Alain Tressaud *Editor*

Progress in Science, Progress in Society

Springer

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The main objects of all science, the freedom and happiness of man ...

Thomas Jefferson
Jan. 26th 1810
letter to General Kosciusko

Foreword

On November 18–19, 2016, the European Academy of Sciences organized a conference devoted the theme *Progress in Science, Progress in Society*, in cooperation with the Académie royale de Belgique. The conference took place at the Palais des Académies in Brussels, Belgium. We are glad to publish the proceedings of this conference for the general public.

The European Academy of Sciences is an international non-profit organization aiming at promoting excellence in science and technology. Based on Brussels (Headquarters) and Liège (Operations Centre), Belgium, it is a community of highly selected, top-level scientists in limited number (about 500) from all over Europe, and open to a restricted number of non-European scientists with strong research links to Europe. The Academy is also honoured to have several Nobel Prize winners and Fields Medal winners amongst its ranks, which include scientists from both fundamental and applied research fields. The Academy is organized in nine specialized divisions: Mathematics; Computational and Information Sciences; Physics; Chemistry; Materials Science; Earth and Environmental Sciences; Medicine and Life Sciences; Engineering; Socio-economic Sciences and Humanities. In recent years, the Academy, acting in cooperation with universities in Europe, organized conferences on such topics as *Science and Ethics* (Porto, 2014) and *Impacts on Climate Change* (Brest, 2015). Following these multidisciplinary meetings on very timely subjects, the conference on *Progress in Science, Progress in Society*, is a significant moment in the life of the Academy.

Progress is a common feature of science and human societies generally speaking. There is no doubt that one of the driving forces of the material and intellectual progress of mankind has been science and technology. However, these are not the only forces acting on human history, so that their role is not always fully recognized and even sometimes refused. Does Progress in Science ultimately mean Progress in Society? How to ensure that scientific progress becomes both materially and intellectually beneficial to society, including people who are far away from it and socially excluded from it?

One of the reasons for the lack of recognition of the value of science for society may be that there is an increasing gap between the internal perception of science by scientists and science as perceived by society, perhaps because the extremely rapid scientific advances and their potential applications are poorly perceived by many. Indeed, there is no direct implication leading from science to the public understanding of science, in spite of enormous, never-ending efforts made recently. Science remains in its very nature a demanding, elitist exercise, far from the ordinary concerns of most people. Science does not appear to people as an end in itself. It is only a means among other ones for the service of society at large.

Indeed, an increasing number of citizens, even in modern developed countries, in Europe and elsewhere, show a growing distrust for science or even for any kind of progress, due to an increasing sensitiveness for risks, thus hampering knowledge acquisition and consequent improvement of living conditions. In the current context of individualism, the freedom of refusing is a way of asserting the primacy of the individual with regard to objective knowledge. There is an enduring conflict between objective knowledge and subjective legitimacy, because objective knowledge stands out frequently in sharp contrast to common views. Indeed science, which means well-established facts rather than uncertain beliefs, is more needed than ever to ensure success rather than failures in human affairs, although not every part of human knowledge has become scientifically sound and mature.

In domains like life sciences and medicine, one can observe that fundamentalist anti-science attitudes are rapidly gaining weight in some parts of society. There is a need of an empirical sociological analysis of these attitudes, or of other attitudes like the refusal of medical practices in the field of public health. The value of science is often underestimated, with potential consequences at the political level. Another danger encountered by scientific progress has to do with the varying delays between fundamental research and its applications, leading to short-term policies and possibly to the neglect of long-term investment.

In this present context, it seems timely to contribute to the reflection at the European scale on issues like trust, distrust, communication, and scientific governance and organization.

I am particularly grateful to Prof. Charles Joachain, President of the Académie Royale de Belgique, and to Prof. Hervé Hasquin, Standing Secretary of the Académie, for their help in the organization of this Conference. The Académie Royale de Belgique is also present in the Conference by several of its members. I am particularly grateful to all our speakers. They will forgive me to give my sincere thanks to Prof. Catherine Bréchignac, current Standing Secretary of the Académie des sciences, Ambassador for Science and Technology of the French Government and former President of the International Council for Science, and to Prof. Jean-François Bach, former Standing Secretary of the Académie des sciences, for their participation. I wish also to thank Mr. Philippe Keraudren, member of the DG Research and Innovation of the European Commission, who was able to participate. Mrs. Hélène de Rode, Perpetual Secretary and Founder of the European Academy of Sciences, and Mrs. Ludivine Dubois deserve a special recognition from the scientific community for their constant involvement in the development of the European Academy of Sciences. I thank also for their generous support the

Ministry of Higher Education and Research of the Fédération Wallonie-Bruxelles, and the Janssen Pharmaceutical Company.

Claude Debru
Emeritus Professor of Philosophy of Science
Ecole Normale Supérieure, Paris President
European Academy of Sciences (2014–16)

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Is Progress in Science, Progress for Society?

Catherine Bréchignac

Abstract Science progresses in a cumulative way, each step corresponding to as many changes of paradigms, with successive theories gradually approaching more general concepts. Thus, in the eighteenth century, Lavoisier, using mathematics to explain chemical reactions and express the law of mass conservation, brought chemistry into modernity. At the dawn of the twentieth century, another revolution resulted from the discovery of laws specific to properties at the atomic scale, which made it possible to understand, for instance, the laser effect, on which our modern technology is based, from medicine to defense and metrology to everyday items such as optical drives, microcomputers, and GPS. However, the values that set up our societies hardly fit the increasing speed of technological progresses. This lack of necessary distance for a more thoughtful judgment leads both to the unreasoned rejection of acquired progress such as vaccination and to harmful over-appropriation of information communication techniques when they lack the necessary critical analysis. It is therefore essential, in view of the rapid growth of science and technology, to take time to think about the values we want to give to our societies.

Keywords Progress · Science · Paradigm · Mass conservation law
Stoichiometry · Elements · Compounds · Periodic table · Atom
Laser · GPS · Vaccination · Communication · Internet · Values

The French word “progrès” like the English “progress” comes from the Latin word “progressus” which refers to the action of walking forward. The definition given by French dictionaries since 1694 has been “any type of movement forward, increase or growth.” With time, the definition evolved, and “progress” is now used to describe any advancement in time or development.

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There is no doubt that science progresses. It does so by the accumulation of knowledge. To contribute to scientific knowledge, all the links in the chain of what has been acquired before must be known. Since Galileo, this chain has been built following the scientific method, that is to say, a confrontation between theory and experiment. This cumulative science has not developed linearly but by stages, often associated with changes in paradigms that progressively, in time, evolve toward better understanding. The successive theories gradually converge toward more general theories. *Science is continually correcting what it has said* wrote Victor Hugo in his book on William Shakespeare.

Progress in science reflects its history. For example, in the eighteenth century, Lavoisier who is considered historically the father of modern chemistry brought about a conceptual leap in chemistry by using mathematics to explain chemical reactions, something no one before him had formulated. His starting principle was that it is possible to write a chemical reaction in the form of an equation, a quantitative equality that can be verified by weighing the bodies before and after a reaction. The principle of conservation of mass is conveyed by the famous quote "*In nature nothing is created, nothing is lost, everything changes.*" In his *Treatise on Elementary Chemistry* published in 1789, Lavoisier clearly explained the law of mass conservation and clarified the concepts of simple bodies and complex compounds. A simple body cannot be reduced through decomposition by any known analytical chemistry method. Such, for instance, is the case of oxygen, nitrogen, hydrogen, carbon, zinc, and sulfur. By contrast, complex compounds can be decomposed into simple elements. Their chemical properties differ extensively from those of the simple bodies that constitute them. Lavoisier wrote "*chemistry advances towards its goal and towards its perfection by dividing, sub-dividing and sub-dividing again… Chemistry is the science of analysis.*" Using logic, Lavoisier addressed the myth of transmutation, which imagined under the secret influence of alchemy that the transformation of lead into gold was possible, although no one had ever succeeded in accomplishing it. When the French Revolution started, chemistry had already emerged. On the other side of the channel, John Dalton (1766–1844) was interested in linking atmospheric phenomena and chemistry, and he started with the study of air. He traveled through Britain, from towns to countryside and mountains to valleys, and observed that the composition of air was everywhere the same. He wondered why the mixture of nitrogen, oxygen, and water vapor gases, which composes the air we breathe, was everywhere homogeneous and why the mixture did not separate depending on the density of its components? Like Lavoisier, he performed laboratory measurements and discovered that each component of a gas mixture behaved as if it were alone in the volume of the mixture. In 1801, he established the Law of Partial Pressures, which states that in a mixture, gases do not react with one another, they coexist. This is not the same when they interact. The German chemist Jeremias Benjamin Richter, who left the Prussian army to become a chemist, was much influenced by Lavoisier. In 1791, he wrote that *the reason so little progress has been made in chemistry is due to the fact that chemists only rarely occupy themselves with mathematics and* vice versa. He referred to stoichiometry as the *science that measures the ratios of mass by which* *simple bodies bond to each other*. He devoted his whole life to determining in what ratios of masses simple bodies combined with each other to give complex bodies, as did the French apothecary Joseph Proust, himself son of an apothecary in Angers. Richter like Proust showed that when two simple bodies react together to form a new compound, they only do so if the weight of one of the compounds is a simple ratio of the weight of the other compound. They concluded that *the proportion in which two elements combine cannot vary in a continuous manner*. At the time, this was startling. Dalton compiled all the results from previous experiments and published in 1803 the Law of Multiple Proportions, which stipulated that any complex body can only be described using simple ratios of the pure bodies that composed it, two to one, three to four, etc. He developed this much further and formulated a theory of his laws, which he published in 1808 in his treatise *A New System of Chemical Philosophy*. There he deliberately chose the atomic model, which dated back to Antiquity, to describe the composition of matter. Thus, when two simple bodies combine with each other to form a complex compound, the atoms of one body combine with the atoms of the other in a fixed ratio of whole numbers. With hydrogen as the element of reference to which he gave the value of 1, he published a system of atomic weights for 20 elements. Like Dalton, Mendeleev (1834–1907), who was 68 years younger, had a great admiration for Lavoisier. He liked the idea of identifying all the simple bodies as a first step to identifying the architecture of matter. Mendeleev was obsessed with order. He classified the 63 elements that had been discovered until then and presented his project of classification by lines and columns to the Russian Society of Chemistry on March 6, 1869. The chemical symbols of the elements were written on a line of increasing mass order, and elements with similar chemical properties were grouped in columns. He left empty boxes for elements that were as yet unknown (and that would eventually be discovered later). He even predicted some of the chemical properties of these missing elements. His intuition was that a deeper reason beyond simple classification was governing his table. He thought that the solution would come from the atom, which no one had yet observed. History proved him right. Relying on the steps overcome by Lavoisier, Dalton, and Mendeleev, chemistry progressively built its alphabet, which contributed significantly to its progress and to the invention of new materials we use today.

Physics was not interested in atoms until the beginning of the twentieth century. When it did, physics looked at the atoms not as the smallest elements of a body that conserve their chemical properties and bond to others to form matter, but as subjects of study in and of themselves. It generated an unprecedented revolution in thinking. At the atomic scale, the laws of classical mechanics are not valid anymore. The states of an atom are characterized by the energy that it has accumulated. The latter can only take on discontinuous values which are represented on an energy scale. In a group of atoms of same nature in thermal equilibrium, the lowest levels of the scale are those that are filled. The process of optical pumping toward the higher levels can generate a grouping of atoms each containing greater energy. A population inversion is said to have occurred when more atoms have a high energy compared to atoms that have not accumulated energy. The stimulation of this population can generate a synchronous return of the atoms to their fundamental state. This is the laser effect (Light Amplification by Stimulated Emission of Radiation) the development of which had quite an extraordinary history. In 1950, Alfred Kastler discovered optical pumping, or how to generate a population inversion for which he was awarded the Nobel Prize 16 years later. From 1951 to 1954, Bassov, Townes, and Prokhorov (1964 Nobel Prize) discovered the laser effect in microwaves. The scientific community considered it an anecdotal curiosity. What could be the use of this directed light which does not shine? Townes then set out to obtain a laser effect with visible light. He discussed it with Gordon Gould who was a Ph.D. student at Columbia University. The latter found a solution in November 1957. He noted it in his lab notebook and realizing the importance of his discovery entrusted a lawyer with the notebook in order to file a patent. He left Columbia and started working at TRG (Technical Research Group) in March 1958. TRG signed a one million dollar contract with the Advanced Research Projects Agency (ARPA), later to become DARPA, created the same year by the US Department of Defense to develop the laser without involving Gould. Gordon Gould filed many lawsuits to have his patents and rights on the invention of the laser recognized. He finally won the legal battle 30 years later. He gained rights on all of the lasers that had been built and became a millionaire. Meanwhile, Arthur Schawlow, Townes's collaborator and brother-in-law, had independently found a solution to the visible-light laser. Schawlow and Townes published their article in December 1958. Unlike Gould, they were primarily interested in scientific recognition. Schawlow was awarded the Nobel Prize 23 years later for the use of laser in spectroscopy.

As early as 1958, after the discovery of the visible-light effect of the laser, a race to build the first laser began. The first to be built was the ruby laser, in 1960.

1960 First telephone communication by laser (Bell Labs)
1961 First retina laser therapy
1963 First laser welding (CO_2 laser)
1969 First measurement of the Earth–Moon distance by laser
1970 Start of research on combat lasers
1974 Laser barcode scanners
1982 First optical disks
End 1990s Development of microcomputers made possible by lasers
2015 Inertial confinement fusion by laser: 10 million degrees.

Science and technology progress by giant strides.

Although society appropriates from science what it needs, it does not dictate its development. In fact, society embraces technology, not science. It is mainly the results of technology that interest society. How many people who wait in line with their shopping cart full of items with a code-bar label that will be scanned by a laser reader remember how a laser works, how long it took to discover its intricacies, the battles it generated and the cost of its technological development? The same is true for the GPS. How many people know that the location of their car indicated on their

GPS screen is determined by a network of satellites located 20,200 km from Earth at an orbital velocity of 3870 ms^{-1}? Such speeds generate a time dilation onboard the satellite relative to the time of observation on Earth and vice versa. After 24 h, if we do not take the theory of *general relativity* into account when calculating the position of the car, there is a delay of 6.9 μs between the satellite and Earth clocks, which translates to a 2-m error per minute in the position indicated by the GPS.

Recording progress is observing a qualitative or quantitative change in a situation between two dates. For society, the question of progress is above all recognizing that all the changes that our societies have undergone throughout the centuries gave rise to better societies. It is clear that the biological and medical sciences, as well as pharmaceutical chemistry, have allowed humans to live longer and to overcome many diseases. Energy domestication, improved transport, and housing make it possible to live more comfortably. Progress in science and technology has improved the quality of life of mankind. However, our societies are composed of organized groups of human beings bound together by communication and built on values the future evolution of which we find difficult, if not impossible, to comprehend today. One might expect that the social man of today, being freed of the constraints which hindered the life of his ancestors, would take time to think more deeply in order to change the fundamental values of the society to which he belongs. This does not seem to be the case. Furthermore, the increasing speed of communication and the tremendous growth of information, the veracity of which is often not verified and which circulates in an endless loop on social media, often creates irrational collective reactions. For instance, vaccination protects society but is the source of individual fears which, once they are amplified by social media, incite individuals not to get vaccinated at the risk of triggering new epidemics. This is also the case in the controversy about GMO consumption in French society, which imports them nonetheless. Some think that their well-being depends on banning GMOs while others think their use will lead to a better quality of life. Although the study and creation of GMOs is a scientific and technological progress, their use is understood in a relative manner according to the values on which societies have been founded. France was a pioneer in the scientific study of GMOs but is now torn apart regarding their use. The French scientists involved in this area of study have left the country to carry on their research elsewhere. Yet, for many millennia, agriculture selected plants to be better adapted to particular soils. GMOs are just an acceleration of genetic selection and undoubtedly the fear they spur is due to this acceleration. Digital developments have revolutionized communications. Professional life has become increasingly intrusive, and private life, a hard-won prerogative of our modern societies, is less and less respected. One word escapes you and a tweet circulates in a loop around social networks. The speed of communication hinders expression. Such dissemination of information has given way to a new vortex that leaves no time for analysis and criticism, which are indispensable. The speed of information exacerbates emotions; these take precedence over reason and immediacy triumphs. Everything becomes urgent. Stimuli of all kinds, which are increasingly frequent, drag us in spite of ourselves into haphazard movements that have no precise direction. The attraction to all that is new without taking the time to understand its utility is an economic tool that prompts people to buy the most recent novelties. A prime example is that of the mobile telephone because nowadays this object is much more than a phone, it is a miniature computer that does everything in matters of communication, even what we do not ask it to do. Soon directed by the Internet of Things, it will instruct us on what to do. What societies have we generated? Are our values progressing? The subjective character of values makes it more difficult to answer these questions.

Mankind has built societies. Humans have existed for millions of years and will exist for millions of years still. While science has only been around for several centuries, it is essential that given the rapid advancement of progress in the sciences and technology to take the time to think through the values we wish to give to our societies and then, maybe, make them also progress.

Science and Social Communication

Natividad Carpintero-Santamaría

Abstract Social communication has an important sociological and psychological impact; the way scientific developments are transmitted to society can significantly affect the way they are perceived. Scientific findings need to be adequately presented and their interest and value must be stressed if they are to be understood and appreciated by society. In many cases, scientific issues are not satisfactorily transmitted or assessed and are misunderstood or ignored by nonspecialist audiences. Traditional mass media instruments such as newspapers, radio, and TV are being overtaken by the powerful influence of the internet, with its ability to reach remote places and social groups. The transmission of science through social mass media can help people to accept its benefits but may also lead to misapprehensions. The internet is perceived by a large sector of society as a reliable source of information, but this powerful new communication channel requires a greater awareness on the part of its users to avoid the misunderstanding—and, in the worst possible scenario, the misuse—of the information it contains. This paper focuses on a range of areas such as the social perception of science, the role of the internet, limits, and ethics in scientific communication, and the endeavor of the European Union in science transmission.

Keywords Social perception of science · The role of internet · Limits and ethics of scientific communication

Introduction

Human communication is a dynamic, interactive, and intrinsically social phenomenon which involves the development of psychosocial capacities of relationship. Communication is also an important strategic tool in a world

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increasingly accustomed to real-time interaction. Globalization and the internationalization of societies have created a new communication model in which the communication of science has a key role to play. The twenty-first century is an age of near-total dependence on communication technologies whose influence on society has substantially altered the way we see the reality around us, especially in relation to scientific and technological issues.

The right to communication was recognized by the Universal Declaration of Human Rights proclaimed in 1948 after Second World War by the Security Council of the United Nations. Two out of its 30 articles refer to this right:

> Article 19 Everyone has the right to freedom of opinion and expression; this right includes freedom to hold opinions without interference and to seek, receive, and impart information and ideas through any media and regardless of frontiers.
>
> Article 27.1. Everyone has the right freely to participate in the cultural life of the community, to enjoy the arts and to share in scientific advancement and its benefits.

Several definitions of science communication have been proposed. According to Burns et al. (2003):

> Science communication (SciCom) is not simply encouraging scientists to talk more about their work, nor is it an offshoot of the discipline of communications. Although people may use the term "science communication" as a synonym for public awareness of science (PAS), public understanding of science (PUS), scientific culture (SC), or scientific literacy (SL)—in fact many of these terms are often used interchangeably—it should not be confused with these important and closely related terms.

Other perspectives can be found by Fujun et al. (2012):

> Science communication is neither a device applied by the scientific community to achieve its own purposes, nor a unilateral one-way dissemination of scientific knowledge by the government but an activity in the formation of culture

The inherent cultural value of science is undeniable, as is its capacity to transcend global borders. Social progress through different civilizations has been made possible by scientific and technological advances. Engineering, for instance, emerged at the time when humans abandoned their nomadic lifestyles and adopted sedentism; in order to survive, they were now obliged to protect their crops, their cattle, their territory, and their possessions with techniques and tools that became ever more sophisticated as the centuries passed.

In spite of its obvious value, it is not always easy for society to understand science; in some cases, science can be seen as harmful and negative. Even when scientists use down-to-earth language, many people confuse fundamental concepts. A good example is the conflation of two completely different concepts, nuclear fission, and nuclear fusion. *Nuclear fission* occurs in the nuclei beyond iron in the Periodic Table when they are bombarded with neutrons, giving rise to two nuclei whose mass is inferior to the initial one. This loss of mass is transformed into energy and each fissioned kilogram gives rise to 24 million kilowatt hours. Nuclear fission is the process via which nuclear reactors produce electric power using uranium, plutonium, and so on, as fuel. *Nuclear fusion* occurs in the light nuclei from hydrogen to iron in the Periodic Table when they are heated to hundreds of millions of degrees giving rise to a lighter nucleus, so that the loss of mass is transformed into energy. The fusion of each kilogram of deuterium–tritium results in 94 million kilowatt hours. Nuclear fusion is the energy that is produced in the stars and, in particular, in the Sun; research is currently underway to produce a future massive source of energy by using lasers, particle beams or magnetic fields in the deuterium and tritium nuclei.

In addition to common confusions of this kind, other factors such as the dissemination of pseudoscientific concepts can produce disinformation and prejudice.

