possible or not to have different physical constants. But at this point we don't know, we don't know whether there is one universe or many universes, whether the different universes have the same constants or not.

SCIENCE NEVER ENDS: A NEW PARADIGM IS BEING BORN IN BIOLOGY

RAFAEL VICUÑA

Does science have an end?

The spiraling advances in our knowledge of the natural world appear to drive the paradox that sooner or later science will no longer have questions left to answer. Distinguished thinkers thought that such a transcendental moment had already arrived. Of note is the case of physicist Albert Michelson, who in 1894, upon delivering the main address during the dedication of the Ryerson Physical Laboratory at the University of Chicago, declared that the more important fundamental laws and facts of physical science had all been discovered. According to Michelson, future research would be oriented towards the application of these principles and to perfect the precision of measurements. The same kind of assertion had been foretold by the eminent Lord Kelvin. A few years following the predictions of Michelson and Kelvin, the revolutionary theories of relativity and quantum mechanics emerged and completely changed the outlook on how the universe is viewed. Ironically, the experiments of Michelson relating to the speed of light helped to inspire Einstein's special theory of relativity.

In a book published in 1996, entitled *The end of science*,[1] the author John Horgan discusses the limits of knowledge with scholars from a broad range of disciplines. Among the interviewees is Gunther Stent, who has been one of the foremost proponents of 'the end of science'. Born in 1924 in Germany, Gunther Stent settled fourteen years later in Chicago, where he would later receive a Ph.D. in Chemistry from the University of Illinois. He was one of several physicists attracted to the biological sciences after

[1] Horgan, J., *The end of science*. Broadway Books, New York, 1996.

reading the now classic work *What is life*[2] written by Erwin Schrödinger. Gunther Stent, together with Max Delbrück, Leo Szilard, Francis Crick, Rosalin Franklin and Maurice Wilkins, among others, left the scientific discipline in which they had been trained to tackle the mysteries of living organisms. Stent was soon working along with Delbrück at the California Institute of Technology. Both were members of the famous *Phage Group*, which also included Salvador Luria, Alfred Hershey and James Watson. Later, in 1952, he would establish himself at the University of California at Berkeley, where he works until this day. There he founded the Department of Molecular Biology, and later he entered the fields of neurobiology and philosophy of science.

In 1969, Stent published *The coming of the golden age: a view of the end of progress*,[3] in which he develops the hypothesis that reality possesses limits and therefore soon nothing important will remain to be discovered. He utilized the fields of anatomy and geography as examples of scientific endpoints. According to Stent, chemistry had already reached its heights in the 30s when Linus Pauling demonstrated that every molecular interaction could be understood in terms of quantum mechanics. For their part, physicists had already described the physical universe, from the microcosmos of quarks and electrons to the macrocosmos of planets, stars and galaxies. Furthermore, a consensus had been reached in which the universe exploded about 15 billion years ago and that all matter is governed by four forces: gravity, electromagnetism and the weak and strong nuclear forces. The field of biology would be left with only three fundamental problems to explore: the origin of life on Earth, embryonic development and the processing of information by the brain. According to Gunther Stent, students of the nervous system would form the avant-garde of biological research, with the challenging perspective that the inability to even imagine any reasonable molecular explanation for consciousness offers some hope that new laws of physics might be revealed.

The remainder of the larger picture in the biological sciences had been clarified with the publication of the *Origin of the species by means of natural selection* by Darwin, the resolution of the DNA structure by Watson and Crick and the deciphering of the genetic code. These latter two discoveries

[2] Schrödinger, E., *What is life? The physical aspect of the living cell*. Cambridge, Cambridge University Press, 1944.

[3] Stent, G.S., *The coming of the golden age: a view of the end of progress*. The Natural History Press, Garden City, New York, 1969.

seemed not to have left room for new advances in the field of molecular biology, a premise which would lead Stent to publish in the journal *Science* in the year 1968 a provocative article entitled: 'That was the molecular biology that was'.[4] In the first paragraph of this article, Stent declared '... the approaching decline of molecular biology, only yesterday an avant-garde but today definitely a workaday field'.

Gunther Stent was not alone in the twentieth century with this fatalistic vision of science. Other protagonists included the physicist Leo Kodanoff and the former president of the American Association for the Advancement of Science, Bentley Glass, who observed that 'experiments of increasing costs are designed to solve more and more irrelevant details'.

A journey through the central dogma of molecular biology

About 34 years after the publication of *The coming of the golden age*, we could ask ourselves how accurate was Stent's prediction related to the end of molecular biology. The so-called central dogma of this discipline, enunciated by Francis Crick in the 60s, seems a viable reference point for a quick analysis on this matter. As it was written in its initial version, the dogma maintained that the flow of genetic information always goes from DNA to RNA and then to proteins. It also established that both DNA and RNA have capacity to replicate themselves.

Subsequent studies on the replication of the DNA confirmed what Watson and Crick predicted in their classic publication in the journal Nature in 1953:[5] 'It has not escaped our notice that the specific pairing we have postulated immediately suggests a possible copying mechanism for the genetic material'. Although there has since been no discovery that could be classified as revolutionary in the field of DNA replication, the synthesis of this fundamental polymer has demonstrated to be extraordinarily more complex than initially imagined. In the bacterium *Escherichia coli*, for example, more than 50 proteins contribute to this process, including five enzymes (DNA polymerases) with the capacity to catalyze the synthesis of DNA. The most prominent of these, DNA polymerase III holoenzyme, is in charge of copying the bacterial chromosome in anticipation of cellular division, a task performed at the astounding speed of 700 nucleotides per second. The discovery of topoisomerases, enzymes that solve the problem of

[4] Stent, G.S., *Science* 160, 390-395, 1968.
[5] Watson, J. and Crick, F., *Nature* 171, 737-738, 1953.

the advancing DNA replication fork through two strands that are coiled around each other, also constitutes a conceptual novelty difficult to predict in the early 50s. In this respect, there are still important aspects to solve, particularly the mechanisms that regulate the process in higher cells.

In 1970, Howard Temin and David Baltimore demonstrated independently that the flow of information from DNA to RNA was not strictly unidirectional, as some viruses have an enzyme called reverse transcriptase that is able to copy DNA using RNA as template. These viruses, known as retroviruses, are of great importance to human health as they are responsible for AIDS and certain cancers. Both investigators received the Nobel prize in Medicine in 1975 for this discovery. Another enzyme possessing this reverse action is telomerase, which is of major importance in the synthesis of chromosomal ends and whose action is altered in cancer cells.

The central dogma also failed to predict two unexpected transformations which messenger RNA (mRNA) undergoes before the encoded information is translated into proteins. These alterations consist of the removal of multiple sections of internal sequences or introns, a phenomenon known as *splicing*, and in the chemical modification of the mRNA in a process called *editing*, which alters the information originally encoded by the DNA template. Both modifications to the mRNA, while not contradicting the dogma, certainly shake it in its foundations, to say the least. Today we are still baffled by the existence of splicing and editing, as it would seem a more efficient use of cellular energy if evolution had chosen to directly alter the chromosomal DNA instead of the mRNA. More recently, the phenomenon of trans-splicing has been uncovered. It consists of a covalent union of mRNA fragments originating from both DNA strands, extending the initial concept still further that a gene is a continuous segment of genetic information.[6]

But still, this is not the complete story. Studies on RNA splicing mechanisms lead in 1982 to the surprising discovery that some introns have the capacity to excise themselves without the participation of enzymes. This catalytic activity of introns was later found in several RNAs that participate in diverse pathways of cellular metabolism. Typical examples of these now called ribozymes are the RNAs catalyzing peptide linking during protein synthesis and those which are responsible for the processing of transfer RNA (tRNA) precursors. It was for their work in this field that Thomas

[6] Labrador, M., Mongelard, F., Plata-Rengifo, P., Baxter, E.M., Corces, V.G. and Gerasimova, T.I. *Nature* 409, 1000, 2001.

Cech and Sidney Altman were awarded with the Nobel prize in Chemistry in 1989. In recent years investigators have selected synthetic RNAs of such catalytic versatility, that the hypothesis that ribozymes must have played a fundamental role in the first evolutionary stages of the life on Earth has been given a strong fortification. Examples of ribozyme activities generated in the laboratory by random sequence selection include phosphodiester cleavage, RNA ligation, RNA phosphorylation, RNA aminoacylation, peptide bond formation, glycosidic bond formation, RNA alkylation and cyclic phosphate hydrolysis, among others.[7] It has further been demonstrated that under specific conditions, RNA has the ability to catalyse the synthesis of its own nucleotides and moreover to replicate itself.[8] This *in vitro* selection of specific ribozyme activities is of such effectiveness that it has been used in the selection of deoxyribozymes. That is to say, the traditionally inert DNA molecule can also be compelled to perform a surprising variety of chemical reactions, such as RNA transesterification, DNA cleavage, DNA ligation, DNA phosphorylation and porphyrin methylation.[9]

The flow of information from RNA to proteins has also been a source of interesting surprises with respect to the central dogma. When the genetic code was solved in 60s, the attention was immediately drawn to the observation that this code was universal. All organisms in nature seemed to use the same language to store and transmit genetic information. In the course of the following years, it was discovered that several organisms fell outside this norm, particularly in their expression of the message contained in minute cytoplasmic organelles called mitochondria.

Additional findings substantially extending our perspective on the central dogma, relate to unexpected properties of some proteins. For example, certain proteins from bacteria and yeast have the capacity to remove internal fragments from themselves in an autocatalytic manner. The intervening polypeptide (intein) is precisely excised from the precursor protein and the flanking polypeptides (exteins) are ligated to form the mature protein.[10] The biological meaning of this splicing of proteins is still unknown, although most inteins harbor homing endonucleases which turn inteins into infectious elements by mediating horizontal transfer of the intein coding

[7] For a review, see Bartel, D.P. and Unrau, P.J., *Trends Biochem. Sci.* 9, M9-M13, 1999.

[8] Johnston, W.K. *et al*, *Science* 292, 1319-1325, 2001.

[9] Li, Y. and Breaker, R.R., *Curr. Op. Struct. Biol.* 9, 315-323, 1999; Breaker, R.R., *Science* 290, 2095-2096, 2000.

[10] Paulus, H., *Ann. Rev. Biochem*. 69, 447-496, 2000.

sequence. Prions are also a good example of a novel concept within the dogma. These protein agents, which affect the mammalian nervous system leading to diseases such as Creutzfeldt-Jakob, kuru and scrapie, can cause a non-physiological modification of other proteins seemingly without the need for genetic material.[11]

The Functional Genome

It is quite possible that if Gunther Stent had known that after the publication of his work there would appear exceptions to the universality of the genetic code, splicing and editing of the RNA, the reverse transcription of RNA, the splicing of proteins, the presence of catalytic DNA and RNA, etc., he may have abstained in 1968 of his prediction about 'the approaching decline of molecular biology'. And yet, it is highly likely that molecular biology has yet to reveal many of its greatest and surprising secrets, upon the unfolding of functional genomics. This novel field studies the organization of the genes, the mechanisms that control their expression and the interactions that are established among them to make up the physiology of an organism.

The fundamental discovery of Watson and Crick took center stage only one year after Martha Chase and Alfred Hershey, based on the observations of Oswald Avery, confirmed that DNA was the genetic material. Doubt no longer existed that this polymer was the structural key to the development and organization of living organisms. Then, it was assumed that a simple relationship between phenotype and genotype would allow an interpretation at the genetic level for every characteristic exhibited by living organisms. Possibly, this somewhat straightforward and ingenuous vision of the problem was influenced by the extreme reductionism championed by Francis Crick.

Later investigations, nevertheless, demonstrated that the genome is considerable more complex and that multiple factors influence phenotypes. An initial source of astonishment came from the observation that the amount of DNA contained within a genome and the place of organisms in the evolutionary scale do not follow a linear relationship. Thus, for example, many plants have more DNA than mammals, and still more surprising, the amoeba, a very small unicellular organism, has 200 times more DNA than *Homo sapiens*. This phenomenon is referred to as the *C*

[11] Prusiner, S.B., *Proc. Natl. Acad. Sci. USA*. 95, 13363-83, 1998.

value paradox. Although today we correlate this phenomenon with the fact that only a fraction of the genome has a coherent message (around a 1.3% in the man and a still smaller percentage in plants), the function of the non-coding DNA is for the most part unknown. For whatever reason, this portion of the genome must be essential, as its maintenance requires high energy consumption.

The Human Genome Project has brought new surprises that have come to defy the basis of genetic determinism, i.e. the traditionally sustained belief of the existence of simple causality between phenotype and genotype. As it is commonly known, this project anticipates reading (sequencing) of the genome in its totality, the elucidation of the genes encoded and their corresponding chromosomal locations (genetic map). The Human Genome Project also incorporates the study of genomes from other organisms, with the purpose of making comparative analyses among them.

Without a doubt, the most remarkable discovery that has been contributed by the Human Genome Project was not only the confirmation that there is no simple correspondence between the degree of morphologic complexity and DNA content, but neither is there a correlation between this physical property with the number of genes in the different organisms. Thus, one sees that solely within the group of the bacteria, the number of genes ranges from 473 (*Mycoplasma genitalum*) to nearly 8,000 (*Myxococcus xanthus*). Among them, the *Escherichia coli* bacterium, widely used in laboratory experiments, has a genome made up of about 4,500 genes. The yeast *Saccharomyces cereviciae*, also unicellular, possesses 6,034 genes. Since the latter is larger and possesses a more elaborate structure than bacteria, a greater difference in the number of genes had been expected. Among the metazoans (multicellular beings), the fruitfly *Drosophila melanogaster* appears with 13,061 genes, whereas the roundworm *Caenorabditis elegans*, that measures a millimeter in length and displays a more basic morphology, has 19,099 genes. Furthermore, *Arabidopsis thaliana*, a cress plant whose genetic simplicity makes it a useful model for laboratory studies, has a genome of 25,500 genes.

How many genes should be expected for the human species? Until a few years ago an estimate near 100,000 was postulated, although some experts elevated this number as far as 165,000. Then, in February of 2001, data published in Nature by the Human Genome Project consortium,[12] as well

[12] International Human Genome Sequencing Consortium, *Nature* 409, 860-921, 2001.

as that published in Science magazine by the biotech company Celera,[13] threw out an unexpectedly low number. The genome of the human species seems to have about 30,000 genes, little more than the cress *A. thaliana* and only 50% more than *C. elegans* worm. Other genomes whose study has not yet been concluded, such as those of the mouse and the chimpanzee, are expected to contain a gene number very similar to that of our own.

But it is not merely the low gene number that draws our attention. Something equally unexpected is that the genomes of the yeast, the fruitfly and the worm share 46, 61 and 43 percent similarity with the human genome. These observations raise fundamental questions. How is it that this low number of genes contains all the information required by a complex organism such as man? How do we explain that genomes sharing such a high degree of homology can give rise to such different organisms?

We do not have answers to these questions yet. The observation that more than a third of the human genes can undergo remodeling leading to the production of several functionally distinct proteins from each gene – a phenomenon called alternative splicing – does not appear to be a sufficient explanation. The DSCAM gene of the fruitfly *Drosophila*, which is involved in nervous system development, could theoretically give rise to 38,000 proteins by means of this alternative splicing. Therefore, it is clear that we must change our traditional vision of the genome and analyze its behavior like that of a complex system whose final product is superior to the mere sum of its parts. In other words, it is becoming more and more evident that although the number of genes are a determining factor in the phenotype of an organism, of equal importance are the inter-genetic interactions (epistasis), as well as the influence in gene expression exerted by the environment.

Thus, rather than saying that we have identified the gene for obesity, the gene responsible for cognitive abilities or the gene responsible for Alzheimer's disease, it would be more accurate to state that these genes are involved in the expression of these characteristics. In reality, the phenotype of each individual is dependent both on the properties of the genome as a whole and upon the interaction with the environment. This explains why the same mutation in a particular gene can give rise to dissimilar effects in different individuals, including failing to be expressed. Although this phenomenon is less frequent in characteristics arising from

[13] Venter, J.C. *et al*, *Science* 291, 1304-1351, 2001.

a single gene, it is certainly evident in the case of characteristics of multi-genetic origin. A textbook example of this latter point is observed with the gene associated with increased risk of mammary and ovarian cancer, BRCA1. When both alleles of BRCA1, that is to say, when the genes derived from the father and the mother are mutated, the risk of contracting cancer is not greater than if only one allele is present. It is as a result of situations such as this one that geneticists have coined the concepts of penetrance and genetic expressivity, to mean, respectively, the proportion of individuals with a specific genotype that is manifested as a phenotype and the degree to which this expression occurs.

In relation to the previous example, it is possible to deduce that although certain risks can be affected by alterations in a single gene, it does not necessarily imply that altering the dose of this gene by means of genetic manipulation is necessarily going to harness the expression of this characteristic in beneficial and harmonic form. This is perhaps the most important challenge that faces gene therapy, the practice that was initiated over two decades ago as a promising alternative to alleviate the monogenetic diseases. To complicate matters still further, it has been known for some time that mutations of genes whose alteration simultaneously affects multiple functions does not always shed light on relationship among these functions. The existence of these genes, referred to as pleiotrophic, constitute further evidence as to why genome related studies must be approached in both a systematic and open-minded manner.

Research in microorganisms has demonstrated this apparent lack of direct correspondence between genotype and phenotype. Comparative analyses of genomes of microorganisms that live at high temperatures, have not explained the genetic bases of thermostability. Equally puzzling is the failure to elucidate the genes responsible for the remarkable resistance exhibited by the bacterium *Deinococcus radiodurans* to radiation. Recent investigations on minimal genomes using the knockout approach have brought to light unanticipated findings in this issue. This technology involves introducing mutations that disable a gene in order to examine the consequences on the viability of the organism. Observations in yeast, for example, show that of the 6,034 genes already mentioned only about 1,000 are essential for survival. It is assumed that functional redundancy occurs, in which similar genes (paralogues) can assume the tasks of the deleted ones. Statistical extrapolations of these works throw out a number of 300 genes which are absolutely essential to sustain life. In metazoans, knockout technology has also demonstrated some highly unexpected results, an example being that the deletion of both oestrogen receptors still allows the birth of a healthy, although sterile, individual.

The concept of genomic plasticity had already been applied to the discipline of evolutionary genetics, accounting for the observation that certain morphologic characters remain unchanged in spite of a substantial genetic variability. These characteristics have been named canalized characters, since their manifestation stays within narrow limits in spite of stimuli having the potential to disturb them. A classic example is demonstrated by HOX gene clusters, which define the vertebrate body plan. All vertebrates, from sharks to man, have a similar body plan brought about by the presence of four HOX clusters. The bony fish have undergone a genome duplication of these gene clusters and now possess seven HOX clusters, yet still maintaining the same body plan. Further studies in this field have demonstrated that distant organisms in the evolutionary scale have very similar genes (orthologues) which possess completely different functions. One of the notable examples on the matter is the *otx* gene, which in the vertebrate lineage participates in head formation, whereas in the aquatic coelenterate Hydra this gene is associated with movement. In the same vein, genes that code for the eye crystal proteins have orthologues involved in responses to thermal shock and other stimuli that induce cellular stress.

Science has no end

The biologist Adam Wilkins, after examining the influence of Mendel, Darwin and Watson-Crick, suggested that in biology a Kuhnian style revolution which entails a new paradigm replacing a still effective one, has not occurred.[14] Strictly speaking, contends Wilkins, none of the seminal contributions of these prominent scientists constituted a new theory that substituted an existing one, as what really existed previously in each case was simply ignorance. In accordance with this, Richard Strohman maintains that a true revolution is currently taking place, where the existing traditional genetic determinism is being supplanted by a more systematic approach to genetics. The prevailing paradigm of the last several decades, reinforced by the reductionism of some leading scientists, found support in the statement: DNA to RNA to protein to phenotype. This axiom continues in its validity, declares Strohman, solely for those characteristics that are

[14] Wilkins, A.S., *BioEssays* 18, 695-696, 1996.

encoded by a single gene. But the vast majority of the cellular functions depend on the interaction of several genes, which are also influenced by the environment. It is for this very reason that it is easier to predict the appearance of a monogenetic disease (haemophilia, serious immunodeficiency, hypercholesterolemia) than those of a multifactorial origin (schizophrenia, Alzheimer's disease). According to Strohman, the new paradigm that is being heralded is that of epigenetics, the discipline that incorporates the study of mechanisms that impart spatial and temporal control of gene expression in the development from the zygote to the adult stage of complex organisms.[15,16] In this complex epigenetic network it is implied that once synthesized, proteins can establish a series of interactions using guidelines not originally encoded in the DNA. To phrase this another way, the network of interactions between the genes that is established by the proteins they encode, in conjunction with the influences of environmental factors on these interactions, constitute an epigenetic adaptive system that is complex and incompatible with the marked determinism that prevailed in the last century.

It will not be long before the views of Richard Strohman are verified. Either way, it seems clear that the application of a reductionistic logic in science can lead to false interpretations by limiting the confines of what remains to be explored. We must consider that biological systems are complex and experience demonstrates that as knowledge progresses new scenarios appear that could not have been foreseen with the previously available information. Scientific research always leads to new questions. For this reason, molecular biology, far from having found its limits proposed by Stent, is more vigorous than ever and most likely it is about to give birth to a new paradigm that will revolutionize the biological sciences.

[15] Strohman, R., *Bio/Technology* 12, 156-164, 1994.
[16] Strohman, R., *Nature Biotechnology* 15, 194-200, 1997.

DISCUSSION ON THE PAPER BY VICUÑA

CABIBBO: A great question is: will biology continue? Will physics continue? Who knows?

RAO: I think other than biology, there are a lot of other sciences, so let me say something. It's foolish of people to say that chemistry ended with the Dirac equation; Dirac himself said that, and that is unfortunate. And of course people say that Linus Pauling created modern chemistry when he put two dots and said there is a chemical bond.

CABIBBO: Nanotubes, etc.

RAO: The real point in chemistry is not based on this premise. The fundamental premise that explaining a chemical bond is not the end of chemistry. It's a wrong assumption: statements about the end of science, the end of the world, etc., are generally misplaced.

CABIBBO: I tend to agree.

RAO: This seems to be wrong in all these cases.

CABIBBO: I tend to agree. In fact probably even geography still has a lot of interesting aspects to be discovered.

VICUÑA: Well, at the begining of my talk I mentioned the book by Paul Horgan. He interviewed many scholars in different fields. Supposedly, all of them were more or less in favour of the end of science. But I heard this morning from the previous speaker, Dr. Shea, that many of the interviewees of Horgan in that book are not very pleased with the interpretation of their statements made by this journalist. But there have been prestigeous scientists in favour of the end of science. I didn't mention for example Leo

Kodanoff and the former President of the American Association for the Advancement of Science, Bentley Glass, who also said things such as 'experiments of increasing cost are designed to solve more and more irrelevant details'. As I said, he was President of AAAS. So, we have to be careful.

CABIBBO: Individual people may become tired of making experiments, but there'll be new people doing that.

THE UNIQUE AND GROWING INFLUENCE OF THE NEUROSCIENCES ON THE DEVELOPMENT OF OUR CULTURE

ROBERT J. WHITE

If we are to define and refine the cultural values of science in relation to human existence, we must continue to gain a greater understanding of the human mind and the brain. In the process, we must pause and once again ask ourselves the deep fundamental question: Who are we? In addressing this concept, we must take up the issue of: What are we? The classical Christian response to these questions is, of course, 'You are composed of body and soul and made in the image and likeness of God' in a Thomistic sense, primary matter and substantial form.

Perhaps, in an attempt to analyze this state we might begin with the physical body. Obviously, we can all describe the visual appearance of a person utilizing our senses but since we cannot physically observe the human soul the problem immediately arises as to where it is located, for example, within or outside the body or diffused throughout the substance of the entire soma.

What one would like to emphasize in the brief presentation above is that in the framework of our culture and its evolution and future to come, a single bodily entity, the human brain, has been totally responsible for all of the accomplishments of mankind since time immemorial. What we are saying is quite overwhelming for we are stating, categorically, that a living substance weighing no more than 3.5 pounds has discovered, constructed and learned all we know about the universe and ourselves. It is, then, the repository of all human knowledge gained to date and is completely responsible for all activities, be they good, bad or indifferent, of all generations in the past, the present and the future. Many medical scientists believe that the body itself represents nothing more than a power pack whose primary responsibility is to keep the brain viable. The Central Nervous System's (CNS) other anatomical element, the spinal cord, is equipped with peripheral nerves as is the brain with its cranial nerves to conduct information to this organ and to convey instructions from it to all systems of the body. Thus, this cellular structure must provide for the assimilation and processing of all this information from these sensory sources that often arrives simultaneously requiring decision-making within milli-seconds.

