The Cultural Values of Science
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SCIENCE AND CULTURE

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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 7th and the 15th 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.

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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.

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

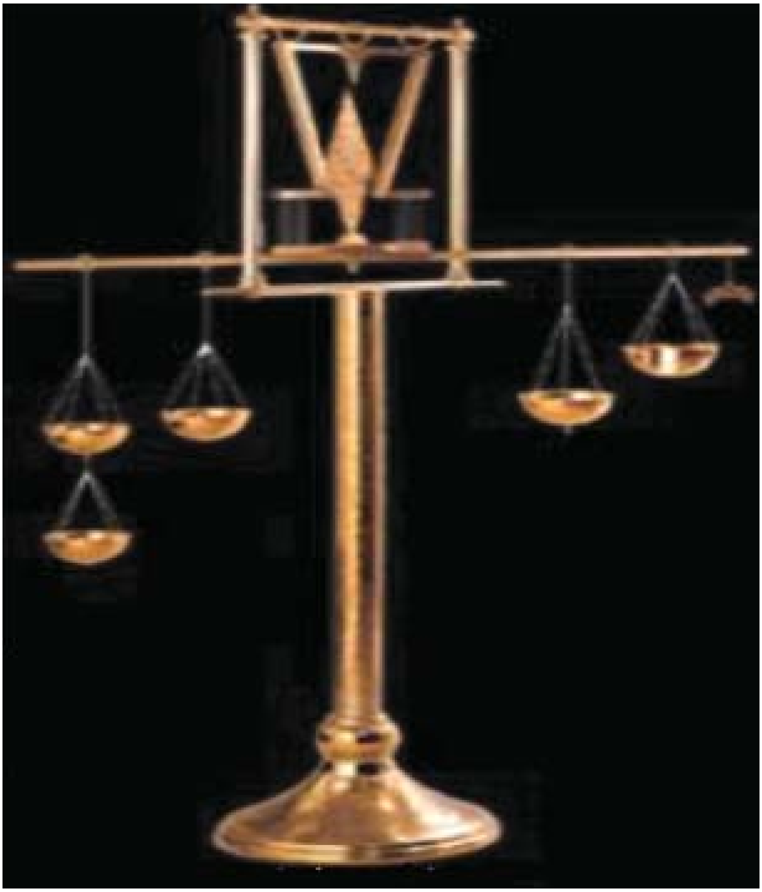

Fig. 8. This is a spectacular and fairly accurate Balance. Produced out of copper, it can be seen at the Institute of Arabic Islamic Science in Frankfurt Germany.