The Internet: Its Impact on Science Communication

When the Spanish engineer and mathematician Leonardo Torres Quevedo presented at the Paris Academy of Sciences in 1920 his electro-mechanical arithmometer, the first digital computer in the world, he could have never imagined the impact that computers would have on human lives within only a few decades. Today, traditional mass media instruments such as newspapers, radio, and TV are being replaced by the internet, which is now the most common form of personal, professional, and social communication. It is a network of networks that interconnects millions of computers, with no borders and without any governance—a decentralized system linking 190 countries. To quote Beal (2016), the total number of websites is currently 1,065,468,807 and "[…] as of August 12, 2016 there was an estimated 3,432,809,100 internet users worldwide. The number of internet users represents nearly 40 percent of the world's population. The largest number of internet users by country is China, followed by the United States and India." The following are the percentages of internet users in the world by regions: Asia (50.2%); Europe (17.1%); Latin America/Caribbean (10.3%); Africa (9.3%), North America (8.6%), Middle East (3.6%), and Oceania/Australia (0.7%) (Internet World Stats 2017).

The Internet has transformed the way we interact with the world and our everyday life, providing virtual applications for banking, hospitals, business, and shopping. It has also changed the way we learn. According to Harley (2013):

> Over two decades many have predicted that models of scholarly communication enabled by emerging technologies will transform how research is conducted, disseminated, and rewarded. The transformation would be driven by new generations of scholars weaned on file sharing, digital piracy, Facebook, Twitter and yet-unrealized social media technologies.

However, although internet provides easy access to information, it is also a platform through which illegal, manipulated, or prejudicial information can be disseminated. As Clarke (2008) points out:

> Internet is full of erroneous and even dangerous information that is difficult for people without a scientific education or training to interpret in context, particularly given the uncertainties inherent in the scientific process.

Since the Internet is a highly effective means of communication, science transmission can quickly reach most corners of the world and opens up an immense field of freedom of expression. It provides accessibility, simplicity, low cost, greater speed, larger data catalogs, continuous updating, and access to new contents in the form of patents and articles. However, though all these features might be considered a priori positive, this is not always the case. The internet requires an infrastructure and traceability is difficult. In addition, the availability of so many opinions or evaluations can lead to misjudgments, misunderstandings, and confusion among the audience who find it difficult to distinguish the true elements from the false or speculative ones. Cyberspace also provides a place for impunity for unethical actions such as plagiarism, the appropriation of intellectual property or the downloading of copyrighted materials for free.

As Dumon (2013) points out:

> By 2000, digital versions of more than 11 million research articles and the first e-books became available and by the end of the first decade of the new century, international sales growth for digital academic content surpassed hard copy. More than 1.5 million research papers are currently generated by over 200 countries and e-marketing of such content through the use of social networks now is the norm.

However, the ready availability of huge numbers of digital publications—with no effective checks on their quality or accuracy—poses a real challenge to the authority of these conventional channels of the transmission of knowledge, and can easily spread unreliable information.

Limits and Ethics of Scientific Communication

Science is social capital. However, scientific communication imposes a series of limits that must be taken into consideration, especially when this information may entail a risk for safety and security. In many countries, national security criteria are applied to scientific information whose dissemination can be harmful or counterproductive. According to the Report of the US National Scientific Foundation (1988):

> There are, however, valid reasons for withholding and controlling information and for allowing limits on open dissemination. Such grounds include national security, the conduct of diplomacy, individual privacy, commercialization of intellectual property and international competitiveness.

Among the factors which are applied to scientific communication are the scientists' own criteria about the sensitivity of their research. This question is difficult to elucidate. In words of Malakoff (2013):

> Every research field has findings so sensitive that scientists can spend countless hours fretting over when, where, and how to publish them—or whether to share them at all. For microbiologists and chemists, it might be a technique that could be misused to create a terrifying weapon. For biomedical and social scientists, huge databases of personal health and behavioral information pose threats to privacy. Archaeologists and wildlife biologists worry about pinpointing some study sites, fearful they could guide looters and poachers to priceless artifacts or vulnerable species.

Disinformation or fraudulent scientific information can cause a great deal of harm to the social perception of science. As Clarke (2008) points out:

> Some scientists and ex scientists are prime movers in promoting disinformation on the internet, and some journalists, are keen to promote causes or angles for their own reasons that have nothing to do with 'pure' science communication. Many scientists have commercial and other vested interests, or strong political ideologies, rather than being dedicated to objective interpretation.

Unsatisfactory transmission of science or inappropriate assessments of scientific issues may lead to misjudgments and social rejection. One of the most significant examples is to be found in the way nuclear energy is often manipulatively presented to society, especially by some mass media, thus eliciting an emotional reaction that has nothing to do with scientific or empirical facts. As Garvey (1979) states:

> Scientific progress could actually be curtailed if mass-media newspapers reports of research findings become a legitimate medium in the communication structure of science. That is, without rigorous scrutiny by qualified scientists a great deal of such information would be unreliable (both in terms of its replicability and relevance to science) and the foundations of scientific knowledge would become enfeebled by "unscientific information".

A relevant example of the distortion of scientific communication occurred in 2011 after the accident in the nuclear power plant of Fukushima in Japan. On 11 March of that year, Japan suffered its largest ever recorded earthquake with a magnitude of 9.0 on the Richter scale. The Japanese nuclear power plants shut down successfully. However, 40 mins afterward, the earthquake generated massive tsunami waves that peaked at heights of 46 m which destroyed the emergency cooling systems of Units 1–3 at the Fukushima Daiichi Power Plant. Reactor cores went into meltdown and released iodine 131 and, in much smaller quantity, caesium 137 radionuclides into the environment. Within the efficient emergency plan developed by the Japanese government to minimize the radiological impact on the population, stable iodine tablets were immediately distributed to saturate the thyroid gland to avoid cancer that would have caused the iodine 131. Inaccurate reports of what had happened at Fukushima provoked further anxiety among the Japanese people who, in the middle of the devastation of the earthquake and the tsunami, received stressful and apocalyptic messages through the Internet.

After the accident, international experts and observers from the World Health Organization (WHO) carried out a comprehensive damage evaluation study by entitled "*Health risk assessment from the nuclear accident after the* (2011) *Great*

East Japan Earthquake and Tsunami based on a preliminary dose estimation". The report included an evaluation of the risks of cancers and other diseases as well as public health considerations. The WHO report (2013) says:

> Cancer data from Fukushima were likely to be comparable to those from other parts of Japan. This determination was made on the basis of the similarity of cancer incidence in two neighboring prefectures for which cancer registries are available (Miyagi and Yamagata) and the other Japanese cancer registries. Also, similarities were found between cancer mortality data in those two neighboring prefectures compared with cancer mortality data in Fukushima and data from the rest of Japan. From a global health perspective, the health risks directly related to radiation exposure are low in Japan and extremely low in neighboring countries and the rest of the world.

Cases of scientific misconduct have triggered a new debate about the ethics of scientific communication. The use of internet has exacerbated the misuse of intellectual property, confidentiality, plagiarism, data falsification, and so on, which has had a negative effect on the social perception of science and science transmission. With respect to research integrity, the first report and recommendations of the Commission High Level Expert Group on the European Open Science Cloud (2016) states:

> […] there is an alarming lack of reproducibility of current published research, together with scientific fraud, this cause enormous damage to the reputation of science. This is partly due to the lack of deep and rigorous knowledge on how to render data and the associated methodology and tools in a format that allows others to reproduce results.

According to Fang et al. (2012), 6.4% of 2047 retracted biomedical and life sciences research articles were due to misconduct, 43.4% for fraud or suspected fraud, 14.2% due to duplication, and 9.8% for plagiarism; only 21.3% were retracted for errors. These figures are negligible among the very high number of research papers published, but the existence of retractions reflects the potential harm that misconduct may cause.

Before the Internet era, the World Intellectual Property Organization (WIPO) was established as an agency of the United Nations in 1967 in Geneva in order to combat breaches of intellectual property and currently has 189 members. The Law for Intellectual Property currently has four different classification systems to make intellectual property searches easier and faster: (1) *The International Patent Classification*. (2) *The Nice Classification* (for marks). (3) *The Vienna Classification* (for figurative elements of marks). (4) *The Locarno Classification*. Furthermore, five other systems also help to protect intellectual property in its different areas: (1) *The International Patent System*. (2) *Madrid—The International Trademark System*. (3) *The Hague—The International Design System*. (4) *Lisbon—The International System of Appellations of Origin*. (5) *Budapest—The International Microorganism Deposit System*. (6) *Article 6ter on the Paris Convention* (this is a structural search which looks for the 3387 documents contained in its data collection up to March 2017). (WIPO 2017).

In 1931, the International Council for Science (ICSU) was created to promote "the Universality of Science in the basis that science is a common human endeavor that transcends national boundaries and is to be shared by all people". According to the Council, scientific activity for the good of mankind, scientific work should be communicated with integrity, respect, fairness, trustworthiness, and transparency, recognizing its benefits and possible harms. (ICSU 2017).

Improving Scientific Communication

Without scientific transmission, there can be no scientific progress. A poor or inadequate communication technique may mean that a brilliant scientific discovery will not be understood in all its magnitude. The lack of effective communication skills by scientists or engineers has been stressed for decades. Today this drawback in scientific transmission is being increasingly overcome due in part to new technologies that allow versatile means of graphic transmission such as videos, photos, interactive maps, and so on.

Another improvement in scientific communication is due to the focus in the engineering and scientific world on communication skills, acknowledging that learning to communicate should be an integral part of researcher training and of scientific education. Scientific education must overcome communication barriers of many different kinds. As regards psychological barriers, we cannot forget that each person produces and interprets messages based on their values, prejudices, norms, customs, and cultural heritage. The strength of philosophical barriers is revealed when there are different ways of thinking due to the different ways of interpreting both the world and life.

Effective scientific communication also requires scientists to take into consideration the public's needs and views and to try to use a clear and concise style to make their message easily understood. The use of complicated sentences or arguments does not help the general public to understand the essence of the message.

The Social Perception of Science in Spain

Since 2002, the Spanish Foundation for Science and Technology (FECYT) of the Ministry of the Economy has carried out a survey on the Social Perception of Science. The survey analyses various aspects of how science is perceived by the public in Spain, according to sex, age, size of town/city where they reside, and region.

In 2014 the *VII Encuesta de Percepción Social de la Ciencia* survey was carried out throughout the whole of Spain, including the Balearics and the Canary Islands. This quantitative study was based on a semi-structured questionnaire administered in personal and home interviews. Respondents were persons living in Spain for at least 5 years aged 15 and older. A total of 6355 interviews were conducted, distributed by regions (VII Encuesta de Percepción Social de la Ciencia 2014).

The survey was based on the following issues:

- Spontaneous interest in current topics.
- Spontaneous interest in science and technology.
- Reasons for lack of interest in science.
- Social image of science.
- Social image of the scientific profession
- Scientific education.
- Scientific literacy.
- Information deficit on questions of interest.
- Sources of scientific information.
- Sources of scientific information in internet.

Respondents completed a number of multiple choice questions, and some of the results are presented below. The answers may add up to more than 100%.

These percentages show that the world of science still belongs to a relatively small social sector, as has traditionally been the case. To redress the lack of understanding a new and pragmatic approach to scientific communication should be considered so as to make science attractive to the general public (Fig. 1).

The finding that 26.1% of the sample thought that the benefits and harm of science are balanced is a cause for concern. Again, new strategies of communication should be found to overcome this pessimistic and negative result. These strategies should include messages showing how science and technology contribute to social progress in most fields of everyday life, from the eradication of diseases to the improvement in people's standard of living (Fig. 2).

Television continues to be the most common means of social communication. This fact is understandable since there are still large sectors of the population who have not integrated new technologies in their everyday lives (Fig. 3).

The responses show that there are various options for using the internet to obtain scientific information (Fig. 4).

Not arouse my interest:	39.4%
I don't understand it	35.9%
No specific reason:	9.9%
I have never thought about this issue	8.4%
I don't have time	7.7%
I don't need it:	7.1%
Others:	0.9%
No answer	6.5%

Fig. 1 Reasons for lack of interest in science

The benefits of science are greater than its damage	59.5%
The benefits and harms of science are balanced	26.1%
Damages of science and technology outweigh the benefits	5.3 %
I have no opinion on this topic	6.9%
No answer	2.1%

Fig. 2 Social image of science. Contributions of scientific knowledge to the global reality

Internet	56.7%
TV	72.1%
Daily newspapers	28.9%
Free newspapers	15.5%
Radio	31.0%
Books	17.8%
Scientific journals	13.2%
General information journals	6.7%
Other	1.2%
None	0.4%
Don't know	5.9%

Fig. 3 Scientific information sources

Wikipedia	32.7%
General digital media	31.5%
Social networks	30.8%
Videos	29.7%
Blogs	25.4%
Science and technology digital media	22.8%
Radio	7.6%

Fig. 4 The internet as scientific information source

Scientific Communication in the European Union

For centuries, Europe has maintained a great tradition of scientific research that gave birth to pillars of universal main scientific fields. Until the emergence of the new technologies, the scientific exchange was made through traditional means such as the publication of results, verbal communication in meetings, mobility of researchers, and so on. However, as we have seen, in the twenty-first century this way of scientific communication has very much changed. In 2008, the European

Commission adopted the *Strategic European Framework for International Science and Technology Cooperation* in order to establish cooperation between EU countries and the rest of the countries of the world. The Framework looked for factors that could influence research cooperation and identify indicators of appropriate practices.

The EU considers it vital that science should be communicated among EU countries as efficiently as possible. This communication could be encouraged by means of efficient new data exchange mechanisms and platforms for generating an effective flow of information between participants and thus to improve coordination between different scientific communities and countries.

In order to achieve these objectives, several programs are currently being developed by the European Union: (1) *EU Framework Programme for Research and Innovation Horizon* 2020 which aims to improve communication inside the scientific community by providing specific guidelines for project coordinators and scientists. (2) *The European Open Science Cloud (EOSC) for Research* which provides support for dealing with the huge amount of scientific data and creates a tool that will aid scientific computing, storage, and connectivity.

The following are considered key factors for the effective implementation of the EOSC: (1) Core data experts need to be trained and their career perspectives significantly improved; (2) A real stimulus of multidisciplinary collaboration requires specific measures in terms of review, funding, and infrastructure; (3) The transition from scientific insights to innovation needs a dedicated support policy; (4) The EOSC needs to be developed as a data infrastructure commons which is an ecosystem of infrastructures; (5) Where possible, the EOSC should enable automation of data processing; therefore, machine actionability is key; (6) Lightweight but internationally effective guiding governance should be developed.

Effective science communication among European Union member states would help to reinforce the present capacities, enhance research visibility, encourage researcher mobility and open up new research fields of common interest.

Conclusion

Scientific progress is synonymous with social progress. Scientific research is a fundamental pillar of human development and it depends on an open, honest, responsible, and ethical scientific exchange. Communication is the essence of science, a fundamental factor for scientific advance. Science should be communicated with integrity, transparency, and respect; both its benefits and its detrimental effects must be recognized and it should always be accompanied by a sense of social responsibility.

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Understanding Phenomena by Building Models: Methodological Studies on Physical Chemistry

Martin Carrier, Armin Gölzhäuser and Katharina Kohse-Höinghaus

Abstract We seek to elucidate the explanatory and exploratory roles of models in physical chemistry. Models are mostly understood as cognitive instruments supposed to account for a restricted range of data. We elaborate general dimensions of model-building in this first section and distinguish between model-building by enriching and reducing a nomological core. We focus on intermediate and idealized models. Intermediate models incorporate basic principles of physics, but their more detailed results are shaped by additional suppositions. Idealization involves the reduction of the nomological core of models. Models can also be used for exploratory purposes. Cognitive models are heuristically useful because they serve to evaluate quantities inaccessible otherwise. In a similar vein, we examine the exploratory use of concrete realizations or analog models in studying problems from surface science. Our general claim is that considering the two dimensions of model-building, that is, enriching and reducing the nomological core, is suited and sufficient to account for the explanatory power and the exploratory fruitfulness of models in physical chemistry. This suitability depends on the possibility of constructing modular or non-holistic models. Such models are distinguished by the context-independent impact of specific assumptions on the model outcome. In holistic models, one and the same assumption may produce quite distinct empirical consequences in different model environments. The features we highlight are supposed to be generalizable to model-building in the physical sciences.

Keywords Model-building · Explanation · Heuristics · Physical chemistry Surface science

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Elements of Model-Building

Scientific activity today is strongly shaped by constructing models. Models are essential scientific tools for analyzing phenomena and intervening in them; they serve to interlace the general and the particular. In this contribution, we attempt to clarify the explanatory and exploratory roles of models in natural science, and we use physical chemistry as our focus area. The reason for choosing this area is that its complexity and its richness in theoretical accounts and sophisticated measuring procedures make it typical of modern advanced research. More specifically, our examples are taken from combustion and catalysis. Although the particulars addressed are from this area, we take the methodological conclusions we draw to be generalizable to related fields.

Models are mostly understood as cognitive instruments supposed to account for a restricted range of data. We elaborate general dimensions of model-building in this first section and distinguish, in particular, between model-building by enriching and reducing a nomological core. We move on to cognitive models in combustion chemistry in Section "Building Models of Combustion Processes", and discuss their exploratory use in Section "The Exploratory Use of Cognitive Models". Models need not be cognitive in nature; they may also be concrete realizations of physical conditions. We examine the use of such material models for exploratory purposes in Section "The Exploratory Use of Material Realizations". Our general claim is that considering the two dimensions of model-building, that is, enriching and reducing the nomological core, is suited and sufficient to account for the explanatory power and the exploratory use of models in physical chemistry. We emphasize that this suitability is not a matter of course but rather depends on the possibility of constructing modular or non-holistic models. Such models are distinguished by the unambiguous or context-independent impact of specific assumptions on the model outcome. In holistic models, one and the same assumption may produce quite distinct empirical consequences in different model environments.

Models are distinguished from general theories or laws of nature by being directed at particular classes of phenomena. Other than laws of nature, they are not universal but limited in scope. Models typically draw on laws of nature or other generalizations and specify pertinent initial and boundary conditions. However, as a rule, theoretical principles need support from elements that are linked more closely to experience. The so-called model debate of the 1990s has brought to light that, first, it is much more difficult than anticipated to bring general principles to bear on experience, but that, second, such principles are still essential in that they shape models in conceptual respect. General principles and comprehensive theories need models as "mediators" for bridging the gap between overarching laws and the subtleties of experience. The pivotal point is that models turn out to be much more complex than previously assumed. In addition to initial and boundary conditions, they often contain generalizations and empirical adjustments of various sorts, including model parameters and auxiliary assumptions. Still, models often exhibit a conceptual structure that is shaped by general theory. While models often merely modify a theory-based conceptual framework, their outcome is influenced significantly or even dominated by the necessary empirical adjustments (Morrison 1999; Carrier 2004, 2009; Gelfert 2016).

Painting with broader strokes, we can identify three major components of models: first, the *nomological core*, that is, laws of nature or other theory-based generalizations; second, *auxiliary assumptions* such as empirical regularities, parameterizations, or correction factors; third, *initial and boundary conditions*. Depending on the relative weight of each of these components, models of a different character emerge; they can be predominantly of *theoretical*, *intermediate*, or *empirical* character. In a different vein, *idealized* models do not add features to the nomological core, but rather reduce it by abstracting from certain relations or factors that do, in fact, contribute to the outcome.

If the nomological core dominates, we deal with a theoretical model. The planetary system is dealt with by means of a theoretical model of classical mechanics; the emission of electromagnetic waves from an oscillating charge is accounted for by a theoretical model of Maxwell's equations. In theoretical models, only initial and boundary conditions need to be added to the laws.

Models of the second, intermediate category incorporate basic principles of physics, but their more detailed results are often shaped by additional suppositions. We sketch two examples. The added elements are anchored on theory in the first case and close to experience in the second. The first example is superconductivity. The basis of the standard account is the introduction of so-called Cooper pairs, that is, coupled electrons moving with the same speed in opposite directions. Cooper pairs could be shown to exhibit an attractive interaction through phonon exchange with the surrounding lattice. On the basis of such a representational model, a suitable Hamiltonian could be devised. The point is that such a more specific configuration is necessary in order to get the abstract machinery of quantum mechanics to work in the first place. General theories are too abstract to supply illuminating accounts of specific kinds of phenomena on their own. In the case at hand, the representational model furnishes the causal mechanism of superconductivity and provides the justification for imposing certain constraints on the wave function (Morrison 2008). Second, at the opposite end of the spectrum lies the so-called orifice problem in hydrodynamics, which concerns the calculation of the amount of liquid that pours out of a container through an opening. The account given by Daniel Bernoulli in the eighteenth century appeals to the conservation of mechanical energy and takes the kinetic energy of the liquid streaming through the opening to be equal to the potential energy of the fluid in the tank. However, the observed amount of release is much smaller than the estimate based on this first-principles treatment; the theoretical prediction can be up to 40% off the mark (depending on the circumstances). This deviation is customarily taken care of by appending a correction factor. The qualitative explanation of the diminished flow is fairly obvious: in streaming out, the liquid converges on the opening so that a kind of fluid congestion is built up. This congestion encumbers the flow through the hole so that the amount of discharged liquid is reduced. However, no reliable quantitative estimate of the reduction can be given on first principles. Rather, the correction factor is assessed empirically for various orifice shapes (Bod 2006, 14–15). While theory is still essential for structuring the problem situation in conceptual respect and for highlighting significant features, such as the height of the tank, the empirical results are largely produced by the empirical adjustment added, i.e., the correction factor.

Third, empirical models are characterized by being strongly dominated by experience. Tidal flow is a case in point. The prediction of the tides for a particular harbor is not based on the known causal mechanism underlying the phenomenon but is rather achieved by performing a Fourier analysis of the tidal oscillations observed in the past. The reason is that the influence of a multitude of factors relevant for the quantitative details of tidal flow (such as coastline, water depth, currents) can hardly be assessed on first principles so that employing empirical correlations as the basis of local predictions proves much more reliable (Sauer 2004). A prominent more recent example of empirical models is neural networks. Such models provide a general framework that is filled by training the model for performing particular tasks. The empirical demands at hand and the mathematical algorithms used to tackle them serve to structure the model.