One must apologize for this rather simplistic discussion of the human nervous system that enjoys such cellular and molecular complexity and architectural uniqueness. Think for a moment, of a musician playing the piano and singing an aria from some classical repertoire. Just try to imagine how many areas of both cerebral hemispheres must be involved to carry out this performance. In spite of all the research conducted on music, and the brain, we still have very little understanding as to how all of these functions fit so beautifully together. Yes, the human brain is the most complex, most incredible 'object' in the entire universe as we know it. Many would be inclined to argue these extraordinary properties that brain tissue provides are anchored to its biochemical and physiological base, but still more appropriately thought to be more 'correctly' identified with the mind.

Thus, is the mind just a sum of all the abilities and functions displayed by the physical structure – the brain? Or, is it a special form that inherits the brain but is not an organic part of it? All of these relationships are, obviously, important if not critical to our discussion of science and culture, for in the final analysis it is the mind/brain consortium that produces, amplifies, and modifies our culture in all of its dimensions.

What is being emphasized in this presentation is the simple axiom that whatever culture is, or becomes, in all of its elements, the human brain/mind is responsible. Thus, our appreciation of the universe in terms of space, time, and energy, is extremely limited and, in time, even our present concepts may be found to be totally incorrect. What is fascinating, is that in spite of all the scientific efforts of such men as Fr. George Coyne, with all their incredible telescopic equipment and computers, in the final analysis, they (the cosmologists), as human beings, must gather and interpret data defining what our universe really is. Once again, it is their brain/mind interface that will accomplish this awesome task.

When we examine the many factors that encompass our civilization and define our culture now, and in the future, the immediate issue arises: Who is responsible for its design and development? Obviously, we, the world's population, are! It is imperative that we work to eliminate poverty and increase the level of education in the world. As a result, this critical responsibility and special attention must be focused on providing a scientific education for the youth of all nations. Within this educational effort, the discipline of neuroscience must be emphasized. Without the knowledge and understanding of the human brain/mind consortium, the advance of world culture and civilization could be severely compromised. As our human population moves into the future, the Earth could potentially become an inhospitable place with a severe shortage of resources such as lack of water, fuel, food and/or land for living. Thus, our evolving civilization and culture will be severely tested in the future requiring dramatic advances in many fields of science. Not only will this require important acquisitions of new knowledge, but the creation of technologies that presently do not exist if mankind is to survive well into the future. With birthrates in third world countries continuing to increase (although their overall populations are now being modified by the AIDS infection epidemic) and starvation, as well as the continuing overuse of the Earth's resources by the advanced countries, this will bring about serious limitations and will require major alterations in how we will live in the future. As a consequence, our civilization, and its associated culture, will demand overwhelming changes in all aspects of life to accommodate the evolutionary nature of our world as well as the universe. As has been emphasized over and over again, the necessary achievements required to sustain the viability of humanity are obviously through scientific advancement, which involves the intense participation of the human mind/brain.

While we have stated this crucial concept before, it is simply not easy to convince even the scientists themselves that this integrated relationship between the physical brain and mind must, in the final analysis, be at the very center of human existence as we know it. Everything we know, everything we do, results from this extraordinary relationship. While all scientific endeavors will continue to be essential to the formation of our culture in all of its dimensions, it remains for the discipline of neuroscientists to discover the origins of the 'bonding' of mind and brain and, in the process, be able to characterize the unique functions of this organ. Some would argue that in spite of outstanding research with subhuman primate models by Professor Singer, and others, our knowledge of the brain and mind is still severely limited and fragmentary at best. Such seemingly simple questions as: What is consciousness? What is memory? How and where is cognitive activity taking place? These are just a few of the fascinating capabilities of the human brain/mind. Yes, this is the most intricate and foreboding entity in the entire universe. Within its cellular/fiber architecture, embedded in a watery gel, these absolutely unique properties exist and perform. Yes, it is in this miniature organic edifice that all these activities are taking place, often simultaneously. While many of these attributes of the human brain are thought to be unique unto themselves, the basic neurochemistry and physiology of the human brain appear to be essentially similar to what has been documented in the mammalian brain of lower animals. This is also true of the fundamental cellular structure and arrangement. However, the size and weight of man's brain favors the human. Also, the number of brain cells (neurons) and their connections (axons and dendrites) are markedly increased in the human brain represented by tissue impaction as seen on microscopic examination of CNS tissue histology. Thus, with this incredible biological mechanism man constructs and destructs our civilization and our culture.

Yes, this simple thesis dramatically demonstrates the importance of neuroscience, the scientific specialty charged with studying and explaining the human nervous system. In the process, we must charge it with the responsibility of not only discovering the loci of emotions, the regions for cognitive performance (including storage of intelligence and decision-making) and, of course, memory in all of its dimensions. This list of functions of cerebral tissue represents only a small number of activities that this organ is responsible for. One might ask at this point: Is there a cellular center for good and evil thinking, free will, love and hate, and sin? If such physical representations for these activities do not exist in the human brain, then, how do we appreciate and define beauty as supplied by a visual and auditory input? In other words, how and where do our cerebral hemispheres decide a piece of art, or music, in beautiful? There is literally no aspect of our culture (in which there is always an advancing and changing concept with multiple facets) that is not directly and totally produced and influenced by the human brain. Thus, it is obvious how important neuroscience, in the process of studying the brain, is to our developing culture.

Excitingly, there have been significant achievements in recent years in an attempt to explain these incredible functions of man's central nervous system. Much of this advancement is related to the introduction of highly sophisticated instruments that actually permit the neuroscientist to observe and collate information during directed activities in the human cerebrum.

These specialized imaging machines known as Positron Emission Tomography (PET) scans, and functional Magnetic Resonance Imaging (fMRI) scans, generally provide recordings of changes in regional cerebral blood flow as well as measurements of localized metabolic activity utilizing radioactive labeled chemicals such as molecular O2 and glucose that are rapidly utilized by cerebral tissue during metabolic performance. While these instruments have extremely important functions in neuromedicine, they continue to represent one of the most critical advancements in neurotechnology for the investigation of the human brain in terms of locating the basic cellular areas responsible for various functions. For example, the location of such function such as movement, audiation and vision have been anatomically defined for at least a century. Now, with brain imaging studies the exact locations, often multiple, for these functions can be precisely documented in the cerebral cortex. In a clinical sense, brain imaging can now diagnose neurodegenerative conditions as well as malignant changes on the basis of their energy status. Evidence is also accumulating that psychiatric disorders such as schizophrenia and depression, even violent behavior, present with lower metabolic activity in certain areas of the brain. If you can identify a region in the human brain where there are metabolic alterations occurring, for example associated with violent behavior, then, with further refinements of this biotechnology, we will be able to find the anatomical areas in the brain in which the refinements of human performance (discussed previously) will be documented. Hopefully, as this neuroimaging technology carries forward, ancillary studies in cognitive psychology, neurophysiology, neurochemistry, and computer simulation will assist in understanding how the physical areas of this organ actually perform. Having this neuro-information available should, at long last, assist mankind in accepting how humanity structures the elements of our society, and how it forms and defines our culture bringing it literally into existence. All this knowledge of the brain carries an additional factor in terms of effecting our culture and civilization itself; which, in final analysis, could be a supremely crucial factor both in a positive and negative way. We are discussing here an entirely new field, that of neuroaugmentation. At present, this is best presented in two ways: First, the neuropharmacology effect on the neurochemical format of the brain that will result in subtle or even dramatic changes in cerebral performance. In time, significant improvements in memory, cognition and intelligence will be produced as a result of brain/mind functional chemical enhancements. Second, through the intervention of brain surgery. Obviously, the science of neuropharmacology has already provided hundreds of mood altering drugs but, in time, with further research the surgical-neurological area will become very important. Its beginning can be traced to the era of tissue ablative operations for pain and frontal lobotomies for intractable psychiatric disease. Now, we are rapidly reaching the time when surgery/electronic control of brain function will be possible.

Already such diseases as Parkinsonism have their neurological symptoms decrease through a stimulation procedure via precise stereotaxically placed electrode systems in the depth of the brain. There is growing evidence that with further design of this already sophisticated equipment, significant mental control of an individual would be possible. Thus, we must be prepared to harness the mega contributions from neuroscience research for the good of our evolving culture. At the same time, we must be extremely careful about permitting any chemical or surgical biotechnologies to alter the fundamental nature of man. Neuroscience, as all sciences, must continue to contribute to, as well as help shape, our culture, but always in a positive and moral way.

DISCUSSION ON THE PAPER BY WHITE

PAVAN: I do agree entirely with the value and purpose of the brain, but how does the brain operate in relation to culture? What are the mechanisms, the main mechanisms by which culture is made? Could I say that this is language, or are there other more important factors?

WHITE: Well, the difficulty is that in so many ways we have a great understanding of how the brain functions physically, but even with the superb presentation of Professor Singer today, I would say that much of what we attempt to understand is still very difficult. Although it may be true in the range of subhuman primates, when we ask how culture is developed and conceived, as I said in my paper, we know that the brain is the organ in which these tasks are performed, but how it works, how it assembles the facts, and how they may change or modify, I think that a great deal of that activity is still not appreciated. It can be appreciated, but just as we saw, we're talking about location, it doesn't tell us how we do it. For example, one thing we do not know is just exactly what happens if, for example, you want to raise your arm. Where does that command come from? Why was that done? Well, I think it's the same way when you are shaping, augmenting and changing what we call culture in all of its aspects: we don't know where it's done in the brain yet.

CABIBBO: Well, if I may say something as a physicist, it might be that the difference between a human and a chimpanzee is only a difference of quantity. There are many examples in physics where a small difference in quantity makes a fantastic difference in quality. Well, just to make one example, the atomic bomb, you need a certain critical mass. If you have less than that, you just have an inert piece of metal, if you have more it explodes. Another example is given by phase transitions: at a certain temperature there is agitation of atoms; if you heat water at 99 Celsius it is water, if it is at 100.0001 Celsius it becomes vapour. So, it's clear that there is a phase transition, that there's a huge difference between man with his capacity for communication, for formal thought, for storing in a communal database, I mean, because it's true that the brain has notions of a science, but there is not a single brain which knows everything, each brain contains a little bit, it is a community of science and writing, etc., which makes a big difference, and it might be that at least certain people like you or like other scientists of the brain will tell us whether there is a qualitative difference between the human brain and other brains, I don't know, different organisations etc., but even if there is no such difference in organisation maybe a small, relatively small difference in quantity is what is needed to make this jump. You can see that animals are very close to communicating. People who have dogs or cats claim they communicate with their pets. Obviously the communication is very small. At a certain point you start a chain reaction and culture begins.

WHITE: A chain reaction, yes. But the simple thing, as I mentioned, is obviously that the size of the brain is in favour of man, and yet there are larger brains, some of the larger animals do have brains that weigh more, but it's the impaction, it's the number of neurons and the number of cells, connections, and synaptic relationships that again favour the human brain. The fascinating thing though, Professor, is that the same chemical reactions, the same histology, the appearance of the brain under the microscope, the same electrical phenomena that we see and we measure, there's nothing between these features in the human brain and what we would see in a Rhesus monkey's brain, and yet, as you point out, the difference between performance, understanding and accomplishment is overwhelming. Like Professor Singer, I've spent years working with monkeys, and I can tell you they are incredible creatures, but I haven't seen any of them build a St. Peter's yet! I went to a conference recently in America where they were trying to put together a group of lawyers who support legal rights for subhuman primates and remove them as properties under the law and they would become persons. One of the lawyers who were opposing this, stood up and said, 'Well, I don't see any of them here in the audience that are asking to have a lawyer.' But you are right: the similarities are absolutely fascinating. On the other hand, the brain is such an incredible organ, yet how can you arrest the circulation of the human brain for an hour at a very low temperature and have it be rewarmed and retain the same intellectual capabilities and personality? After all, we've stressed the fact that it doesn't have redundancy, which it does have, incidentally. It is just incredible; we have much to learn.

SCIENTIFIC CULTURE AND THE TEN STATEMENTS OF JOHN PAUL II *

ANTONINO ZICHICHI

Introduction

From the very earliest days of his Pontificate, Karol Woytila has maintained a particular relationship with Science and its values. Just a few days after his election, he opened the doors of the Church to Science, giving life to a continuing relationship with the international scientific community. This relationship has played an invaluable role in eradicating the danger of a Nuclear Holocaust, and in confronting, through factual projects, the danger of an Environmental Holocaust in the undeclared war between the planet's North (the rich) and South (the poor). No better guide exists for the scientific community in undertaking this task than the Pope's ten statements, which have given life to a Scientific Culture in communion, not in conflict, with Faith.

The role of this pastoral work of the Pope is analysed in the context of modern culture in which – up until the arrival of John Paul II – the dominant part of atheist culture had raged, using popularisation of so-called science as an effective weapon for achieving the transformation of streams of falsehood into truth itself. Mystification of culture in the 20th century became a powerful arm of the two atheist cultures, Nazism and Stalinism, which had the common goal of outlawing Faith as Science's number one enemy. These two fearful cultures were deliberately blind to the fact that Science was not born in atheism's home, but in the heart of our Christian

* Original in Italian. English translation by Mrs Susan Biggin, edited by Mrs Jean Engster-Montgomery and Eng. Claude Manoli.

culture, with Galileo Galilei, as an act of Faith in He who made the world, and that Science was (and is) a source of values that are in communion, and not conflict, with Faith. It is these values that have been given a new life with the Apostolate of John Paul II, whose ten statements sum up the values of Science and its role within the culture of our time.

There are three chapters here. The first covers the ten statements followed by a brief discussion. The second chapter is dedicated to the ninth statement, which has special significance for this Symposium. John Paul II in fact says that Science is born in the Immanent but brings man towards the Transcendent. We shall see if this is true. The third chapter examines the so-called popularisation of science and the issuing cultural falsehoods. The conclusion gives a summary.

1. The Ten Statements of John Paul II

1.1. *Error and Forgiveness – The First Statement*

On the 30th March 1979, His Holiness John Paul II met with physicists of Europe at the Vatican, to open the doors of the Church to Science, thereby allowing the Catholic Culture to take back home what in truth are its own treasures of the Galilean Scientific Culture. John Paul II says:

> Whatever is born of an act of Love must never be punished. If misunderstood, thus if it seems in error, this act of Love must be forgiven. Indeed, when understood, this act of Love will enrich our Faith.

This statement of John Paul II follows the teaching of Sant'Agostino on the preminent role of Love. In fact Sant'Agostino says: 'Love and do what you will'.[1] The relevance of 'Love' is of major significance for Galilean Science. At that time, no one understood that Science was born of an act of Faith and Love towards Creation. It escaped everyone, then, that, studying the material world, Galilei had uncovered the first footprints of the Creator of all things visible and invisible. And yet it was these traces that he said he wanted to seek, through an act of Faith in the Creator.

The Fundamental Laws of Nature enrich our Faith, but when they were discovered, they were confused with a detail that seemed offensive to the act of Faith: the fact that it is the Earth that moves, not the Sun. The three levels of scientific credibility had not yet been discovered, and it was there-

[1] 'Ama et fac quod vis' (*Epistolam Joannis ad Parthos*, tractatus 7, sect. 8).

fore difficult to understand how and why this apparent offence was linked to an act of Faith and Love towards Creation. This Act of Love enriched Faith, giving it, in the Immanent, the foundations of logical rigour that no one could have imagined possible, precisely because they were rooted in the material component of our very own existence.

Galilei studied stones in order to discover the Logic of Creation. He could have instead discovered chaos. Had Galilei not existed, we would know nothing about the existence of the Fundamental Laws of Nature. So two questions arise:

– what did Galilei know about the fact that the Fundamental Laws of Nature had to exist?

– and on what foundations was he able to conceive that these Laws had to be Universal and Immutable?

Imagining the existence of Universal and Immutable Fundamental Laws does not involve acts of Reason and nothing else, but of Faith in the Creator of the world.

Were it not for Galilean Science, we would not be able to say that Fundamental Laws of Nature, Universal and Immutable, exist; nor that these Laws lead to the unification of all the phenomena studied in the visible Universe, which appears to us with just four dimensions.

The Grand Unification brings with it the need for a Superworld, a scientific reality with forty-three dimensions: eleven of the 'boson' type and thirty-two of a 'fermion' nature.

We are beholding the most extraordinary conceptual synthesis of all time. And, we repeat, man has arrived at this magnificent synthesis through an act of Faith and Love towards Creation, born in the heart of our culture, an act of Faith that, in the first statement of John Paul II, receives its first and ultimate seal.

1.2. *Science and Faith – The Second Statement*

In 1979, John Paul II not only opened the doors of the Church to Science, but placed Science on the same pedestal as the values of Faith, saying: 'Science and Faith are both gifts of God'.

And indeed, Science studies the Fundamental Laws that govern the material structures of Creation. These laws could not exist if we were the children of chaos. These laws are the proof that in the Immanent there exists a rigorous Logic that is valid everywhere: from the heart of a proton to the edges of the Cosmos.

Among the innumerable forms of living matter, we are the only one that has been granted the gift of knowing how to decipher the footprints left in the Immanent by the Creator of all things visible and invisible.

It is this statement that led to a new alliance between John Paul II and the broadest scientific community ever brought together in the world – the WFS (World Federation of Scientists): ten thousand scientists from one hundred and fifteen nations, who, as we shall see, met with the Pope at the Erice Centre on the 8th May 1993.

1.3. *Science and Technology – The Third Statement*

We live in a culture that attributes to pure scientific research responsibilities that belong in their entirety to Technology (use of Science).

It is not the dominant atheist culture that came to the defence of Science against crimes it never committed (the arms race and irresponsible industrialisation), but John Paul II.

And the third statement of John Paul II is the proof:

> The use of Science is not anymore Science; this is why Technology could either be beneficial or harmful to life's values and human dignity.

A clear distinction must be maintained between Science and the use of Science (which is given the name Technology). The great scientific discoveries must be distinguished from technologies for warfare, from reckless industrialisation, from genetic manipulation.

To succeed in deciphering what is written on a page of the Book opened by Galilei has no connection whatsoever with the use that political and economic aggression can make of that discovery.

By placing Science on the same pedestal as the values of Faith, John Paul II gives Science the power to defend itself from attacks of the dominant atheist culture, separating quite clearly Science (the study of the Logic of Creation) and Technology (the use of Science, whether for good or for evil).

For the first time in the History of the so-called modern era, a clear distinction is made between Science and Technology. This separation confers an extraordinary cultural dignity on the great scientific discoveries, and allows them to be distinguished from technological applications, from the violence wrought on the environment, from thoughtless industrialisation, and from genetic manipulation used against life and against the very dignity of this form of living matter, called man, made in the image and likeness of the Creator.

1.4. *Dangers of Technology and Scientific Truth – The Fourth Statement*

In a message to the WFS, John Paul II says:

> Man could perish from the effects of technology that he himself develops, not from the truth that he discovers by means of scientific research.

This fourth statement of the Pope allows the great scientific discoveries to be distinguished from technology for warfare, from thoughtless industrialisation, from genetic manipulation. The effort made by John Paul II in defence of Science – as distinct from its use – has led a large percentage of the public finally to understand the radical difference that exists between Science and Technology. The declarations of the Holy Father have also encouraged scientists to speak out against the mystifications of the dominant atheist culture.

This statement of John Paul II allows us to understand that Science can be put to use for the common good, but that it can also be used for evil ends, and that the choice between good and evil is not scientific but ethical and cultural.

The Pope's earnest encouragement instilled in the scientific community of one hundred and fifteen countries the desire to create the International Committee 'Science for Peace', thereby bringing this community down from its ivory towers to get to work against the dominant culture and its mystifications, through the publication in 1982, of the Erice Statement.

Before the fall of the Berlin Wall, an awareness had arisen in our community of scientists of the need to leave the ivory towers, in order to let the wide public know about the profound difference that exists between 'scientific culture' and 'scientific popularisation'. Ten thousand scientists from one hundred and fifteen nations signed the Erice Statement, specifically since here, this time, the real and great Science was talking, in first person, without mediators. This document was drawn up by three people: Kapitza, Dirac[2] and the present author.

[2] A note about Kapitza and Dirac. Pëtr Kapitza was the only scientist in the USSR to have had the courage to say no to Stalin, who wanted him to direct the project for the most devastating bomb ever conceived: the one based on nuclear fusion. In the USA, the proposal of Oppenheimer was being discussed. He wanted to shut down the nuclear arms race. This proposal led to him being investigated, as if he knew about Stalin's decision. We would do well to remember that the great Kapitza (discoverer of superfluidity) was stripped of his title and reduced to living in hardship until the death of the greatest communist criminal in History. Dirac (father of the equation that opened up to Science the horizons of antimatter, never conceived by anyone before) worked on the project for the free world's first nuclear bomb, terrified that Hitler might arrive first.

1.5. *Missiles and the Heart of Man – The Fifth Statement*

To the scientists of Erice engaged in the study of how to overcome the danger of a Nuclear Holocaust in the horrific conflict between the two Superpowers (USA-USSR), John Paul II said:

> As in the time of spears and swords, so today, in the missile age, to kill, more than arms, is the heart of man.

This statement of John Paul II made a decisive contribution to the effort undertaken by the largest East-West-North-South scientific community that ever existed, to examine the foundations for a scientific-technological agreement between the two Superpowers, designed to avoid the danger of a Nuclear Holocaust issuing from the USA-USSR confrontation.

The joint effort of John Paul II and the scientists signatories of the Erice Statement made a crucial contribution to the fall of the Berlin Wall, upholding with concrete facts the validity of this Great Alliance between the scientists of Erice and John Paul II.

1.6. *Scientific Voluntariate – The Sixth Statement*

With the danger of the Nuclear Holocaust overcome, the Holy Father initiated another action within the great movement of scientists, engaged for a long time in studying the danger of the Nuclear Holocaust, saying in one of His messages to the WFS:

> Voluntary Science is one of the noblest expressions of love for one's fellow men.

The aim of this great plan was to study the Planetary Emergencies. In 1993 the Pope came to Erice to meet with the WFS scientists representing 115 Nations. The presence at Erice of John Paul II on the 8th May 1993 crowned a series of meetings and initiatives whose roots lie in the Papal *Magister*. For this extraordinary Pope has known how to open the doors of the Church to Science, without ideological, political, or racial distinction, and beyond any geographical barrier. In so doing, he has been able to give new drive to the culture of our time such that, after endless cultural mystification that threatened the very values of human dignity, great scientific discoveries have managed to penetrate the heart of the culture of our time – so-called modern, but in reality pre-Galilean and so very dispossessed of the truth.

The Earth belongs to everyone: rich and poor, believers and non-believers. A careful examination is needed of the vital features of this satellite of the Sun, a study that leads to a use of Science with the aims of peace, progress, and the defence of Nature. Do this, says the Pope, putting into action another form – one of the most noble – of love for your fellow man: the Scientific Voluntariate.

And so it was that the international scientific community, encouraged by John Paul II, put into action the Scientific Voluntariate, carrying out in a global collaboration (East-West-North-South) fifty-five pilot projects whose results allowed the conclusion that it is possible – provided that there is the political will – to face and resolve the Planetary Emergencies in the new millennium, giving future generations the hope of a life of well-being and brotherhood, in communion with all people of the Earth.

It should not be forgotten that the Earth is threatened by the danger of an Environmental Holocaust in an undeclared and hidden war between rich (North) and poor (South). John Paul II urges the scientists of the WFS to commit themselves through the Scientific Voluntariate to a study of the state of health of this space shuttle on which we have been graced to have been born.

The third millennium has need of the fundamental values of our culture, which is based on Love, to create a new society where Brotherhood, Charity, Forgiveness and Friendship among people triumph. This statement of John Paul II forms the foundation stone on which the whole of Humanity, in a Great Alliance between Science and Faith, can build the Hope to defeat the danger of an Environmental Holocaust. The results obtained from the pilot projects are the only material proof that the scientific community has been able to give to the G8 governments to convince them of the fact that, if there is political will, it is possible to defeat the Planetary Emergencies.

1.7. *The Use of Science for the Good of Humanity – The Seventh Statement*

Were it not for political and economic violence, scientific discoveries would find one single route for application: that whose goal is to improve the quality of life and the defence of dignity for all creatures travelling on this satellite of the Sun.

Science would continue to progress in deciphering the Book of Nature, and neither the arms race nor irresponsible industrialisation would exist. In a world in which a culture of Love, Brotherhood and Solidarity triumphed, the use of Science would serve only good purposes, and would correspond to a continuation of the Work of Creation. Indeed, the seventh statement of the Holy Father says:

> The use of Science for the good of humanity is a living testimony of an extraordinary continuity and a constant unity with the work of Creation.

The use of Science for the purpose of good has been the force behind the study and research that have led the world to carry out pilot projects for defeating the Planetary Emergencies. The seventh statement clearly shows that it is vital for the struggle against the Planetary Emergencies to take a firm place within modern culture.

1.8. *Love and Frontiers – The Eighth Statement*

In 1990, the Holy Father as a consequence of the meetings with the WFS scientists, made an appeal, while in Aversa, to convince all, scientists and non scientists, of the need to promote a Civilisation based on Love, saying:

> Love conquers all, demolishes frontiers, shatters the barriers between human beings. Love creates a new society.

1.9. *The Transcendent and the Immanent – The Ninth Statement*

The great appeal of our existence lies in the duality that characterises all we do, moment by moment, day by day, during the course of our lives. The two supporting columns of this duality are Science in the Immanent, and Faith in the Transcendent. In a message to the WFS, the Pope says:

> Science has its roots in the Immanent but leads man towards the Transcendent.

This statement by John Paul II has been taken up most enthusiastically by one illustrious member of the WFS – Professor Čerenkov – as indeed by the entire international scientific community. Chapter 2 gives a closer examination.

1.10. *The Great Alliance Between Faith and Reason – The Tenth Statement*

The tenth statement projects the necessary alliance for the culture of the third millennium into the future. John Paul II in fact says:

> The non-believers are thinkers; the believers are thinkers who pray; together, believers and non-believers act in good faith to implement the Great Alliance between Faith and Reason.

The future will be dominated by two factors. One is linked to our Transcendental Sphere, and is Faith. The other is part of our existence in the Immanent and makes increasing reference to the rigorous component of our thought and our activity, and is Reason.

Within the Great Alliance between Faith and Reason lies a strong source of hope, such that the world may see the defeat of those who show contempt for Faith or Reason. Although of Islamic faith, Professor Abdus Salam[3] loved the Pope. He was convinced that the world's future had to be built on a Great Alliance between Faith and Reason, and that Science should have been taught from the world's altars.

2. Let us See if it is True that 'Science Is Born in the Immanent but Brings Man Towards the Transcendent'

This chapter – as we have already noted – is dedicated to the ninth statement of the Holy Father, who says:

> Science has roots in the Immanent but brings man towards the Transcendent.

Let us see if this is true.

2.1. *Reason According to Believers and the Three Levels of Scientific Credibility*

For believers, Reason is a God-given gift and has allowed us to discover:

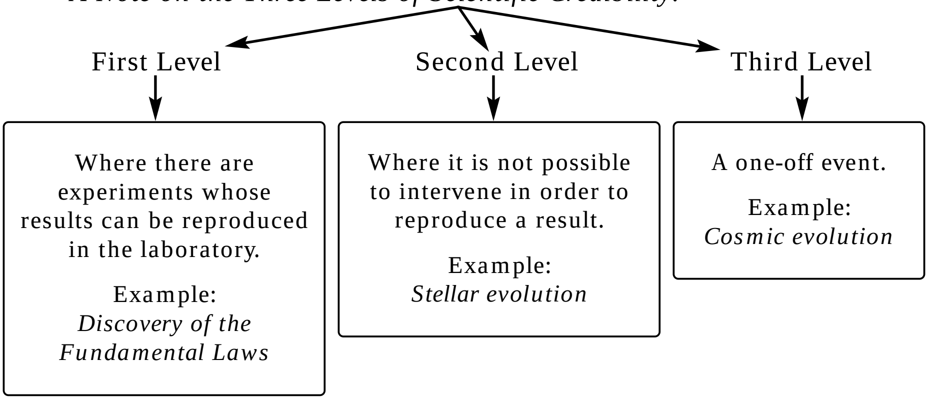
– Language, from which collective and permanent memory is born, thanks to Writing.

– Rigorous Logic, which has given rise to the great constructions of Geometry, Arithmetic, Analysis, Algebra, Topology.

– Science (with its three levels), which allows the certainty that the world is not ruled by chaos but rather by a rigorous Logic with laws that are valid from the heart of a proton (a millionth of a billionth of a centimetre) to the fringes of the Universe (a million billion billion kilometres).

[3] A note about Professor Abdus Salam: Nobel Laureate for his exceptional contribution to the understanding of the electro-weak forces, he dedicated his life to the young Galilean talents of developing countries. He held John Paul II in the highest regard, and considered the tenth statement to be a contribution of fundamental value to the culture of our time.

– *A Note on the Three Levels of Scientific Credibility*:



All the levels should be formulated in a rigorous way, and there should be no contradiction among them. An example of the link between the three levels of scientific credibility: Cosmic Evolution must be formulated in a rigorously mathematical way, and must be based on the discoveries of the Fundamental Laws made at the first level.

No phenomena known in the Galilean sense (i.e. rigorously reproducible) exist that cannot be explained as a consequence of the Logic of Creation: this represents the greatest conquest of Reason in the Immanent.

This study, undertaken by Galilei just four centuries ago, leads us to conceive of the existence of a reality even more exciting than the one we are used to – a reality of extraordinary symmetry which we hinted at in Section 1.1, and to which the name Superworld has been given.

2.2. *Reason According to Atheists*

For the atheist culture, Reason is the outcome of Biological Evolution of the Human Species. The Biological Evolution of the Human Species (BEHS), however, lies below the third level of scientific credibility. It is far from being comparable with Cosmic Evolution inasmuch as BEHS lacks rigorous mathematical formulation and is not based on reproducible experiments at the first level. If BEHS were Science at the first level, then the equation of BEHS should exist that leads to the outcome of Reason. And that is not all. There are innumerable forms of living matter. None of these, however, has been able to discover Science, or rigorous Logic, or Collective Memory. BEHS is unable to explain how it is that we are the only form of living matter that has the faculty of Reason.

2.3. *Atheism is Self-Contradictory*

Atheism is a contradictory logical construction. In fact, it denies the existence of the Transcendent.

If everything finds expression within the Immanent alone, then what BEHS would have is true: Reason is born and dies in the Immanent Sphere of our existence.

Since the greatest conquests of Reason are (as we have said) Language, Logic and Science, then Mathematics (the rigorous form of Reason) should be able to demonstrate that God does not exist, and Science should be able to discover that God does not exist.

Mathematics has not demonstrated the Theorem of the Denial of God and Science has not discovered the scientific proof of the non-existence of God.

If everything finds expression within the Immanent alone, how is it possible that there is no Theorem of the Denial of God, nor the scientific discovery of the non-existence of God? Here is the contradictory nature of the logical construction of Atheism.

2.4. *The Transcendent Solves the Contradiction of Atheism*

In the Logical Structure of the Believer, there exists the Transcendental Sphere, and Reason is a gift of God.

God has given us this unique privilege that has allowed us the Three Great Conquests. Logical Mathematics is not able to demonstrate the Theorem of the Existence of God in that, if it could, God could be Mathematics alone. God instead is everything. The same is true for Science. If Science were to manage to discover God, then God would have to be just Science. But instead, God is everything. It is the task of philosophical thought to demonstrate that God exists through the Transcendental Sphere of our existence and its connections with the Immanent Sphere of everyday life.

2.5. *To Discover the Logic of Creation*

If Language were sufficient to discover Science, this would have been discovered at the dawn of civilisation. If rigorous Logic were sufficient to discover Science, this would have been discovered by the Greeks.

To discover Science, it is not sufficient to think and reflect (Language), or to resort to rigorous reasoning (Mathematical Logic). To discover Science (Logic of Creation), there is one single route: to present rigorously formulated questions to the Creator. This requires an act of humility: recognition that the Creator is more intelligent than any of us – philosophers, thinkers, mathematicians, logicians, scientists. It is necessary to surrender ourselves before the intellectual Majesty of He who made the world.

It was Galilei who understood this. He it was who said that the footprints of the Creator were to be found in the stones (just as in the Stars). Galilei brought the Logic of the Stars into common matter (stones, string, wood), through an act of Faith and Love towards Creation.

In pre-Galilean thinking, for atheists and believers alike, matter could not be a depository of fundamental truth. The Fathers of the Church were the first to say that Nature is a Book written by God. Galilei had the privilege of understanding that the characters of that Book had by nature to be mathematical, and that it was not enough to reflect on the heavens and Stars.

All preceding cultures attributed to the heavens properties that lay above those of the stones. Galilei brought the Logic of Creation into stones and common matter, saying that our intellect has a power below that of the Creator. And thus it is necessary to bow before His intellectual Majesty and ask humbly how He has made the world. In other words, what rigorous Logic – of all possible logics – did He follow to make the world as it appears to our eyes and our intellect? The significance of a rigorous and reproducible experiment is precisely that intended and experienced by Galilei: to present in humility a question to the Creator.

2.6. *Ten Thousand Years Compared with Four Centuries*

This is how, in just four centuries, we have managed to decipher a good part of the Logic of the Creator. And we have managed to understand just how right was the humility of Galilei. In fact, from the dawn of civilisation right up to Galilei – in other words, for a good ten thousand years – all that man thought he had discovered about how the world was made, without ever carrying out an experiment, turned out to be wrong. Still today, Galilean teaching rules the logic of all the scientific laboratories in which the Fundamental Laws of Nature are studied.

Here is a last example of enormous interest today. No one can tell us if the Superworld exists or not. And yet this theoretical reality has been placed on rigorous and mathematical foundations. It is on these foundations that we believe we have understood so many properties of the world in which we live. But even so, the Galilean proof to be certain of the existence of the Superworld is lacking.

Logical rigour is not sufficient; Galilean proof is needed, in that this is the reply the Creator gives to our questions. To know more about the Logic of Creation, as always, it is necessary to present the right questions to He who made the world. This is how, in just four centuries, we have reached the threshold of the Superworld.

2.7. *From the Immanent to the Transcendent*

Science has the goal of understanding what God has written, using the rigour of Mathematics. Galilei said and thought that the Fundamental Laws of Nature are in fact expressed as precise mathematical equations. What did the father of Science know, how did his studies of oscillating pendulums or stones rolling down an inclined plane allow him to deduce that rigorous laws had to emerge? Chaos, randomness, whim might just as possibly have appeared instead: one day like this, a year later quite different. One law for Pisa, another for the Moon.

Galilei instead was thinking in terms of fundamental and universal laws, expressible in rigorously mathematical form. Together, these laws were to represent, and *de facto* do represent, the Logic of Creation.

'In that stone there is the hand of the Lord. By studying *common objects* I will discover the Laws of He who has made the world'. This was the Faith that inspired Galilei to challenge the dominant culture of his time. He simply wanted to read the Book of Nature, written by the Creator in mathematical characters.

The Book of Nature reveals to us how the world has been made: the work of Creation. This opus could have been written in no other way but rigorously, in mathematical characters. It is the scientist, in the first person, who has to strive in order that everyone should know how to read that astonishing and fascinating Book.

In it is written how the world is made. Since it is dealing with a construction, its language has to be rigorous. Knowing how to read it means making available for the benefit of man the laws that rule the Cosmos, in communion, not in antithesis, with the word of God, that is, the Bible. The Bible is written in a simple way, so that everyone can understand it; its purpose is not to explain how the Immanent part of our existence is made. Instead, it has the goal of tracing out for man the path that leads to the Lord. Science gives us the certainty of not being children of Chaos, but of a rigorous Logic. Who is the Author of this Logic? Atheism replies: no one. This is why Science, born in the Immanent, brings man towards the Transcendent, because it is absurd that a rigorous Logic does not have an Author.

2.8. *'The Light of the World'*

The twentieth century will go down in History as the era in which the use of Science (Technology) was at the service of political violence. This era led to the tragic dark periods of Nazism and Stalinism.

Professor Pëtr Kapitza, discoverer of superfluidity and expelled from university, reduced to living – as noted in Section 1.4 – without income until the death of Stalin for having refused to manage the Soviet H bomb project, defined John Paul II as being the:

> Light of the World set alight to dispel the tragic shadows of Nazism and Stalinism.

2.9. *The Berlin Wall was to Fall in the Fourth Millennium. Instead ...*

During the seventies, various meetings were held at Erice behind closed doors, to reflect on the danger of an East-West Nuclear Holocaust. Participants in the meetings included a number of twentieth-century giants of Galilean Science. These included Paul Dirac, Eugene Wigner, Pëtr Kapitza, Edward Teller, Isidor Rabi, Victor Weisskopf, Richard Feynman and Robert Wilson. As we have mentioned before, Kapitza had had the courage to say no to Stalin, who wanted him as director of the Soviet H bomb project. This refusal had cost him expulsion from all university and scientific duties, with consequences that can easily be imagined. Kapitza fell from being a prominent member of academia (discoverer of superfluidity) to maintenance technician of electrical equipment until the death of Stalin. Along with Wigner and Teller, Dirac had participated in the Manhattan Project, refusing any payment. Teller and Wigner were the fathers of the American H bomb project.

The conclusion of these meetings was: conflict is to be avoided at all costs. However, sooner or later, unfortunately, something will happen.

Kapitza feared the arrival of someone crazy and irresponsible at the head of the USSR.

Had this happened, the first shot would have been fired by the USSR. And in a nuclear exchange, first shot means certain victory. Unfortunately – even without an irresponsible leader in the USSR – there was always the potential weakness, typical of a free and democratic system, to contend with.

If in the USA – through normal democratic process – a weak president had been elected, the USSR head, while in no way an irresponsible criminal but a politician educated on Leninism and Stalinism, might have decided to grasp the opportunity with both hands. And to fire – on the basis of some pretext devised for the purpose – the first shot. But only a country whose governmental structure lacked the check of public opinion – and no other – could take advantage of the temporary weakness of the political adversary. The USSR held a potential for warfare twice that of the USA.

Conclusion: the USSR would have taken over Europe. And we would have had many centuries of 'real socialism'. The United States of America would never have envisaged a war to free Europe. They would have accepted the *modus vivendi*, just as they had accepted the surrender of eastern Europe to Soviet Imperialism.

The prediction, in the closed-door discussions of these scientific summits, was that our culture would have been reborn – not as a result of liberation by the USA – but rather as a consequence of the slow shift, very slow but inexorable, of 'real socialism' towards democracy and freedom. Estimated timescale: several centuries, perhaps a thousand years.

No one had predicted the arrival of John Paul II and that the Berlin Wall would fall.

This Pope brought about a rebirth of our culture with its values and conquests before the beginning of the third millennium. In this rebirth, right at the front, lies Galilean Science. The closed-door discussions held at Erice over the course of many years have convinced me of the importance of a totally unexpected and unforeseeable fact. A fact that in the history books of future millennia will be described as a miraculous event: the totally unpredicted irruption of this Pope into the History of the world. The Berlin Wall fell in the second millennium, not the fourth.

3. So-Called Scientific Popularisation and the Most Serious of All Cultural Lies: Science and Faith are Enemies

Atheist culture has used so-called *popularisation of science* to endorse so much cultural untruth. It has never spoken of Galilean truth nor has it ever talked about how Science came into being. Instead, through its propaganda campaigns, it has spread the most serious of cultural falsehoods, which would have 'Science and Faith as enemies'. And the pillar underlying this lie would have us believe that Science cannot be a source of values.

3.1. *The Values of Science and Faith are Closely Linked*

We will now see, instead, that Science is a source of values, and that these values are in perfect harmony with the values of Faith, not in antithesis. Below is a short summary of the values that Science has in common with Faith.

Revolution

We begin with the concept of revolution. When a scientific discovery arises, the dominant culture loves to point out that a real revolution has taken place.

The scientific revolution has never produced deaths or injuries. The concept of 'revolution' derives from the discovery that it was the Earth and the other satellites of the Sun that move, going around in their orbits. It was the 'revolution of the orbits' that gave life to Galilean Science. The term 'revolution' intended to emphasise the impact of the 'revolution of the orbits' of the planets on the history of the world. With the passage of time, cultural mystification is at work such that the scientific term 'revolution of the orbits' comes to take on the meaning of 'socio-political revolution' like the October Revolution that led to the first example of a Republic with Atheism as State religion, causing many millions of victims.

Instead, following a scientific revolution, everyone is richer than before. It would be more correct to speak of construction, rather than revolution. In Science, there is never denial of the past: it is improved, taken on board and built on. It is as if, when climbing an immense mountain, what we took to be the summit opens up a panorama never before observed – and, as if this were not enough, with it comes the discovery that there is another, even higher, peak.

The term scientific *revolution* does not in any way justify social revolution. But this is what the dominant atheist culture indeed did, in order to persuade that, after all, scientific rigour had necessarily to go down the road of *revolution*, understood in the commonly accepted sense of revolt, with attendant massacres and horrors of every type.

Racism

A scientist cannot say:

> I am unable to believe in this new scientific discovery because it was made by a man whose skin has a different colour from mine.

Science is an intellectual activity that rejects racism outright.

Universality

Man has always been in search of universal values. Science shows that Universal Laws exist. The Weak Forces that produce measurable phenomena in our laboratories are the same as those that make the Sun work. The light produced by a match is analogous to that produced by the Stars. The Gravitational Force, which makes a stone fall downwards and that holds us to the Earth is the same Force that oversees the formation of our Solar System and of the Galaxies.

Elevation of the Individual

Science exalts the individual and his work. The value of a scientist is not established by the power of the military tank, but by his intellect and research labours.

And here the entire sum of contribution must be recognised. Albert Einstein is inconceivable without Max Planck, James Maxwell, Isaac Newton and Galileo Galilei. All scientists, giants of Science: all believers.

Intellectual Stimulus

Science spurs man on to reach out for further conquests. There is no rest in our endeavour to extend and improve our knowledge. Instead, an ideology is put forward as if it were the final goal of an intellectual conquest. And this holds man back, century after century, on frontiers created from abstract speculations, which in no time at all become dogma.

Science accepts the dogma of the Transcendent. But it rejects dogma of the Immanent.

Humility

The scientist in his daily work faces problems he is unable to resolve. Galilei took more than a decade to understand friction and thereby arrive at the formulation of the first law of motion. Einstein dedicated eleven years, from 1905 to 1916, to get to the bottom of the significance of Galilei's experiments of the fall of material bodies. Eleven years, to manage to succeed in writing one equation. Science is made up of unresolved problems. Something happens, and we move on to the next thing. And there our difficulties begin again. Einstein worked for the last thirty years of his life in an attempt at unification of all the Forces of Nature. It was the great, *unfinished* opus. How can a man who is unable to reply to a question be arrogant? Science, as we have said before, is made up of unresolved questions. This is why it is based on a pillar of intellectual humility. Arrogance is born of ignorance.

Truth

Should a scientist tell a lie, he would be excluded from the scientific context. For Science, something that is true has to be reproducible. The scientist, when he comes to understand something or make a discovery, has to explain in full detail how he has arrived at that result. Whoever, no matter what the colour of his skin, and wherever, and at any given moment, he has to be able to reproduce that scientific truth. Mystification and falsehood lie outside scientific activity.

Reflection on Facts

Science teaches us to reflect, to not rush to conclusions without checking every consequence of a discovery in the known sectors of the fundamental structures of Creation. Science trains us for objective, not emotive, judgement. It relies on facts, experimental proof that is reproducible, the baptism of Galilean scientific legitimacy. It does not rely on words and abstract formulae. Nor does it make sense to say that a theory is mathematically beautiful or ugly. It can be only true or false, although it also happens, almost always, that when a piece of research reaches its conclusion, when in a specific field everything has finally been understood, then the mathematical formulation turns out to be more elegant than anticipated.

Goodness and Tolerance

Science teaches intellectual goodness and tolerance. Extremes have to be understood, not defeated. Things that appear to be poles apart can both turn out to be necessary for a description of the fundamental phenomena of Nature. Just one example should suffice: the wave and particle property. Light, for a long time, was considered to be a particle phenomenon. Then wave-like. And the two descriptions seemed to be mutually exclusive. Instead, light is at one and the same time both wave and particle. Many centuries have been needed to come to this understanding. The wave-particle *duality* is valid not only for light, but for all particles. This duality is one of the most significant conquests in the history of scientific thought.

Fight Against Preconceptions

Science fights an unceasing battle against preconceptions: even if centuries are needed to dismantle them. The great difference between Classical Physics and Modern Physics lies in the fact that a tiny quantity (the so-called *Planck's Constant*) was considered to be exactly zero. Another enormous quantity (the speed of light) was considered infinite. Three hundred years to break down two preconceptions.

Generosity

Science also has important facets of generosity. To explain to others the results of a discovery is something that enriches both scientist and listener. Science teaches that there exists a form, absolutely perfect, of generosity and love for our neighbour. He who gives up a piece of bread carries out an action of good, but clearly suffers if he has little bread. He who gives away what he knows, loses nothing, even if he ends up giving away everything he has.

Freedom of Thought

Freedom of thought is of vital importance for Science. This includes respect for that form of living matter known as man, and therefore respect for his dignity. Of all the forms of living matter, we in fact are the only one which has been granted the privilege of understanding the Logic He followed in creating the reality in which we live and of which we are made. This unique privilege is the source of the highest dignity to which one can aspire: that of being made in the image and likeness of the Creator of all things visible and invisible. To read the Book of Nature, written by the Creator, one needs to be free of any prejudice. The only guide being the replies given by He who has made the world when we put forward a question. The intellectual freedom to put a question to He who has made the world has to be absolute.

3.2. *If We Were to Live in the Era of Science*

If we lived in the era of Science, these values would form an integral part of so-called modern culture. In fact, they are truths that render Science an intellectual activity that is in perfect communion with religious thought. We are dealing with two essential components that make up our existence: one that operates within the Immanent, Science; the other that operates within the Transcendent, Faith.

And this is the conclusion one comes to. Science, by studying the Immanent in the most rigorous way that human intellect has ever been able to conceive, discovers a series of truths, whose values are in perfect harmony with those that the same form of living matter, called *man*, learns from the Revealed Truth.

Four centuries after the time of Galilei, that which the father of Science was able to see with a pure act of Faith and Love towards Creation becomes visible in dazzling clarity: Nature and the Bible are both works by the same Author.

The Bible – said Galilei – is the word of God. Nature instead is His writing.

If we lived in the era of Science, these truths would be the cultural heritage of everyone.

3.3. *The Other Cultural Mystifications of 'Scientific' Popularisation*

Scientific Culture has the duty to correct the cultural mystifications of popularisation of science, mystifications that might at first sight seem mistakes committed in good faith. But the fact that they are all bound to a common cultural substrate confirms that they are not. In fact, the mystification that Faith and Science are in antithesis is not the only instance where falsehood is elevated to truth by popularisation of science. There are many more. Here are a few examples.

Popularisation of Science has:

- *confused* Science with Technology.
- *never explained* that the three great conquests of Reason are: Language, Logic and Science.
- *always kept silent* regarding the Galilean distinction of the *three levels* of scientific credibility.
- *attributed to Science the responsibilities of the Planetary Emergencies*; these responsibilities belong to political violence

(planet packed with chemical, bacteriological and nuclear bombs) and economic violence (irresponsible industrialisation).

- *elected itself spokesman* of ideas (for example: scientific materialism) that are in total contradiction with the conquests of scientific thought.
- *endorsed* as frontiers of true and great Science research activities that still lie below the third level of scientific credibility (for example: BEHS, biological evolution of the human species).

Our epoch will go down in History as that in which *cultural mystification* has raged: *falsehood becomes truth*.

The main author of this *mystification* has been the *dominant culture*, first Marxist then leftist.

In this way, Science and Technology have been deliberately confused. And blame continues to be laid at the feet of Science, blame that instead belongs to political violence. Violence which, in the twentieth century, had examples of terrifying power in Hitler and Stalin, who exploited the use of Science (Technology) for political ends, not for progress or civilisation.

3.4. *If Everything is Science, Nothing is Science*

'Scientific Culture' is the only form of defence against cultural pollution, maintained Dirac, Kapitza and Fermi. If everything is Science then nothing is Science. And it is impossible to explain that scientific Marxism is the exact opposite of Science. It is thus necessary to distinguish Science from the other conquests of Reason – i.e., from Mathematical Logic and Language.

The umbrella of Language covers Poetry, Art, Philosophy and all intellectual activity that is not concerned with reading the Book of Nature in order to decipher the Logic followed by He who has made the world. Using Language, in all its forms, everything can be said and its contrary. Language – as Borges says – has the supreme aspiration of 'magnificent' structures such as a Poem can have, leaving aside Logic and Science, which is the Logic of the Creation.

Scientific knowledge is engaged full time in studying – in a Galilean reproducible way – this Logic. The key to distinguishing this activity from all others lies in intellectual humility, without which scientific knowledge would never have been born nor able to grow. This intellectual humility, which is vital for scientific knowledge, is not always present – in fact, often quite the reverse – in intellectual activities that contribute to the growth of non-scientific knowledge. This is why there is only one Science, while there are many forms of Art, Literature and Philosophy and other intellectual activities, often in contradiction one with another. This has been the case in the past and will continue to be so in the future. Even so, it is philosophical thought that produces fundamental contributions in the study of the Transcendental Sphere of our existence.

The contradiction intrinsic in Language's very structure is surmounted when Philosophy comes into play: its roots allow an understanding of how and why this contradiction does not have to extend beyond the conquests of Language.