While intermediate models are generated by enriching the theoretical core with additional assumptions, idealization moves in the opposite direction. Idealized models deliberately distort the situation at hand in leaving out factors known to be operative or dismissing generalizations known to be relevant. Some idealizations are introduced for pragmatic purposes, i.e., for simplifying a system such that a treatment becomes feasible. Disregarding friction or air resistance in studying terrestrial motion is a case in point. Another example is approximating molecular vibration by normal-mode harmonic motion. In such cases, the maxim is to eventually recover the missing considerations and to thereby improve the fit with the data. However, not all idealizations are invoked for making calculations easier. Rather, so-called minimalist idealizations or minimal models are constructed in order to capture the essential characteristics of a phenomenon (Weisberg 2013). The energy-based account of the orifice problem is intended to bring out the physically pivotal aspect of the phenomenon. Analogously, the Ising model, an array of binary states each of which is affected by its nearest neighbors, is of this kind. Its goal is to bring out the causal core of a variety of prima-facie different phenomena, ranging from ferromagnetism to protein folding and opinion formation. The goal is not to reincorporate the details into the model, since it is the idealization that illuminates the core features of an entire class of materially distinct systems. This unifying effect essentially relies on leaving out the underlying micro-details that are specific for each case in question.

All the categories introduced for classifying models, that is, theoretical, intermediate, empirical, and idealized models, are to be taken as ideal types that provide a conceptual frame of reference for organizing the much more messy cases actually found in practice. That is to say, we encounter a range of models with varying amounts of contributions from theoretical principles, empirical adjustments and corrections, and idealizations. Such models differ in the explanatory burden that is borne by theoretical principles and theory-independent auxiliaries, respectively. Furthermore, one and the same model can enrich the nomological core in one respect and reduce it in a different one.

In what follows, we focus on intermediate and idealized models that represent the most widely employed model types in the physical sciences. In intermediate models, the conceptual backbone is supplied by theory, while the empirical outcome is mostly provided by auxiliary assumptions. It is characteristic that these auxiliaries fit into a scheme that is set up by theory; they do not shape the conceptual structure of models as a whole (as it is the case in empirical models). Yet, the influence of auxiliaries on model outcome is significant and shows how difficult it is to make it from universal assumptions to the details of evidence.

Building Models of Combustion Processes

Combustion processes underlie power generation, transportation, and many industrial procedures. Advanced combustion-based techniques enable the synthesis of nanoparticles with useful properties that may be tailored by process variables such as temperature, pressure, and combustible mixture (Kelesides et al. 2017). Understanding combustion is also vital for predicting fire and explosion hazards and the spread of fires in buildings, industrial areas, or in the wild (Torero 2013). Optimization of systems, processes, and techniques as well as hazard prevention demands predictions of properties and their temporal and spatial changes upon altering important conditions of operation. Achieving this goal requires models that represent such processes.

In order to appreciate the complexity of the problem, it is useful to look at the chemistry and the fluid dynamics of combustion processes first. It is the chemical energy stored in the fuel molecules that is released as heat and used to do mechanical work. The product of combustion, i.e., carbon dioxide, is often held responsible for climate effects. Also, dangerous emissions such as nitrogen oxides, carbon monoxide, and soot particles may result and cause health and environmental problems. The nature and amount of such emissions are linked not only to the condition of the process, e.g., the availability of enough oxygen to prevent incomplete combustion, but also to the molecular structure of the fuel. For advanced transportation, fuels from biomass are considered attractive because of their potentially more benign carbon footprint (Corma et al. 2007; Steen et al. 2010). Such assessment of their emission potential in relation to the chemical functions in the fuel molecule is becoming available for model construction (Sarathy et al. 2014; Leitner et al. 2017). These models include hundreds or thousands of reactions (Lu and Law 2009) and even more at certain technically relevant conditions such as autoignition at low temperatures (Zadór et al. 2011; Battin-Leclerc et al. 2010; Musculus et al. 2013) or soot formation from fuel-rich combustion zones (Wang 2011). These manifold interlinked reactions usually proceed in a turbulent flow field, where fuel and oxidizer are mixed for safety reasons only shortly before ignition, and the swirling flow ensures rapid molecular-level contact of both components.

The chief question pursued in this section is what kinds of relations obtain between the physicochemical principles underlying combustion processes and the empirical results of the pertinent models. It should be noted, first, that using empirical models and experience-based generalizations is not a viable approach to mastering complexity. This is revealed by the highly limited success of analyzing and predicting fire behavior on the basis of such empirical relations (Torero 2013). Analyzing large metropolitan fires has produced correlations that were useful under given conditions and have actually prompted important adjustments in building structures and the diminished employment of inflammable material. Relevant risk factors are the advent of high-rises, the introduction of polymer fibers in carpets and furniture stuffing, the increase of thermal load by additional facilities, the installation of larger windows, and the switch to more open office spacing. Such empirical relationships, as derived from many incidents, can clarify in hindsight the reason why a fire disaster occurred. However, such empirical models are tied to the specific circumstances for which they were formulated and are thus difficult to generalize. As a result, they are severely limited in their predictive power. Their viability is restricted to certain boundary conditions and is lost once major alterations are introduced.

In order to broaden the scope of the model and to still arrive at reliable results, recourse to the physicochemically sound description of the combustion process is indispensable. Results are extracted out of such models by numerical simulation. Given the recent surge in computing power, processes of considerable complexity can be traced via simulation models. This is why the import of physicochemical principles has largely expanded in the past decades. However, it is still beyond the reach of present-day computational methods to pursue in detail the complex interaction of a huge number of reactions occurring under the conditions of technically relevant applications. Our question is how typical procedures employed in modeling combustion processes match with the general picture of intermediate and idealized models as drawn in Section "Elements of Model-Building." Here is a sample of characteristic strategies.

A first thing to note is that the characteristic of intermediate models, as introduced in Section "Elements of Model-Building," is present in combustion chemistry. For instance, bringing chemical (or quantum mechanical) principles to bear on the process of soot formation demands to distinguish mechanisms, an important starting point being the hydrogen-abstraction/carbon-addition mechanism (HACA). HACA involves the replacement of a hydrogen atom of a polycyclic aromatic hydrocarbon molecule by acetylene. Featuring this mechanism of soot formation generates a representational model similar in its bearing to the concept of a Cooper pair with respect to modeling superconductivity. It is such an enriched nomological core to which quantum mechanical procedures, such as density functional theory (DFT), can be applied (Wang 2011). At the other end of the spectrum, parameter evaluations are of critical importance. Reaction pathways and rates involved in soot formation are strongly dependent on local flame conditions and fuel composition. Model-building requires choosing parameter values such as sticking probabilities involved in particle collisions and coalescence. Such selection of parameter values resembles the use of correction factors in the orifice example (while keeping in mind that the former quantities are unmeasurable, whereas the latter are not understood).

Speaking more generally, physical chemistry abounds with intermediate models that combine quantum theoretical principles with empirical estimates. For instance, if reaction rates have been established for some process involving short-chain alkanes, the modifications required for extending the scheme to larger alkanes are provided by chemical experience. If accounts of combustion are supposed to be generalized to fuels rich in oxygen (such as ethanol), past experience with such substances leads the way. Concrete explanations are based on conjoining high-level principles, empirical regularities, and observations.

In addition, strategies of idealization that involve the reduction of the nomological core are of pivotal importance. A first approach is *aspect selection* or emphasizing one feature at the expense of another. Generally speaking, two chief aspects of combustion phenomena should be accounted for together: fluid flow or turbulence, for one, and the pertinent chemical reactions, for another. However, their combined simulation is ruled out by computational complexity. The intricate nature of the processes and the huge width of scales preclude simulation with full models that can track both turbulence and chemistry. Timescales reach from the sub-nanosecond rearrangement of chemical structure to milliseconds to seconds of mixing and spatial dimensions from the sub-nanometer molecular bonds to the size of an aircraft engine or an industrial combustor. It is already a challenge to capture turbulent motion with its fluctuations in space and time in models across this spectrum of scales, and it is equally challenging to follow the course of the multitude of reactions from the fuel decomposition to emissions such as soot. Coupling both systems, the flow and the reaction, that is, describing their interactions, cannot be handled fully today. A trade-off emerges in the simulation of such systems between modeling turbulence adequately and using only rough approximations for the reaction kinetics, on the one hand, or modeling the chemical reactions by using appropriate reaction mechanisms while including only limited details regarding the flow field, on the other hand. For example, larger vortices may be decoupled from smaller ones in the cascade of kinetic energy in the system. However, chemistry and turbulence are intertwined, in fact; chemical reactions may interact with the turbulent motion. The correct account of chemically sensitive aspects in many processes, such as the formation of soot, has to rely on the sufficiently detailed treatment of both the molecular domain and the turbulent flow field. Further complications arise from phase changes and two-phase interactions such as injection of liquid fuel and spray formation, flame–wall interactions, pressure changes, and sub-to-supercritical phase transitions, as well as from changes in boundary conditions.

As a result, whereas the theoretically adequate picture needs to develop both turbulence and reactions as the two major aspects involved in combustion, numerical restrictions force us to make a choice. At present, simulation models can explore either branch, but not both. As a consequence, the simulation outcome is limited in its impact and reliability. This is why aspect selection distorts the overall picture and constitutes an idealization strategy.

Another such strategy used is *coarse-graining*. This is a general scheme used in bottom-up modeling. Many differences on the molecular level do not matter on the level of collective, large-scale properties and can be disregarded without altering the outcome of the simulation model. Global features are left unaffected by ignoring certain micro-details. This is achieved by lumping together various reactions in equivalence classes. It does not matter which reaction occurs precisely; it is sufficient to treat the entire class generically (Saggese et al. 2015; Sarathy et al. 2014). This approach serves to reduce the number of reactions that need to be handled. Still, an important maxim guiding this coarse-graining procedure is to retain as many physicochemical principles as possible.

A third approach is *modularization*. A combustion model has many ingredients that can in part be independently described and coupled afterward. For an engine, fuel injection and delivery, mixing, the flow field, the chemical reactions including key intermediate and product species leading to emissions, the exhaust composition, and aftertreatment can all be dealt with separately first and then coupled with realistic pressures and geometries. Only one aspect, namely, the chemical reaction sequence, shall be discussed in a bit more detail. For soot formation, one of the most complex and efficient chemical "assembly lines" from small molecular precursors via often harmful polycyclic aromatic compounds via carbon clusters to particles, the number of reactions increases massively with the size of the chemical structures and the potential structural arrangements they can assume. The smallest hydrocarbon that can exist in two isomeric structures, C_3H_4, can either contain a triple and a single carbon–carbon bond (propyne) or two double bonds (allene). However, while such "twins" can still be handled easily in a reaction model, the number of isomers increases exponentially with the number of atoms in a molecule. It is this structural diversity that drives up chemical mechanisms to huge numbers of elementary reactions, all with their temperature and pressure dependences. Modularized treatment can help fencing in such complexity. In addition, aspect selection, that is, the strategy of modeling particular features while neglecting others, can be combined with the other model reduction strategies such as coarse-graining and modularization. For instance, a particular aspect of the phenomenon, such as flame speed, ignition time, or nitric oxide formation, is selected and the model is reduced by mathematical routines and thus adapted for this specific purpose. Such model reduction will then represent only one aspect from the range of possible properties; it is constructed according to the purposes at hand.

The general strategy underlying these three modes of building reduced models is to focus on the most striking features of the phenomenon for the purpose in question, to appeal to relevant fundamental physicochemical principles as conceptual backbones of the model to be constructed, and and to weed out all detail that appears to be less than significant for the particular objective. The analysis of the practice of model-building reveals the importance of abandoning elements of the full theoretical account. The art of physicochemical modeling is the skill of leaving out what is insignificant for a particular purpose.

More generally speaking, our analysis has brought to light the importance of the two complementary model-building strategies of reducing and enriching the nomological core. In particular, we have elaborated the idealization pathway to model-building in a more detailed fashion. Attending more closely to the structure of models and the relationship between theoretical principles and experience illuminates pathways to clarifying the complex processes involved in combustion. Although fire has fascinated humankind for millennia, and although the decisive role of "taming fire" in civilization has been stressed multiple times, combustion remains incompletely understood. Use a match and light a candle—feel the warmth, enjoy the light, and blow it out—none of these processes (ignition, heat transfer, soot formation and incandescence, extinction, and blowout) can be fully captured from scratch by present-day models. Yet, it is still possible to approach these features by constructing models and to arrive at sufficiently accurate representations of fire and flame, albeit many of them partial in kind and coarse-grained in nature.

The Exploratory Use of Cognitive Models

Simulation models of the sort under consideration can be related to experience, tested empirically, and used for heuristic purposes. They are dissimilar, therefore, to minimal models such as Bernoulli's account of the orifice problem. Models of the latter kind are strongly idealized and, as a result, are difficult to test empirically. After all, it is presupposed that minimal models are not empirically adequate. At most, comparison with experience serves to evaluate parameters and correction factors. It is true that, in many cases, certain invariance requirements apply in different uses of the same minimal model, but the threshold thereby set for empirical adequacy is not demanding. This is different for simulation models of the kind under consideration.

The predicament is that minimal models are unable to produce empirically adequate accounts, whereas empirical models with specific, observation-based assumptions cannot be generalized to related circumstances. This is why empirical models are heuristically barren, whereas minimal models, due to the diversity of their applications, can be heuristically fruitful (see Section "Elements of Model-Building"). We wish to draw attention to a different mechanism of exploratory use. Appropriately reduced simulation models are able to formulate specific predictions for a variety of relevant conditions. Such models are subject to validation experiments (Egolfopoulos et al. 2014; Saggese et al. 2013) and can be used as exploratory instruments for this reason. They are able to make specific predictions and can therefore be used to chart unknown territory. These validation experiments must be carefully planned for boundary conditions that allow for a meaningful experimental investigation of the process, often addressing pure or undistorted states. Experiments made to validate models can lead to unexpected and surprising results that must then be integrated into the model. Recent examples include the detection of the thermodynamically lesser stable substance class of enols in flames (Taatjes et al. 2005) or the formation of a multitude of fuel-specific highly oxygenized compounds at low ignition temperatures (Zádor et al. 2011; Battin-Leclerc et al. 2010; Moshammer et al. 2016).

Validation experiments often include modeling the data or producing data models, since data interpretation from raw signals is seldom possible without constructing models. For example, individual rate coefficients for chemical reactions and their temperature dependences can be determined experimentally in shock tube reactors where a prepared stable molecular sample undergoes extremely fast heating induced by the shock wave. With this technique, molecular bonds can be broken under rather controlled conditions to release the desired reactive compound (and a complementing molecular fragment from the initial stable substance) whose reaction is the target of the study. To extract the reaction rate coefficients from the measured raw data, e.g., spectroscopic intensity signals from the reacting molecules probed, a data model for the initial reaction sequence induced by the destruction of the stable molecules by the shock wave must be used (Hanson 2011). The reason is that more molecular fragments than the desired one will inevitably contribute to the overall reaction behavior and thus change the observable quantities. The model thus serves to understand the contribution of the reactive fragment of interest. Further examples of data models concern the use of fluorescent tracer substances that can be used to track the local mixing and combustion behavior of a (typically nonfluorescent) fuel in situ by laser techniques. Such additions of combustible fluorescent fuel tracers will alter, even if well selected for this purpose, the overall fuel properties such as heat of vaporization or ignition behavior, and since only the tracer substance will cause an observable signal, a model must be used to infer the contribution of the tracer to the system and deduce the behavior of the fuel itself (Zabeti et al. 2015).

Once empirically confirmed, models can be used to explore relations and determine quantities that are inaccessible by direct measurement. Such models serve to fill lacunae left by theory and experiment. For example, in the complex reaction pathways of soot formation from small molecular precursors to solid nanoparticles, an almost “dark zone” emerges that is still experimentally largely inaccessible, in spite of techniques such as helium ion microscopy (HIM) that can now detect such particles down to the size of a few nanometers (Schenk et al. 2013, 2015; Betrancourt et al. 2017). The knowledge to fill such decisive gaps is derived from combinations of experiments, theory, and simulations, sometimes using parametric relations to describe the system’s behavior. Experiments at the very boundary of observable dimensions may attempt narrowing the gap from both sides. From the molecular end, they include mass spectrometry to detect large carbon structures, performed to gain more information on molecular growth, and from the particle side, they rely on laser-induced incandescence and advanced microscopy down to about a nanometer to extend the observable range into the nucleation regime and beyond (Skeen et al. 2013; Grotheer et al. 2011; Botero et al. 2016; Betrancourt et al. 2017). Theory may provide probable intermediate-sized carbon clusters or infant-particle-like structures from using plausible and physicochemically sound assumptions (Wang 2011; Totton et al. 2010; Adkins et al. 2017) such as stacking or agglomeration of smaller entities. Simulation may make use of all this information by taking them as a kind of stepping stones. The crucial item is that using models constituted by physicochemical principles and assumptions checked by data is the best available strategy for venturing into such dark zones (and certainly superior to using purely empirical relations) (Saggese et al. 2015). Cognitive models and simulations are heuristically useful because they serve to evaluate quantities inaccessible otherwise.

Such heuristic modeling can also contribute to designing advanced technological processes. For example, combustion engines operating differently from conventional Otto or Diesel devices, such as homogeneous charge ignition compression (HCCI) engines, rely considerably on the fundamental understanding of the physicochemical knowledge on fuel reactivity. This understanding is supported by a complete model of this process that combines near-perfect mixture on the molecular scale (such as in Otto engines) with the auto-ignition of the combustible mixture (such as in Diesel engines). The heuristic role of models thus extends into the technological realm.

The Exploratory Use of Material Realizations

Models used for exploratory or heuristic purposes need not be cognitive, as the models hitherto considered, but can also be material. They can be "analog models," that is, concrete realizations of physical conditions that stand for the phenomenon in question. Such a model may represent, for instance, the San Francisco Bay in that it is physically scaled to the Bay's features, including its tidal cycle and salinity gradient (Weisberg 2013). On the one hand, such models need to be simplified in order to provide better access to the relevant features than addressing the original target system. The conditions are idealized and less than relevant features are left out of account. Such a reduction in complexity makes the models manageable and generalizable. On the other hand, it is often useful for heuristic purposes if the models retain their descriptive adequacy. While it is true that minimal models may invite generalization because the abstract nomological core can be differently instantiated, exploratory models at a more advanced state, that is, models which are supposed to help discover empirical details, need to be descriptively adequate (see Section "The Exploratory Use of Cognitive Models"). In order to support this sort of heuristic use, models need to remain sufficiently close to the data and to make sure that the factors and mechanisms featuring in the model are the ones that are efficacious and approximately sufficient for producing the relevant effects in the target system. Useful heuristic models strike a balance between manageability and generalizability, on the one hand, and empirical significance, on the other hand.

In what follows, we focus on the exploratory use of analog models in studying problems from surface science. The point we wish to develop is the fruitful use of such material idealizations in exploring complex phenomena. The relevant challenge we place at center stage is to understand heterogeneous catalysis. In this problem, the catalyst and the reactants of a chemical reaction are present in different phases, for example, as gas and solid. In many industrial processes, the heterogeneous catalyst is usually a solid and the reactants are gases or liquids. The presence of the catalyst does not affect the energetics of the chemical reaction but it affects the rate of a chemical reaction without being part of its end products, with the effect that otherwise very slow chemical reactions proceed much faster in the presence of a catalyst. The example we address is how the role of catalysts in the Haber–Bosch process was determined.

Ammonia synthesis was made possible by a catalytic reaction discovered by Fritz Haber and Carl Bosch in 1908. They developed a process to synthesize ammonia in an energy-efficient chemical reaction between atmospheric nitrogen and hydrogen on heterogeneous iron contacts. Ammonia is used for various products, among them fertilizers, and their wide and cheap availability contributes to the nutrition of a large part of the world's population. The Haber–Bosch process was introduced into chemical production immediately after its discovery and was slowly optimized in the performance of its catalyst by trial and error. A theory or model was lacking initially.

In spite of the existence of quantum mechanics as a general, valid theory covering atomic interactions, it remained extremely difficult to understand the molecular and atomic mechanisms involved in heterogeneous catalysis. As Gerhard Ertl stated in his Nobel Prize lecture, "the rate-limiting step in ammonia synthesis over iron catalysts is the chemisorption of nitrogen. The question as to whether the nitrogen species involved is molecular or atomic is still not conclusively resolved" (Ertl 2007). It took many years until scientists managed to develop a coherent picture of heterogeneous catalysis. Using a combination of innovative experiments together with a ground-breaking modeling procedure, Gerhard Ertl, Gabor Somorjai, and many others approached catalysis in a way different from previous attempts. They focused on the investigation of the catalyst's surface on which they expected the reaction to happen. Surface science combined a variety of elements, most importantly a number of novel and very sensitive techniques for the inspection of surfaces and surface properties. These instruments include X-Ray Photoelectron Spectroscopy (XPS), Low-Energy Electron Diffraction (LEED), Scanning Tunneling Microscopy (STM), Atomic Force Microscopy (AFM), Helium Atom Scattering (HAS), Thermal Desorption Spectroscopy (TDS), Low-Energy Electron Microscopy (LEEM), and many others that help to determine the elemental composition and the spatial arrangement of surface atoms as well as of the atoms and molecules interacting with them. Some of these methods reached very high levels of accuracy—AFM and STM can resolve single atoms and HAS can detect their motions down to a fraction of an atomic diameter—and are now commonplace in many laboratories.