In other words, the fact that there are various forms of Poetry, Art, Music cannot be taken as a basis on which to build a humanistic culture in contrast with Scientific Culture. The contradiction lies in the Creativity of Language itself, from which arise various expressions of our way of hearing and seeing the world. It is right that it is so. It is required by Language's very structure. It is here that the links with the Transcendental Sphere of our existence come into being, links that extend to Logic and Science through the creative processes of these great conquests of Reason in the Immanent. Creativity in Language finds its maximum structure in philosophical thought, without which it would not be possible to reflect on the Transcendental Sphere of our life. It is at this frontier that Philosophy expresses the highest creative power.

Creativity in Science has to coincide with the Logic chosen by He who has made the world to create the reality we are made of and in which we live. We scientists are not able to invent the existence of the third lepton. We can imagine its existence on the basis of experimental results, which can suggest new avenues for us to follow.

But whether the third lepton exists is known to the Creator, before any scientist in the world. It is He who has decided to include this 'third column' in the structure of Creation.

We have been granted the privilege of discovering that it does indeed exist.

With Mathematical Logic, the significance of Creativity is different. It is a legitimate act of the intellect to invent a new mathematical structure: with its rules and theorems. This structure does not necessarily have its correspondence in the Logic of Creation.

In order for this mathematical-logical structure to exist, the only condition is the principle of non-contradiction. But the principle of non-contradiction arises in philosophical thought, an integral part of Language. Logic formulates this principle rigorously, and uses it to underpin any of its structures. A structure – completely invented by the intellect – must not lead to a theorem and the negation of the theorem itself.

Having said this, the problem of the role of Mathematics in the Logic of the Creation remains open: this topic has impassioned the very best mathematicians of all time. There is no doubt that a formidable logical-mathematical structure can exist (and therefore be non-contradictory), without there being any correspondence with the reality of the world in which we live and of which we are made.

This in no way diminishes the fascination of the Creativity in the two conquests of Reason (Language and Logic), which, as distinct from Science, do not fall under Galilean-type experimental confirmation.

However, it is of fundamental importance to distinguish Science from the other two conquests of the Reason of the Immanent, in that, if everything is Science, then nothing is Science, with all the devastating cultural consequences, some of which are referred to in this Section.

3.5. *Cultural Pollution*

Kapitza said:

> Cultural pollution is the most difficult Planetary Emergency to overcome.

Here is an example. In the USSR, very few knew of the ecological disasters caused by the triumphs of the 'five-year plans' made known everywhere through propaganda campaigns, even in the western world, where they were taken as models of unprecedented development. In Italy, Communist Party members made great reference to them. No one, however, spoke of the ecological disasters of *Semipalatinsk* (100 times worse than Chernobyl), the 'Aral Sea' (50% of its waters destroyed), the 'City of Sulphur' (an area as large as half of Piedmont, contaminated to the point where the population had to go around wearing gas masks). These were the times of the cold war and no one dared to hope for a collapse of the USSR. But even so, the hero of Science, Pëtr Kapitza, considered it necessary to start immediately to fight cultural pollution in countries that were free; in those dominated by the USSR it was unthinkable. Dirac said:

> It is easy to declare ourselves as free men where there is democracy and freedom. Try doing this where political violence rages. Kapitza understood the consequences.

Cultural pollution has its roots in political and economic violence, which, by dominating the media (TV, radio, press and other channels), has enabled so many flagrant cultural mystifications to become 'truth'.

A terribly effective arm of cultural pollution is pseudo-scientific confusion, an essential component of popularisation. To cite meaningless data as if they were Galilean proofs of scientific truth; to introduce apparently valid arguments with bibliographic references that add nothing to the inexistent proof of the point in question: this is the technique of cultural pollution that siphons off valuable energy from the struggle for the triumph of Scientific Culture.

3.6. *Science, Art and Mysticism*

According to a number of scholars, the pillars supporting our existence are: 'Science' (rational approach), 'Art' (aesthetic approach) and 'Mysticism' (religious approach). These theories have nothing new to say about the conquests of Reason. Rather, they go backwards in time because they ignore Galilean teaching. In fact, they confuse the Transcendental Sphere of our existence (to which Mysticism belongs) with the Immanent Sphere (to which Science belongs). Furthermore, they include in the so-called 'rational approach' both Science and Mathematics, confusing Science with Logic. Galilei teaches that, to discover Science, the rigour of Mathematical Logic (thus, the rational approach) is not sufficient.

If it were so, the Logic of Creation would have been discovered by the Greeks, two thousand years before Galilei. If mathematical rigour sufficed, we could say that the Superworld existed. The Galilean thesis is based on 'Language', 'Logic' and 'Science' and it could not be more rigorous in distinguishing the three conquests of Reason. Art in fact belongs to Language.

Summary and Conclusions

The ten statements of John Paul II have given life to a Scientific Culture that lies in communion, and not conflict, with Faith. In the 1980s, this Culture strove to make a real contribution to overcoming the risk of a Nuclear Holocaust. Then, with the fall of the Berlin Wall came the need to avoid the danger of an Environmental Holocaust created by the political and economic violence that fired the undeclared War between the planet's North (the rich) and South (the poor). Once again, Scientific Culture in communion with Faith took action to avoid the latent danger of an Environmental Holocaust, by implementing pilot projects related to the Planetary Emergencies, through the scientific voluntariate of its community.

Atheist Culture, using as its arm public dissemination of what is passed off as Science, has instead wanted all to believe that Science and Faith are enemies. It has always confused Science with Technology, has never explained that the three towering conquests of Reason are: Language, Logic and Science, never mentioned the Galilean distinction between the three levels of scientific credibility, and has laid at Science's feet the responsibility for the Planetary Emergencies – responsibility that instead belongs to political violence (planet packed with chemical, bacteriological and nuclear bombs) and economic intemperance (unaccountable industrialisation). Atheist Culture too has acted as spokesman of ideas, such as scientific materialism, that lie in utter contradiction with the conquests of scientific thought, and has endorsed as frontiers of real and true Science, research activities that still lie below the third level of scientific credibility (for example: biological evolution of the human species: BEHS).

Had Atheist Culture itself discovered Science, then the ten statements of John Paul II would never have been conceived. These represent the cultural guide to the concrete deeds of which the Holy Father has been author, right from the very first days of his Pontificate. And it is this guide that has made possible the birth of a Scientific Culture in communion, not antithesis, with Faith. The influence of the Great Alliance with Science and its values has enabled the danger of the Nuclear Holocaust to be overthrown (Erice Statement), and allowed the creation of scientific and technological foundations from which to confront issues of the Environmental Holocaust (pilot projects for the Planetary Emergencies).

The 20th century will take its place in History for having seen the fall of the Berlin Wall and the start of an undeclared War between North (the rich) and South (the poor). The third millennium has need of a Scientific Culture that is the fruit of the Great Alliance between the two most important conquests of Reason, which are Science, in the Immanent of our existence, and the God-given gift connected with Reason in the Transcendent of our being, Faith. We would do well to recall that St. Paul and all our theological tradition define Faith as a gift from God. A gift linked to Reason, as described by St. Thomas of Aquinas:

> Naturalis ratio per creaturas in Dei cognitionem ascendit, fidei vero cognitio a Deo in nos e converso divina revelatione descendit.[4]

[4] 'Natural reason ascends to a knowledge of God through creatures and, conversely, the knowledge of faith descends from God to us by divine revelation' (ScG IV 1, 3349).

While emphasising the rational aspect of Faith, the entire Christian biblical tradition attributes it to the inner touch by the Spirit of God (*instinctus Dei invitantis* by St. Thomas of Aquinas) that awakens the dynamism of freewill. Faith is thus considered by Christian theology as a gift from God within man's Reason, which under the impulse of this same freewill, and aided by the Holy Spirit, accepts the gift.

We are the only form of living matter that has been granted the privilege of the gift of Reason and freewill. Let us seek to use it well. The third millennium must open up man's heart to hope through a Scientific Culture in synergy with Faith, not in antithesis. This is why, as this remarkable Pope teaches, Science must do all in its power to ensure the triumph of the values of the Galilean Scientific Culture.

ADDENDUM

ELEMENTS OF SCIENTIFIC RIGOR IN THE THEORY OF EVOLUTION

1. *Premise*

During this Conference the problem of 'evolution' was discussed. My paper (*Scientific Culture and the Ten Statements of John Paul II*) was not intended to deal with this problem. On various occasions, I have made remarks on the need for a 'rigorous' attempt to describe 'evolution', especially as it regards the Human Species. This paper is a coherent synthesis of my attempt to encourage our colleagues in the biological Sciences to introduce the Galilean rules in their research work concerning evolution.

2. *More About the Three Levels of Scientific Credibility*

The scope of this work is to lay out a rigorous, Galilean-type scientific foundation for the Biological Evolutionism of the Human Species. As mentioned in my paper, Galilei teaches that three levels of scientific credibility exist. Let me elaborate on the three levels, since the understanding of these levels is closely related to the scientific rigor that is needed in the description of the Biological Evolutionism of the Human Species.

The first is that which entails: (1) mathematical rigor as a fundamental referent in the formulation of a problem, (2) the invention of an instrument capable of carrying out the key experiment for giving an answer to the problem, and (3) the reproducibility of the result obtained. The reproducible result is one of the foundation blocks of Galilean Science. It is obvious that the result also must be expressed in mathematically rigorous terms, and it is this that permits the elaboration of a theory able to describe not only the reproducible result that is obtained thanks to the invention of the original instrument, but also to point out further experiments to be conducted with new instruments in order to put the new theoretical formulation to the scrutiny of further experimental tests. An example of present day frontier of Physics: the Superworld. We think that a description of the phenomena known so far requires a Space-Time with 43 dimensions: 11 bosonic and 32 fermionic. The elaboration of the mathematical structure that describes this reality has arrived at the conclusion that new particles must exist; we have dedicated the last decade to the search for these particles without being able to obtain any reproducible experimental proof.

The Superworld theory is an example in which there is mathematical rigor in the formulation of the problem but there is no reproducible experimental proof. Therefore it could be that the Superworld theory is not part of the Logic of Nature. This is what the years to come will tell. The Superworld is an example of first-level Galilean Science to the extent that the experimental tests are susceptible to direct control: in case of doubt it is possible to intervene by repeating the experiments and by inventing new instruments that allow us to overcome doubts that may arise in the course of data analysis for a particular experiment. An experiment that we are able to keep totally under control, here on Earth.

The *second level* of scientific credibility is that in which it is not possible to keep the experimental test under control. There is mathematical rigor in the formulation of the problem and there is the invention of new instruments for observing the effects searched for, but there is no direct intervention. An example: the theory of stellar evolution. In one part of the sky, we observe the birth of a Star. In another part, the shining of a Star born for some time. In yet another part, the death of a Star. Different observations of many Stars being born, of others that are living and still others that are collapsing, allow the elaboration of a theory of stellar evolution. There is mathematical rigor. Reproducibility is guaranteed by the observation of different examples of Stars as they are being born, during their lifetime and as they are dying. What is missing, however, is the possibility of direct intervention. In cases of doubt we cannot turn off or turn on a Star. We cannot change the characteristics of a particular star in order to scrutinize, through experimental tests, a finding that could be born from the theory of stellar evolution's mathematical elaboration itself. This theory is strongly linked to the first-level Galilean Science. Example: in the theory of stellar evolution no astrophysicist could have imagined the existence of neutron stars. It was first necessary to discover neutrons here on Earth by conducting Galilean-type experiments at the first level of scientific credibility. It was the discovery of the neutron that permitted the elaboration of mathematical models that led to the theoretical hypothesis of the existence of neutron Stars. Quite recently, the observation of certain stellar phenomena has been interpreted as indicating the possible existence of 'quark Stars'. The existence of this new class of particles, the quarks themselves, however, was discovered here on Earth by conducting Galilean-type experiments at the first level of scientific credibility. This is the link that should exist between the second and the first level.

Moving on to the third. This level of scientific credibility refers to phenomena that occur only one time. At first glance it could seem that the third level contradicts the notion of 'experimental reproducibility'. This is not so. The third level does not in fact leave the first level out of consideration. An example of a phenomenon that happens only one time is that which is described by cosmic evolution. The Cosmos has the Physics of pre-Big Bang as its initial phase. Then comes the Big Bang with Time intervals that range from billionths of billionths of billionths of billionths of billionths of a second (10^{-45}: Planck's Time) to the Time needed for cosmic evolution with the energy of the vacuum (Alan Guth's Time: 10^{-34} sec) to the evolutionary period in which – other than gravitational force – enter into play the Three Fundamental Forces (strong subnuclear, weak subnuclear and electromagnetic) of the so-called Standard Model with its three building blocks of fundamental particles, each of which is composed of two 'quarks' and two 'leptons'. The Time intervals in play for this phase of cosmic evolution are tenths of billionths of a second. And so one arrives at the few seconds necessary for making the Cosmos with the particles familiar to us (protons, neutrons and electrons) and finally the plasma of these particles in the sea of 'photons' that lasts a few hundreds of thousands of years (according to the most recent data, the Time interval is 380 thousand years). At this point the Cosmos, made essentially of protons, electrons and photons, passes into the phase in which the Stars and the Galaxies are born. According to the most recent theories, it could be 'Black Holes' (made with the very primitive form of matter which existed much before the one of the 'Standard Model' particles) that act as nuclei for the formation of galactic structures in which stars are born. The duration of this phase of cosmic evolution is millions of years. After 15 billion years we reach the present with ourselves, the Sun, the Earth, the Moon, the oceans, the mountains, the sunrises and sunsets, the Cathedrals, Michelangelo's Pietà and the incredible detail that in this cosmic evolution there is, in addition to the inert matter, also the living matter, both vegetable and animal. Among the countless forms of living matter there is one and only one that is endowed with Reason. It is in fact thanks to Reason that it has been possible to discover Permanent Collective Memory, rigorous Logic and Science.

3. *The Evolution of the Universe: an Example of the Third Level*

Cosmic evolution is Galilean Science to the extent that it is formulated in rigorous mathematical terms and linked to the first level. From the pre-Big Bang on, everything is based on that which has been discovered at the first level. It is not possible to prove experimentally the reproducibility of cosmic evolution.

No one knows how to make a Big Bang to verify the details that we would like to put under experimental testing. We can only conduct experiments to understand what happens as we come close to the Big Bang. Today we have arrived at a tenth of a millionth of a second (10^{-10} sec). Keeping in mind that Planck's Time lasts 10^{-45} sec, it is wise not to forget that a good 35 orders of ten separate us from the instant before inflationary expansion bursts forth. These 35 powers of ten are the measure of our ignorance in the rigorous knowledge of that which we call the 'theory of cosmic evolution'.

This theory helps us to understand just how difficult the study of phenomena belonging to the third level of Galilean scientific credibility is.

4. *The Evolution in Terms of Galilean Rigor and Experimental Reproducibility*

To this level, we repeat, belong all the phenomena that happen only one time, as in the example of the Biological Evolutionism of the Human Species. Our species being the only form of living matter endowed with Reason, it is well to subject the 'theory of Biological Evolutionism of the Human Species' to Galilean-type rigor.

There are those who say that this 'theory' represents the frontier of Galilean Science. We would like this to be true. To accomplish this, however, it is necessary to establish for this theory a foundation in mathematical rigor and experimental reproducibility. Doing this requires an analysis that is attentive to the phenomenon called 'evolutionism'. Evolution exists at the level of elementary particles, at the level of aggregates made up of inert matter, and at the level of aggregates of living matter.

First of all, a clarification. While being studied, the phenomenon called 'evolution' can reveal itself only in 'Space-Time'. The first rigorous study of evolution at the level of elementary particles concerns electrons. It is not by chance that the electron itself is the first example of an 'elementary particle' (discovered by Thomson in 1897).

Dirac, fascinated by the discovery of Lorentz that Space-Time could not be a real quantity but instead a complex one (if Space is real, Time must be imaginary, and vice versa), decided to study with rigor the evolution of the electron in Time and Space. This was how he discovered his equation.

The rigorous study of evolutionism at the level of elementary particles brought Dirac to discover a reality that no philosopher, no poet, no thinker of any epoch or civilization was able to imagine. This reality begins with antiparticles and brings us to the discovery of antimatter, antistars and antigalaxies to arrive at our world, which seems to be made up only of matter, stars and galaxies, without any antistars or antigalaxies. An experiment to be conducted in the year 2008 in the International Space Station will tell us if it is really true that in the course of cosmic evolution every trace of antimatter was broken down in order to build up a Universe, like the one in which we are living, that consists only of matter. If in our laboratories we had discovered that antimatter could not exist, the problem of a Universe made only of matter would not exist. This is not so. The existence of antimatter was confirmed in a rigorously Galilean manner in 1965. Nevertheless, in the Universe there is no more antimatter.

It is possible to formulate in a mathematically rigorous mode the theory of cosmic evolution that cancels out antimatter at a certain point. According to this theory of cosmic evolution, we are here thanks to the fact that, in the process of 'cancellation', a tiny fraction (one part in 10 thousand million (10^{10})) of matter prevailed over antimatter. No one could say if this theory is that which corresponds to the cosmic reality of which we are a minimal part. The only certainty is that this theory will be scrutinized closely via Galilean-type experimental tests in the years to come.

Starting from the evolution of an elementary particle we have arrived at the problems of cosmic evolution. This means that we have passed from typical structures of the subnuclear world (10^{-17} cm) to galactic structures that reach to the confines of the Universe (10^{29} cm); better still, if the inflationary evolutionism of Alan Guth is true, to even greater cosmic distances. The theory of evolution in the study of inert matter, from the heart of a proton to the confines of the Cosmos, enables one to interlink within a single structure everything that happens in zones of space that are differentiated by at least 46 powers of ten. We have done this using the three levels of Galilean scientific credibility.

This is the most rigorous knowledge we have when dealing with the concept of the evolution of the fundamental structure of inert matter. Let us call this level number 1. The Table below describes the details of this level.

Table 1. EVOLUTION AND SCIENCE

LEVEL NUMBER ONE

I **Evolution in the Fundamental Structure of Inert Matter:**

I-1 **Evolution** in Space-Time of the lightest electrically charged lepton: the **Dirac equation**.

I-2 **Evolution** in the description of the elementary processes involving inert matter: the **Feynman diagrams** and the problem of **Renormalization** (i.e. no divergent results in theoretical calculations).

I-3 **Evolution** in the Universe and in its structure.

I-3-1 The Physics of the **Pre-Big-Bang**.

I-3-2 The Physics of the **Big-Bang**.

I-3-3 The basic structure of matter and of the Fundamental Forces in the Evolution of the Universe: from the **Planck Scale** to present day.

I-3-4 **The origin of Galaxies** and their **distribution** in Space-Time.

I-3-5 **The origin of a Star** and its evolution (Gravitational, Electroweak and Strong Forces).

I-3-6 **The origin** of condensed forms of cold matter (Planets, Asteroids, Comets and others).

The level number 2 refers to the evolution of the macroscopic structure of inert matter. This and the other levels are schematically given in the Table 2 below.

Table 2. EVOLUTION AND SCIENCE

LEVEL NUMBER TWO

II **EVOLUTION IN THE MACROSCOPIC STRUCTURE OF INERT MATTER**.

II-1 The crystals.

II-2 Other forms of conglomerate matter and the understanding of their properties.

THE OTHER LEVELS

III **THE TRANSITION** FROM **INERT MATTER TO LIVING MATTER**.

IV **EVOLUTION** IN THE ENORMOUS VARIETY OF '**NON-ANIMAL**' LIVING MATTER.

V **THE TRANSITION** FROM 'NON-ANIMAL' TO 'ANIMAL' FORMS OF LIVING MATTER.

VI **THE EVOLUTION** IN THE ENORMOUS VARIETY OF 'ANIMAL' FORMS OF LIVING MATTER.

VII **THE TRANSITION** FROM THE INNUMERABLE POSSIBILITIES OF NON-REASONING LIVING FORMS OF MATTER TO THAT OF LIVING MATTER WITH 'REASON'.

VIII **THE EVOLUTION** OF THE SPECIFIC FORM OF LIVING MATTER CALLED 'THE HUMAN SPECIES'.

IX **THE DISCOVERY OF COLLECTIVE MEMORY**, i.e. **WRITTEN LANGUAGE**.

X **THE DISCOVERY OF LOGIC** AND OF ITS MOST RIGOROUS FORM: **MATHEMATICS**.

XI **THE DISCOVERY OF SCIENCE**: THE **LOGIC OF NATURE**.

XII **REFLECTIONS** ON HOW IT HAPPENS THAT WE ARE THE **ONLY FORM OF LIVING MATTER** WITH 'REASON'.

All these levels need to be fully understood before we reach the level where we need to think about how we happen to be the only form of living matter with 'Reason' (level XII).

In fact, the extraordinary characteristic of the world in which we live is that the Hardware is the same for all forms of matter: from the most elementary inert element (the electron) to the most advanced form of matter with Life and Reason (the Human Species).

The Table below (Table 3) illustrates the five points that represent the Hardware.

Table 3. THIS HARDWARE (i.e. OUR OWN) OBEYS THE FOLLOWING LOGIC

① RGEs (Grand Unification).

② Gauge Principle (hidden & expanded dimensions).

③ The Physics of Imaginary Masses: SSB.

④ Flavour Mixings & CP$\neq$, T$\neq$.

⑤ Anomalies & Instantons.

↓

From the structure of a Proton (10^{-17} cm)
to the
extreme borders of the Universe (10^{29} cm).

↓

Atoms, Molecules, Inert and Living Matter.

More detailed information on the Hardware is given in Table 4.

Table 4. DETAILED INFORMATION ON THE HARDWARE

① RGEs (α_i ($i \equiv 1, 2, 3$); m_j ($j \equiv q, l, G, H$)) : f (k^2).
- GUT ($\alpha_{GUT} \cong 1/24$) & GAP ($10^{16} - 10^{18}$) GeV.
- SUSY (to stabilize $m_F/m_P \cong 10^{-17}$).
- RQST (to quantize Gravity).

② Gauge Principle (hidden and expanded dimensions).
— How a Fundamental Force is generated: SU(3); SU(2); U(1) and Gravity.

③ The Physics of Imaginary Masses: SSB.
— The Imaginary Mass in SU(2) × U(1) produces masses ($m_{W^\pm}$; m_{Z^0}; m_q; m_l), including $m_\gamma = 0$.
— The Imaginary Mass in SU(5)⇒SU(3)×SU(2)×U(1) or in any higher Symmetry Group (not containing U(1))⇒SU(3)×SU(2)×U(1) produces Monopoles.
— The Imaginary Mass in $SU(3)_c$ generates Confinement.

④ **Flavour Mixings & CP ≠ , T ≠ .**
— No need for it but it is there.

⑤ **Anomalies & Instantons.**
— Basic Features of all Non-Abelian Forces.

NOTE:

q	≡ quark and squark;	m_F	≡ Fermi mass scale;
l	≡ lepton and slepton;	m_P	≡ Planck mass scale;
G	≡ Gauge boson and Gaugino;	k	≡ quadrimomentum;
H	≡ Higgs and Shiggs;	C	≡ Charge Conjugation;
RGEs	≡ Renormalization Group Equations;	P	≡ Parity;
GUT	≡ Grand Unified Theory;	T	≡ Time Reversal;
SUSY	≡ Supersymmetry;	≠	≡ Breakdown of Symmetry Operators.
RQST	≡ Relativistic Quantum String Theory;		
SSB	≡ Spontaneous Symmetry Breaking.		

The five basic steps in our understanding of nature. ① The renormalization group equations (RGEs) imply that the gauge couplings (α_i) and the masses (m_j) all run with k^2. It is this running which allows GUT, suggests SUSY and produces the need for a non point-like description (RQST) of physics processes, thus opening the way to quantize gravity. ② All forces originate in the same way: the gauge principle. ③ Imaginary masses play a central role in describing nature. ④ The mass-eigenstates are mixed when the Fermi forces come in. ⑤ The Abelian force QED has lost its role of being the guide for all fundamental forces. The non-Abelian gauge forces dominate and have features which are not present in QED.

Since the Hardware is the same, the following remarks are in order.

It could very well have been that the basic Hardware was there, but not Life itself.

It could have been that the basic Hardware and Life were there, but no Consciousness (free will).

It could have also been that the basic Hardware plus Life plus Consciousness were there, but no Reason.

These points are illustrated in Table 5.

It happens that Reason is there with its three great achievements: Language, Rigorous Logic and Science as reported in Table 6.

Table 5.

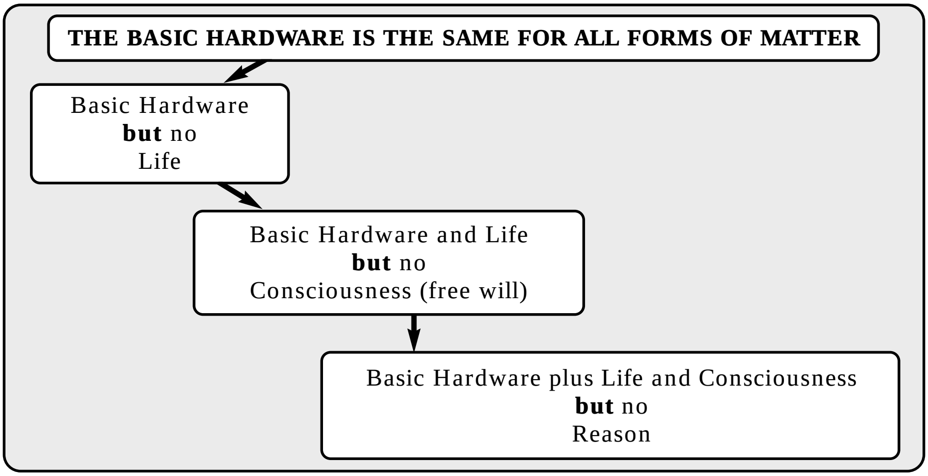
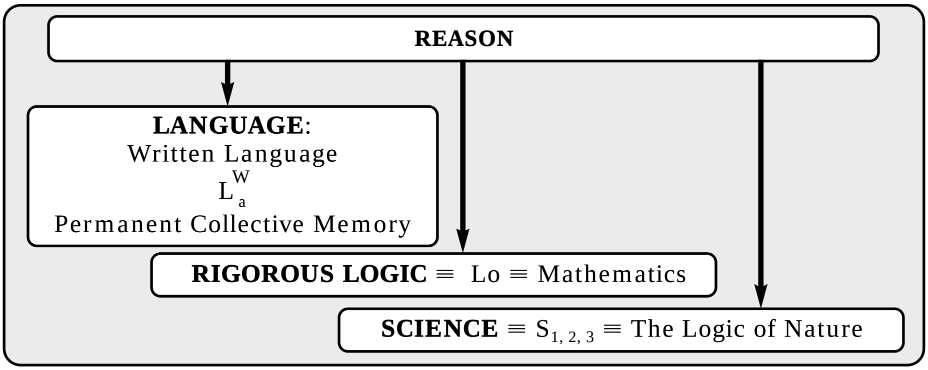
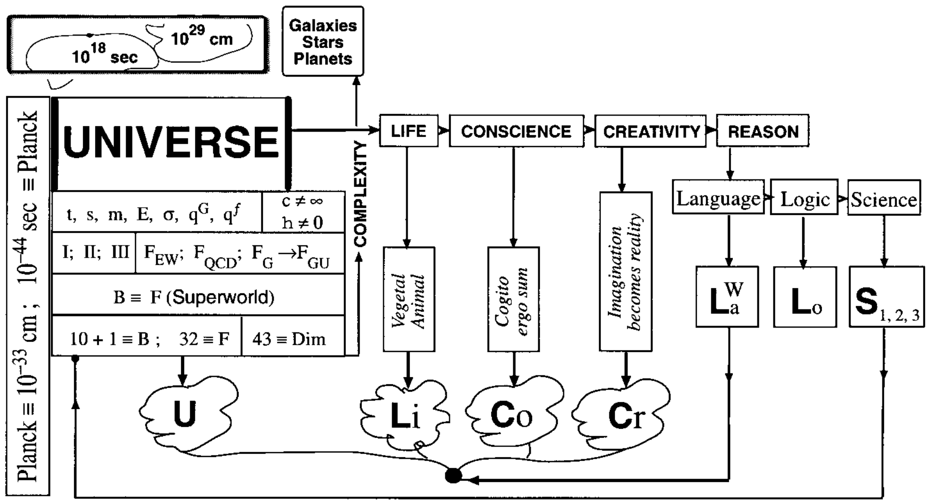


Table 6.



5. *Conclusion*

To conclude: when we speak about evolution we should not forget the basic constituents of Galilean Science: mathematical rigor and experimental reproducibility. The Biological Evolutionism of the Human Species is below the third level of Galilean Science, as can be deduced when we compare this form of evolution with the evolution of the Universe. The Figure below is a synthesis of all I have said regarding the rigorous description of the concept called 'evolution'. A full explanation of this Table would bring us too far out. I have decided to show it to you in order to give you an idea of how complex it is to describe 'evolution' when we want to include all we think we know of the world where we live.



We would like to encourage our colleagues engaged in the study of biological evolution to follow our suggestions in order to reach the goal of bringing the Biological Evolutionism of the Human Species to the third level of Galilean Science, like cosmic evolution.

DISCUSSION ON THE PAPER BY ZICHICHI

JAKI: I've struggled with myself during your presentation whether to make a comment or not, but I decided I had to speak up. When you made the statement – I leave aside such impossible statements of yours that John Paul II opened the doors of the Church to science and similar things – but when you referred to the intellectual humility of Galileo I felt I had to say something, because already from your previous statements, when it came to the history of physics, I felt very uneasy. Now, with respect to the intellectual humility of Galileo, I would like to say in brief only this much: had Galileo's utter pride prevailed, Newtonian science would have never been born. That utter pride forced Galileo to stick with the strictly circular orbit of planets, that utter pride of Galileo, and I'm talking only of scientific matters, that utter pride of Galileo forced him to ignore Kepler's work, the *Stella Martis*, which contained the elliptical orbit of planets, and the utter pride of Galileo forced Galileo to ignore two other books of Kepler, one of them the *Harmonice mundi*, which contained the two other laws of Kepler, and, had it not been for a little-known English scientist, astronomer, his name was Jeremiah Horrocks, who died at the age of 21, just the year he was taken away by the bubonic plague, who put together a readable summary of Kepler's achievements, and had it not been for Horrock's teacher Wallis in Cambridge, Newton would have never learnt of the three laws of Kepler, and without those three laws we would neither have Galilean science, nor Newtonian science, nor Einsteinian science. I deeply resent the fact that an eminent scientist like you, a physicist, can run roughshod over elementary facts in the history of modern physics.

ZICHICHI: Well, I've written a book on Galilei which has 150 quotations. In this book I proved that the acceleration by gravity could have been measured ten thousand years before with the invention of the inclined plane. Without the measurement of the acceleration of gravity, Newton could have done nothing, despite the discoveries of Kepler and all you mentioned. The key point was the measurement of the acceleration by gravity. Point number two: how can you explain, due to the fact that you think you are right, that for ten thousand years the error in the measurement of time was always one second every day, and after Galilei, now, we've 2 minutes in 20 billion years, and I could do my gadget in 1965 at the level of a few picoseconds thanks to Galilei, not to anyone else. You quoted the circular orbits, and if you read my book, which I would be pleased to send to you, this is the proof that Galilei was a man of faith. Why? Because when he received the news, the discovery of the Mars orbit, which could not be circular but elliptic, as you correctly pointed out, Galilei said, 'No. God could not choose imperfect geometrical objects'. This is the proof of Galilei's faith. You should read my book. In my book I write down all the discoveries of Galilei. And if you read the book and you disagree, write to me, say, page number x, this is wrong. I was very careful in listing the incredible number of correct discoveries made by Galilei. The story of the orbit is fantastic proof against all members of the dominant atheistic culture who claim Galilei was not a man of faith, that he was just afraid of the Church. No. Galilei wrote that he wanted to look for the footprint of the Creator. He died convinced that Kepler made a mistake, because he was thinking about the fact that the orbits had to be perfect geometrical figures, due to the act of creation. So, the proof of Galilei being a man of faith is exactly what you have stated.

MÖSSBAUER: I would like to come to the 10^{-33} centimetres and to the 10^{-44} seconds. We don't know how to quantize gravitation, apart from string theory where nothing is proved. It is mathematical philosophy, you're right, so we don't know how to quantise it.

ZICHICHI: Correct. But the point I wanted to emphasize is that your compatriot Planck was the first man on this planet to realise that the units, centimetre, second and gramme, are just mankind, anthropomorphic: what would be the correspondent values for length, time and mass if the basic unit in nature were taken to be the fundamental constants: the speed of light, Planck action and Newton gravitation? This was the great achievement of Plank. I insist in saying that Planck has not been correctly given the right tribute for this incredible achievement. When we knew nothing about the unification of the fundamental forces, he realised: what are you talking about? Centimetres, no! Let us use the fundamental constants. What are the units? Fantastic. They are still there.

CABIBBO: He was made a member of this Academy on the first possible occasion.

ZICHICHI: Yes, and he should be celebrated, because he is really one of the greatest of them all; it is incredible what he did. And people forget, they start mentioning other people.

PAVAN: I had difficulty in following you and in understanding everything you said, but, since we don't have much time for discussion, I would like you to explain to me what you mean by atheist culture has used so-called popularisation of science to enclose so much cultural untruth. Are you against the popularisation of science?

ZICHICHI: No. I'm for the popularisation of science in a correct way. For example, make a list of the greatest scientists in the history of science who've said science and faith are in contradiction. No one, zero. Nevertheless, if you take a taxi and you tell the taxi driver: 'I'm a scientist, I'm coming from the Vatican', he will tell you: 'Professor Pavan, how can there be a scientist who goes to the Vatican?' I was asked this question in 1979. Now it's different, because in Italy I've been involved quite a lot, but in 1979, and for many years, I was questioned like this, 'You are a scientist, and you go to Church?" *Ubi major est, minor cessat*. You must pick up the most important of all effects if you want to understand anything. You must pick up the number one: how can you justify the existence of this life? This is mystification. I'm against the erroneous popularisation of science. This is why I'm trying to help honest people. I don't know your country, so I can only speak about Italy, but in Italy science popularisation is dominated by atheists at the 99% level.

PAVAN: Not in Brazil.

ZICHICHI: I'm very glad.

VICUÑA: Over these days, Professor Zichichi, you have insisted that science and technology can be differentiated clearly, and we scientists can be searching for the truth and people with wrong intentions can be using this knowledge for technology in various fields, and I would like to come again with a comment I made the other day to you, but there wasn't any time to pursue it, that there are areas in which science and technology cannot be clearly differentiated, and what I see from my standpoint is that there are many scientists these days in these areas some of whom are colliding with ethical norms that we would all like to respect, and therefore I don't see a scientist anymore as I would like to see, so immaculate just looking for the truth, and some of them are getting into areas which are related to technology, and I don't think they are using the tools and the methods that we would have dreamed for scientists who are after the truth or pure knowledge only.

ZICHICHI: A telegraphic answer: science is the study of the logic of nature. In so far as you study the logic of nature you do science. As soon as you go out of this, you are out of science. I've been involved in technological inventions, in scientific discoveries, so I know exactly that these two items can be clearly classified, and it is in the interest of science, because if you start with a confusion, then the confusion will go on and we should not forget that we reached the stage where John Paul II was the only person on the planet who stood up and made his important declaration when we were accused of being the authors of the earth packed with H bombs. Enrico Fermi is not the father of the Hiroshima bomb; that was Hitler. Edward Teller is not the father of the H bomb; that was Stalin. But try to ask people around, and you see the answer. Why? Because the atheistic popularisation of science has deliberately created the confusion between science and the application of scientific discoveries, i.e. technology. Science is the study of the logic of nature, period.

VICUÑA: Mr. President, one very short question: is the human genome project science or technology, Professor Zichichi?

ZICHICHI: Technology. Applied science. I'm sorry but this is the truth. When you will reach the end, you'll discover the Maxwell equations.

CABIBBO: I don't think many of the people here would agree with you, but we will put it on record as your opinion.

GERMAIN: Je peux dire un mot. Notre confrère Zichichi nous a décrit une science idéale, qui est, d'ailleurs, l'idéal que j'ai de cette science, mais avec sa volonté de distinguer complètement science et technologie. Alors il se met dans une position très facile: pour les scientifiques, les choses ne sont pas aussi simples. Je pense à beaucoup de ce que vous avez dit et puisque c'est la conclusion de notre Conseil, je pense que ce que nous avons à faire, c'est justement de sauver la science là où elle apparaît dans le monde, et elle apparaît dans le monde avec les applications, et là alors il faut en quelque sort éduquer le peuple, nos concitoyens pour qu'ils apprennent, dans cette espèce de monde dans lequel nous nous trouvons, dans lequel effectivement les applications de la science sont partout, à faire une distinction. Mais dire: 'La science est parfaite et la technologie est tout-à-fait infernale', est une position très facile. Vous êtes un physicien théoricien, alors là c'est facile. Pour d'autres qui ont constamment à faire avec des questions pratiques qui intéressent tout notre peuple, alors la situation n'est pas aussi facile. Par conséquent, je suis d'accord avec vous, malheureusement je crois que votre conférence se place dans un monde idéal qui n'est pas celui dans lequel nous nous trouvons. Merci.

ZICHICHI: Je vous remercie beaucoup, mais je dois dire que je n'ai pas dit que la technologie est tout méchante, non, j'ai dit, 'La science c'est l'étude de la logique de la nature'. Cette logique peut être utilisé pro et contre, mais le choix entre pro et contre n'est pas scientifique, c'est culturel.

GERMAIN: Oui, mais alors, si vous vous désintéressez de savoir comment les applications de la science sont faites, vous vous en désintéressez en disant: 'La société se débrouillera à faire ce qui est favorable, et à ne pas faire ce qui est défavorable'. Nous ne pouvons pas nous en désintéresser. Dans cette Académie nous devons dire à nos concitoyens: 'Oui, la science arrive dans un état des choses compliqué et mélangé, et c'est très difficile'. Alors, il faut les aider à comprendre, parce que c'est eux finalement qui choisissent. Mais nous devons participer, et ce que je reproche c'est qu'avec votre position vous dîtes: 'C'est pour les autres, alors nous, nous avons bonne conscience'.

ZICHICHI: Alors, je répète: la science on ne peut pas la confondre avec ses applications, il faut être rigoureusement logique. Alors, s'il y a une chose qu'on appelle mathématique, ça c'est mathématique, on ne peut pas la confondre avec une autre discipline.

GERMAIN: Les mathématiques, ça c'est facile.

ZICHICHI: La science est la logique de la nature; étudier la logique de la nature c'est science. Les applications de la science sont la technologie. Ce n'est pas moi qui le dit, c'est la rigueur logique. Si on commence à réfléchir, on arrive à cette conclusion. Je pense que nous avons intérêt à faire de la culture scientifique, et à mettre au point les choses avec une grande clarté et rigueur. Donc, il faut dire au grand et vaste public qui ne fait pas de science que l'on aurait pu avoir les mêmes résultats scientifiques sans avoir une seule bombe. Vous êtes d'accord ou non? Evidemment. Pourquoi a-t-on les applications néfastes de la science? Parce que les applications de la science ont toujours échappé au contrôle des scientifiques, il ne faut pas oublier ça.

GERMAIN: Mais bien sûr, mais bien sûr. Mais c'est normal, je trouve, que les applications de la science échappent au contrôle des scientifiques. Mais les scientifiques doivent s'en occuper.

ZICHICHI: Il ne faut pas dire ça à moi, parce que je m'en suis occupé plus que tous mes collègues en moyenne. Les applications de la science dites technologies, peuvent être avec le signe plus et le signe moins.

GERMAIN: D'accord, d'accord.

ZICHICHI: C'est cela que je dis.

GERMAIN: D'accord.

SURGERY OF THE SOUL

JOSEPH E. MURRAY

I thank the Pontifical Academy of Sciences for allowing me to speak at this plenary session on *The Cultural Values of Science*. As a medical student sixty years ago, I thought of surgery merely as a series of operations developed over the years to: (1) save life; (2) restore function; or (3) relieve pain. Following graduation from medical school in 1943 and a nine-month surgical internship I was drafted into the United Sates Army Medical Corps and served on active duty for three years until my discharge in late 1947. My army experience consisted of surgery on battle casualties from the European, African, and Pacific theatres. This influenced my entire professional life. It was here that I recognised an additional indication for surgery, i.e. to improve quality of life.

VALUE OF LIFE
INDICATIONS FOR SURGERY

1. *Save life*
2. *Restore function*
3. *Relieve pain*
4. *Improve 'quality of life'*

The title of today's talk was suggested by a book editor who happened to hear me speak about my surgical career at Harvard Medical School. My life in surgery has been a fortuitous blend of science and humanity. I chose to attend a small liberal arts college, College of the Holy Cross, and concentrated on Latin, Greek, Philosophy, and English. Assuming I'd receive ample science in medical school, I took the minimum of chemistry, physics and biology. I entered Harvard Medical School expecting to return to my hometown near Boston as a general surgeon. However, as Louis Pasteur wrote, I was to find myself pulled into pure research through my application of medical school knowledge:

> No category of science exists to which one could give the name of applied science. There are science and the application of science, linked together as a fruit is to the tree that has borne it.
>
> Louis Pasteur

Science and plastic surgery entered my life when I helped care for Charles Woods. Charles is a United States aviator who was 70% burned in a crash flying over the Himalayan Mountains between Burma and China. China was then our ally against Japan. Charles was flown halfway around the world to our army hospital in Valley Forge, Pennsylvania. Here is a slide showing Charles today. He is 83 years old, the same age as I. (Slide 4, see page 382).

The next two slides show Charles as he was when he arrived at Valley Forge Hospital. (Slide 5 and 6, see page 383).

You can see in this slide that we covered his open burns with skin taken from other parts of his body. Charles went on to become a successful businessman. His family and mine have stayed quite close over the years, and I still hear from them regularly.

While working at Valley Forge Hospital on patients including Charles Woods, we often encountered the challenge of covering the burns with skin to permit healing to take place. We sometimes used skin from cadavers, but it was always eventually rejected. I became fascinated with this problem. Thus began my two major surgical interests: plastic surgery, and transplantation biology.

Along the way I have operated on many continents. In India I operated on leprosy patients at the Christian Medical College in Vellore, correcting hand and facial deformities. As with the battle casualties, it was the spirit and the soul of these patients that carried them through their trials. The patients were reconstructed and then taught to use their improved hands in making saleable items. With their reconstructed hands they create hand-made toys and other items including a wooden plaque bearing the motto 'Difficulties Are Opportunities'. These patients' functional hands give them the chance for employment so that they did not have to go on begging for a living. The sign sits on my desk as an inspiration, an example of the many times that patients have enlarged me with their courage and faith.

As decades passed and surgery became more skilful and safer, we surgeons expanded the numbers of treatable conditions. Birth defects are a good example. Here is a child born in the seventies with severe facial and cranial distortion. (Slide 9, see page 384).

The parents were strongly advised to place him in an institution for handicapped children in order to protect their five other 'normal' children. After two years of weekly visits to the institution with no sign of improvement, the parents took him home. This picture shows him as I first saw him with his twin brother at age seven, after surgery performed elsewhere. (Slide 10, see page 384).

We performed six craniofacial operations over five years to restore some degree of facial, cranial, and orbital symmetry. He then entered the public school system that his brother attended. Unbelievably, he graduated with higher grades than his brother. (Slide 11, see page 385).

It is appropriate to mention during this occasion in Rome that Italy herself has made historical contributions to the field of plastic surgery. Gaspare Tagliacozzi, 1545-1599, was practicing a form of plastic surgery rebuilding the noses of those whose nose had been removed as punishment for crime. Tagliacozzi also recognized quality of life as a reason for surgery:

> We restore, repair and make whole those parts of the body which nature has given but which fortune has taken away, not so much that they may delight the eye but that they may buoy up the spirit and help the mind of the afflicted.
>
> Tagliacozzi, 1597

All surgeons around the world owe immense gratitude to the pioneer surgeon, Paul Tessier, of Nantes and Paris, France, for showing us the way to operate safely on the orbits and skulls to correct craniofacial deformities in infants. This speciality of craniofacial surgery emerged after World War

II. The next three slides show a good example of the application of Dr. Tessier's innovative surgery in infants. (Slide 13, see page 386).

In slide 13 you can see the asymmetrical face and cranium, which we studied carefully before performing surgery. I would take a picture of a patient and cut it up into puzzle pieces, sliding them around to visualise how the operation would proceed. Nowadays of course these preparations are made with the aid of computers. (Slide 14, see page 386).

Slide 14 shows segments of the child's skull which have been detached from the head. These segments were reshaped on a side table before being replaced. This reshaping of the cranium allows the skull to grow symmetrically larger under the influence of the growing brain. At the top of this picture, you can see the bone grafts taken from the child's hip which were inserted into the gaps left by this procedure. (Slide 15, see page 387).

Slide 15 shows the same child post-operatively, with his appearance and skull size near-normal. In addition to observing improved post-operative appearance, parents of our post-surgical craniofacial patients often commented on improved behavior as well.

To proceed to another topic: Organ transplantation is one of the most dramatic biological advances of the 20th century. 'Spare parts surgery' had been dreamed of for centuries. Throughout our travels I sought out depictions of the twin Saints Cosmos and Damian. (Slide 16, see page 388).

According to legend, Cosmos and Damian were physicians who successfully transplanted the limb of a dead Moor onto a patient whose leg required amputation. It was almost as if fate had decreed that identical twins would play a role in successful organ transplantation. You can see in this slide the twin saints attaching the black leg to their lighter-skinned patient.

In the early 50's, organ transplantation was considered an impossible dream by practically everyone – except surgeons and physicians caring for patients with severe burns or severe kidney disease. Drs. Barrett Brown and Brad Cannon, Chiefs of Plastic Surgery at Valley Forge General Hospital, had used skin from dead persons to temporarily replace skin in burn patients. Nephrologists had experimented with hemodialysis as a temporary substitute for diseased kidneys. Brown had shown that skin exchanged between identical twins could survive permanently. (Slide 17, see page 335).

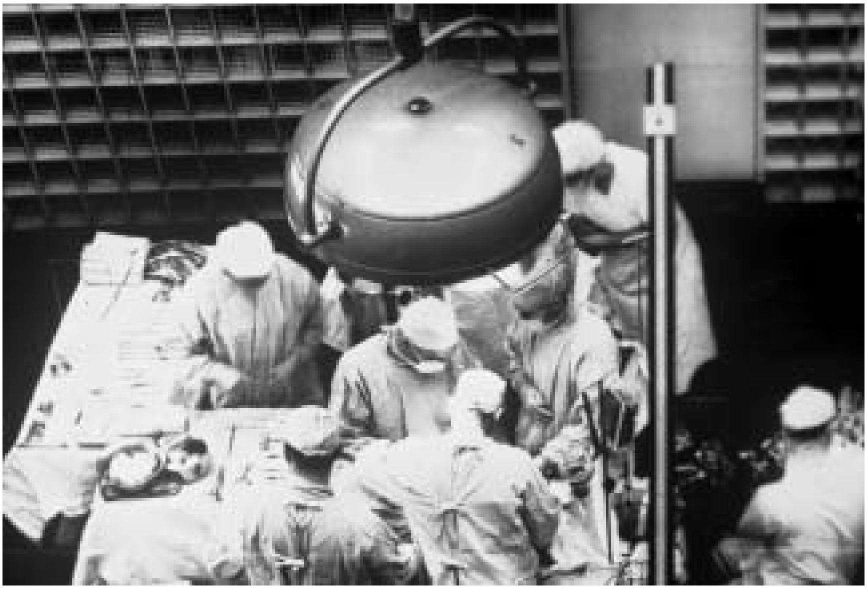
In this slide you can see identical twins displaying the successful skin grafts where a small patch of skin from the forearm has been transferred to the other's arm.

With the case of Charles Woods in mind, after the war I eagerly joined the transplant team at Brigham Hospital and Harvard Medical School in Boston.

Slide 17. Brown's twins.

Soon I had developed a predictable operation for kidney transplants in dogs. At the same time, hemodyalisis was first used at the Brigham. A patient was referred for terminal renal failure who had an identical twin brother anxious to donate one of his kidneys. We did go ahead with the transplant operation, but only after serious consideration of the many ethical problems involved. We met first with a number of doctors and clerics as well as with the family members to discuss the concept. (Slide 18, see page 336).

This slide of this historical operation shows the transplantation team preparing the sick twin to receive a kidney from the healthy twin, who is being operated on in an adjoining operating room. Following five weeks of excellent function of the transplanted kidney, we had a decision to make about removal of the diseased kidneys. I favored removing the diseased kidneys immediately, while my colleague wanted to leave them in place as a backup in case the transplant did not 'take', and with the hope that they might recover. After discussing the situation with my superior, I bowed to my colleague's wishes, as he was the medical doctor in charge of managing the renal disease. Later we learned that diseased kidneys should be



Slide 18. Intra-op photo of kidney transplant operation.

removed so they do not infect the transplanted one, but at the time we were all doing what we thought was best. (Slide 19, see page 337).

Here are the young men leaving the hospital after the successful operation. The sick twin is in the wheelchair, which is being pushed by the donor twin. The recipient lived for another seven years before dying of renal failure after he developed the original renal disease in the transplanted kidney.

Chief of surgery Dr. Francis Moore commented years later that as a result of this accomplishment, the ethical assumption of physicians 'to do no harm' would be forever challenged.

None of these advances could have occurred without the benefits of animal research. Our research lab, where we developed our transplantation techniques, depended on the most careful care of our animals. They were treated like royalty in every way. But even though we protected them to the best of our ability, two of them managed to get together when Mona was in heat, and she presented us with a healthy litter of pups as you can see in the next slide. (Slide 21, see page 339).