However, a major drawback is that many of these techniques operate under ultra-high vacuum (UHV) conditions, i.e., pressures of about 10^{-11} mbar. The reason for this is twofold. First, many methods use electrons (or ions) to interact with the surface and probe its properties. During this process, the electrons should not interact with other particles (from the ambient gas, for example), as such additional scattering of electrons with other atoms or molecules strongly affects and often completely obstructs the measurement. The second reason why surface science is performed in UHV comes from the fact that at ambient pressure, molecules or atoms permanently collide with surface atoms. Even at a moderate vacuum of 10^{-6} mbar, each surface atom is on the average hit once per second, a rate that strongly interferes with the measurement of relevant surface properties. Thus, most surface science studies necessarily must take place in UHV. However, in the chemical plant almost all catalysis occurs at much higher pressures; the Haber–Bosch process typically operates at around 2×10^5 mbar. Hence, the pressure difference between surface science in the laboratory and industrial catalysis spans up to 16 orders of magnitude, a phenomenon denoted as the "pressure-gap."

To make things even more complicated, real catalyst surfaces and the idealized surfaces studied in surface science differ in one more respect. While the surfaces of technical catalysts are often complex with poorly defined crystallinity and elemental composition, the surfaces studied in surface science are prepared in a way that they are defect-free crystal faces with a well-defined structure. In sum, complex surfaces of real catalysts operating at high pressure are modeled by single-crystal surfaces in ultra-high vacuum. The interactions of these "model surfaces" with the potential reactants were then studied by instruments and techniques specially designed for this purpose.

A surface science experiment cannot operate under industrial conditions, so the attempt to understand catalysis with the help of surface science techniques seems rather courageous. However, it is exactly this strategy of *restriction to simplified model systems* that proved to be successful and it is worthwhile to ask why this is so. More specifically, surface science experiments produced manageable data, which provide information critical to a better understanding of many things that happen at and about the surface: the crystal orientation, atomic positions, the paths of individual molecules, and atoms onto surface locations as well as thermodynamic and electrical parameters. Experimentation opened the eyes for an enormous variety; an example is the determination of binding sites on metal surfaces. When an atom or molecule approaches a metal surface from the gas phase, it can adsorb directly *on-top* of a surface atom, it may *bridge* two adjacent surface atoms, or it may bind in a *hollow-site* in which it binds with three or four surface atoms. Which binding geometry is realized depends on the atom or molecule and the surface, and when different surfaces are exposed to different atoms or molecules, many binding geometries can be observed. Oxygen binds differently with iron than with nickel surfaces; hydrogen atoms bind differently on platinum than on tungsten and sulfur atoms on gold surfaces, and these are all dependent on the local electronic structure of the surface site. Over the years, the energetics of many surface-binding events have been determined, for example, by thermal desorption spectroscopy. The diversity of binding sites provided valuable quantitative information on the energetics of adsorption. Special situations as in the Haber–Bosch process have been understood by probing into the nature and energetics of nitrogen and hydrogen interacting with crystal surfaces of iron, nickel, and other transition metals. All steps

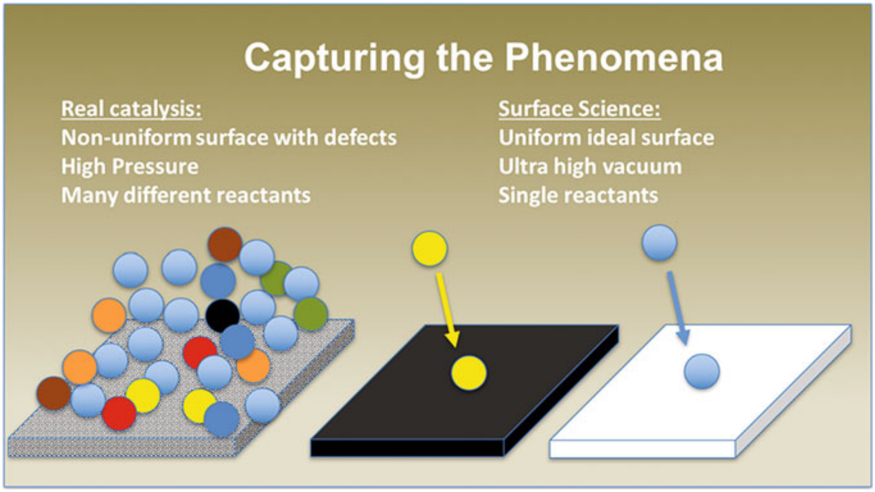

Fig. 1 Explaining a complex phenomenon from idealized analog models

involved in the ammonia synthesis reaction could be identified and analyzed, and such studies are instrumental in the development of the overall mechanism of the catalytic reaction process (Ertl 1980).

This example reveals characteristic features of the exploratory use of analog models. The difficulty encountered in this case is that the process under investigation cannot be dealt with by direct experimentation with enough resolution. The reason is that the real-life situation as in the Haber–Bosch process is dominated by distortions, such as further collisions of relevant surface sites with atoms and molecules, so that the critical events are eclipsed and inaccessible. These critical events can only be subjected to measurement under strongly idealized conditions. We have a significant mismatch between the technological operating conditions and the conditions that permit access to key phenomena. However, measurements performed on the pure or undistorted state made it possible to ascertain critical quantities that are also essential for the dynamics of the process under realistic conditions. The quantities measured under strongly idealized circumstances also govern the perturbed counterpart. This procedure worked successfully because the significant quantities remained unperturbed by the distortions. This is why they could be used to generate a comprehensive picture that extended even to distorted conditions. And in this way, an overall mechanism could be assembled from building blocks that are constitutive of the pure state in question (Fig. 1).

The success of the surface science approach in catalysis is based on the availability of many observations under idealized conditions. The complex reality of an industrial catalyst is probed by a number of detailed experiments directed at highly simplified situations. The availability of a manifold of model surfaces helps to mimic the real catalyst. The quantities determined could later be fed into DFT (see Section "Building Models of Combustion Processes"), which serves to adapt quantum mechanics to solid-state physics and provides the theoretical basis for extension and extrapolation about the bonding of atoms and molecules to practical catalyst surfaces. Again, the path to such explanations was paved by experiments on pure or undistorted states. Analog models realized such idealized states and thus supplied the building blocks from which the full picture could eventually be assembled.

We have argued that the explanatory use of idealized cognitive models takes advantage of their modularized character (see Section "Building Models of Combustion Processes"). It turns out that the exploratory use of idealized material realizations depends on the modularized character of the complex phenomenon in question. In both cases, accounting for a phenomenon bottom-up is based on the condition that the effect of a given factor or assumption is largely context-independent and does not vary significantly with altered circumstances. This is why idealized building blocks can be used to assemble complex features. In models structured in a more holistic way, such a strategy of constructing wholes piecemeal from idealized parts would fail.

It is interesting to speculate whether recourse to such idealized states is indispensable. What if big-data technology had been available before the relevant mechanisms had been cleared up? Could a large number of results and relations obtained for a wide variety of real working conditions of catalysts have provided the information necessary to disclose the underlying mechanism? Does this mean that the advancement of data processing technology prompts the rise of empirical models at the expense of theory-based models? A frequently articulated concern is that extracting patterns from huge amounts of data is helpful for exploratory purposes and enhances predictive abilities, but tends to encumber the gain of understanding (Napoletani et al. 2011). Be that as it may, the actual course of events invoked real configurations under undistorted conditions and showed that material idealizations offer a valuable pathway to understanding complex phenomena.

It is likewise interesting to compare the exploratory use of computational models (studied in Section "The Exploratory Use of Cognitive Models") and analog models. The first aspect to note is that these two modes of exploration are not tied to combustion science and surface science, respectively, but that they rather denote general methodological options. In both fields, simulation models and idealized experiments are employed. Our account is supposed to stake out general ways of venturing into the unknown rather than contrasting different fields of chemistry in methodological respect. Second, a distinction between the two approaches is that computational models can be handled more easily and allow proxy experiments (i.e., varying parameters in the computer simulation), but analog models can be examined more directly empirically and may thus be more reliable. Likewise, computational models can more easily be expanded to more complex systems, but are in need of independent verification.

Conclusion

In the previous sections, we have discussed examples from physical chemistry including combustion and catalysis, both fields of large societal impact. Progress in model-building in such fields is intricately linked to further design and development of societally relevant processes. We have examined the model-building practice in physical chemistry against the background of the received views of model-building. The message developed in our contribution is fourfold. First, we have confirmed the importance of intermediate models that combine empirical generalizations with the nomological core. It deserves notice in this connection that the models we identified were all coherent. In the relevant literature, models feature prominently in which generalizations of different characters are cobbled together. The existing models of the atomic nucleus and ferromagnetic properties both involve the uneasy coalescence of classical and quantum principles. Such models lack a consistent nomological core. We failed to come across such incoherent models in physical chemistry.

Second, we have studied idealization strategies which involve a reduction of the nomological core and are thus complementary to constructing intermediate models. We suggested three relevant strategies: aspect selection, coarse-graining, and modularization.

Third, the heuristic use of models is usually emphasized for minimal models, which are untestable due to their strongly reduced character. However, models used for heuristic purposes can also be sufficiently elaborated to enable the evaluation of significant quantities. On the contrary, yielding empirical results is often part of heuristic use in that the models are thereby enabled to venture into the unknown.

Fourth, this heuristic use is also possible for models that are material rather than cognitive and involve the physical realization of relevant configurations. In the examples studied, the use of idealized analog models of this sort is striking. A comprehensive picture can be obtained by assembling accounts of idealized partial configurations. A presupposition is that no strong interactions between these basic configurations occur in the comprehensive picture. That is, the different partial accounts can be added without substantial modification.

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Making Education More Inclusive and More Integrated

Claude Debru

Abstract Improving education is a major concern for every government. Social inequalities are strengthened by inadequate educational practices. In this presentation, we will deal with two different initiatives. The first one, *Hands On* in the US, followed by *La main à la Pâte* in France, aimed at making the teaching of science at the elementary school much more practical, thus improving the results of the pupils belonging to lower social classes and their overall acceptance of the school system. This approach is now extended to the preschool and to the first years of secondary education in several European countries. Another initiative aims at creating more bridges between disciplines in sciences and humanities during the last years of secondary education, making education more integrated.

Keywords Science education · Educational initiatives · Attractive teaching of science · Observation · Experimentation and reasoning · Bridges between disciplines

According to some observers, science is no more the most important concern of our societies. This is clearly a challenge for Academies of sciences, and certainly an important one for us here. Part of this challenge is education, an important concern for academies either. In this presentation, I will focus on science education as a tool and a part of a more inclusive society—which is also on the European agenda. Regarding integration by way of education, the results are not always clear. I will concentrate on elementary and secondary schools in my country, and I will focus on two initiatives, one more ancient and highly successful, *Hands On*, aimed at helping pupils in elementary schools in America, then in France under the name of *La Main à la Pâte* (Charpak, Léna and Quéré, 2005), and the other one more recent and still

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in a state of experimentation, regarding a highly desirable collaboration between teachers of various, scientific and humanistic disciplines at the end of secondary education in France. So first, I will wonder how to improve the teaching of science to pupils at the elementary schools to make it more interesting, successful and above all more inclusive regarding social groups. Second, I will wonder how to create bridges between natural sciences and human and social sciences during the last stages of secondary education, so that students in these latter disciplines including philosophy, become more aware of what science really is and of why it does really matter. The overall aim of both initiatives and of this presentation is to integrate the scientific attitude into the general way of thinking thanks to education.

It is well known that the American Nobel Prize in Physics Leon Lederman started his so-called *Hands On* programme in 1992 in very poor districts of Chicago, in order to foster the interest of pupils for scientific investigation, to make them participate in the class, and to put them on a more successful course. At about the same time, the President of the American Academy of Sciences Bruce Alberts took a strong interest in the subject, so that the Academy published detailed recommendations about science education, which should rely more on investigation and experimentation. Lederman was the real founder of this movement. It is also well known that another Nobel Prize in Physics, Georges Charpak, together with two of his colleagues at the French Academy of Sciences, Pierre Léna and Yves Quéré, proposed in 1995 to the Ministry of Education a (in the French context) revolutionary programme, whose name *La Main à la Pâte* is known worldwide now. Its aim was to recreate, on a new basis, the teaching of natural science which had almost completely disappeared—except mathematics—from elementary schools.

Here we are at the very heart of our subject, *Progress in Science, Progress in Society*. Charpak made quite important remarks at the beginning of his book *La Main à la Pâte* in 1997. Science plays an essential role in our contemporary societies. However, entire sectors of our societies take no interest at all in science. People are happy to enjoy its results and products, especially regarding health, but there is no special interest in it. In some parts of our elites, it is true that science is rather admired, supported and sometimes practiced. So, the same elite people are deeply disturbed when they have to recognize that in many parts of our societies, there is a deep feeling of disenchantment towards science, and they are even more disturbed when they observe that religious beliefs of the most obscure kind take the lead in some parts of our societies. Such was Charpak's diagnosis.

He said that the remedy is a more attractive teaching of science. It is a remedy against social inequality between the elites and the remainder of the population. Elite families cultivate the gifts of beautiful language, rhetoric and argumentation. This is less so in the basic population. In this case, the teaching of science in a most practical way should provide a substitute to rhetoric by fostering argumentation on natural phenomena. This was Charpak's point. It seems to be true, according to subsequent experience and evaluations. Science for all seems to be a good remedy against school rejection. On both American and French sides, there was a strong willingness, not only to increase the interest for science, but also to take science as a tool to increase the interest of the pupils for their own education, for what happens in the classroom, and especially in the classrooms in very poor neighbourhoods. As a matter of fact, this was a very rapid success, since the number of teachers interested in this kind of initiative increased rapidly. At the international level, the French initiative *La Main à la Pâte* underwent a tremendous success, since according to data published in 2013, more than fifty countries participated in this programme, with the help of the Ministry of Foreign Affairs and local diplomats. Among the many countries all over the world which are presently involved, European countries like Belgium, Germany, Italy, Portugal, Spain, and other ones in Europe should be mentioned. The European Commission took much interest in this venture and founded the so-called "Pollen" programme, "Seed cities for science, a community approach for a sustainable growth of science education in Europe". Among the universities which were involved in 2009, the Université Libre de Bruxelles, the Freie Universität Berlin, the Ecole Normale Supérieure de Paris, are members. Another EC supported programme, the Fibonacci project is aimed at "Disseminating Inquiry-Based Science and Mathematics Education". It's a remarkable fact that mathematics is involved in this programme because mathematics had never disappeared from elementary schools. Indeed, *La Main à la Pâte* was founded by physicists trying to revive the spirit of the so-called "leçon de choses" which was basic in the old structure of elementary education in France at a time when most of the schools were rural schools. The "leçon de choses" was not at all a French invention. It was a British and American invention of the mid-nineteenth century, inspired by the philosophy of empiricism and utilitarianism. Anyway, and as a matter of fact, the kind of teaching which is proposed by *La Main à la Pâte* is now extended to the preschool on the one hand, and to the beginning of the secondary education on the other hand.

Now some words about the actual themes which are developed by *La Main à la Pâte* in its publications. These are very contemporary themes, which include not only pure science but also technology. Some of these themes are the Sun, the Earth (the ocean, my planet and me), time, materials, colours, music and vibrations, the cell, biodiversity, the forest, and other ones. How to explore such themes for pupils of the elementary schools? I will take the example of the Earth, and rely on a chapter written by Jean-Paul Poirier, a geophysicist, in the book *Graines de sciences* (1999). In this chapter, you find comments on the shape of the Earth, on its internal constitution, its minerals, its internal dynamics, the dynamics of the Earth's plates, on Earthquakes, and on volcanoes—just to mention the diversity of questions which may be asked on a single natural object. The shape of the Earth is an interesting subject, because children at the elementary school do not understand gravitational forces, are not ready to admit that the Earth is a spherical body, and once they admit it, they tend to think that humans who are located on the other side of the Earth are due to fall in the emptiness. In order to avoid this unfortunate circumstance, some children think that people stand up on the internal surface of the sphere, other ones imagine that people stand on the plane of a half-sphere. They elaborate these wrong representations because they have no idea of gravitational forces.

The conclusion of this analysis is that it is useless to try to force children to understand phenomena which they are unable to understand at their age, and that teachers have to wait for some time before imagining devices or experiments (like Galileo and his famous inclined plane on which a ball is rolling), which would allow children to assimilate the idea of a gravitational force. One of the ways to improve this assimilation of new ideas is to create in the mind of the children so-called “intermediary representations”, which are neither entirely true nor entirely false, in order to facilitate the assimilation of the true idea at a later stage. Indeed, this may be already the case with the Galileo experiment even before the elementary school. You can deal with balls of different sizes to reach intermediary conclusions which are certainly useful at a much later stage. This most classical example is very interesting because it shows to the children that Nature gives unexpected answers to the questions we ask to it when we set up an experimental device. The expected answer would be a constant speed for a falling body. The real answer is the idea of an accelerated movement.

As a matter of fact, this kind of teaching based on observation, experimentation and reasoning turned out to be extremely successful even for children in a situation of failure, who consequently may become quite successful. Indeed, the practice of experimental science at elementary schools may be a way of completely unblocking children, so that they make progress also in other fields of activity, and become reconciled with the school (Inspection générale de l’enseignement primaire, 1999). Obviously, this kind of teaching may be a remedy against social inequalities of any kind. It seems to be an important tool in shaping a more inclusive society.

My second point is about the so-called “two cultures”, so designated by C. P. Snow. In my own educational system, the gap between the teaching of natural sciences on the one hand, and the human and social sciences, on the other hand, is more important than ever at the level of the high school, during the last three years of secondary education. In more ancient times, the philosophy teachers gave much attention to science. Apparently, this is no more the case, in spite of the official programmes, or only in a very superficial way. The spirit of science, the true spirit of scientific research, is no more transmitted through the channel of philosophy to many students. For a philosopher of science like me, this is a matter of concern. For this reason, a series of two conferences were organized at the Del Duca Foundation in Paris on the teaching of philosophy and the sciences, a gathering of scientists and philosophers co-organized by the French Academy of Sciences and the Inspection Générale of the Ministry of National Education (Académie des sciences, 2012). On this occasion, we realized that the situation was not that desperate, that things could be done and had already been done as a matter of fact at some spots in a spontaneous way. Collaborations between teachers in natural sciences and philosophy teachers did happen in existing frameworks, in existing schedules. Collaborations between philosophy and other disciplines, including literature, is encouraged anyway. So there is a general trend in creating bridges, softening the barriers, and encouraging communication between disciplines. Regarding the interaction between philosophy and natural sciences, there are indeed many possible subjects, but some subjects are more popular than other ones, in life sciences, and earth sciences for instance: biotechnologies, bioethics, procreation, gift of organs, man and the animals, the place of the human species among the other biological species, and also astrophysics. It is clear that these interactions are extremely well received by the students—between 15 and 18 years old students—in high schools which are not necessarily located in the most favoured parts of our cities. So we go back to the spirit of *Hands On* or *La Main à la Pâte*. There is no doubt that the interaction between natural sciences, technology, and the human and social sciences is a key four our scientific as well as social future.

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The Contribution of Social Sciences and the Humanities to Research Addressing Societal Challenges. Towards a Policy for Interdisciplinarity at European Level?

Philippe Keraudren

Abstract This chapter is about the policies being applied at European level by the European Commission to promote interdisciplinarity throughout its main policy tool since 1984, the Framework Programme (FP). In this context, interdisciplinarity is defined as the combination of knowledges between the social sciences and the humanities (SSH) and the 'natural' or 'life' sciences (also called 'STEM' sometimes) in order to tackle societal and technological challenges that need to be integrated in a wider social, economic, cultural and political perspective which constrain technological development. The history of the FP shows that the promotion of interdisciplinarity in FPs was based on a 'two-legs' approach with, on the one hand, a dedicated European research programme on the main social, economic, cultural and political challenges of Europe, and on the other hand, attempts at promoting interdisciplinarity between SSH and STEM. FP8 (2014–2020), called Horizon 2020, is a significant departure from past practices since it calls exclusively for the integration of SSH across the whole FP without a dedicated research programme on Europe's main social, economic, cultural and political issues. The preliminary results of this new policy of interdisciplinarity are reviewed and lead to several suggestions as to how to strengthen a long-term effective EU research policy for interdisciplinarity between SSH and STEM research, while preserving the benefits of disciplinary research or of other kinds of interdisciplinarity.

Keywords Social Sciences and the Humanities · Interdisciplinarity
Human potential programme · Research and technological development
Integration

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Introduction

This chapter is not about the epistemology of interdisciplinarity nor about the pros and cons of interdisciplinarity which have received tonnes and decades of detailed attention and passionate debate (see for instance Nowotny et al. 2001; Barry and Born 2013; Gulbenkian Commission 1996; Horizons for Social Sciences and Humanities 2013). It is not either about an empirical sociology of interdisciplinarity between natural and social sciences which remains to be addressed. It is not, finally, about interdisciplinarity within the broad group of disciplines called the social sciences and the humanities (SSH), nor within the 'natural' and engineering sciences.

This chapter is about the policies being applied at European level by the European Commission to promote interdisciplinarity throughout its main policy tool since 1984, the Framework Programme, i.e. a multi-annual funding programme of—mainly collaborative—research benefitting the researchers of the 28 members of the European Union, but also those in Associated States and even researchers across the world. It also has a specific definition of interdisciplinarity: interdisciplinarity here is defined as interdisciplinarity between the SSH and the 'natural' sciences (also called STEM sometimes).[1] We are thus not dealing here at all with either interdisciplinarity within the SSH or interdisciplinarity within the STEM group of disciplines.

After reviewing the history of the attempts at promoting interdisciplinarity in previous Framework Programmes (FP), this chapter will expose the current policy of interdisciplinarity developed under FP8 (2014–2020) called Horizon 2020, and will then sketch out the requirements for an effective EU research policy for interdisciplinarity.