This unexpected event proved fortunate, as we did not know whether the immunosuppressive drugs would interfere with pregnancy, or whether

Slide 19. Twins leaving hospital.

they would lead to birth defects. Since then we have learned that neither is the case, and there have been many successful pregnancies within the population of transplanted patients living on immunosuppressive drugs.

The success of this first twin transplant in 1954, followed by a successful sibling transplant in 1959 and a similar successful transplant from a cadaver in 1962, opened the door for worldwide transplantation.

INTERNATIONAL TRANSPLANT SURVIVAL RECORD

Longest surviving recipient with continuous function:

Kidney	31 years	Heart	23 years
Kidney-Pancreas	13 years	Heart-Lung	11 years
Pancreas	16 years	Single Lung	8 years
Liver	24 years	Double Lung	7 years
Bone Marrow	20 years		

This table shows the longest survival times for kidney, heart, liver, kidney-pancreas, bone marrow, heart-lung, single lung, and double lung transplants. At the time that we were developing the kidney transplant operation to benefit our patients with severe kidney disease, none of us had any idea that these other transplantation surgeries would soon become possible.

The transplant story comes full circle in the next slide. (Slide 22, see page 389).

Here we see a young man who has undergone a successful double hand transplant holding in his transplanted hands a copy of my book, *Surgery of the Soul*. Dr. Max Dubernard of Lyon, France sent me this slide recently, and it certainly illustrates the far-reaching impact that our original research in the dog lab and with identical twins has had in our culture. During my career, research pursued in the care of patients has shaped the direction of medicine and indeed has affected our society's culture.

In closing, I would like to read excerpts from a patient highlighted in my book.

The full benefits from plastic surgery are epitomized and encapsulated in the care of one extraordinary human being, Raymond McMillan. Ray was born with severe facial deformity. With no control of his facial muscles, he drooled constantly. His lips were blue and cyanotic. His tongue hung out and his ears were only little blobs of tissue. He was diagnosed as Moebius Syndrome (a not uncommon congenital facial problem) and he also had a heart defect.

Ray had an exceptional spirit despite the physical and emotional hardships he had endured since childhood. After spending the first five years of his life with his mother, he was sent to live at the Wrentham State School (Chapter 17), the same mental institution where Jimmy Hickey had been.

Slide 21. Mona and pups.

Ray survived the next 16 years there, and was released at the age of 21. One year later, he was referred to us at the Brigham by either a local newspaper editor or a parish priest.

Ray's problems were so extensive that it was difficult for us to know where to begin. After study, we decided to tackle his facial deformities first, because it was his most visible and compelling problem, and also the most easily repaired. At that time, in the late 1950s, cardiac surgery was non-existent; heart-lung pumps were still undergoing research development.

We started our reconstruction by dividing his lower jawbone into two sections and repositioning each section so that he could close his mouth and control his saliva. A few months later, we detached portions of whatever functional facial muscles he had, and reattached them to the corners of his mouth. This gave Ray the ability to smile, albeit in a limited way, for the first time.

Subsequently, we operated on his palate to help improve his speech and made revisions to the shape of his nose. These moderate improvements increased his self-esteem, another example of a slight physical improvement being more beneficial than an onlooker – or even the surgeon – might expect.

By the next decade, cardiac surgery had progressed remarkably and. Drs. John Collins and Larry Cohn were able to repair Ray's heart, giving him considerably more strength and stamina.

Ray lived alone and was self-sufficient. I helped him get a job in one of the labs at the Dana-Farber and Children's Hospitals and, on his way to or from work, he frequently dropped by my office. I enjoyed these casual visits and, during one of them, suggested he study for his high school equivalency diploma. A few years later, he bounded into my office, waving his diploma. I was deeply touched when he asked if I would keep it! I suppose in some way I had become a father figure to him.

Later, I suggested he do some writing. Apparently he acted on my suggestion. These excerpts from his unfinished memoir, uncovered after his death in 1997, were written as Ray sat on a park bench in the Boston Common. This is where George Washington took command of the American troops and began training them for the American Revolution.

'*It is a beautiful day*', begins Ray's memoir. '*I have a wonderful free, serene feeling just watching the people go by. I am writing this in the hope that it might help someone today.*

This story begins with despair and ends with hope. My name is Raymond Francis McMillan and I was born in Malden, Massachusetts on January 15, 1943. I spent my first five years with my mother, whom I never really got to know.

Because of my deafness, malformed heart and facial deformity, my mother and two social agents admitted me to the Wrentham State School. The School is situated in the New England countryside thirty miles from Boston. The oppressive Victorian buildings of a state hospital still stand, symbol of a time when people abandoned those with whom they could or would not deal. Historically, the hospital was the home of the unloved, the indigent, the handicapped and the insane. It was the total world and experience to thousands of emotionally bereft people. The corridors echo with neglect suffered and cruelties done. And the institution was more like a prison, instead of a mental hospital. It was the antithesis of a nurturing environment; it was an unlikely place for me with my handicaps and I did indeed survive! I survived because I was blessed with a beautiful intelligence, humor and courage. Today I enjoy a normal life and a bright future.

While I was a resident at Wrentham State School, it took some time to get used to because I was very young and I was scared, lost, lonely and confused. My 16 years were a total nightmare and I wonder how I ever survived under those conditions and still was able to keep my head on straight. I was no longer wanted and I found it very difficult to live with the idea of being rejected by my own mother and family because of heart, hearing, and facial malformation. My family only visited me twice during my ordeal. My father came to visit me when I was 12; my stepfather came to visit me five years later and I saw my mother for the first time then. But that was the last time I saw either of them!

I got about four years of good education between 1959 and 1963. Of course living at the School was an education in itself. Under the circumstances I did my very best but I did not graduate nor did anyone else. There was no such thing as a high school diploma at a mental institution.

The people who were in charge at Wrentham State School did not think or feel that I could make it on my own in the outside world because of my handicaps and poor health. The longer I stayed at the institution the more angry I got and I can't count how many times I ran away from the place. When I got caught I knew I was in trouble and after so many beatings it became an everyday thing.

I was paroled (that's the word they used in those days) in April, 1964 at the age of 21. Boy was I glad to see that day come! I knew I had a long hill to climb and it wasn't easy at first but I was so happy to get out of the place they call Wrentham State School that I never looked back! I was not in the best of health but I was so excited to get out on my own for the first time. It felt so good to be free!

"... to preserve freedom, we must begin with peace within ourselves and then spread it to others. Freedom is not a store-bought commodity. There are many ways freedom can be preserved, but with every freedom there is a responsibility and with every right there is an obligation ...". Vida Ivanouskas

On my first day on my own in the outside world, the weather was beautiful. It was a Friday. My first stop was at the White Swan Motel where I was to share a room with three other former residents of the Wrentham State School. The next day I went out looking for an apartment because I wanted total independence and wanted to be alone to prove to myself that I could make it on my own and in the community. I became a dishwasher and salad bar helper at the Lafayette House Restaurant.

My first year, 1964, was a very difficult year. I had trouble making the transition and I didn't know to whom, where or how to go for help. I didn't speak English very well since I had very defective speech. It made it very difficult to *talk. Abraham Lincoln once said: "Most folks are about as happy as they make up their minds to be". You know, he was right! The following year, 1965, I promised myself to be so strong that nothing could disturb my peace of mind. To talk health and make all my friends feel that there is something in them. To look on the sunny side of everything and make my optimism come true. To forget the mistakes of the past and press on to the greater achievements of the future. To wear a cheerful countenance at all times and to have a smile ready for every living creature I meet. To give so much time to the improvement of myself that I have no time to criticize others. To be too large for worry, too noble for anger, too strong for fear and too happy to permit the presence of trouble. To think well of myself and to proclaim this fact to the world – not in loud words but in great deeds. To live in the faith that the world is on my side so long as I am true to the best that is in me.*

That same year I had an appointment with Dr. Joseph E. Murray, a plastic surgeon at the Peter Bent Brigham Hospital. He told me that he could help me and make my life a lot easier to handle. As the years went by I continued to see Dr. Murray even until this day. Throughout 1965 I spent a great deal of time as an outpatient. Four to six months was spent getting my jaw ready and strengthened for my first operation in 1966. I didn't know what to expect of the outcome but I knew there was a lot of work to be done and that I would have to be strong and have a lot of heart and to be brave and courageous and to do what is right and to take responsibility for my own actions. I expect nothing from the world but I realize that as I give to the world, the world will give to me.

I had my first operation in 1966, and addition operations in 1967, 1968 and 1969. They could only do a little at a time because I had a weak heart. Then in 1970 I went and had the open heart surgery and I was in the hospital for about seven weeks. I can honestly say they did a wonderful job. The surgery was performed by Dr. John Collins and Dr. Lawrence Cohn. I had my last operation in 1977. In the meantime, I did a lot of reading as part of my self education. I couldn't read well or understand all that I was reading. I kept on reading anyway!

Many people have severe facial deformities, either congenitally or as a result of injury or disease. They do not look like other people and because they are different, they are treated differently. They may even come to think of themselves as less than human. But beauty is not determined by a perfect figure and features. It is determined by the way you respect and honor yourself.

I had a very difficult time with my handicap and sometimes I had to fight with my fists. I had to fight to survive. Handicapped people are a part of our

society that are beaten down time and time again. But we are a strong-willed and extremely proud people who desire no handouts, no charity and want nothing more than the simple chance to support ourselves through our own abilities. There are ups and downs and you can never be a quitter. There is a reason for living! There is a reason for being here. And there is always a way. No matter what you are going through, there is always a way'.
Raymond Francis McMillan

Ray died suddenly in 1997, seated in a car beside his best friend, on the way to lunch at a favored restaurant. At his funeral, a circle of people far beyond his hometown of Wrentham came to mourn his passing. Many described Ray as a beloved friend. Jack Collins, Larry Cohn and I agree that Ray was one of the most remarkable patients we have ever had the privilege to care for. We feel fortunate to have known him.

The impact the hospital staff and I had on Ray's life only partially involved scalpels and sutures. Simply because we cared for him and showed him compassion and basic human kindness, we gave him a feeling of worth and helped heal his spirit. The greatest benefit we gave Ray was not so much the freedom of facial muscles, but rather the freedom for his inner self to glow and grow. The cosmetic improvements we made to his exterior simply removed what had been a constant impediment to his daily living. Surely this was a case of "surgery of the soul".

ANTHROPICAL COSMOLOGY AND PERSONAL THEOLOGY

NICOLA DALLAPORTA

If by 'culture' in its strongest meaning we understand the totality of knowledge at any possible level contributing to the construction of a world picture as extended and complete as possible, we should easily recognize that such a picture must include all the domains of thought present in our psychical being; and we instinctively feel the impulse to connect to each other such domains in order to form a general coherent frame of reference into which any viewpoint finds its adequate location. What I am proposing here to present of such a vast frame is one of those possible connections, related on the one hand to science, as requested by the theme of this conference, and on the other to one of the most conspicuous fields of internal investigation, for almost anybody I might venture. In fact the main cultural and most valuable derivation yielded to me from science is its contribution to the growing of my understanding beyond the sensible evidence and the logical rationality. I will therefore try to show how, at least on my personal account, the evolving picture of science during the decades of my living time has gradually contributed to develop, extend and increase my metaphysical and religious approach to reality.

We will try, above all, to update the view by which we can look at the cosmos today.

The body of opinion has been, during the last few centuries, the preferred ground for the development of what, under the generic name 'science', has been constructed as a body of self-convincing and autonomous knowledge, according to an outlook which is essentially mechanistic. Today however, after a long period in which determinism seemed to dominate uncontested, a picture of the physical world is spreading more and more, based both on the microscopic domain which is subject to quantum mechanics, and on the so-called 'deterministic chaos' of complex systems;

for both the exact predictability of physical phenomena, once considered the essence of physics itself, seems, instead, to be a type of limited case that acts as an excellent approximation only in very simple problems which are defined by a small number of variables; whereas real situations range from sets of molecules to galaxies of stars. It is such complications that make it practically inconceivable to analyse them in detail. Complications of this genre have become the daily bread of all that which goes under the name of complexity, from fluid dynamics to multi-molecular structures which are present in every aspect of biology. Consequently, the general explanatory picture of the physical world is gradually moving away from the idea of exact predictability of the future, which inevitably follows from detailed knowledge of a given initial situation, towards an unpredictability, which generally increases as the length of time increases. Therefore the prospective of 'total necessity', inherent in the Galilean laws of physics, was inevitably overlapped by a zone of growing cognitive indeterminability, which made the future less and less predictable.

Independently of the preceding developments the fundamental idea itself of strict causal deduction of one physical phenomenon from another, also found itself confronting an interpretative difficulty because the situations under consideration had become complicated. If, already, an excessive number of variables, as for example the total of the coordinates and momenta of the component particles of a gas, had asked, in dealing with it, recourse to purely statistical considerations, a heterogeneous system, formed by chains of diverse atoms, which one meets in macromolecular chemistry, seems to make almost obligatory a vision in which one can only deal with by simplifying and appealing to 'randomness'. It is on 'chance' in fact that the Darwinist vision of biology is founded. Now, instead, various researchers, on the basis of the most recent scientific results, are realising how biological experimentation is bringing to light the insufficiencies of Darwinism in explaining several of paleontology's fundamental data. Without going into detail, it is enough to specify that the attribution, due to pure chance, of the meeting between various biological molecular groups would require a period of time billions of times longer than the life of the universe; therefore the state of our earth would constitute, in itself, a type of 'miracle', accomplished once and for all, in spite of all predictable probability.

If the concurrence of billions of micro-causes between the constituent atoms and molecules, over a period of time billions of times longer than the life of the universe, is required in order to form any portion of living substance, it appears clear how, in order to deal with the physically 'complex' situations, it is opportune to devise new ways of thinking: first, that of overturning the sense of time, and instead of starting from the antecedent of the past, fix instead on the future, and therefore on the 'ends' which can be accomplished for any phenomenon. Physically speaking, the symmetry between past and future is an integral part of a four-dimensional vision: it is only the unidirectional flow of time which, for the human mind and life, differentiates it in such a large manner. Precisely for this reason, one would maybe expect that, with the polarization on the future, our intelligence could enter into a new perspective, complementary and integrating with that, which up to now, was confined to science.

That expectation, as is well known, has been encouraged by biology: if the large variety of micro-causes which play between the molecules makes a decipherable analysis of their reciprocal interactions extremely difficult, the final destination for which this complexity aims, comes together in a set of relatively simple properties, which summarise the objectives and the way that this complexity 'lives', that is eats, drinks, breathes, mates, reproduces; otherwise, it gives way to certain functions un-analysable in their microscopic detail, but it is the 'total behaviour' which forms that which constitutes a plant, an animal, a living being. For this the biological morphology, in its complexity, is much better described by this set of 'finalist' properties than by the unreachable multiplicity of the sets of micro-causes.

For this reason, from the view of the beings, it seems a general directive has almost emerged that alternates from the complementary prospective of 'causalism' on the one hand, 'finalism' on the other; in situations which are physically 'simple' the first is undisputed, whereas in those which are complex the latter is prevalent. This explains why, in the physics of Galilean phenomena only causality seemed necessary to explain the connection between these phenomena, whereas for those which, plausibly, are central to the biological structure, it is the 'finalism' view which, maybe, better captures the sense which we try to find in the panorama which surrounds us and in what we are. The complicated pass from the physics view to that of biology, is the crucial point which, to be understood, probably requires the superimposition of the two views, key to the unifying approach to that which is unexplainable around us and in us.

Does there exist maybe, today, some field within which it seems that this type of superimposition occurs? We think that there is, and consists of that set of data which goes under the name of 'anthropic observations'. Without going into too much detail, we will satisfy ourselves by emphasising how this perspective originates, in the ambit of physics itself, not with the usual question of 'how?' a certain phenomenon occurs, but 'why?' it happens.

As is well known, the general laws of physics depend on a certain number of fundamental constants – such as the speed of light, Plank's constant, electron mass and charge, intensity of various types of forces and so on – which we take for that which they are; and we observe that, by these micro-laws, complex, physical structure results as being capable of becoming the receptacle of life. It can easily be verified that if certain of these fundamental constants are changed by a few percent of their actual value, the physical substrate which leads to living beings would not have been realized in the universe. We do not intend to go over the reasons which lead to these observations here and are, in general, well known in scientific circles, in the strict sense of the word. Here we limit ourselves by assuming that such anthropical observations are a given fact and deduce the likely consequences.

To try to reduce to a purely 'casual' coincidence this unforeseen and sometimes very precise correlation between values of the fundamental laws of physics and the beginning of life, the so-called theory of the 'infinite universes' was created, in which each of these universes is equipped with one of this infinite combinations of all the possible values of the fundamental constants. It is then clear that, for almost all their entirety, the constants chosen by chance are inadequate to allow life to establish itself; this is possible only where the constants are correct, as therefore in our universe – and in few others. Nothing wonderful, then, about such a correlation between the fundamental laws and life; such is the explanation with the 'casual' presence of the infinite universes in the basic structure of the cosmos.

Why then, the invention of such a complicated theory with infinite universes of which, as far as I am aware, we don't have any indication in experimental observation? It is, therefore, to escape a metaphysical implication which could link the beginning of life with a 'preordained plan' chosen before the fundamental laws, and to escape in this way from having to postulate a non-casual nature of the cosmos and mankind.

It is worth noting that this objective contradicts itself right from the beginning: there would be nothing to say against the hypothesis in itself, if not for the fact that it is often viewed as a 'physical' hypothesis, whereas it is a purely 'metaphysical' model. To be 'physical' these infinite universes would have to be observable by us in some way: but since until now nothing has been seen, it is pure hypothesis in a field which has nothing in common with experimental science. Therefore, to avoid the metaphysical interference of a 'prior plan' that foresaw the beginning of life in the cosmos, and therefore a 'Designer', scientism has invented an alternative hypothesis; but nevertheless it is metaphysical: this the only approach of the 'infinite universes' theory. The conclusion is in the fact that the anthropical observations cannot be explained with only physical arguments: and so a metaphysical finality which cannot be renounced emerges with the following inversion: if the laws of physics permit the passing from microphysics to that of the living structures, it does not appear to be prohibited to think that the microphysical world was chosen as such, so that it could derive the structure suitable to sustain life.

Naturally, such a proposal goes beyond the scientific views of anthropical observations: it transforms them into an anthropical principle, which is taking its place in the field of not physical but metaphysical cosmology. It is clear then that, scientifically speaking, nothing is prohibited, to those who want to adhere to the scientism view, appealing to the metaphysics of the 'infinite universes', as the experimental field, based on empiricism and reason, does not contain anything in itself which can supply clues about the true metaphysical. But if I, in so much as I am a man, spontaneously feel a need to adopt one or other metaphysics, I do not feel any hesitation in declaring my personal conviction that the anthropic view, that is the intentional primordiality of the project 'man' in the cosmos, assumed as a principle of cosmology, seems immensely more likely and convincing than that of the 'infinite universes': above all because of the role of exception that is attributed to life in the economy of the universe; and for this reason, as now we will try to acknowledge, not only to the physical nature, but also to the metaphysical in man.

If the majority of the conditions which allow the creation of biological beings in the cosmos refer to how to make the substrate of purely bodily life – which may be sufficient for inferior life-forms – much less, and in a less precise way, is to be said for those necessary to create the psychic level; and even less for a spiritual being; for the prevailing opinion is that we still know very little about the relationships between body, psyche and spirit. In spite of this, the fact that the name 'anthropic' is given to the above-mentioned observations demonstrates that the deep reason for our interest in this is, not only that they join the cosmos with life, but above all, because they form the first steps towards linking the cosmos with human life.

And what allows us to arrive at the creation of man? Not only a very long period of evolution, but more than anything else that, in the sequence of biological forms of more and more complex molecular structures, a point of stoppage is inserted to a given structure, that stamps a unique hallmark, special, foreseen in all the great religious traditions and expressed succinctly in the Bible: man as 'the image of God'.

We will certainly not try to comment on this biblical definition. We are convinced that any human babbling cannot dim the implications. And if therefore, despite its total incomprehensibility, we are now pushed to mention it, it is because we find it accomplished in us, on this earth, and are pushed to the following conclusions. If man appeared in the cosmos, and if the corporeity of this terrestrial world is controlled by the laws of physics, the obvious suspicion arises that it was foreseen that this cosmos must bring man into being. And if such correlations exist, why can't they be more drastically confirmed? That is if the laws of physics are exactly as they are, it was to allow the physical world to be a substrate suitable for the creation of man. In such a perspective, man appears then to be the end for which God created the world and man becomes the destination of the whole of creation.

If, in the field of physics, we believe that one can go further forward only with difficulty, there is nothing to prohibit us from taking further steps forward in the realms of metaphysics, which can, and in fact must, encourage the reconciliation of the apparently distant levels, but converging in a synthesizing picture which encloses them. If man, as 'the image of God', can be considered the ultimate purpose of the creation, is it not, maybe so, that in creation there would be a being which as 'the truthful image', would be suitable to host God himself the day in which He wanted to manifest himself directly to the world, not in His transcendence, but in a form accessible to the eyes and the human senses? For this reason the anthropic vision of the cosmos is really that which, leaving us to glimpse a structure suitable for the Incarnation, lends itself, better than all others, to support a metaphysically Christ-centred view. This reflection, it seems, aims to prepare for the bringing together of the two perspectives mentioned in the title of this paper. And from this point on, I cannot do other than emphasise that which for me constitutes the true metaphysics, with all due respect for the different opinions that many may have regarding this. If indeed the view of the cosmos was modified by the moving from the interests of the field of physics to those of biology and therefore human, a shift in a certain corresponding way, must obviously plausibly result in the centrality of the metaphysical, which moves us from a prevalently impersonal view to that which highlights some other Aspect of the Infinity of the Supreme Origin itself.

Maybe the metaphysical, which seems to lend itself better to a comparison bringing together how, in the western view of the cosmos, 'nature' was intended, is the dominant Entity of the Hindu metaphysics 'Brahma nirguna', totally boundless and indeterminable, of which it cannot even be said to be 'One' but rather 'non-dual', because even the idea of 'Unity' would be too restrictive; and less often is 'Brahma saguna' referred to, the divine Aspect defined as Being, whose relationship with creation is 'personal', essentially tied to man.

Now this personal Aspect of God, secondary in India, is the prevailing conclusion from when the central point of the divine Attention moves towards Syria and Palestine to manifest itself to Abraham. And it is from this moment that the history of the personal God is given prominence, the protagonist in the events which will happen in the Occidental theatre, leaving the divine Impersonality in the metaphysical background.

It needs to be immediately noted how this passage, in the view of man, is fulfilled by various centuries, and perhaps a millennium, before any grasp of understanding of the physical field of our world. Therefore, when at the beginning of the 17th century, the experimentation and rationalization of Galileo and Descartes established the scientific view, the separation between the metaphysical-religious point of view and that of the physical-scientific was all but complete, to the extent of a practically total split in the 19th century between metaphysics based on the God-person and a physics which obeys the Impersonality of the laws of physics.

This is, in my opinion, the origin of the absurdity that has run rampant for at least three centuries in western culture about the incompatibility between science and religion. I have tried in various occasions to demonstrate that such an incompatibility does not exist and I have generally done so making a comparison between the physical view of the world and the impersonal view of God from the Hindu point of view.

But if now the main body of opinion in the world tends to shift more and more from the physical towards the biological, and centres itself on man, it will appear natural to spiritually jump on the related metaphysical step, for which, from Abraham's Revelation onwards, the divine Personality emerges from the 'Impersonality', dominant until now, to appear like a new protagonist. And how is it that such a divine Personality manifests himself if not through the word of the Sent, of Messengers, of the Prophets, of the 'Avatara' to use a Hindu word, human Spokespersons who speak of what surpasses the man, but which only in man is reflected and takes voice. In this way, by a double movement reciprocally inverse to the perspectives, physics on the one hand and metaphysics on the other, both tending to unity in man, notwithstanding his apparent cosmic insignificance, who finds himself to be the element in which the creation is summarized, chosen as a support and as the conclusive element in successive theophanies in which the Divinity is revealed all along the whole of the creation events.

As it follows naturally I would now like to demonstrate, not only how man's role corresponds to the specifically Christian view, but that, in a certain sense, it is its most immediate accomplishment; not contenting ourselves, of course, with the superficial but diving into the deepest theological doctrine which today is most explicitly expressed in its fundamental centre which is intact and complete in the Eastern Church, in Orthodoxy.

In fact, the Truths on which the present Orthodox Church is founded are, in their totality, the fruit of the first seven Great Ecumenical Councils held at Constantinople or in the Middle East prior to 1054. Now before that year the schism between the Eastern and the Western Church still had not happened. The significance of this is that this Truth was not only typical of the Eastern Church but represented the belief of the whole Christian Church. And even if, with the addition of the famous 'Filioque' the Roman Church broke away from Orthodoxy, it is a fact that the doctrine that was to be discussed there, which was before the schism, was at the basis of the two churches. And if the Western Church, because of various events in its history, made revisions which moved it away from certain aspects of its origins, the fact remains that these basic aspects, even if they are often neglected or toned down in different ways, are still inherent in its belief. The significance of which is that we are induced to evaluate the observations which here we will develop not as a focus on the characteristics of Orthodoxy but as the hidden centre, also when not explicit, of almost the totality of original Christianity itself.

I must for various reasons, limit myself to touching on only three essential points that I have in mind and do so in such a way as to emphasise both that which is shared and that which particularity distinguishes the Christian view from the other great traditions. On this premise of intent, it is necessary to start, for each of the points to be considered of the exemplified metaphysics, from the formalization of Hinduism, in order to reveal that which precisely defines the exceptionality of the Christian view.

First of all we will consider the relationship between the transcendent and immanent aspects of the Deity in both traditions. The absolute Reality, whatever it may be, is enveloped in all the wrappings of Maya, the cosmic illusion, which can be represented as a series of veils of varying thickness hiding one behind the other until finally the ultimate Reality appears. In the case where a veil is sufficiently transparent and part of the divine light manages to shine through it, this makes us feel God as immanent in the whole of creation. But when the veils are thick and block all the signals behind them, this then is God as an inaccessible part of the cosmos and seems to be transcendent and totally unknowable in comparison to the weaknesses of humans means.

Now, even if the image of the veils isn't taken up in the ancient Christian tradition, this in itself is not enough not to make use of a symbol which, nevertheless, allows an equivalent type of deduction, as explicitly confirmed by many Fathers of the Church: the distinction, in the divine Nature itself, between that which forms the Essence and that which manifests itself as its Energies. And if the first, the Essence, is in itself unknowable and incommunicable, it is not the same for the Energies. In fact a religion, to be such, cannot only consist of a theology in the abstract which counters the Creator with the created. Its ultimate end cannot be but a road, that which takes us from the existing state upwards, approaching the One who, unknowable in himself, must leave us to discern from some signs which reveal, to those who seek them, the right direction to travel along. Given that the Essence of God is inaccessible and impenetrable to man, it is necessary to direct him to the correct path which, in some way, God communicates, always in Himself, but outside His inaccessible Essence, through the Energies or divine Operations which are an intrinsic part of His uncreated Nature, but which allow Him to proceed towards the external, to be communicated, to give of Himself. And this independently from whatever His surroundings, also in the absence of creation and even before the creation, God, in His incommunicable Essence manifests himself, nevertheless, through the irradiation of His Energies.

Thus we recognise that God is, as for India, immanent and at the same transcendent, totally transcendent in his incommunicable Essence and immanent in the cosmos through His continuous interventions with the multi-form Energies.

The first large distinction in the area of the non-created Nature of God which we have now mentioned between the Essence and the divine Energies, gives us the answer to another point regarding the nature and the role of the Sent or the Lord's Messengers. All of these, according to their own tradition, are bearers of the Word of God and, in some way, are sharers of a certain 'something' inherent in the divine Nature itself. If the Sent announces even only 'something' of such a Nature, the question immediately arises as to what depth of the divine Nature this 'something' must be related. The answer does not seem in doubt, the function of the

Sent, at whatever level he places himself, is that of demonstrating to the world this 'something'. He is therefore part of the divine Nature which is made known, which irradiates, which erupts out of Himself, he is part of the divine Energies, the Saints, the Prophets, the Sent and the Avatara demonstrate him in their profound essence, they are the irradiation rays of the Lord's Nature.

The third point that I wish to consider is in itself the decisive approach for an adequate evaluation of the role of Christ with respect to all the other great traditions. And this decisive point concerns that which until now was mentioned with a single word; the 'unknowable', as regards the Essence of the Deity, which we will try now to explain as far as possible.

Generally, a metaphysical system which wishes to represent the entire cosmos, gradually spreads in manifestation from the top down through the various levels, first informal (non-representational), then psychic formal and finally bodily formal, and the different steps little by little make our understanding of the premise more specific and detailed. For this reason it is a 'positive' theology called 'cataphatic' in that every level reached contributes to a better explanation of what was contained in the cause which produces it. Therefore, going back to the Principle, it becomes more and more specific and detailed from the body of knowledge which derives from Him, knowledge however which is incomplete or imperfect in that the infinite God can never be reduced to a finite sum no matter how large. On the contrary in the Hindu metaphysical view, one does not come close to God with that which He is, instead one stresses that which He is not, not body, not physic, not spirit, not intellect, he is above and beyond the Being itself. Given that any positive title acts as a restriction of His Nature, the only way to describe Him is in the use of negative epithets such as Unlimited, Infinite, Immeasurable, Unknowable, Uncontainable, and so on. Such a theology called 'apophatic' which goes from the bottom up, always less defined and comprehensible, cannot do other than lead to a total Unknowability of the divine Essence and His total transcendence with respect to every aspect of the created, the only fundamental certainty which human beings can arrive at.

Now if in India the denial of the duality constitutes the main way to try to see that which is unseeable in itself, this same denial of the 'dual', which separates and divides, is that which best marks out the Christian tradition. The denial of the 'two' expresses itself here, however, with the affirmation of the Three, that general symbol of how much it goes beyond every possible separation. Orthodoxy, today, and therefore all of ancient Christianity, saw in the Trinity of God the same symbol of the divine unknowability which the Indian sees as non-duality.[1] The same incomprehensibility and elusivity for India is the non-duality of Brahma, the same incomprehensibility and elusivity for us are the Trinitarian Characteristics of God, a single Nature but Three persons, an incomprehensible mystery in itself, uniquely revealed to us which is explicitly confirmed in the Scriptures, concerning the coming of the Son from the Father and of the procession of the Spirit from the Father: in this way the Unity is included in the Triplicity, and the Triplicity itself gives the Unity a structure in which the One is Three and at the same time the Three reduces to the One.

The contrast between the two ways, 'cataphatic' and 'apophatic', is clearly found around the fifth century after Christ in the treatise about mystic Theology by Dionysius the Areopagite. It is from him that, within Christianity, the categorical affirmation comes that the main way to attempt to ascend to God is the negative 'apophatic', the unbreakable premise is the unknowability of God. If God is unknowable, all that we perceive or know acts as a screen or obstacle in approaching Him. Therefore every layer, visual, sentimental, intellectual must be stripped away in order to rise up into the unknown and gradually penetrate the divine Mystery.

The best example of this is Moses climbing up Mount Sinai leaving behind the camp, the men and even the priests to penetrate alone the mysterious Unknowability of the Deity with whom he speaks but whom he does not see.

The affirmation of the 'apophatic' method, inaugurated by the writings of Dionysus, was then adopted by most of Christianity by all the important theologians, above all from the Byzantine, Sinai and Greek areas, such as Gregory of Nyssa and Gregory Palamas, to surface in the field of philosophy and mysticism in Western Christianity, from John Scottus Eriugena up to Eckhart. There can be no doubt, regarding the spiritual realization, that the ancient contemplations of India found their natural successor in early Christianity.

Moreover the analogy can be inverted. If this was thought to be an element in favour of the efficiency and the universality of Hinduism to direct man who aspires to know God, well cannot one also turn the parallel upside down, and to discern in the Hindu meditative practices an anticipation of some centuries which later will become the oldest and most authentic of Christian practice to open the road which leads to God?

[1] See V. Lossky, *Thèologie mystique de l'Eglise d'Orient*, Chapter III.

I certainly do not have the ability, beyond these inadequate words, to go deeply into the examination of what is inexpressible in itself and of which others, with much better competence, have let us glimpse some tracks.

Therefore, I believe the point has been reached which makes clear the intention of this contribution: to accentuate the essential role of man in the cosmos both from physics on the one hand and metaphysics on the other. It seems to me that such an accentuation assumes a level of importance which is different according to the perspective with which each of us sees the world.

Those who limit their interest only to the physical field can omit all of the second part of this paper and concentrate their attention on how the physical world can reveal to us the role of man.

Those who, and under whatever form, be it religious or philosophical, feel again the presence of God in the cosmos, would recognise in the present considerations that specific metaphysical vision which corresponds to their faith.

Finally whoever adheres to Christianity finds that Father, Son and Paraclete are taken for their intrinsic Reality, whose setting, within the framework we have just discussed, places them in the Unknowability of the divine Essence, and would be themselves inexpressible and elusive, had not the Person of the Son, in himself unconceivable and unreachable, for a unique event in history, wanted to become incarnate in human form. And because the uniqueness of this event breaks the line of all the other great Sent, expressions of the Divine Energies, He came to create a unique and unrepeatable fact, since He who in this manifested and revealed himself is, nevertheless, the Un-revealable and Un-manifestable Himself.

This in our opinion, is the true exceptionality of Christianity: not only the Trinitarian view, the distinction of the three Persons, Father, Son and Holy Spirit, which – not being remotely imaginable for the human mind if not through the anthropomorphic models, and thus of all unreal – is none other than an expression, as already said, of the total unknowability of the Divine Essence; but that this unknowable mystery manifested itself in a human being and therefore subject to all the events in life.

One may not accept it; but if one does accept it, then the manifestation of Christ cannot do other than differentiate it from all the other great Sent, even if nothing is taken away from the full validity of the other Revelations into which He frames in, and summarises them in Himself.

The choice, between the two options, does not happen, in my opinion, at a rational level: it is a question of internal adherence, of direct intuition, of faith and therefore of environment. No one is better than another for having made a given choice; whether one adheres to a particular philosophy, or to one of the divine Energies, or whether one points directly to the Essence, it is always the climb towards God which is looked for, both by all the believers on the earth and sometimes also by those who do not directly think about it.

I have thought that, if the development and fine tuning of the situation in the various sciences constitutes the main objective of an Academy such as ours, its most refined quality of being 'pontifical' should suggest not to overlook the connections of sciences that constitute the metaphysical background on which, to my mind, even the objectivity of the world is rooted. This is why I have ventured to present this perhaps too personal contribution; although such a precise focalisation is not frequently practised, I am induced to think that its happening from time to time might not constitute, even for those with completely different views on the subject, an inadequate occasion of reflection for meetings as the present one.

A NOTE ON ASPECTS OF CLASSICAL PHYSICS IN THE TWENTIETH CENTURY

RAYMOND HIDE

Preamble

If 'culture' is the general state of intellectual development in society as a whole then 'science' is an important and distinctive component of culture. Herein must surely lie the main cultural value of science, the subject with which this meeting of the Pontifical Academy of Sciences is concerned.

A systematic way of dealing with experience, science is [1] 'the creation of the human mind, with its freely invented ideas and concepts.

– (Scientific theories) try to form a picture of reality and establish its connection with the wide world of sense impressions.

– (Thus) we find our way through a maze of observed facts, to order and understand the world of sense impressions.

– (Without) this belief in the inner harmony of the world there would be no science'.

But the scientist is no stranger to ignorance and doubt [2], 'being fully aware that scientific knowledge is a body of statements of varying degrees of certainty – some most unsure, some nearly sure, but none *absolutely* certain. Great (scientific) progress comes from a satisfactory philosophy of ignorance'.

Science swallows its past! Unlike all other forms of knowledge, scientific knowledge is such that [3] 'the insights of the past are digested and incorporated into the present in the same way that the genetic material of our ancestors is incorporated into the fabric of our body'. No person now alive [4] 'could understand Shakespearean experience better than Shakespeare (himself), whereas (within the foreseeable future) any decent eighteen-year-old student of physics will know more physics than Newton'.

Science [5] 'makes great demands on the purely cognitive side of human nature, (but) it also speaks to the affective side. To achieve a significant advance in science makes just as great a demand on the intellect, imagination and personality as does the work of creative writers, poets, painters, sculptors and composers'.

Aspects of Classical Physics

Physics is the scientific discipline that is concerned with matter and energy and their interactions. Possibly the most stupendous development ever to have occurred in science was the rise of *modern* physics in the twentieth century [6]. Less impressive though still very significant were concomitant advances in most areas of *classical* physics, which is based on laws applicable to processes on length scales and time scales where both quantum and relativistic effects are negligible.

These laws are concerned with (i) forces and their relation primarily to the motion of bodies of matter ('dynamics'), (ii) relations between heat and other (e.g. mechanical, electrical) forms of energy ('thermodynamics'), and (iii) the effects arising from the interactions of electric currents with magnets, with other currents, or with themselves ('electrodynamics').

The laws were well established by the end of the nineteenth century, but, to paraphrase a prescient warning issued by Maxwell three decades earlier at a meeting arranged to discuss the problem of free will [7], the traditional preoccupation of physicists and applied mathematicians with phenomena that are simple, stable and insensitive to boundary conditions and initial conditions had created over-confidence in the 'all-encompassing influence of the laws of Nature'. Thus, knowing that the general circulation of the gaseous atmosphere of the Earth under the influence of differential solar heating must be governed by the laws of dynamics and thermodynamics, and emboldened by the success of physicists in establishing these laws, one leading scientist when asked in the year 1900 to predict likely developments over the next half-century was rash enough to suggest that little more than routine efforts by meteorologists trained in physics and mathematics would soon lead to highly accurate weather forecasts! Evidently unaware of Maxwell's warning he clearly overlooked the serious mathematical difficulties which still beset physicists and engineers in their attempts to apply the laws to real systems [8-14].

These difficulties are especially severe in theoretical research on turbulent fluid flows and other complex processes encountered in the study of continuous media. The governing partial differential equations in terms of which the physical laws are expressed mathematically certainly provide valuable theorems and other useful diagnostic relationships between key variables. But the essential nonlinearity of the equations makes them virtually impossible to apply directly in most prognostic work, where all the multiple solutions of the equations would have to be found and their stability thoroughly investigated.

Classical physics understandably declined in popularity as modern physics advanced, although some talented practitioners pursued fruitful careers in the subject [15]. Others kept a foot in both camps, at least to start with, including scientists of the calibre of Heisenberg whose well-known contributions to the theory of stability of parallel shear flow and turbulence in fluids [16, 15] were outshone by his great work in quantum mechanics [6]. With many new problems to be tackled in modern physics there was no strong temptation to spend time seeking explanations of natural phenomena such as the Gulf Stream in the Atlantic Ocean and the Great Red Spot in Jupiter's atmosphere. And other phenomena now investigated under the heading of 'geophysical and astrophysical fluid dynamics' such as the magnetism of the Earth and the corona of the Sun would remain enigmatic until pioneering work by Alfvén and others [17, 18] had created the new subject of 'magnetohydrodynamics' (MHD).

MHD involves the application of all the laws of classical physics, for the (pre-Maxwell) equations of electrodynamics are also needed when treating the flow of an electrically-conducting fluid. Much material in the cosmos is both fluid and electrically conducting and on the scale of cosmical systems MHD phenomena abound. But most underlying processes are impossible to reproduce on the very much smaller scale of the terrestrial laboratory, owing mainly to the difficulty with available fluids of achieving high enough values of the 'magnetic Reynolds number' $UL\mu\sigma$ (where U is a characteristic flow speed, L a typical length, μ the magnetic permeability of the fluid and σ its electrical conductivity). Significantly, this obstacle to progress is now being overcome to some extent by the increasing use of powerful computers for integrating the governing equations.

Computational fluid dynamicists strive for breakthroughs in understanding turbulence and other fundamental processes characteristically involving many different length scales and time scales [19]. As in laboratory studies, basic general theorems and dimensionless parameters play a central role in the formulation of crucial investigations and the interpretation and application of experimental results. Dimensionless parameters (such as the magnetic Reynolds number) are readily identified by expressing the governing equations in dimensionless form, but their successful use is less straightforward and remains something of an art [20].

Fortunately, experience shows that it is not always necessary or even desirable to insist on complete geometric and dynamic (and, where appropriate, thermodynamic and electrodynamic) similarity. We now see, for instance, albeit with twenty-twenty hindsight, that if physicists in the late nineteenth century and early twentieth century had made simple but systematic 'curiosity-driven' laboratory investigations of flow phenomena in spinning fluids, unexpected dynamical processes, including deterministic chaos, of direct relevance in meteorology, oceanography and other areas of science and engineering would have been discovered much sooner [12]. Whilst it is impossible in the laboratory to simulate a planetary atmosphere in all its details, much of our knowledge of fully developed 'sloping convection' – a process which underlies many natural phenomena such as highly irregular waves and jet streams seen in the Earth's atmosphere and the more regular large and durable eddies in the atmospheres of the major planets – comes from laboratory experiments on thermal convection in rotating cylindrical (rather than spherical) fluid systems no more than several centimeters in size. These were eventually started half a century ago, long before computers became powerful enough to play a significant role in such research.

At the beginning of the twenty-first century we can be sure that all branches of science will continue to benefit from improving computer technology [19] and fundamental advances in mathematics [10]. But in forecasting detailed future developments scientists in the past have shown little more than modest skill [21], even with the benefit of fascinating insights provided by the imaginations of non-scientific colleagues. We can look forward to many surprises.

REFERENCES

[1] Einstein, A. & Infeld, L., *The evolution of physics*, (re-issue of 1961 second edition), Cambridge University Press. (1971).

[2] Feynman, R., *What do* you *care what other people think*?, Bantam Books, New York (1989).

[3] Burstyn, H.L., 'Tradition and understanding', *School and society*, (November 1969).

[4] Snow, C.P., 'The case of Leavis and the serious case', pp. 81-97 in *Public affairs*, Macmillan, London (1971).
[5] Dainton, F., *Doubts and certainties*, Sheffield Academic Press (2001).
[6] Brown, L., Pais, A. & Pippard, B. (eds.), *Twentieth century physics* (three volumes), Institute of Physics, Bristol (1995).
[7] Barrow, J.D., *Theories of everything*, Oxford University Press (1990).
[8] Poincaré, H., *Les méthodes nouvelles de la mécanique celeste*, Gauthier-Villars, Paris (1892).
[9] Lighthill, J., 'The recently recognized failure of predictability in Newtonian dynamics', pp. 35-50 in *Predictability in science and society*, (eds. Mason, J., Mathias, P. & Wescott, J.H.), Cambridge University Press (1986).
[10] Arnold, V., Atiyah, M., Lax, P. & Mazur, B. (eds.), *Mathematics: Frontiers and perspectives*, American Mathematical Society (2000).
[11] Sussman, G.T. & Wisdom, J., *Structure and interpretation of classical mechanics*, M.I.T. Press, Cambridge, Massachusetts (2001).
[12] Lorenz, E.N., *The essence of chaos*, University of Washington Press (1993).
[13] Bjerknes, V., Bjerknes, J., Solberg, H. & Bergeron, T., *Hydrodynamique physique avec application à la météorologie dynamique*, Les Presses Universitaires, Paris (1934).
[14] Norbury, J. & Roulstone, I. (eds.), *Large-scale atmosphere-ocean dynamics*: *Analytical methods* (vol. 1); *Geometric methods and models* (vol. 2), Cambridge University Press (2002).
[15] Batchelor, G.K., *The life and legacy of G.I. Taylor*, Cambridge University Press (1996).
[16] Heisenberg, W., 'Über Stabilität und Turbulenz von Flussigkeitsströmung', *Ann. Phys. Lpz.* (4) 74, 577-627 (1924).
[17] Alfvén, H., 'On the existence of electromagnetic-hydrodynamic waves', *Arkiv. f. Mat. Astron. Fysik*, 29B, no. 2, 7 pp. (1942); *Cosmical electrodynamics*, Oxford University Press (1950).
[18] Davidson, P.A., *An introduction to magnetohydrodynamics*, Cambridge University Press (2001).
[19] Catlow, R., Burke, P., Goodfellow, J., Tildesley, D. & Wilson, M. (eds.), 'New science from high performance computing', *Phil. Trans. Roy. Soc. London* A360, 1073-1294 (2002).
[20] Birkhoff, G., *Hydrodynamics: A study in logic, fact and similitude*, Princeton University Press (1960).
[21] Thomas, J. Meurig, 'Predictions', *Notes Rec. Roy. Soc. London* 55, 105-117 (2001).

GOD'S TRACES IN THE LAWS OF NATURE

WALTER E. THIRRING

Dear Colleagues,

Far from being able to give a comprehensive review of the vast subject of the relation between Science and Religion, I want to comment on a few points which have not been sufficiently put into focus yet. Many of you might remember that some years ago our highly esteemed colleague Germain told us that his father tried to dissuade him to go into science. He feared that he would loose his religious faith as science conflicts with religion. After thinking for half a century about this question, I am reaching the opposite conclusion. Of course we all have to start from the same facts and I don't claim that I have the only rational way of looking at them. However I think that my view is consistent and logically tenable.

When I speak about religion, I shall restrict myself to monoteistic religions and more specifically to God as revealed in the Bible. Here I want to discuss three aspects, the creating God of the Genesis, the guiding God of the old testament and the loving God of the new testament. All three features have their correspondence in natural science. It seems to me that when looked at the right way science does not conflict with the religious world view but makes it more glorious.

1. The Genesis

To get trivia out of the way, let me start with the following remark: 'Everything can be described on different levels'. There may be a simpler but coarser description which conveys the point one wants to make, though in some ways it is oversimplified or even wrong. There will be a more accurate and detailed description which however is too complicated to bring one's point into a focus. This has nothing to do with religion and there are plenty of examples in science. Take for instance chemistry where the atoms of a molecule are represented by little balls and the bonds between them by little sticks. This notation has become a way of thinking and proved to be so fertile that modern science cannot live without it. Yet we know that it is incorrect. Not just because of the trivial reason that on a sheet three-dimensional objects must be represented by two-dimensional projections but because the whole mental picture does not apply. The correct description is furnished by the Schrödinger equation. It operates with completely different notions and deeper questions like the stability of matter or Bose-Einstein condensation of atoms do not appear in the simpler picture. But a more refined analysis shows that instability does not appear on earth but only for cosmic bodies which are gravity dominated and B-E condensation requires for its realization the high technology of ingenuous experimentators. Thus, chemists may happily go on using their simple pictures, for their purposes it is good enough. I think with Genesis we are in a similar situation, it obviously does not meet our present scientific standards. But what we have learned from our chemistry example is not to criticize the coarser description once one has a more accurate one. This criticism is trivial and can be left to more modest intellects. The question is, does the more accurate description modify the outlook of the coarser one and this is what I want to do now.

From Genesis, I abstract the following message. The universe was created in a single act and the powers of its creator must have infinitely transcended all human capacities. Expressed in this form, Genesis is not only supported by science but also brilliantly illustrated by it.

The big-bang picture of the origin of the universe as a huge exploding fireball is now so well established that I suppose it to be common knowledge. At least what happened after three minutes of its creation is well supported by observation. The first three minutes remain a realm of scientific speculation since their traces have been extinguished but this should not concern us here. To start I have to sketch the laws which governed this terrific explosion. At first sight it seems unexplicable because where should all this immense amount of energy come from? Nevertheless, according to Einstein's theory of gravity this should not be a problem. The gravitational energy is negative which in a high-density object may get so huge as to compensate the positive energy of matter. In fact, in this theory for a closed universe the compensation is exact and its total energy is zero. Amazingly energy conservation does not forbid the *creatio ex nihilo,* however it might be inhibited by some barrier. Thus, the state of nothingness, 'the vacuum', will be unstable against big bangs. If you like, you may picture 'the earth was dark and vaste' of Genesis as the vacuum of quantum gravity and 'there be light' as its breakdown due to its instability. If the whole universe appears in a small region, its gravitational energy will be near $-\infty$ so the energy of its matter must be close to $+\infty$. That is to say, the newly created universe will be very hot and all possible particles will be created. The reason why now we can continue the speculation scientifically is that on a small scale we can reconstruct such a situation using high energy accelerators. At this point, as a physicist, I cannot refrain from sticking in some orders of magnitude; in the cosmic background radiation we actually see the last glow of the first light. By the expansion of the universe the wavelength of this light has been stretched proportionally and is now about 1 mm. With the biggest accelerators, we can reach wavelengths of 10^{-17} cm that is to say smaller by 10^{16}. Thus, we can realize states, which occurred when the universe was smaller by this factor 10^{16} which means when it had the size of the sun since it now measures 10^{28} cm across. Hence we can now leisurely study what comes out of the vacuum in such a highly concentrated situation. High energy events where thousands of particles are created out of vacuum appear chaotic. Nevertheless closer analysis reveals a high degree of symmetry referring to an 'inner space' not visible on the macroscopic scale. This symmetry led people to guess the laws which govern the behaviour of these particles. The deduction of these laws was not logically compelling but used above all arguments of beauty and simplicity. Wonder over wonder as experimental analysis and calculations where refined, one found theory and observations approached each other and are now in agreement within the level of their accuracy of about 1‰. Thus we seem to possess the laws of creation and the following speculations about its creator come to one's mind.