A Brief History of Interdisciplinarity in the Framework Programmes

The European research policy was for long mainly a story of technological research, the objectives being to maintain or improve the European leadership in science and technology and support the technological development of European industries. There were always a few elements of SSH, focusing in particular on the need to develop forecasting and assessments in technology and to support policy (Kastrinos 2000, 2001, 2011). The emphasis on policy relevance which lied at the centre of the research policy of the EU, brought in play complex views on the nexus between science, policy and society, in particular in the environment field (Liberatore 2000).

[1]We acknowledge that such categories as "SSH", "natural" or "STEM" are not without many difficulties but we shall use them as adequate proxies for the sake of the argument.

Although FP 3 (1991–1994) contained interesting SSH research elements, it was not before FP 4 (1994–1998) that SSH research appeared 'on its own' as a distinct research programme called 'Targeted Socio-Economic Research' equivalent, in legitimacy if not in size, to 12 other research programmes in domains like environment, industrial technologies, agriculture and fisheries or transport for instance. The Five Year Assessment of the Targeted Socio-economic Research Programme 1994–1998 made a strong plea for strengthening SSH in future Framework Programmes (Horvat et al. 1997, 25–26).

The first signs of a genuine policy of interdisciplinarity appeared under FP 5 (1998–2002). The decision n 182/1999/EC of the European Parliament and of the Council of 22 December 1998 states that: '*Within these programmes, particular account will be taken of the socioeconomic implications of the implementation, use, and effects of the technologies, processes and scenarios covered by each of these programmes. As an integral part of actions within the first activity, relevant socioeconomic research will be carried out. A particular effort will be made to ensure coherence between these activities in order to optimise the exploitation and dissemination of results by users. These actions will be complemented by socioeconomic research on horizontal issues carried out within the fourth activity*'.[2] Importantly, the decision also adopts the notion of 'key actions' of clear interdisciplinary nature: '*Key actions will be problem-oriented and clearly defined corresponding to the criteria and specifically targeted to the objectives of each programme and to the desired results, taking into account the views of users. They will have a clear European focus. The 'key action' is regarded as a cluster of small and large, applied, generic and, as appropriate, basic research projects directed towards a common European challenge or problem not excluding global issues. The research activities carried out in this context will integrate the entire spectrum of activities and disciplines needed to achieve the objectives, and range from basic research through development to demonstration*'.

Unfortunately, we do not have any systematic evaluation of the implementation of the 'key actions' under FP 5 (The Panel 2004). The high-level group of experts evaluating the FP '*welcomed the introduction of the Key Action concept but felt that more could be done to improve its implementation. Early indications are that the Commission could ensure the greater relevance of projects* via *the provision of better information to potential participants and more guidance to proposal evaluators concerning the precise nature of European Added Value*' (Independent Expert Panel 2000, 5). It even had a rather cautious approach to the EU research policy, noting that '*a more nuanced approach should be taken at the selection stage to ensure that projects in particular domains are relevant to the specific aims of that domain and not necessarily to all the social and economic aims of the Framework Programme as a whole*' (ibid., 8–9). Nevertheless, the high-level group

[2]The term "activity" refers to the structuration of FP5 in 5 different "Activities" which are the main components of FP5. Activity 1 is called "Research, technological development and demonstration programmes" whereas Activity 4 is called "Stimulation of the training and mobility of researchers in the Community".

deemed that research in SSH was effective, necessary and should be reinforced. It also hinted at the fact that a strong research programme in SSH is a pre-requisite to the success of interdisciplinarity: '*the Panel supports the fact that the socio-economic dimension has been formally integrated into all the programmes under FP5.*[3] *However, it recommends that socio-economic research (SER) becomes (again) a Horizontal Programme in FP6, independent of the Human Potential Programme. The Panel supports a stronger Human Potential Programme in FP6. Its share in the future Framework Programme budget should at least double the present level*' (ibid., X). This remark was also shared by another group of experts assessing, in particular, the SSH research component of FP5. Nevertheless, this second group of experts hinted, worryingly, that the European Commission had not taken the proper measures to ensure sufficient interdisciplinarity: '*the proper implementation of coordination of socio-economic analysis across the Framework Programme requires more human resources and, more than that, the development of appropriate tools. The scientific officers and the evaluators should receive a specific training*' (The Panel 2000, 29). Another panel of experts pointed to the same issue at the end of the FP 5 period: '*efforts need to be made to enhance the multidisciplinary interaction potential of key action projects. Such integrative projects are becoming more and more necessary given the complexity of the problems arising across the socio-economic domain*' (The Panel 2003, 41). In some ways, it is, therefore, no surprise that the report for 5-year assessment of the EU research Framework Programmes for the period 1999–2003 (The Panel 2004), which therefore covers most of the period of FP 5 (1998–2002), does not even mention these key actions. Interestingly enough, the word 'interdisciplinarity' itself was never used in these reports during FP5.

There is some limited evidence of the weak success of interdisciplinarity under FP5 from researchers themselves. '*We found disappointingly few projects among those funded in the early calls of the FP5 Programme that seemed by our criteria to be clearly interdisciplinary, particularly in terms of crossing the boundary between natural and social sciences. Although FP5 set ambitious targets for a step change in the amount and quality of interdisciplinary research, there have been formidable constraints to the delivery of these targets… However, the EC alone cannot deliver such an outcome. As we noted above, many of the constraints operating against interdisciplinary research emanating from academic systems in European universities, which still discriminate against interdisciplinary research*' (Bruce et al. 2004, 463).

FP 6 (2002–2006) included an SSH research programme called 'Citizens and governance in a knowledge-based society' which encouraged interdisciplinary research in favour of public policies. Besides, the Specific Programme 'Integrating and Strengthening the European Research Area' stated that appropriate coordination of socio-economic research and foresight elements across the specific programmes

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[3]FP5 had also added to the list of evaluation criteria a specific evaluation criterion called "Contribution to Community social objectives".

should be assured. A new 'priority 8' for scientific support to policies was also created in order to support the socio-economic relevance of research across the FP. The European Commission Directorate General for Research and Technological Development (DG RTD) actually set up a Directorate 'Social Sciences and humanities: foresight' to support the implementation of the SSH research programme and related activities. A socio-economic correspondents group was set up, a vademecum on social and economic dimensions in FP6 was drafted and a specific socio-economic questionnaire for projects was developed in order to draw statistical data about the integration of SSH in various parts of FP6. Nevertheless, observers were rather skeptical about the potential of FP6 to integrate SSH across the various research programmes: '*at mid-term of FP6, no progress with respect to integrating the socio-economic dimension in the project evaluation can be identified. The role of the socio-economic dimensions has been drastically reduced in the design of the FP6 proposal evaluation by the rather rhetoric formulations at all programme levels referring to it, and by the fact, that they are not included in the evaluation criteria anymore*'[4] (Horvat 2004, 24). It was noted that few quantitative data were made available by the Commission, the practices of evaluations did not encourage genuine interdisciplinarity and, despite efforts, the SSH dimension in the work programmes remained weak or elusive: '*this would mean also a step forward from rather vague—sometimes even cloudy—formulations on the integration of socio-economic issues in Work Programmes and Guidelines to concrete and useful advice for proposers and project participants*' (ibid., 74).

This was all the more surprising that the Lisbon Strategy which started in 2000 actually pushed for both ambitious types of research in SSH in key social, economic, cultural and political fields like poverty, growth, education, employment, as well as for cutting-edge interdisciplinary research in all domains of innovation. Actually, another European group of experts appointed by the Commission, called EURAB, had pointed to this in three reports published in 2004: 's*ocial Sciences and Humanities research activities "in their own right" should command a more prominent place in future Framework Programmes in addressing social, economic and political issues and challenges facing the further construction of the European Union and its relations with the rest of the world*' (EURAB 2004a, b, c: 1. 2); '*the "Socio-Economic Dimension" of FP RTD main science and technology programmes should be expanded beyond the present emphasis on ex-post analysis of "social and economic impacts of science and technology" and "foresight" assessments to the full integration of socio-economic research components in the work programmes and "calls for proposals*" (ibid., 3)'. However, EURAB had to observe: '*while the SSH are alluded to and certainly not specifically excluded, neither are they given special attention. Given the important (potential) role of the SSH coupled with their relative under-representation compared to that of the*

[4]Compared to FP5 (see footnote 5 above), FP6 had no specific "socio-economic" criterion, which meant of course that interdisciplinarity between SSH and STEM disciplines in research proposals was less of a requirement.

natural, medical and engineering sciences, this is particularly worrisome… More than ever, the focus seems solely to be on the natural sciences, technological development and innovation. The necessary framework conditions that need to be in place to support these goals and the overall strategy outlined in Lisbon are more or less forgotten' (EURAB 2004a, b, c: 2, 1–2). EURAB thus recommended to make explicit reference in the work programmes to necessary contributions by SSH disciplines across the FP, to increase SSH expertise both in the design of the work programme and the evaluation process of FP6 and to highlight the contribution of humanities to problem-oriented research. In a third report, it went as far as recommending the Commission to adopt a fully fledged policy for interdisciplinarity organised around three pillars: (1) a reassessment, where useful, of disciplinary demarcations, (2) a removal of institutional barriers to performing interdisciplinary research and (3) a rethinking of associated research training (EURAB 2004a, b, c: 3). Interestingly and surprisingly, the ex-post evaluation of FP6 did not deal with interdisciplinarity as if this was an irrelevant consideration in tackling the challenges of the day under FP6 (The Panel 2009).

FP7 (2007–2013) followed a more or less similar and now familiar path than FP6 between resolute ambitions and limited implementation. On the one hand, there was, as always from FP4, a separate collaborative research programme whose impact on science, policy and society has been judged rather positive (IMPACT-EV 2016). SSH was also included in the newly created ERC as one of the three 'domains' (the others being Life Sciences and Physical Sciences/Engineering), with interdisciplinarity being welcome and implemented mainly within domains but also across the three domains (European Research Council 2014, 26). To facilitate interdisciplinary proposals to get an appropriate evaluation, ERC implements 'cross-panel reviews' that is the possibility for proposals to be evaluated also by experts in different evaluation panels than the main one selected in the application. The EURAB group of experts was there again to extol the role of SSH in meeting European challenges: '*a second FP7 challenge comes with the increasing permeability of the boundaries between Social Sciences and the research traditionally discussed under a separate 'Science and Technology' label. EURAB believes this challenge is particularly significant because of the longer term ambitions of FP7, reaching as it does into the middle of the next decade of the 21st century. Though the actual directions and specific issues are hugely uncertain, we can be reasonably sure that by 2013 scientific and technological advances will offer possibilities for major transformations in European society*' (EURAB 2005, 8). On the other hand, implementation met with little success. The group of experts appointed for the evaluation of FP7 noted that: '*embedding SSH in other themes and areas of research has been modest*' (The Panel 2015, 68). It also observed that: '*highly important concerns of European citizens are only marginally addressed (e.g. social cohesion, European integration and combating unemployment). In addition, themes and topics often follow a technological fixing—the problem approach instead of addressing societal causes and major transformation processes. In order to promote a more positive public perception of science and better adoption of new knowledge and innovations, the*

Framework Programmes will have to address citizens' concerns better and involve them in a more substantial role in the future' (ibid., 84).

The Promises of Horizon 2020

The SSH model tried between FP4 and FP7 was therefore based on two legs. One leg was a small but clearly separate collaborative research in SSH set up in order to analyse the main political, social and economic challenges of the decade, such as the so-called Lisbon agenda, mostly described as 'social exclusion', 'citizenship', 'growth', 'Europe in the world', 'identities' among others (See Kastrinos 2010). Another foot was the integration of SSH knowledge across the FP in order to give to STEM research a broader societal relevance and impact, the accepted wisdom being that the SSH should get organised by the European Commission in order to 'migrate' towards STEM research and progressively 'convince' them of the benefits of interdisciplinarity. As the EURAB chair wrote: '*SSH should have their own proper space within FP7 but we also argue for a much stronger and more deliberate integration of SSH into the whole scope and objectives of FP7*' (2005, 5).

This two-legs approach has three distinctive features. First, it states that you cannot achieve interdisciplinarity between SSH and STEM research unless you also have a 'proper space' for SSH and STEM research. This goes into the direction of the classical and widely shared argument that strong disciplinarity is the essential condition necessary to interdisciplinarity.[5] Second, it has an unconscious 'fertility view', i.e. it is up to the SSH to travel to fertilise STEM research rather than the other way round or rather than a more balanced approach of common efforts from both sides. Now the fact that the SSH should have the role and responsibility of organising interdisciplinarity between SSH and STEM research is in itself not only a debatable intellectual and policy choice but also a formidable challenge.[6] Third, in order to succeed, the two-legs approach needed a policy for interdisciplinarity. In our view, this policy never materialised as the European Commission focused its efforts in developing a policy for the 'proper' space of SSH and STEM research, which already included a strong element of internal interdisciplinarity. This is what the Horvat report of 2004 and the EURAB report of 2005 lamented: institutional barriers to organisational learning within the Commission prevented the development of a fully fledged policy of interdisciplinarity between SSH and STEM research. The second leg of SSH research policy was never actively built.

[5]Although it has to be said that the FP collaborative research has for long given up exclusive disciplinary research and has practiced interdisciplinarity within STEM research and within SSH research. Thus, the levels of interdisciplinarity between social sciences and between social sciences and the humanities in FP SSH collaborative research has been strong (with the exception of economics in particular).

[6]See the very cogent remarks of J.L. Fabiani (Horizons for Social Sciences and Humanities 2013, 43–48).

Horizon 2020 has actually been a major change in the EU policy regarding SSH research since FP4 in 1994. While most of the SSH elements in the FP have remained (i.e. in the infrastructures programme, in the Marie Curie-Sklodowska programme and in the ERC), Horizon 2020 innovates by abolishing the separate SSH collaborative research programme that had existed between FP4 and FP7 for nearly 20 years (while all other STEM supported collaborative research programmes in health, food and agriculture, energy, transport, environment and climate change, security have been maintained). Instead, it hails SSH as a cross-cutting dimension throughout the entire research activities, notably under the pillars ‘Industrial Leadership’ and ‘Societal Challenges’. Therefore, although Societal Challenge 6 ‘Europe in a changing world. Inclusive, innovative and reflective societies’ still includes important research domains for SSH research (on migration, inequalities, governance, youth and so on), it is not considered as an SSH Societal Challenge but as a Societal Challenge where SSH should also be integrated along interdisciplinary lines, in particular in ICT oriented research.

This is a major shift in EU research policy and it is therefore important to assess how this new policy of interdisciplinarity has been implemented so far until early 2017. Of course, after only a little more than three years of implementation, it is difficult to draw final lessons. The European Commission has invested time and resources in three main areas. First, it has created a network of SSH liaison officers throughout DG RTD and other relevant research Directorates General in order to monitor the quantity (through the tool of SSH flagged topics) and quality of SSH integration in the work programmes of Horizon 2020. Despite a difficult start, this work is now well established and should progressively give better results because of the effective cooperation between the Unit ‘Open and inclusive societies’ in charge of SSH research in DG RTD and all other units in DG RTD and other relevant DGs in charge of various parts of the work programmes of Horizon 2020. Along the development of the work programme every two years, there have been more and more interactions to determine the quantity and quality of topics meant for interdisciplinarity under a process of ‘flagging SSH topics’. This is useful because ‘SSH flagged topics’ published in the Participants’ Portal of Horizon 2020 give a signal to potential applicants that interdisciplinarity is required in all proposals to these topics. Second, there are regular meetings and contacts with the SSH communities, the various Programme Committees representing the Societal Challenges and Industrial Leadership parts of Horizon 2020, the Expert Advisory Groups and the National Contact Points in order to communicate the SSH integration policy externally. Third, the Commission has established guidance notes towards the evaluators in order to streamline the evaluation of proposals in ‘SSH flagged topics’, whether the evaluation is monitored by the Commission itself or by the executive agencies.

Besides, for the first time in the history of the European Commission, there are finally quantitative indications about the practices of interdisciplinarity under the EU FP! The European Commission has monitored the implementation of these initiatives through a precise analysis of integration of SSH in the projects funded under the SSH flagged topics in 2014 and 2015. Although these data should be complemented and improved, they represent a major step forward in the objective analysis of interdisciplinarity at FP level.

The second monitoring report of SSH integration based on the analysis of the projects funded under the SSH flagged topics in 2015 can actually serve to illustrate the main lessons on the policy of interdisciplinarity (European Commission 2017). There is no place here to repeat the wealth of analyses of this report but it suffices to recall some simple key statistical figures about the presence of SSH research in SSH flagged topics as follows:

- 84% of projects have at least one SSH partner;
- 27% of consortia partners in projects have SSH expertise;
- 25% of projects are coordinated by a SSH partner;
- 22% of the overall budget benefits SSH partners but this share is much lower for projects under pillar II (Industrial Leadership) of Horizon 2020;
- 64% of the SSH partners come from the public sector (universities, ministries, research organisations), 21% from the private sector, 15% from other organisations (mainly NGOs);
- 52% of SSH partners come from 6 countries (UK, Italy, Germany, Spain, Belgium and France);
- Whereas some disciplines are well represented in these projects, such as economics (in 26% of the total number of SSH researchers) and political science and public administration (17%), others are underrepresented, notably in the humanities (for instance anthropology and ethnology 2%).
- The 'quality of SSH integration' calculated on the basis of a composite indicator is good only in 39% of projects, fair in 19% of projects, but also weak in 18% of projects and even inexistent in 24% of projects.

These results undoubtedly show one plain and obvious fact: practices of interdisciplinarity are fragile and will have to be sustained by a long-term policy. The figures above recall that even when the Commission flags topics for interdisciplinarity in its work programmes, there is too little interdisciplinarity and sometimes even no interdisciplinarity at all in the funded projects. They also underline that SSH partners are too often minority partners in the interdisciplinary efforts funded by Horizon 2020. This suggests problems at many levels, in particular in the drafting of research topics, in the practices of evaluation and of course in the structuration of the practices of interdisciplinarity 'out there' in the research fields themselves as well as in universities and research performing organisations. That was already very well described in a chapter in a publication by the OECD in 1982 with the telling title 'Communities have problems and the university has departments' (OECD 1982). In this regard, it is interesting to note that consciousness is rising and that the support to the genuine integration of SSH research to science and even technological development has now become widely debated (FET Advisory Group 2016) because it is increasingly recognised that '*the real-world research* *problems that scientists address rarely arise within orderly disciplinary categories, and neither do their solutions*' (Palmer 2001, VII).

The Way Forward for a Genuine and Effective Policy of Interdisciplinarity at European Level

At this stage of the implementation of the SSH integration policy in Horizon 2020, two main conclusions can be drawn.

The first and obvious one is that in order to succeed, interdisciplinarity must have a long-term policy and the means behind this policy. The role of the European Commission in this regard, as any funding agency, is crucial (Lyal et al. 2013; van Rijnsoever and Hessels 2011). The policy must be long-term and sustained because the social and organisational forces at play against interdisciplinarity or indifferent to interdisciplinarity are formidable (Raasch et al. 2013) given the sheer nature of science as a field of struggles like any other type of field (Bourdieu 2004). Much has already been written about the requirements of such a policy (for instance see Horvat 2004; EURAB 2004c; Horizons for Social Sciences and Humanities 2013, 19–20), nevertheless at mid-term stage of Horizon 2020 it appears that this policy should have six pillars:

(1) Enhancing interdisciplinarity in the work programmes of the FP. This means a collective work within the European Commission services and beyond (with the Programme Committees, the Expert Advisory Groups, the SSH communities, etc.) to select carefully the topics for research and draft them carefully so as to allow genuine interdisciplinarity and therefore an appetite for collaboration between SSH and STEM researchers. Quality of drafting here is much more important than the quantity of topics selected for SSH integration. The Commission could also assess the potential for bottom-up interdisciplinary proposals in open topics in broad areas such as health, environment, industrial development or transport in order to better know the capacities for interdisciplinarity available (or not) in these areas.
(2) Improving the evaluation process. First, interdisciplinarity through the actual integration of SSH research should be clearly included in the evaluation criteria of at least all topics which have a 'SSH flag'. Second, the evaluation panels of 'SSH flagged topics' should be strictly monitored in order to make sure that the interdisciplinary competencies required from evaluators to assess the integration of SSH are gathered. This means an effort to scan the potential for interdisciplinary experts in the EU and outside the EU.
(3) Monitoring interdisciplinary results of the FP. The field of interdisciplinarity needs to be objectivated by facts. Regular reporting about the integration of SSH in the FP and it benefits is therefore necessary.
(4) Analysing the actual practices of interdisciplinarity in the FP. Monitoring the state of interdisciplinarity in the projects funded under the FP does not allow to

assess the actual practices of interdisciplinarity in these projects. There is a need to analyse these practices in order to assess the levels of multi/inter/trans disciplinarity of EU research and draw lessons for more or less policy efforts in all research fields. This is a very important aspect of this needed policy because the knowledge on the practices of interdisciplinarity in EU funded projects is currently very low.

(5) Training and education in interdisciplinarity. The European Commission cannot only support interdisciplinary research with funds if at an earlier stage there is obvious caution or disregard for interdisciplinary education and training, in particular, because scientists have clearer and more stable career prospects in disciplinary fields. The FP should, therefore, include support to interdisciplinary education alongside support to interdisciplinary research activities. Closer cooperation and coordination with DG EAC and the MSCA scheme are advisable in that regard.[7]

(6) Integrating interdisciplinarity within the communication activities. There is no question of propaganda in favour of interdisciplinarity but rather a need for many more reasoned exchanges on the benefits and disadvantages of interdisciplinarity. Besides, the European Commission should organise spaces for encounters between SSH and STEM researchers in research areas where potential synergies or actual attempts at cooperation can be observed and possibly supported.

(7) The programme Responsible Research and Innovation (RRI) should also support the application of interdisciplinary research combining SSH and STEM perspective.

In order to support an ambitious implementation of interdisciplinarity, an advanced concept of technology in its broader societal context should be promoted that encompasses the different perspectives that are necessarily to be taken for developing solutions for societal challenges, as shown for instance in the graph (Fig. 1).

The second conclusion relates to the broader SSH policy of the European Commission. The major policy shift introduced by Horizon 2020 marked a clear departure from the two-legs policy established between FP4 and FP7. The underlying question is whether interdisciplinarity in the FP can succeed without a solid proper space for SSH collaborative research. It has received no definite nor scientific answer but it is interesting to note that all STEM disciplines have kept their proper research space under Horizon 2020 in all three pillars, while SSH has their own space in the ERC only. The positions of EURAB (2004c, 2005) and of the Horvat report (2004) on the need for a proper space for SSH were very clear. This debate was also central in the Lithuanian Presidency conference which led to the

[7] Not to mention, of course, that only a very small percentage of PhDs choose the academic career track. Therefore, for a large majority of PhD holders, interdisciplinarity competence is essential in their non-academic professional life and is likely to be beneficial to the process of innovation which the Framework Programmes are supposed to support.

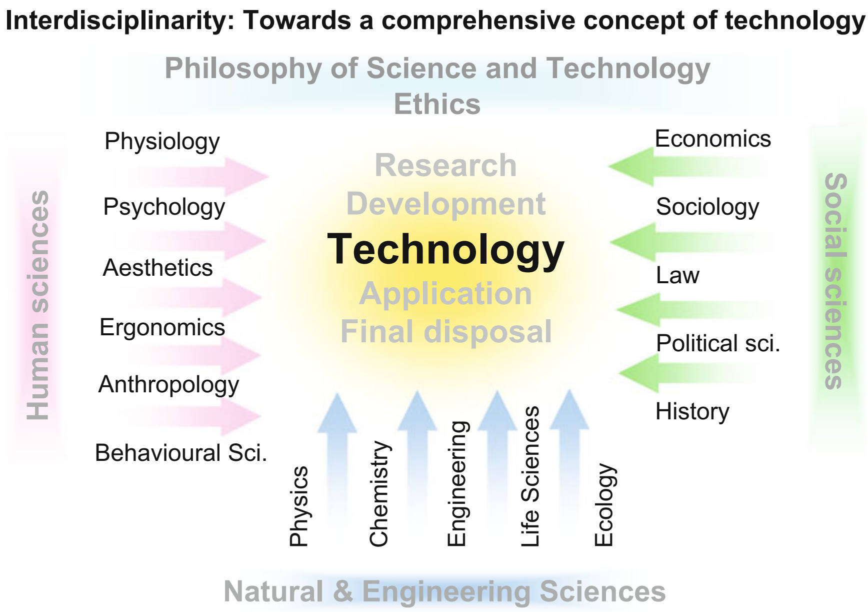

Fig. 1 Interdisciplinarity: Towards a comprehensive concept of technology. *Source* Horvat (2009, 17)

important Vilnius declaration of 24 September 2013, under the auspices of Helga Nowotny, also former Chairwoman of EURAB, which defined conditions for the successful integration of SSH into Horizon 2020. The Vilnius declaration states that '*the effective integration of SSH requires that they are valued, researched and taught in their own right as well as in partnership with other disciplinary approaches*' as in the EURAB publications. Out of nine recommendations three (recommendations 2, 3 and 4) support a comprehensive SSH research policy. It also recalls that '*European Social Sciences and Humanities are world class, especially considering their diversity. They are indispensable in generating knowledge about the dynamic changes in human values, identities and citizenship that transform our societies. They are engaged in research, design and transfer of practical solutions for a better and sustainable functioning of democracy*'. The debate is therefore open and would deserve to receive more contributions as Horizon 2020 unfolds and implements its new approach.

Final Remarks

The European Union set its ambition for interdisciplinarity as from FP4 given the sensitivity of European research policy to policy relevance and societal impact. For long, the evaluation criterion about the impact of the FP funded European research on policy and society was and still is a useful element of integration of some social, economic, political and cultural research elements in the evaluation of proposals in collaborative research. At the same time, there never was at FP level a genuine policy for interdisciplinarity despite generous rhetoric in favour of SSH integration and laudable efforts to establish the relevance of comparative SSH research at European level. The forces against interdisciplinarity between SSH and STEM disciplines are strong but should not be under-estimated nor discarded since they positively bring a number of solid arguments to the building of science, which is of common interest not only to scientists but also to all European citizens. Interdisciplinarity is not an obligation, it is a choice and the why, how, where and when are important questions for its relevance.

At the same time, a large number of people active in science policy believe that the EU should tackle interdisciplinarity with more determination. Not interdisciplinarity always but where it is worth and provided the conditions to support it are improved. Inspired rhetoric without a clear long-term policy will not allow interdisciplinarity to foster. The ambition should not be to replace disciplinarity with interdisciplinarity but to find the right blend of both activities in all scientific fields. This is the reasonable lesson that the EU Framework Programmes tell us to follow and which should determine the policy for interdisciplinarity in the future.

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Science in an Age of (Non)Reason

John R. Porter and Bernd Wollenweber

Abstract In this chapter, we wish to reflect on some of the issues we see as affecting our work, how we see the ethos of our research institutions changing, the role of science in an age in which 'experts' are seen as an unnecessary luxury who stand in the way of popular and populist movements but in which, at the same time, people crave the products invented, developed and produced by such 'experts'. We take a structured approach that uses the norms of science defined by the social scientist Robert Merton (the so-called Mertonian norms) and examine how each of them is affected by the current climate for science. We also look at some cases—historical and current—to help specify the intrinsic and extrinsic challenges that a reason- and evidence-based approach to knowledge is now facing.

Keywords Mertonian norms · Scientific freedom and autonomy
Evidence-based facts · Fake news · Skepticism · Objectivity

Introduction

We are practising natural scientists who, in our daily work, are confronted with the issues facing our profession in 2017. We concern ourselves with plant sciences, food security and climate change and our interests run from basic understanding of biological processes at all levels of organisation from cells to (agro-) ecosystems. We often use mathematical descriptions and dynamic computer models of processes to help understand, give counter-intuitive insights into our theories and experiments, predict outcomes for new situations such as a changed climate and suggest

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phenotypes of crops that would be either higher yielding or have improved qualities, in terms of protein levels.

What are current threats to science? To answer this, we try to answer three questions:

1. What are the function(s) of the Mertonian norms?
2. How do the norms of society affect the Mertonian norms either in defining them or implementing them?
3. Do the Mertonian norms still have a role in the increasingly 'post-academic' science?

Our general conclusion is in some agreement with the postmodernist self-evident view that science is a socially constructed human process—it cannot be anything else as it is a human activity that simply reflects the way that humans think. This psychological fact is the main reason why science will survive and thrive in the future. However, we do not argue, as many constructivists do, that 'opinions' without evidence are as convincing or correct as evidence-based experimentation or unifying theories of natural phenomena.

The logical conclusion of 'science as a social construction' is that facts as objective truths do not exist and *ipso facto* the assertion that 'there is no such thing as a fact'; the problem being that this postulate is illogically circular as a fact is being stated in making such a statement and terminates logically in solipsism—since the only thing one can really be sure of is that something only exists in a personal context. There is a delightful story of an eminent logician, Mrs. Christine Ladd-Franklin, writing to the British philosopher Sir Bertrand Russell postulating the benefits of solipsism and concluding her letter with the comment that she was surprised that there were not more people who agreed with her view (Russell 1948).

So, what we do mean is that science will survive because drawing conclusions on the basis of knowledge and evidence is intrinsic to the way that human beings think—in other words science cannot be anything else but a 'constructed human process' but not in the trivial way meant by social constructivists.

Extrinsic Constraints to Science—The Changing Role of Society

Science can be defined as organised knowledge production by investigating phenomena via systematic observation and experiment, and the formulation, testing and modification of hypotheses, thereby acquiring new, or modifying existing, understanding. Science as organised knowledge is rational (communicated unambiguously), reliable (because it is based on reason) and specialised (based on empirical evidence from expert studies). Science is authoritative because it is evaluated by well-organised societal systems dedicated to knowledge production (institutions). Science nowadays is vital to health, wealth and human happiness and is a major element of the economy and has adapted more and more to the requirements of policy (Ziman 2008a). Whether this realignment is beneficial in the long run is open to question.

Different societies have and have had different political agendas for science (Ziman 2008b)—from *traditional societies* as hunter-gatherers to agricultural empires, where production of knowledge was not an organised social activity; to *theocratic* societies, where the role of science was to sustain the authority of religious beliefs; and *totalitarian* societies in which scientific activity was and is incorporated into the credo of the state apparatus so as not to conflict with the state's ideology (Roll-Hansen 2015). Finally, in *technocratic* societies, scientific research is linked to technological innovation and undertaken by companies and public research organisations seeking to profit economically from the knowledge produced (Ziman 2008b).

Changing cultures over the last hundred years or so have had a large impact on the institutions pursuing science as well as on the nature of research. Thus, academic science as pure *basic* research at universities has been facing competition from post-academic science in the form of *strategic* research mainly done in government labs and *applied* research with and within the industry. Thus, what science gets done is nowadays largely driven and shaped by governmental, financial, industrial, military and legal demands for knowledge and products. Public perception and science policy are both questioning increasingly the trustworthiness of science and dividing resources between 'theoretical' and 'practical' science, often under the rubric of 'societal problem solving'. This last definition would be the one that resonates most closely with a western public's view of the reason—more the need for—science. In this way, society is defining ever more a role for science that is consistent with predominating political agendas, as exemplified by the move from politically, but perhaps not culturally, neutral 'theoretical' science for the common good to 'practical' science dealing with specific technological problems.

The autonomy of science (and of liberal democracy) can be undermined as exemplified, perhaps *in extremis*, by the regimes in Nazi Germany and in Stalinist Soviet Russia (Graham 1992; Soyfer 2001; Roll-Hansen 2015). In response, scientific freedom and autonomy were defended *inter alia* by the philosophers Karl Popper and Thomas Kuhn, although with different aims (Fuller 2003). Robert K. Merton contributed importantly to this debate by introducing four regulated principles or norms for the ethos of science (Merton 1942). As science is not only knowledge in itself but the product of society, these epistemic norms have been also linked to social norms. They can be summarised as CUDOS: Communality: All scientists should have common ownership of scientific knowledge because scientific findings are always a product of collaborative efforts and 'constitute a common heritage in which the equity of the individual producer is severely limited'. Universalism: Scientific work should be evaluated on the basis of 'pre-established impersonal criteria: consonance with observation and with previously confirmed knowledge' because scientific validity should be independent of the sociopolitical status and person. Disinterestedness: Scientific work should remain uncorrupted by self-interested motivations. It is defined by objectivity, reliability and credibility; its results as facts and theories lead to paradigms and models of the working of the world and wider and act for the benefit of a common scientific enterprise, rather than for the personal gain of individuals within them. Organised Scepticism: Scientific facts and results need to be tested and justified, and should be exposed to 'detached scrutiny of beliefs in terms of empirical and logical criteria' before being accepted. This means that scientific findings are presented transparently so that they can be assessed and judged by society according to accepted standards and criteria. An important question to ask however is whether these Mertonian norms still have a role in post-academic science.

Do the Mertonian Norms Still Have a Role in 'Post-Academic Science'?

Although creating knowledge, post-academic science does not fully conform to Merton's norms (Ziman 2008b). In academic science, the norm of Communality requires scientists to produce evidence for a specific hypothesis. References are limited to accepted and cited literature. In post-academic science, the norm of Communality is extended and replaced by 'Communication'. The need to get the latest information via alternative means of communication such as preprints frequently enables the availability of results before being assessed completely by reviewers. This increase in popularisation of science comes with the danger of misinterpretation and can lead to compromised credibility. In addition, scientists are increasingly pressed by politicians/industry for so-called quantitative assessments of their careers and output known as 'bean-counting' via, *inter alia*, H-index, impact factors, number of patents. In fact, the scientific role played by such indices is illusory because hiding within the comfort zone of quantification does not necessarily furnish any strategic usefulness. The established peer review system for scientific manuscripts has increasingly been questioned but without satisfactory suggestions as to its replacement (Schroter et al. 2008; Siebert et al. 2015).

Academic freedom is constrained as contracts with companies who finance research frequently demanding that all research activities must be recorded systematically and be kept secret. The argument that is often made is that companies have invested large resources in developing the scientific products demanded by society such that they earn the right in law to patent and restrict the divulgence of research results. Two comments are relevant here—the first is that among the legal criteria for patents are that they are rewards for particular types of invention and not for the amount of effort needed to develop the products of research; the second is that for many years Switzerland had a strict no-patent policy in an attempt to foster the development of fledgling chemical and later pharmaceutical industries (Vatiero 2016)—the message here being that start-ups are not likely to benefit from strict intellectual property agreements and it is mainly more mature concerns looking to protect their market share that finds them especially useful.

While in academic science the norm of Universalism applies, in post-academic science, Universalism is replaced by Utilitarianism. Researchers are constantly reminded that their work is sponsored and that the application of research results, therefore, must be profitable in a narrow sense. In academic science, the norm of Disinterestedness applies. In post-academic science, it is dismissed because of funding constraints and disclosure agreements by the industry which could lead to conflict of interests (Ziman 2008a).

A sceptical view of research, which has been performed, is an important norm in academic science. It is instantiated by asking the questions to be researched (falsification of hypotheses sensu Popper) and setting the answers obtained into a context (i.e. paradigms sensu Kuhn). Post-academic science does not apply this norm fully as it is too dependent on funding agencies and politics such that proposals are based on work to be done. Thus, contract research is ordered by funding bodies who request proposals which still have to present their originality but limit possibilities for creativity because these proposals have to fit into politically defined programs. Often nothing new can be started until a grant for a specific project is obtained. Fierce competition for funding and evaluation of these proposals can lead to nepotism, plagiarism and conflicts of interest. The reproducibility of scientific investigations is an integrated part of the scientific method. There has been increased awareness that some experiments cannot be replicated (Baker 2016) and efforts to overcome the 'replication crisis' have been discussed (Schooler 2014).

Science and Policy

Distinct scientific disciplines have merged with technological disciplines. The outcome is that basic and fundamental research (original investigation of phenomena without an application) has merged with strategic and applied research and development (R&D; knowledge towards a specific aim, products or practical gains) emphasising economic goals and achievements. 'Techno-science' (sensu Latour 1987) has become a substitute for science, signalling the view that the difference between science and technology is not important (Roll-Hansen 2015). As a result, society via science policy increasingly demands that science is extended by R&D and contributes to innovation and creation of wealth. In totalitarian states, it can become an instrument of oppression while in democratic countries it is often influenced by the competing interests of government policy and the industrial economy which in turn inhibits a vision of any other role of science in society. Thus, as research priorities and programmes are defined and the performance of scientists are evaluated, science has become identical with its usability and Merton's norms have been replaced by utilitarianism writ large. Academic freedom and autonomy, while dependent on liberal democracy, have become more and more obsolete as academic science is losing its institutional independence.

However, basic and fundamental science is still relevant and beneficial for society as a source of reliable, rational, unbiased and independent expertise. The norms of originality (novelty) and scepticism (appreciation of the strengths and weaknesses) of academic science still apply, as results need to be tested, justified and shared with others (communalism). For example, the impact of global warming was at first mostly overlooked, i.e. regarded as academic science, but the science of climate change has since become utilitarian and a highly political topic. Post-factual politics as typified by the recent Brexit campaign in Great Britain and the US presidential campaign are deeply disturbing (Hossenfelder 2017). Thus, the role of science in political decision making has changed, as science policy has become politicised science. This is exemplified by the disdain for 'so-called' experts on the evidence of anthropogenic sources of climate change. The New York Times environmental correspondent has postulated that we now live in a 'fact-less society' in which opinions carry as much weight as evidence and personal narratives and experiences are seen every day in social media and news programs—the personal has become the message of the media, to misquote McLuhan (1967).

On the other hand, evidence has come under attack from interest groups opposed to doing anything about issues such as climate change or the use and introduction of the products of biotechnology in Europe—on the basis that the evidence is either not strong enough or that actions to deal with these issues are not warranted. Such pressure from lobby groups have been seen many times before, as exemplified by Naomi Oreskes and Erik Conway who in their book 'The Merchants of Doubt' have shown how the public, on issues such as the link between tobacco and cancer, acid rain, the ozone hole and global warming, has been influenced using replays of the same tricks and methods to discredit scientific research that threatens private interests (Oreskes and Conway 2012). Thus, scientists were used to dispute findings of other scientists. Alternative 'facts' and explanations for observations were provided, thus creating the impression in mass media that there are more sides to every question.

The situation is fluid, however—the IPCC Fifth Assessment Report was met with little opposition from the fossil fuel lobby when compared with the Fourth Assessment Report, since one cannot really pull the same stunt twice. The case with biotechnology where medical biotechnology engenders almost no resistance in Europe, whereas agricultural biotechnology meets considerable resistance, shows again the two-eyed attitude of society towards science. Issues related to these two ends of the spectrum are the questions of who benefits, the status and use of patenting and a bucolic view of agriculture.

Intrinsic Constraints to Science—Agronomy and Food Production as an Example

Agronomy is the applied science of crop and plant production for food, fibre and energy. It is intrinsically multidisciplinary—it encompasses plant genetics, plant and crop physiology, climate and meteorology and soil science and expresses these interactions in terms of interactions between genotype (G), environment (E), management and technology (M).

Agronomy has to anticipate the contributions that can be made by novel developments in other disciplines, such as gene technology, remote sensing, systems theory, software developments as important for predictive simulation modelling. Agronomists need to have knowledge of biology, chemistry, ecology, climate, soils and genetics. Agronomy also has to move away from traditional approaches towards a more integrated focus on the multiple functions of agro systems rather than on short-term yield alone, while maintaining its primary focus on understanding, describing and predicting the consequences of sustainable primary production. A tangible and acute issue for agronomy is that of raising the productivity of cropping in the face of climate change and more variable conditions for crop growth. How might agronomy and how might other disciplines approach this issue?

What is to be absolutely avoided in this debate is ideology, typified by the current conventional wisdom that '-omics' has the major part to play in improving yields as exemplified, for example, by the claim that improving Rubisco's carbon-dioxide-fixing capability by genetic engineering is able to enhance crop productivity significantly on its own (Ellis 2010). There is a current tendency towards genetic determinism in many areas. The 'gene-as-determinant' tendency is not driven by scientific principles but by large corporations that see both profit and market control in biotechnological products such as genetically modified organisms (GMOs). In order to claim originality, usefulness and thus patent rights require the establishment of the conventional wisdom and ideology that genes dictate nearly all properties of organisms and secondly that using biotechnological tools creates inventions. This 'gene-as-determinant' concept is also highly scale dependent; the notion that genes control processes may apply at the level of individual plants. However, the frequency with which genes appear at the level of a population depends on processes such as competition, symbiosis, parasitism that affect gene frequencies—in other words the field of population genetics.

Ideologically-based plant breeding can lead to disaster (Soyfer 2001). In the 1920s, the Russian botanist Nikolai Vavilov identified the historic centres of variation and origin of crop plants. For this, he was awarded the Order of Lenin. However, in 1940 he was imprisoned and later died on the pretext that he was an advocate of the 'bourgeois pseudo-science' of genetics (Janick 2015). The reason for such a human and scientific *volte-face* lies with the 'peasant scientist' Trofim Denisovich Lysenko, who was helped by Vavilov through the Soviet scientific hierarchy to become a Fellow of the Ukrainian Academy of Sciences, president of the Lenin Academy and thereby administrator of Soviet agricultural science under Joseph Stalin. Lysenko rejected genetics and the classical inheritance theory for which Vavilov was an exponent, for the almost 'occult' hybridization theory that approached Lamarckism; that the environment during a life cycle affects hereditary characteristics which are then passed on to subsequent generations (Soyfer 1989).

We know today that there is evidence that the perception of environmental stress induces signals that in turn induce changes in the activity and/or expression of epigenetic regulators. Epigenetics is ‘the structural adaptation of chromosomal regions so as to register, signal, or perpetuate altered activity states’ (Bird 2007). While the DNA sequence is mostly static and identical for essentially all cells of a given organism, chromatin structure is highly dynamic and cell-type specific. It has recently been shown that epigenetic regulation is based on the structure and confirmation properties of chromatin modulated by small RNA’s, methylation of DNA and different modifications of histones. The accumulating knowledge on chromatin structure and dynamics resulted in the concept of a chromatin ‘code’ (Thellier and Lüttge 2013). It has been suggested that this code can store information as epigenetic memory (Eichten et al. 2014) while other changes can lead to transient acclimation responses (Chinnusamy and Zhu 2009). However, whether these epigenetic modifications are involved in intra- or even trans-generational responses in crops is an important question that needs further investigations. On the other hand, there may be cases where non-nuclear DNA, the structure of which can be changed during ontogeny, could lead to inherited phenology’s giving a *sotto voce* of support for the theories of Lamarck.

Epigenetics provides a small potential for ‘Lamarckism’, but in the Soviet Union of the 1930s, Lysenkoism was the conventional wisdom because it was in agreement with Marxist theory that the environment was totally decisive for things as diverse as wheat yields and societal development. The deployment of Lysenko’s theories contributed to famine in the Soviet Union in the 1930s. Lysenko has become an unpleasant footnote in the history of genetics but his story shows the danger of basing plant breeding on ideology, from whichever side of the political spectrum it comes (Roll-Hansen 2005). Nevertheless, inspired by the connection between epigenetics and inheritance there has been a recent rebirth of ‘Lysenkoism’ and calls for rehabilitation of Lamarck and Lysenko by many scientists in Russia as documented in a recent book by Loren Graham (Graham 2016). In addition, the conversion of spring wheat into winter wheat and vice versa has recently been discussed (Li and Liu 2010). Incidentally, biotechnology policy in the USA has been linked to the ‘ghost of Lysenko’ (Miller 1995). The same has been applied to global warming (Ollier 2009).