1.1. *God is spiritual, omnipotent and omnipresent*

The laws reveal their simplicity and beauty not to the simple mind but only to minds at home in higher levels of mathematical abstraction. Thus their architect must possess these highly spiritual qualities and He must have engraved them in nature in a way beyond human understanding. These laws are simple on a conceptual but not on a computational level and we need all the powers of our supercomputers to work out their consequences. Yet these tiny particles, 10^{-15} cm across, follow these laws and somehow can easily solve these difficult equations in 10^{-25} sec. On a human scale this appears far beyond anything feasible which to me represents a sign of God's omnipotence. The omnipresence is directly shown by the fact that, as far as we can see, these laws are valid all over the world.

1.2. *Man is God's image*

If we call these laws 'Gods words' ('the logos') then man is able to read them in an unexplicable way. One cannot argue that these laws are just archetypes set in our brain by evolution since our evolution of life never met energies of 100 GeV or distances of 10^{-16} cm. The mathematical images appearing in our laws were created by man only in the past decades and must have received their inspiration from somewhere else. Somehow the human mind is tuned to God's wavelength.

1.3. *Man is the coronation of the creation*

It is often argued that man is nothing, being only an infinitesimal part of the universe. But I think lifetime or size is not what matters, even the universe was once as tiny as the head of a pin. What is important is that we are able to understand the laws of nature and as far as we can see we are the only ones. It is true that there are about 10^{10} galaxies, each containing about 10^{11} stars and many of them might have planetary systems. Thus, the probability for the existence of incredibly robust unicellular creatures somewhere is overwhelming. However, for these cells to get organized to higher forms of life took on earth 3 billion years. For this evolution we need planets with a stable climate over such a stretch of time and this will be highly improbable. Even granting that still one has to wait until dinosaurs are eradicated and then a 'Newton' needs to be born for science to emerge. How long this chain of events takes somewhere else is everybody's guess. The probability for higher extraterrestrial intelligence is the product of a huge and a tiny factor. Which one wins out cannot be pinned down. Thus the outcome can only be settled by observational evidence and so far there is none.

Up to now, I have been talking about a creator without saying why I assume there is one. In fact, positivists will say this in an unprovable and unnecessary hypothesis and this is logically correct. But the positivistic attitude, though sometimes quite healthy, may also be counter-productive because an unprovable hypothesis may very well pave the way to deeper understanding. Let's return to our scientific example. When Demokritos postulated the existence of atoms he thought this was a way to reconcile the undestructibility of matter with its ever changing forms. At this time, one was far from being able to prove this assumption and up to the beginning of the 20^{th} century positivists objected to it. Now we not only have to say that it is as if there where atoms but we can even see them. So everybody thinks that Demokritos was right. However, atoms show some unexpected features and it's not so clear that what he was talking about really exists.

In science we always start with an 'as if' situation in order to relate the unknown to the known. To show in which sense a putative element exists is not the most rewarding task. Rather one has to show that its assumption leads to a consistent scheme. If it turns out to be inconsistent, it ought to be modified, if it works well, the 'as if' is eventually dropped. Take an example from pure thought, namely from mathematics, our notions of numbers. To start with we have the natural numbers 1, 2, 3 .... They exist in the sense that we can count them with our fingers. However, they are not a perfect scheme since subtraction is not always possible, it is as if they are only part of a more complete set. Indeed by incorporating 0, -1, -2, one arrives at the integers. At this stage, one does neither worry that we do not have negative fingers nor ask in which platonic sense the new elements exist, but just notes that one can always subtract. The scheme still lacks perfection since one cannot always divide so one incorporates the fractions ½, ⅓, ⅔, ... Now one has a nice scheme and these numbers are called the rational numbers. Yet, there must exist more numbers. Already the Greeks found to their horror that the diagonal of a square cannot be expressed by rational numbers. Such numbers were punished by being called 'irrational' but it was found that they are the majority. Though called irrational everybody believes that these numbers exist. Not so much because they can be realized by mental constructs like the Dedekind cut or converging ultrafilters but because they lead to a powerful and consistent tool. Such a process has been repeated on and on in mathematics up to nonstandard analysis, which essentially assumes that limits always exist. But then the problem is that the limit may not have the desired properties. Thus returning to our discussion we have to state which properties the creating God shows. First of all it is clear that God must possess properties so vastly different from what we are used to. We can state:

1) *God the creator cannot be pictured by any natural object*:

On this point the three abrahamic religions agree but our reasoning suggest even more.

2) *God the creator cannot be called the good Lord or the loving Father*:

In fact, gnostic theologians thought the creator was cruel and terrible. But to me it seems that these adjectives do not apply either. Admittedly, the early universe was a terrible place and completedly hostile to life. But since there was nobody to complain about it, this can hardly be called cruel. But more generally

3) *God the creator does not show any personal features*:

I think that this is the reason why many scientists believe in some sort of creator but have difficulty in picturing a personal God. Such features appear only if we follow His traces to the further stages of the evolution of the universe.

2. The guiding God

Here I have to discuss first the limitations of the predictive power of the laws of physics. By its laws the state of a system at a later time is determined from the initial state by the equations of motion. Great pains have led to equations where the solution is unique and therefore laws are deterministic insofar as the present determines the future. This also holds in quantum mechanics except that there are no states where the values of all observables are completely fixed so not only the future but even the present contains uncertainties. More importantly when considering the whole universe, we can never completely determine its state because only finitely many measurements are feasible. Of course we are free to measure whatever we please and such a finite number of measurements determines a state of the system within what is mathematically called a weak neighbourhood. Now for a system as complex or chaotic as the whole universe the state at much later times depends so sensitively on the initial state, that any weak neighbourhood leaves enough leeway that practically anything can come out of it. This does not only concern minor details but also which path is chosen at important crossroads that eventually determines the future fate of the universe. Actually the state of the universe at a much later time is, in Gellman's words 'the product of many frozen in accidents'. In particular our present form of the laws of nature contains many parameters, masses of particles and strengths of interactions, which we cannot explain and which may be the result of frozen in accidents. However, whether the universe is a livable place or not depends essentially on such quantities as I shall now illustrate with a few examples.

2.1. *The age of the universe*

The big bang is the explosion of a highly compressed system kept together by gravity. How long this keeps expanding depends on the strength of the initial thrust relative to the gravitational pull due to its mass. It is like lauching a satellite into an orbit which should circle the earth many times. With too much thrust it escapes the earth, with too little it falls back. It took humanity some time to learn this fine tuning but for the universe it needs far finer tuning. For the big bang the characteristic time to collapse again is the Planck time 10^{-43} seconds. To get a universe capable of producing life like ours you need about 10^{10} years = 10^{17} seconds. Thus, you need fine tuning by a factor 10^{60}.

2.2. *Stability of matter*

There are far more reasons favouring instability of matter than there are for stability. One obvious condition for the existence of matter is the stability of the proton. But there is its neutral brother the neutron, and which of the two is the stable one depends on which one is lighter. Usually, the neutral brothers are lighter but here we have an anomaly, which appears accidental, the neutron is heavier by about 1/1000. Thus it decays in about one quarter of an hour into a proton which then is stable. If it were the other way around, there would be no stable proton and therefore no hydrogen. Not only there would be no water for us to drink but there would be no earth, no stars, only lumps of neutrons held together by gravity floating as dark matter in the vast space. A *triste* world.

2.3. *The formation of heavier elements*

For life to evolve we need not only hydrogen but also carbon and oxygen. The big bang starts out with hydrogen which in the concentrated phase may fuse into He nuclei (= α-particles). The ladder to heavier nuclei is however missing one step. 3α-particles give carbon (C^{12}) and 4α-particles give oxygen (0^{16}) but 2-α-particles don't stick together at all. This means that the corresponding nucleus Be^8 has no ground state but only more or less short-lived excited states. A carbon nucleus can only form if within the short lifetime of Be^8 a third α-particle comes along with an appropriate energy and they all fuse into C^{12}. Whether this actually happens essentially depends on the exact form of the nuclear forces and their strength relative to the electric repulsion of α-particles. In some parameter space is only a small window through which such escape to heavier elements is possible.

These examples of the accidental nature of the circumstances in which life can emerge are only three among the many which have been collected in thick books.

The Anthropic Principle

It states that on the many crossroads met in the evolution of the universe the path chosen is the one which eventually leads to life.

Now some explanations are in order:

1. It is called principle not law of nature since it is not deducible from fundamental laws.
2. It is called anthropic since it refers to the emergence of man. At this point I prefer to talk about the emergence of life as the necessary conditions for the steps from life to men are even less understood.
3. Some people think it is not even a principle but a tautology as there would be nobody to state the principle if the conditions were not met. So maybe the vacuum fluctuations which lead to the big bang also lead to many different big bangs and among these innumerous universes there was bound to be one qualified for producing life and this is ours. Though logically possible this kind of Darwinistic explanation lacks any scientific substance as long as we do not see any signs of these many alternative universes.
4. One might think it may be explained in probabilistic terms according to the idea that all roads eventually lead to Rome. I don't believe this because of the following reason. At the beginning there must have been the state of infinite temperature which assigns all possibilities the same probability. Since their number is legion whatever comes out is exceedingly unlikely. But then one is not interested in a particular possibility but in the occurrence in any one of those where the highly ordered structures which we call life exist. But this subset of all possibilities is such a minority that the probability is still practically null. One might object that there can be situations where life develops by necessity but then these situations are exceptional on a global scale. Thus a priori probability will lead us nowhere.

At this stage, it is tempting for theology to take advantage of the failure of rational explanations of the anthropic principle and to say it is as if God were guiding the evolution of the cosmos such that eventually He can create His image. This immediately triggers a question. First I have been talking about a God who uses His laws to create the universe and now I talk about a God who uses the ambiguities left by his laws to let the universe develop in the direction he likes. Is this still the same God? I must refute this question because it presupposes an illegitimate picture of God. The notion of sameness, though obvious for material objects, may not apply to immaterial ones. For instance the question whether I wake up in the morning at the same point in space where I fell asleep the night before cannot definitely be answered. First we tend to say yes but remembering that in the meantime the earth has moved a bit around the sun, one would say no. Only by uniting all points in space to 'the space' we can say I wake up in the same space but whether at the same point depends on the frame I choose.

The great breakthroughs in science have been made by uniting into a more universal entity things which first appear different to us. This started with Newton who had the inspiration that what pulls the apple onto his head is the same as keeps the moon in his orbit around the earth. This went on to Einstein who united all points in space with all instances of time into the 'Minkowski space' and recognized that this was the natural arena of all events and finally leading to Glashow, Salam and Weinberg who united forces which appear entirely different, namely the ones governing electromagnetisms with the ones producing β-decay. So the question whether space and time are to be considered the same is not an unqualified 'yes' or 'no' rather a 'no but they are simply different aspects of the same object, namely Minkowski space'.

On its way to further unification, physics is now stuck at a 'trinitarian' situation. We are left with three fundamental forces, gravity, electroweak forces and nuclear forces but most of us physicists think they are just different aspects of 'the Force' which we don't know yet how to formulate. Coming back to God's sameness if one searches for an answer, it would be reasonable to say 'It is God who and by whatever means guided the evolution towards the creation of men, but whoever wants to emphasize different aspects of this long road should not be burned as heretic'.

3. The universally loving God

When we turn from evolution of the universe to evolution of life we encounter as the main driving force Darwin's 'survival of the fittest'. Though originally banned as heresey, now it seems obvious if not tautological: fit is what enables survival. However, the great watersheds were when evolution turned against this dictum. I shall call it 'antidarwinistic' though my biological friends tell me that Darwin had already understood that. The first crucial crossroad we encountered before. The earth became livable about 4 billion years ago and soon after unicellular organisms developed. They perfected fitness to an amazing degree. They can live in the deep sea where magma bursts into the water and it is several hundred degrees hot. They are found in polar ice or in places of the earth mantle where nothing else can live. Above all they are immortal in the sense that they don't die of old age like us. According to Darwin's dictum this should be the endpoint of evolution and indeed it took about 3 billion years to get beyond it. There must have been innumerable abortive attempts but once multicellular organisms succeeded they spread like a firestorm around the earth and created this marvellous diversity of species we find today. It was like a phase transition in physics but whether this was progress may be a matter of dispute. Owing to their immortality, the unicellulars are still among us, in fact they are the main contributors to the biomass on earth. Yet there can be no doubt that though mortal we are their masters. We can cultivate them, manipulate them, exploit them.

These kinds of watersheds to higher organisational units kept reappearing along the way up to the evolution of men. About 40 thousand years ago the Neanderthals were replaced by Chromagnons despite the fact that the individual Neanderthal must have been a highly fit creature in order to survive under the terrible climatic circumstances of that time. Presumably, they lacked organizational skills so they lived in small clans each including a handful of people. On the other hand Chromagnon reached a higher cultural level so they could coordinate large tribes. As a consequence the Neanderthals had no chance of survival despite their fitness, again a sign of antidarwinism. This ability – coordinating even larger tribes and people – brought about yet another phase transition in human evolution which in turn led to amazing architectural and artistic achievments of the ancient cultures. The idea of a nation as the human unity is also reflected by the religions of the various people. They mainly served to deify the ruling class and their Gods had a certain local flavour. Even when finally monotheism was reached as presented in the old testament, God was seen in relation to some people. In an act of universal validity, as the statement of the ten commandments, God first identifies himself as the God who led the people of Israel out of Egypt. By necessity the next step in human evolution was to see the whole humanity as the relevant unit. This step was taken by Jesus Christ who turned to people irrespectively of their social level, professional activities or ethnic origin. He did not divide humanity into friends and enemies, on the contrary he preached love extended to your enemies. This is obviously in our sense antidarwinistic but necessary to bring peace to mankind. Thus, I see the importance of Christianity and also the reason for its success in its universality: one God for all people. Unfortunately, the corresponding phase transition in human evolution had not yet taken place, it is as if the nationalistic thinking were genetically engraved in our brains. Our generation still learned at school 'Recht ist was dem Volke nützt, Unrecht was ihm schadet' and even today all over the world fights get ignited by ethnic prejudices. Do we have to wait the genetically relevant time of 40 million years of Teilhard de Chardin to reach his Ω point? I hope not as I am afraid if we don't reach it earlier we will never get there.

To summarize I see in the evolution of the cosmos a continuing strive for higher organisational structures leading up to humanity. Nietzsche declared God to be dead since Darwin could explain the biological evolution 'naturally'. This means you expect of a living God a spectacular miracle and to show us that he breaks his laws. As J. Monod emphasized in his famous book *Le hasard et la necessité* this does not seem to happen in the biological evolution. It does not contradict the fundamental laws of physics but it cannot be predicted by them either. It could have happened but need not happen the way it did. We have seen such a situation all along the way in the evolution of the universe. At crossroads it always took the path such that finally we could evolve. If in a vessel with gas one atom is near a corner this does not contradict any law nor if there are two. If all are there we would call it a miracle since it contradicts all our probability estimates. What is now the probability that at all bifurcations the universe evolves so as to create more ordered structures? Surely low but how low is hard to estimate convincingly. I don't want to call it a miracle but I see in it the guiding hand of the invisible God.

STATEMENT ON THE CULTURAL VALUES OF SCIENCE BY PROF. ANTONINO ZICHICHI

The discovery of Modern Science represents one of the greatest achievements of mankind in the immanent sphere of our existence. This achievement was made possible thanks to Galileo Galilei, two millennia after the study of Nature by ancient Greeks, as a selfless form of research for truth. Galilei realised, and said openly, that God is more intelligent than us all. Consequently, if we want to discover the logic of Nature there is only one way: to pose, in a rigorous manner, the question to the Creator and this means performing an experiment. If we seek the correct answer, the result of the experiment must be reproducible. The rigour is granted by mathematics, the correctness is ascertained by reproducibility. This is how Galilei discovered the first fundamental laws of nature, which brought him to formulate the principle of relativity and to invent the 'Gedanken Experiments'.

The values of Modern Science have their roots in the act of faith towards the Creator, as expressed by Galilei when he explained the reason for which he was using stones and 'vulgar' matter, as the footprints of God were also to be found in vulgar matter, not only in the stars. History tells us this is how *Modern* Science was discovered. Even nowadays, in the most advanced laboratories worldwide, the Galilei teaching is the only one which allows us to further our knowledge of the logic of Nature.

It is our duty to ensure that *the world* be made aware of the role played by John Paul II in defining the meaning of Science, its clear distinction from Technology and the need for a Third Millennium culture which would be in harmony rather than in conflict with Faith.

STATEMENT ON THE CULTURAL VALUES OF THE NATURAL SCIENCES

At its Plenary Session of 8-11 November 2002, the Pontifical Academy of Sciences discussed the various contributions made by scientific activity and education to the culture of humankind. Seeing 'culture' as a set of free and responsible learned ways of acting, behaving and taking decisions, as opposed to inherited patterns of behaviour and instincts, the Pontifical Academy of Sciences wishes to issue the following Statement.

If by science we mean the sophisticated arts of mathematics, aesthetics, architecture and metallurgy, it is possible to describe ancient Egypt, China and Mesopotamia as the first homes of science. The knowledge base built up by studies in the natural sciences beginning with the theoretical practice of the ancient Greeks as a selfless form of the search for truth, and then developed by the method of Galileo and his heirs, constitutes a fundamental dimension of human culture. Since that time, this dimension has shaped human history and is now an irreversible part of one's destiny. It is a value in itself which provides both a science-based view of the world and people and extensive opportunities to improve living conditions through applications in such areas as health, life expectancy, food security, sustainable growth, energy and water resources, information and communication, and the preservation of the environment. In the context of these applications, a worldview where science and its values play their role in the quest for truth, together with the ethical wisdom developed down the centuries, can be of great help in assessing policies and technology so as to reduce the possible risks that accompany many such applications. Thus, a global awareness of the need to engage in a responsible evaluation of human impact can lead to the implementation of sustainable developments which guarantee good for all people. Many national and regional Academies of Science, as well as international scientific unions and inter-academy organisations, are ready to help political and cultural leaders, governments and companies in a careful and prudent assessment of the new technologies.

The rigorous standards generally applied in scientific research with regard to data collection and interpretation and experimental design, and the ethical rules that govern scientific practice, impart intrinsic cultural value to scientific work. Similarly, the steadily enriched scientific knowledge base, sharing the values and contents of science, represents a force of great value for education and can act to improve the conditions of human lives. For these reasons, the broad knowledge base of the natural sciences constitutes a dynamic and open trans-disciplinary foundation that is of relevance to all human beings at all levels of education. In order to benefit fully from this knowledge base, societies should develop scientific education, starting from primary school, and ensure that their scientists responsibly take care that the progress of science and technology goes to the advantage of all men and women.

Successful scientific research strongly depends on originality, creativity and invention. These requirements are similar to those of other cultural activities in the various fields of the arts and in the social and human sciences. All of these fields make their specific contributions to the heritage of human culture; they are complementary and cannot replace each other. Today, more than ever before, what is required is a new humanism which takes into account all aspects of human culture, and where human, social and natural sciences can work together as partners. This will greatly contribute to improving the overall knowledge of our world and our place in it, to increasing the respect for future generations, to promoting what is human in people, to safeguarding the environment, and to fostering sustainable growth and development. In this way, science will help to unite minds and hearts, and encourage dialogue not only between individual researchers and political and cultural leaders, but also between nations and cultures, making a priceless contribution to peace and harmony amongst the peoples of the world. Science, so much appreciated in the teaching of John Paul II, when it is in harmony with faith can fully participate in this new humanism. The members of the Pontifical Academy of Sciences make an appeal to the readers of this Statement to fully recognise the valuable contribution made by the natural sciences to human culture.

TABLES

GEOGRAPHY

Fig. 5. A Globe representing Al Mamoun's Map of the World, developed by the geographers in Baghdad during the period 813-833 AD.

CHEMISTRY

Fig. 6.

MEASUREMENTS

Fig. 7. An original astrolabe used by the Arab astronomers during the 10th-15th centuries.

PHYSICS

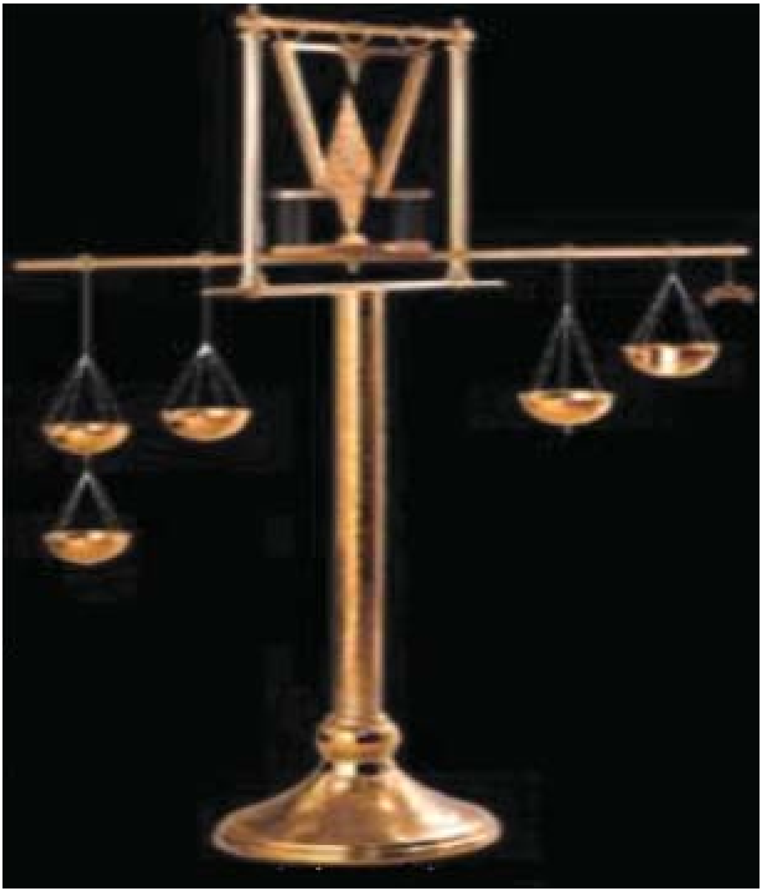


Fig. 8. This is a spectacular and fairly accurate Balance. Produced out of copper, it can be seen at the Institute of Arabic Islamic Science in Frankfurt Germany.

Slide 4. Charles as he looks today.

Slide 5. Charles on arrival at VFGH.

Slide 6. Charles with skin allografts.

Slide 9. Patient at birth.

Slide 10. With twin brother as I first saw him.

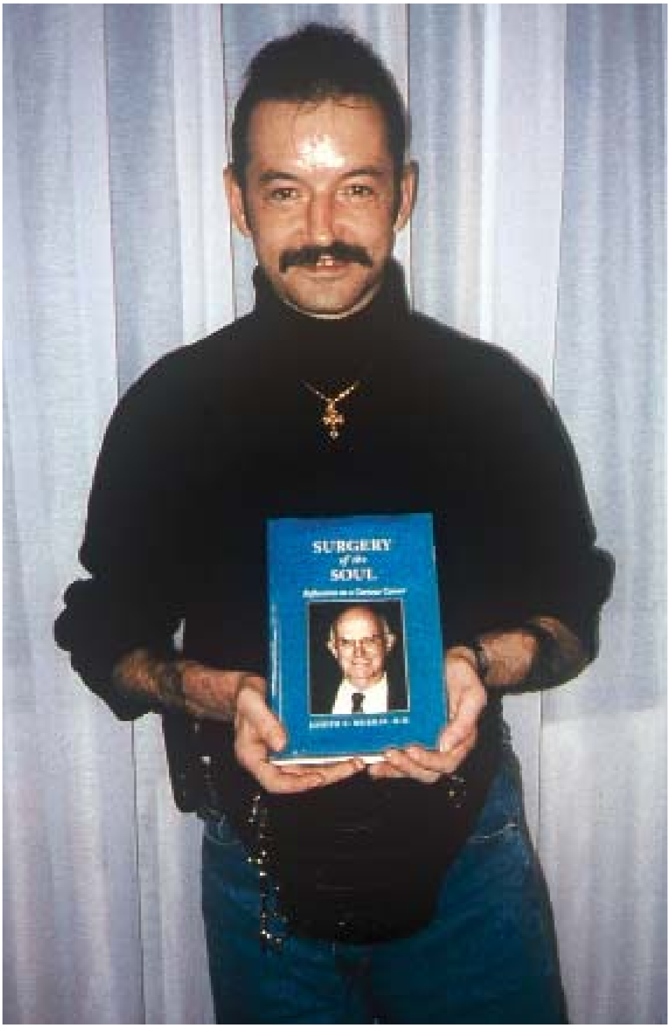
Slide 11. The two brothers later in an office visit.

Slide 13. Asymmetrical infant face and cranium.

Slide 14. Skull and hip bone segments.

Slide 15. Post-op photo of infant.

Slide 16. Cosmos and Damian.



Slide 22. Double hand transplant, courtesy of Dr. Max Dubernard of Lyon, France.