Improving global food security in the face or climate change and population growth is a many-faceted challenge that is not even restricted to the production of food, let alone the production of the basic food commodities like rice, wheat and maize. It encompasses the demand side of the equation (i.e. diet and animal feeds) as much as the supply side; it has to take account of demographic shifts from rural to urban living and how we could process and use waste. In the end, it requires a shift in values from food and its production being a private and commercial activity to becoming more of a public–private partnership. GMOs cannot solve the global problem of feeding people. This can only occur via an alliance between G, E and M brought about by more interdisciplinary than single-disciplinary research efforts.

Interdisciplinary projects are seen as unconventional and are often not funded. The authors have argued for the need for more multidisciplinary research approaches to tackle the study of climate change on crop yield and quality (Wollenweber et al. 2005). This is important because, as scientific disciplines have become increasingly diversified, a more complete understanding of the mechanisms by which genetic and environmental variation modify grain yield and composition is needed. Despite recent achievements in conventional plant breeding and genomics, the rate of increase of crop yields is declining. There has been recent progress in individual scientific disciplines, but future paradigms need to be characterised by multidisciplinary ‘joint’ efforts in order to achieving sufficient grain yield in the future as advances within a single scientific discipline cannot solve these challenges. Genomics, proteomics and metabolomics may increase our understanding of the regulation of different physiological processes and mechanisms of resistance to stress, but they do not show us the bigger picture.

The capital-driven focus on ‘-omics’ and genes has led to losing two generations of young researchers who know about how whole plants grow and develop in populations in the field—where the best agricultural research has always and always will be performed. It is always easy to allow areas of science to go into decline but it requires much more effort to rebuild disciplines of science once they have gone. The situation with molecular biology in agriculture is that there have been 30 years of ‘promises and more promises’ but with no tangible outcomes to date, except for herbicide resistance and single gene pest resistance. And there will not be major breakthroughs in the areas that really matter such as adaptation to climate change because the methods being employed are, in the words of Wallace and Gromit ‘the wrong trousers to be wearing’. A recognition of the balance and interactions between genotype, environment and management is the intelligent solution to feeding the growing global population (Porter and Wollenweber 2010).

Conclusions

The culture for science in an age verging on the equivalence of opinion and evidence-based knowledge is not good now but it has been much worse in the past and in the end science wins because humans use evidence-based thinking in their daily lives and that is what science is. It is humanly constructivist in the largest sense. We have asked three questions:

1. What are the function(s) of the Mertonian norms?
2. How do the norms of society affect the Mertonian norms either in defining them or implementing them?
3. Do the Mertonian norms still have a role in ‘post-academic science’?

Our answers are:

Current science is increasingly driven by a number of extrinsic and intrinsic constraints to its norms and methods. Scientists, at least the most productive of the tribe, are principally driven by curiosity and a desire to be ‘the first’ to discover or describe and publish a phenomenon (Communality, Universalism). They are generally not much interested in huge sums of money as reward (Disinterestedness) and thus have an ambivalent attitude to the 'corporate culture' that has come to be the driving *leitmotif* of many faculties of post-academic science in those universities who depend on a combination of public and private resources to keep their organisations afloat. The fact is that large organisations, be they public or private, are extremely bureaucratic and many universities have moved far from the original Mertonian norms.

It is probably possible to harvest the industrial interest on previous intellectual capital generated from a 'curiosity culture' for a certain length of time. However, many research funding organisations have essentially started to use university researchers as contract consultants to deal with the problems and issues that are short term and frankly mostly boring for research scientists, with success rates for research applications in many cases below 10%. No industrial concern could tolerate such a waste of talented human resources. The fact is that the notion of 'corporate culture' as practised in universities is in our view one-eyed. It has implemented the competitive aspect *in extremis* in terms of making extremely talented people compete constantly for the limited available funds that often have to cover their own salaries whilst at the same time ignoring the intellectual waste, over-management and burdensome bureaucracy that now characterise many institutions of higher learning.

This situation has led to a culture among scientists to give as little output for as much funding as possible and then use the money to do things they think of as interesting; the moral quandary for scientists is how little they can get away with in using short-term funding yet still do some interesting work—this loss of innocence is a direct result of politicians and industry not understanding or even ignoring the Mertonian norms. This tendency, in the end, is intellectually corrosive and ultimately short-sighted in its application of a 'corporate culture' in extremis in universities—the 'tail wagging the dog syndrome'.

Science has to draw lessons from the past and has to identify and criticise evident pseudo-scientific claims related to faith and religion such as climate change denial, biodynamic agriculture, Lysenkoism, scientific creationism and Intelligent Design. The age of enlightenment (coined by the German philosopher Emanuel Kant), also called the age of reason, brought about by the scientific revolution replaced superstition and religious doctrine in the seventeenth century. If significant advancements in science are to be maintained in the twenty-first century, a new age of dispassionate reason has to include a better dialogue and understanding between science and society. The way ahead is that society, the public and their leaders, have to understand and accept that science provides reasonable, evidence-based facts and not 'fake news'. Global warming has placed scientists in the forefront of the political debate. The power of scientific reasoning lies in its ability to make accurate and precise predictions on basis of systematically acquired evidence. Scientific controversy and organised skepticism are intrinsic norms of scientific endeavours. Threats to the objectivity of science have to be acknowledged and dealt with. A better awareness of scientific pitfalls and balance between academic and post-academic science has to be implemented, more long-term funding for interdisciplinary research efforts and for gifted scientists have to be implemented.

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New Perspectives in Genetic Therapies

Alain Fischer

Abstract Advances in genomics over the last years have opened new perspectives in medicine. Applications to the diagnosis of inherited diseases and cancer as well have become a reality, while therapeutic applications emerge. This started with the safe production of therapeutic proteins by genetic engineering of cultured cells now followed by gene therapy. Introduction of therapeutic genes into diseased cells offers the potential to cure monogenic inherited diseases and also to better fight cancer. Thus it is in these two areas that the first proofs of efficacy have been obtained. Ex vivo retrovirus-mediated gene transfer into autologous hematopoietic stem cells has been shown to provide sustained correction of three forms of severe primary immunodeficiencies in about 120 patients up to now. This approach is now extended to the treatment of more prevalent conditions such as hemoglobinopathies. ln vivo gene transfer based on adeno associated viral vectors is being used with some success in the treatment of hemophilia B and of inherited retinopathies as well while being now tested with promise for inherited neuromuscular diseases. Injection of autologous, ex vivo modified T lymphocytes, engineered to express a chimeric antigen receptor (CAR) recognizing a membrane tumor-expressed antigen has been shown to control some forms of leukemia, a promising entry into the treatment of cancer by gene therapy. Genome editing based on engineered nucleases (such as the CRISPR/Cas 9 system) offers additional hopes for gene therapy either through gene inactivation or gene modification (correction). This new technology, however, still requires additional testing to assess its efficacy, notably in nondividing cells as well as its safety because of the potential risk for « off targets ».

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Some have advocated that this latter technology could be used in the future to fix deleterious mutations in early embryos or even improve health characteristics by gene modification! This approach appears, however, as medically useless in most cases while ethically highly questionable since it implies modification of the germ line genome.

Keywords Genomics · Diagnosis of inherited diseases and cancer
Therapeutic applications · Genetic engineering · Immunodeficiencies
In-vivo and ex-vivo retrovirus-mediated gene transfers · Ethics

Introduction

The second half of the twentieth century has been marked in biological sciences by the advent of molecular genomics that is the description at the molecular level of genes and their products as well as of several aspects of their regulation. Innovative technologies underlined these advances; in return, translated advances occurred in medicine. Diagnostic tools for infectious diseases (identification of genomes of infectious agents by using the polymerase chain amplification-PCR-technology), for identification of mutations associated with inherited diseases and cancer became part of medical workup of patients. Therapeutically wise, since the 80s, engineering of protein production by cultured cells following gene transfer became a safe source of proteins of therapeutic interest such as insulin, coagulation factors, growth hormone, and above all monoclonal antibodies. Large-scale manufacture of such products has become a major field of health industry and remains by far the largest contribution to medicine of molecular biology and genomics. Still, gene therapy as proposed in the early 70s (Friedmann and Roblin 1972) appears as another attractive and somewhat spectacular application to medicine.

Somatic Gene Therapy

The concept is fairly simple. It consists of adding genetic material into patient's cells in order to alleviate or cure manifestation of a given disease. Somatic gene therapy, as applied today, implies that somatic cells only are targeted, sparing germinal cells. Originally, the concept was proposed with the idea to correct monogenic inherited diseases. It was further extended to the treatment of acquired diseases such as cancer or degenerative diseases, based on the acquisition of a new function of cells through the introduction of a gene that can be at least, in part, artificial.

Despite claimed hopes and multiples attempts in the 90s gene therapy did not conclusively demonstrate efficacy at that time. Although adequate vectors (see below) were designed to introduce genes into cells, it appears that obstacles to success were largely underestimated. Such hurdles include an adequate understanding of molecular pathophysiology of the disease to treat, the design of an adequate strategy, the ability to target the appropriate cell/tissue in vitro or in vivo, to achieve persistence of and expression at an adequate level of the therapeutic transgene without causing harm and, finally the avoidance of immune reactivity against the vector and possibly the therapeutic gene product (Orkin and Motulsky 1995).

Significant advances on these many topics led to improvements in gene therapy and achievements of success around the year 2000. Two types of vectors are in use for gene transport as a function of the status of targeted cells. Treatment of mitotic cells (such as the hematopoietic system) requires achieving integration of the transgene into cells' genome in order for this gene to be replicated each time cells divide. Retroviruses (such as γ retrovirus or lentivirus) naturally induce integration of their genetic material into the genome of infected cells. Vectors have thus been derived from such viruses by multiple sets of modifications that prevent in vivo virus replication and, in principle, avoid deleterious effects of these viruses (Mann et al. 1983). Lentiviral vectors turn out to be particularly efficient to transduce cells, notably those that are not cycling at the time of infection, but that need to divide such as hematopoietic stem cells (HSC) (Naldini et al. 1996). In order to achieve gene expression, initially, the viral promoter/enhancer contained in the long terminal repeat (LTR) of such viruses were used. Then, internal promoters for safety reasons explained below replaced them. Such vectors are utilized ex vivo to infect and transduce target cells such as HSC, lymphocytes, or potentially exploitable stem cells such as skin stem cells or other series of stem cells including induced pluripotent stem cells derived from patients' cells.

Another area of gene therapy deals with the modification of post-mitotic cells such as cells of the nervous system, muscles, liver, retina…. There is no need to achieve gene integration into the genome, thus viral (or non viral) vectors achieving gene entry and extra chromosomal persistence are desired. Adeno associated virus (AAV), that are naturally infecting humans (with little consequences) are adequate vectors since they can infect virtually all types of cells and lead to episomal persistence of the genetic material. There again, such viruses were modified to carry genes and a promoter while avoiding virus replication. Manufacture of large-scale AAV vector production has thus been achieved (Xiao et al. 1996). Non viral vectors based on liposomes, other lipid complexes or nanomaterial are also tested, although so far with more limited success due to the less efficient delivery of transgene to the cell nucleus.

Achievements

Proof of principle of success of gene therapy came from the field of inherited diseases of the hematopoietic system, more specifically from the treatment of severe combined immunodeficiencies (SCID), that are rare conditions characterized by defective differentiation of T lymphocytes. This is explained by two favorable circumstances: (i) the high rate of cell division of T lymphocyte precursors that multiply a poorly efficient gene transfer capacity and (ii) the very long life span of T lymphocytes in vivo, i.e., above 50 years. From 1999 onwards, two forms of SCID, i.e., SCIDX1 and adenosine deaminase deficiency (ADA) were accordingly treated. Patient's bone marrow progenitor cells were transduced ex vivo and then reinjected to patients (Cavazzana-Calvo et al. 2000; Hacein-Bey-Abina et al. 2010; Aiuti et al. 2009). This approach led to successful and sustained correction (for > 18 years) of the T cell immunodeficiency, enabling patients to live normally. These very first successes of gene therapy provided a proof of principle that gene therapy can indeed be useful. First results were nevertheless marred by the occurrence in some patients with SCIDX1 of vector-causing T cell leukemias (Hacein-Bey-Abina et al. 2003). Although all but one patient who developed this adverse event were cured of leukemia and still benefit from gene therapy, it led to interruption of such clinical trials. It was then understood that the viral LTR (used to induce transgene transcription), that contains a potent enhancer able to transactivate oncogenes if the integration of the vector in the genome took place in its vicinity. In order to get rid of this risk, new vectors were thus designed so-called self-inactivating vectors (SIN), in which the LTR enhancer element was removed and instead an internal promoter added. Since, such SIN vectors, including more potent lentiviral (HIV) derived SIN vectors have been used to safely and efficiently treat patients with SCIDX1 but now also other primary immunodeficiencies such as the Wiskott Aldrich syndrome (WAS) (Aiuti et al. 2013). About 120 patients have now thus benefited from this approach worldwide.

Gain in safety and efficacy as well logically permitted to consider treating other inherited diseases that affect (at least indirectly) the hematopoietic system. Two neurodegenerative diseases in which the microglia (macrophage-derived) are affected have thus been considered and treated. Adrenoleukodystrophy (ALD) and, more recently metachromatic leukodystrophy (MLD) are two devastating diseases because of progressive demyelization. Respective ex vivo gene transfer into HSC by using lentiviral vectors led to sustained stem cell transduction and expression of the transgene in a fraction of leukocytes with detectable clinical effect (Cartier et al. 2009; Biffi et al. 2013). For MLD, HSC transduction was designed to induce the presence of multiple copies of the transgene so that modified cells express supra-physiological level of the defective enzyme, a strategy that likely accounts for a remarkable and sustained efficacy (Biffi et al. 2013) without jeopardizing safety. One step further has been recently achieved by the treatment of sickle cell disease (SCD). Ex vivo lentiviral mediated gene transfer of the β globin gene (mutated in SCD) led to stable expression of normal hemoglobin and interruption of transfusion 1 year after gene therapy in one patient (Ribeil et al. 2017). This positive preliminary result relies on the addition into the vector of the locus control region sequence enabling restricted expression of β hemoglobin to the erythroid lineage, thus avoiding toxicity.

Retroviral vectors have also been successfully used in a recent past to convey to T lymphocytes a chimeric antigen receptor (CAR) combining a ScFV specific for the B cell CD19 molecule to transducing modules that enables T cells upon binding to CD19+ B cells to be activated and kill the B cells. Thus, armed autologous T cells kill leukemia B cells. This approach has been shown to be efficient, albeit somehow toxic because of the severe inflammation induced to control acute, chronic B cell leukemias as well as B cell lymphomas while being safe in terms of mutagenesis (Khalil et al. 2016). This methodology may be further extended to treat other malignancies provided that there will no harm generated on non-corresponding malignant cells or that T cell receptor recognizing elements are used in the CAR.

In Vivo Gene Therapy

Adeno associated virus vectors (see above) have been used with some success to treat hemophilia B (factor IX deficiency) (Nathwani et al. 2014). Utilization of an AAV subtype (AAV8) in non-preimmunized people by intravenous injections has permitted to achieve sustained (> 3 years) detection of factor IX in plasma at a level sufficient to reduce or even avoid factor IX injection (Nathwani et al. 2014). Transduced hepatocytes account for factor IX production.

No safety issues have been noted with the exception of a reversible mild hepatitis in some patients caused by the immune response to the virus. This approach is likely to be extended to the treatment of hemophilia A and possibly other deficiency in secreted proteins. AAV vectors are also used to provide therapeutic gene defective in inherited retinopathies causing blindness such as Leber's Amaurosis (Bennett et al. 2016). Subretinal injection of AAV particles enables infection of retinal cells (pigmented epithelium, cones, and rods), delivery of the gene and its expression. Sustained clinical benefit has indeed been observed (Naldini 2015) as a basis for further development of early therapy prior loss of retinal cells. Clinical trials with promising results are ongoing for inherited neuromuscular diseases such as mucopolysaccharidosis or spinal amyotrophy based on AAV-based gene transfer following brain or intravenous injection.

Genome Editing

What has been achieved so far by gene therapy with the aim to correct an inherited disease consists in gene addition, not correction of the gene mutation. Therefore, the therapeutic gene is not placed in its physiological environment. It does not matter if the gene is not under strict regulation. In contrast for a gene that is strictly regulated (as insulin for example) it will be required to have the normal gene in its physiological environment. This implies to fix the mutation or to introduce a full copy of the gene at its physiological site. Is this feasible? To do so, one needs to edit the genome at the place of interest, which means (i) to cut the DNA on both strains and

(ii) to induce introduction of a DNA stretch (encoding the normal sequence) by homologous recombination without modifying the surrounding DNA sequence. Over the last years, several nucleases were designed to cut DNA at desired places. These molecules have a nuclease site and a protein segment that binds specifically DNA sequence. Yeast derived meganucleases, Zn finger nucleases and finally, TAL effector nucleases derived from plants were constructed. Zn finger nucleases have already been used in clinical trials to inactivate genes by inducing imprecise DNA repair. Despite the fact that specificity of some of these constructs is now good, they are cumbersome to produce and not all DNA sequences can be targeted. The discovery and engineering of the CRISPR-Cas9 system derived from natural immunity of bacteria against phages constitute a breakthrough in the field because the Cas9 nuclease can be easily targeted to almost any sequence of DNA by a guiding RNA complementary to the sequence to target (Doudna and Charpentier 2014). The latter can easily and rapidly be designed. Combined with the introduction of the DNA template sequence for homologous recombination (HR), this strategy may potentially be amenable to correct every single gene mutations.

The technology has been used to fix mutations in iPS cells from patients with various genetic disorders while its usage to generate modified genes has been demonstrated in various models including monkeys. So, are we close to clinical application as tools to fix mutations causing inherited diseases? There are actually two issues that further need consideration:

(i) the risk of "off targets" creating unwanted damaging lesions in the genome of treated cells and potentially causing oncogene activation? This risk can be assessed in experimental settings by whole-genome sequencing of cloned modified cells. The rapid evolution of the CRISPR-Cas9 system, including analog systems based on related enzymes is likely to reduce this risk, that still needs nevertheless to be carefully evaluated case by case,
(ii) the poor efficacy of HR in non-cycling cells. The HR machinery is only expressed in cycling cells, thus fixing a mutation in cells such as HSC, or other nondividing stem cells or post-mitotic cells main remain a challenge.

The development of the CRISPR-Cas9 technology including its usage to generate genetically modified animal models has led to the idea of treating embryos affected with an inherited disease to prevent disease onset. Although this technology may become reliably feasible, which is not yet the case, its implementation will require for a couple at risk to perform in vitro fecundation (IVF) followed by pre-implantatory diagnosis (PID) before genome editing of the embryo. This does not make sense since PID as performed today logically enables to spare and re-implantate healthy embryos! There are only exceptional cases where this approach may be considered, i.e., when an inherited disease with recessive inheritance affects both parents or, if one of the parents carries biallelic mutation for a disease with dominant inheritance. Others are contemplating the idea to modify embryos to prevent diseases by inactivating the *CCR5* genes, for instance, in order to prevent the risk of HIV infection or PCSK9 to reduce cholesterol level…. Such germ line genome editing is today strictly forbidden. There is a worldwide agreement not to initiate this practice although some do not exclude in the future its application in restricted cases (see the recent report of the US National Academies for example) (US National Academies 2017). It should be remembered that, in addition to the fact it is not yet ready to use, and is useless in the setting of a risk of inherited diseases (see above), it may be harmful to modify a given gene (for instance CCR5 is useful in the context of the infection by the West Nile virus) while ethically speaking, modification of the germ line genome, by definition without consent from the affected generations who do not yet exist, is highly questionable. These issues should continue to attract careful attention from informed citizens in our societies.

Conclusions

Advances in technologies of genome engineering are rapid and therapeutic application to humans disease have begun with limited but significant success, that pave the way to further utilization of gene therapy in the field of inherited diseases and cancer. The technology of genome editing that is evolving even faster may further expand medical applications provided that residual bottlenecks are resolved. Application to germ line genome editing, as spectacular as it looks should be viewed with reluctance.

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Technological Innovation as a Factor of Penetration of Science in Society

François Guinot

Abstract Our civilisation is the first to enjoy such an immense wealth of knowledge and at the same time be able to focus it all on one major question. Our only source of unity is our ability to question. The theme chosen for this symposium '*Progress in Science, Progress in Society*' is in line with André Malraux's reflection. For nobody would consider making a causal link between these two types of progress without increasing the number of questions and without significantly questioning the concept of 'progress in society'.

Keywords Science and technology · Artificial heart · Technological innovation
Social progress · Symbiosis between science and society

Science and Technology: Different in Essence, Symbiotic in Development

Before embarking on any discussion, a clear definition of some terms that are used vaguely far too often, namely technology, invention and innovation, is necessary.

A technology is a coherent set of theoretical and practical knowledge, which ***combines*** *scientific knowledge, techniques and know-how to produce an object or an effect in a controlled manner.*

A technology is **a combination** of different types of knowledge. It becomes **an invention** if it is an **original combination**.

Nous sommes la première civilisation disposant de connaissances immenses, et faisant converger toutes ces connaissances sur un immense point d'interrogation. Notre seule unité, c'est l'interrogation.

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Technological **innovation** is clearly different. It is **a meeting** between an invention and a need felt by society. Innovation is a socio-economic and cultural construction built on an invention. If any one component is lacking, such as being economically impossible, socially unacceptable or culturally incompatible, then society will reject the invention.

Invention is the daughter of reason. Innovation stems from the complexity of individual and collective behaviour, which concerns the humanities, social sciences and philosophy.

Professor Carpentier of the French Academy of Sciences is the father of heart valves, a widespread innovation. The artificial heart called CARMAT is his latest invention. It integrates all scientific knowledge concerning the cardiac function. It also respects Starling's Law, which states that the heart must eject all the blood that it receives. Yet, emotions, shocks and pathological conditions all cause the blood flow to fluctuate. Whether it receives a little or a lot of blood, the heart must maintain blood pressure at an adequate level.

The Carmat is much more than a sturdy pump. It has many other features, in particular four different pressure sensors, an accelerometer triggered by changes in position, as in fighter planes, and an ultrasonic detector to monitor the movement of its walls, together with materials chosen to meet both mechanical and electrical requirements as well as for their compatibility with human tissue, all of which involve other scientific disciplines. The whole set has been miniaturised to become an object weighing only 860 grams.

This wonderful invention is not yet an innovation. Whether it becomes one will depend on the results obtained from the various studies, both clinical and socio-economic, currently under way, and on whether the various cultures will accept the implantation of an artificial heart.

This example is a good illustration of the special nature of the relationship between science and technology.

The combination of knowledge stemming from medicine, computer science, immunology or material sciences, coupled with techniques derived from combat aeronautics, and with the feats achieved in miniaturisation, clearly show that technological innovation is not a stream that flows naturally from a single source, namely science.

On the contrary, there are numerous examples of scientific knowledge that would never have become available without technology, and of scientific progress stemming from technological sources.

Science and technology are inherently different.

Yet, they exist in an increasingly close interaction. The internalisation of science in technology and vice versa technology in science, which began at the end of the nineteenth century, has now become so intense that the term 'symbiosis' applies. It is indeed 'a lasting association that benefits everyone'.

For far too long technological inventions have been considered as just simple 'applications' of science. Nowadays, since science and technology have become inseparable, we are too inclined to erase what distinguishes them by aggregating them in the polysemic noun 'techno-science'.

The word ‘applications’ used to enshrine an opposition between those who wanted to understand purely for their personal pleasure and those who expected to get some means for action, that is, between the noble world of ‘pure’, ‘disinterested’ science and the world of applied science, the abject, common world of profit.

Such dualism, which in France the very different ideology and sociological characteristics of the academic and industrial elites made more acute, has impeded relations between universities and private enterprise for a long time. It was once just stupid. It is now inconceivable.

The word ‘techno-science’ expresses the undeniable mutual internalisation of science and technology. I use it here in its descriptive sense. Some people use it to denounce ‘downstream controlled science’, which is completely subjugated to an unbridled capitalist system. They use ideology to undermine the concept of techno-science.

Others, scared of its unprecedented power, which could get completely out of control, depict techno-science as the Minotaur about to devour our society. This is just another type of ideology. Ideologies have never benefitted science.

Science in Society: Omnipresent and yet Hidden by Technological Innovation

Technological innovation, the carrier of scientific knowledge, makes science ‘useful’ by forcing society to develop and permeating our daily life. This is nothing new.

Thanks to the measurement of longitude at sea, which became possible in the eighteenth century, and after countless shipwrecks, ‘*the islands stopped floating around on the ocean of maps*’, as Pierre Chaunu said so beautifully. The surface area of the oceans ‘increased’ by 130 million square kilometres, that is, by 50%. Between 1750 and 1790, the number of ships, expressed in number of days at sea, increased tenfold. Science freed the seas.

Following Fritz Haber’s invention of ammonia synthesis in 1913, the catastrophic famine predicted for 1940 did not happen. All the experts had predicted it because of the depletion of a natural resource, guano from Chile, which would have caused a shortage of fertilisers. ‘*Haber makes bread out of air and water!*’ Science freed humanity from an age-old terror.

The contraceptive pill, developed by Djerassi and Pincus, turned the transmission of human life into a lucid act in 1960. Science allowed couples the freedom to decide the size of their family. Women acquired a freedom that nature had refused them.

Since then, technological inventions have become more sophisticated. They have ‘metabolised’ knowledge coming from very diverse scientific disciplines. This ‘metabolising’ has rendered the scientific content of innovation opaque, and thus has not facilitated its perception. As a result, paradoxically, **the technological object has introduced a great amount of scientific knowledge into our daily life by hiding it**.

Moreover, the number of technological inventions has increased at a constantly faster rate. Their combinatory nature means that from n separate components to be combined, the number of possible combinations is factorial n (n!). In practice, this acceleration creates another phenomenon, namely, **the forest of inventions hides the trees of science from society**.

This metabolism of science, which distorts its perception, this dynamic screen of innovations that hides it, leads one to believe that all science, other than finalised, will disappear.

This is an illusion.

Admittedly, we are no longer in the time of Plato or Aristotle, when 'episteme' and 'techne' were incompatible. Since Bacon and Descartes, and with the Enlightenment, 'useful science' has been idealised. As a tool for the liberation of man, it had to prove how it could benefit society.

The time taken to introduce a scientific discovery into an invention varies enormously depending on the field. However, the nature of man is such that he will eventually find out how to use any discovery made by fundamental science that he first sought to understand for his own pleasure. It took some time for the theory of general relativity to enter our daily lives. Now, it is everywhere in our GPS. The cashiers in our supermarkets would be amazed and perhaps even happy to know that scanning barcodes connects them to optical pumping and lasers!

How can we make society understand the essential role of an omnipresent yet hidden science?

Educating everyone to understand the strength of the scientific approach, and I would add, to appreciate the beauty of science is vital for a society. This reminds us of what Professor Debru said this morning. It also reminds us of the 'educated discussions', for which Professors Jean-François Bach and Alain Fisher made us feel the burning need. This is vital education for several reasons.

First, every society needs to attract a sufficient number of young people to develop the scientific disciplines, without which its capacity for invention will deteriorate. Our Academies are right to be concerned about the significant drop in recruitment numbers. At a time when symbiosis between science and technology is the norm and does not allow for any loss of time in interfaces, no society can rely entirely on others to drive forward the sciences that are essential for the development of its strategic sectors.

On the other hand, a democratic society needs citizens capable of making informed choices and not individuals subject to all sorts of folly, abused consumers or manipulated activists.

Consumers are abused by **distorted innovations** that no longer satisfy real needs, but are designed **to flatter desires that have been artificially created** thanks to huge advertising and marketing budgets. They are abused again when they are kept ignorant of the **planned obsolescence** of certain innovations.

Activists are manipulated when ideologies blanket any light of reason with their thick veils.

Education provides the antidote to such abuses. Through education, each individual, whatever their limits may be, can discover their ability to understand the world by the methodical use of reasoning.

Even if not everyone feels the need to build their existence on this ability, it is a feature of their citizenship. Thus, education is essential for both social cohesion and democracy.

Progress in Society: The Conditions for Humanisation

Homo sapiens is his own inventor. Hominisation is the result of a very long and gradual symbiosis between hominids and their tools. The Neolithic revolution saw the start of the humanising process, through the creation of society and the symbiosis between society and technique.

Humanisation is a process characterised by an increase in the degree of freedom enjoyed by human beings. Therefore, I understand by 'progress in society' everything that contributes to this increase in freedom.

The symbiosis between society and technology is a necessary condition. It implies social cohesion, guaranteed by the sense of direction on which a society builds its future, and which is widely shared among its members.

It also implies maintaining the ability to mediate by which a society can ensure that its choices are coherent with its chosen direction, and through which it gives itself the means to adapt to those that such and such a technological improvement would hurt.

The measurement of longitude at sea, synthetic fertilisers and the pill in their different ways have served freedom and increased our humanisation.

I will pass over the history of our European civilisation that gave birth to modern science, as well as its roots that led to the philosophy of the Enlightenment.

The latter announced humanity '*freed by knowledge*', as stated by its enthusiastic prophet, Condorcet. In his view, '*If the indefinite improvement of the human species is, as I believe, a general law of nature,* ***man*** *must no longer consider himself as a being confined to a temporary and isolated existence. Instead, he* ***becomes an active part of the great scheme of things*** *and the* ***co-operator of an eternal undertaking***'.

How can one say better that with this philosophy of unlimited perfectibility, **humanity should find within itself the fullness of its hopes**? Although entirely European in its conception, this philosophy aspired to universality, promising humanity a sort of terrestrial eschatology made of universal happiness.

The indissoluble bond between scientific progress and moral progress, the progress of Humanity, progress in society was set as an absolute principle. Condorcet would have reacted strongly to our doubts about this correlation!

For three centuries, scientific and technological progress was at the service of a philosophy that was superior to it, and that gave direction to the progress of society. For three centuries, armed with this philosophy, our civilisation influenced the development of most of the societies throughout the world. It continued through colonisation what it considered its 'civilising mission'.

However, after the death of God, which it had prescribed, the Enlightenment faded in the twentieth century. Born with and through modern science, it soon found itself confronted with the risk that those societies whose very structures were overwhelmed by the various industrial revolutions would lose their cohesion.

At all times, changes brought about by techniques have given rise to strong and sometimes violent reactions from those people on whom painful adjustments are imposed. Society, through its mediating role, used to help humanity adapt to its own work, and allowed it the time to do so. In this way, society saved its cohesion and at the same time maintained its progress by preserving the symbiosis between science and technique.

The reactions were particularly intense during the industrial revolutions. All the disciples of the Enlightenment were affected. They had denounced a heavenly eschatology, but adherence to their new terrestrial eschatology had difficulty in withstanding the harshness of the times.

Karl Marx once said, '*Abolishing religion as an illusory form of happiness for the people implies demanding their real happiness!*' The new knowledge was not seen to be the source of freedom. Did that mean that the Progress of the Enlightenment was just an illusion?

Faced with the speed and extent of change, society was incapable of assuming its mediating role. The believers of the Enlightenment concluded that society itself needed changing.

Saint-Simon, August Comte, the positivists, scientists, Marxists, all of them proposed this solution. Curiously, although their philosophy was based on reason and thus refused all religion, they all developed true 'religions of Progress' complete with their catechisms, churches and rituals.

You all know what happened next. Europe, the uncontested world beacon of scientific and technical progress, source of tremendous human progress, became the gravedigger of the Progress of the Enlightenment.

Fritz Haber, benefactor of humanity in 1913, Nobel prize-winner for chemistry in 1918, was considered as a war criminal in 1919 for having developed, wanted and organised chemical warfare. The technology of pressurised gas that had enabled the industrial synthesis of ammonia became a terrifying weapon. Chemistry, that wonderful factor of progress in the nineteenth century, became the carrier of horror. I date the decline in its image from that moment.

Two world wars, Nazism, communism, the Shoah, the Gulag, all of these horrors originated in Europe, the beacon of knowledge, the light of the world! In this way, Europe showed the senselessness of the principle of an indissoluble bond between scientific progress and social or moral progress, which it had itself proclaimed to the whole world.

Soon the universal character of the Progress that justified its 'civilising mission' was rejected as the mask of a hypocritical West wanting to maintain its dominant position.

From then on, in our twentyfirst century, scientific and technological progress, the orphans of God and the Progress of the Enlightenment seemed to work only to develop their own power.

What was once a servant became a master.

We were marching onwards, guided by the Star of Bethlehem or the radiance of the Enlightenment. **Now we are walking in darkness** and, **heavily pushed forward by the relentless acceleration of scientific and technological progress**, we need to walk quicker and quicker.

The Great Temptation: Identifying Technological Innovation with Social Progress

There is no question of stopping the March forwards.

The needs of a human species that is experiencing an unprecedented increase in population are enormous. For instance, 850 million human beings suffer from hunger, 1.4 billion have no access to electricity, 2.5 billion have no sanitation, another billion no healthcare, 800 million are illiterate and 1.2 billion live below the poverty line. Food, healthcare, education, housing are objectives that form the basis of all humanisation.

In most cases, the knowledge that would allow us to achieve in large part these objectives exists already. If this is not yet the case, it is because our human societies are not organised in such a way that would allow them to play their role of educator and mediator.

They have not known how to integrate those left on the wayside during the knowledge-driven onward March. The demography of the ‘left-behind’ continues to grow and will count for two out of the three billion total increase in the human population expected by 2050.

At the same time, technological innovation is accelerating the speed of human progress like never before. However, in the presence of such an audience, I do not intend to discourse on the digital revolution, the NBICs and their impact on our personal lives and societies.

We are all amazed to learn that we have succeeded in getting the blind to see, the deaf to hear and the paralysed to walk. People suffering from the dreadful locked-in syndrome, described in the moving book ‘*The Diving-Bell and the Butterfly*’ that Dominique Bauby dictated solely by blinking his left eyelid, can hope one day to be able to dictate texts using just the strength of their thoughts, thanks to electrodes attached to the surface of their brain and connected to an ‘intelligent’ machine.

This is all wonderful, but we must also note that the way our society is currently organised does not allow all the blind, deaf and paralysed to be relieved of their handicap. Many will stay on the wayside for a long time still to come.

Moreover, we should really take heed of the extraordinary acceleration in the pace of innovation and of the extent of its influence on our societies.

Performance levels in artificial intelligence, synthetic biology and nanotechnologies double every 18 to 24 months, to the point that some people are talking about a new application of the Moore's Law.

We have all heard of the recent victory of the AlphaGo software over the world champion, the South Korean Lee Sedol. The software was developed by Google's DeepMind and Demis Hassabis, DeepMind's co-founder and head, with hundreds of thousands of dollars at their disposal for research.

We are now seeing how the concept of '*exponential technologies*' is developing.

Our earlier progressions, despite their breakdowns and leaps, remained nevertheless in a sort of linearity. Their duration was sufficiently long to allow enough time to adapt to the politicians, various civil society organisations, businesses and human behaviour, as well as to moral and ethical benchmarks. Exponential kinetics leaves very little time to do this.

The emergence of exponential technology will have a drastic effect on any organisation or business used to living in linear progressions. Much more than a breach, it will be a disruption so fierce and turbulent that it will be destabilising, even deadly.

Google chose to characterise this phenomenon by the word '***singularity***' when in 2008 it set up with other collaborators a private company registered in California called **Singularity University** to promote exponential thinking. The pace of development is '*far too high for business leaders to succeed in integrating exponential technologies in their ways of thinking and strategies*'. Singularity University wants to help them! It exports its training programmes to Europe, where 900 persons, having paid a highly priced entry fee, attended events in Amsterdam in 2014 and in Spain in 2015.

The **time allowed to people to adapt** to their new technological tools is certainly **one of the major issues** of our time. The time needed by politicians, responsible for overseeing society's mediating mission, is not compatible with exponential kinetics. This is an enormous risk with respect to the pursuit of symbiosis, especially in a democracy. **The risk** would be **that humanity becomes** somehow '**unable to adapt to itself**', and that increasing numbers of people who cannot fit into such a forced pace find themselves left on the wayside.

Another important issue is that of limits. There are just a few examples of technologies that human societies have deliberately rejected, even though they mastered them fully. They did so out of respect for their founding values.

Chinese abruptly gave up the construction of impressive ships, far more sophisticated than the small Santa Maria of Columbus! The great eunuch admiral Zheng He was able to undertake transcontinental expeditions a long time before him. But China suddenly decided to drastically reduce its relations with 'barbarians', in order to preserve its identity.

In the same way, Japan abruptly gave up the use of fire guns, despite its perfect mastery of their manufacturing: Samouraïs considered them as incompatible with their honour code of fight.

Our current walk through darkness continues thanks to the pale glimmer of a few decaying principles, such as human rights, the universality of which is being eroded, that of precaution often cited willy-nilly, a distorted, deified respect for nature, and the cries of 'never again' when talking about past calamities.

It is doubtful whether their weak halo will enlighten us sufficiently concerning the choices that we will have to make with respect to the extraordinary opportunities opened up by exponential technology.

Their fragility and incoherence will not prevent contradictory choices. Genetically modified tomatoes seem like a nightmare to some people, who would let themselves be attracted by interventions on our genes that can be transmissible to future generations.

How to define, who will define the limits? Besides, should we accept any limits? Alternatively, **should we accept unlimited innovation as a philosophy of substitution for those that guided us before?**

We see the 'miracles' of exponential technology in artificial intelligence. However, we also hear competent, leading public figures, such as Tesla's CEO Elon Musk, the astrophysicist Stephen Hawking, the Swedish philosopher at Oxford Nick Bostrom, and many others, express openly their anxiety about the great danger that the unlimited development of 'intelligent' machines could represent.

We see the 'miracles' of technology used to repair, or even enhance, human beings. Until they become super-human, post-human or trans-human? Will they still be human? Will we find ourselves slipping towards some form of anti-humanism? Some people, for example Ray Kurzweil, do not want to hear of limits and are working towards the coming of trans-humanism, the fusion of man with intelligent machines, the extension of life expectancy to reach 'immortality'.

Kurzweil is Director of Engineering at Google, which shows the company's commitment to trans-humanism. This is one of the most powerful companies in the world, ranked first worldwide due to its stock-market value of 100 billion dollars. Kurzweil is also one of the team behind Singularity University. However, France has not been left behind. It has its own trans-humanist association, AFT-Transprog, which also aims to increase life expectancy, and enhance the sensorimotor and cognitive abilities of humans, as well as making humanity happier and more empathetic. For AFT-Transprog, '*humanity is an open project*'.

With such followers, we go back to the unlimited perfectibility advocated by Condorcet. However, we are straying from his aims. What will happen to the idea that humanity is '*an active part of the great scheme of things*'? What about '*its participation in a universal undertaking*'? The Enlightenment illuminated the path of humanity by encouraging it to find within itself its own 'transcendence'. It heralded 'infinity', but its deviations led to totalitarianism. Where will this fast-paced march on a dark path towards an 'unlimited unknown' lead humanity?

Do we want to maintain the unity of the species? Do we want societies of super-humans dominating sub-humans? Do we want the infernal paradise of Huxley's 'Brave New World'?

We are all questioning our ability to keep our heads between disaster mongering and naïve optimism.

The Big Question

Our societies swing between fear and fascination in the face of transgression, between huge steps forward and serious risk of setbacks, between resigned submission to the power of 'exponential innovations' and the anxious search for a policy to control it.

This search is all the more anxious because these innovations, like the science that they introduce into society, acquire a universal character. That does not mean that we need to change the definition of innovation given at the beginning of my speech, which considered innovation as socio-economic and cultural construction linked to the perimeters of nations and their cultures. Many of these innovations respond to needs that are felt everywhere, that are truly universal, and for which the definition remains relevant.

However, other innovations satisfy desires awakened and exacerbated by hugely powerful global players who find their interest there. These are the 'distorted' innovations mentioned earlier. These players do not recognise national frontiers. They invest huge resources to standardise the cultural components of individual nations that could cause the rejection of their global 'innovations'. By representing only their self-interest, they weigh heavily on the direction that each society draws from its culture.

Thus, symbiosis, impeded by the new kinetics of innovation, also finds itself oriented towards a sense that has nothing to do with the natural scope of its definition or the practice of mediation. In these circumstances, how can we chart the way forward that will lead the human species towards the fullness of its humanity? Furthermore, is the humanisation process a unanimous wish? Working out the answers, redefining the direction freely chosen by each society and sufficiently shared by all in order to pursue the human adventure is obviously not an easy task!

Regulating technological innovation, in other words, setting the limits at both national and international levels, does however define this direction indirectly on a daily basis, but with a great deal of inconsistency.

The biggest difficulty is getting a global governance structure that the globalisation of innovation and of its most powerful players has rendered indispensable to emerge. If such a structure does emerge, there is also the challenge of granting it a degree of responsiveness adapted to the kinetics of this innovation.

This is not going to be easy!

During the 350th Anniversary of the French Academy of Sciences, the national Academies of 57 countries signed a joint declaration. I was interested to note there the idea that '*the two human constructions, namely science and society, should develop in symbiosis to enable humanity to move forward*'.

In which direction should we move forward? To conclude, we come back to André Malraux. What unites us is this question!

It is not the role of the scientific community to decide on the direction. On the other hand, its role is to anticipate any accidents on the way, signal to humanity and societies any dangerous and irreversible ways, and describe any precipices that it has glimpsed. Furthermore, its role is also to foster symbiosis through education.

To achieve this, I think that our Corporations, together with others, should involve themselves massively in '***observatories***' of the penetration of the sciences in our societies. They would devote themselves to prospective analyses of the medium and long-term impact of this penetration, by trying to anticipate its potential benefits and risks, and proposing solutions to consolidate the former and reduce the latter. They would update their analyses regularly, which would then give rise to 'educated' public discussion.

Our Academies cannot remain silent or inaudible, because they are essential players in this movement for scientific and technological progress that pushes humanity forward, faster and vigorously.

Law Facing Information and Communication Technology (ICT)—Conflict or Alliance?

Yves Poullet

Abstract Internet definitely is everywhere in our life and even models our behaviours and relationships. How the law is approaching the Internet revolution and to what extent the traditional legal fundamentals, structure, concepts and actors are surviving to this revolution? In the other sense, we would like to stress out how the law might also help to frame the technological infrastructure and operation at the service of societal values and the development of human liberties.

Keywords Information and Communication Technology · ICT Law · Internet · Self-regulation · Human liberties · Legal concepts Technological normativity · Data protection

Aim of this contribution Since more than 30 years, as lawyer and philosopher, the relationships between Law and ICT have been for me the essential of my research's concern. If Technology was, 30 years ago, a simple 'well-identified' product in the hands of certain specialists at the service of companies or administration for bettering their activities, obviously it has become with the Internet an integral part of our daily life, being ubiquitous in our activities and modelling our behaviours and our relationships. In that context, if Law has been traditionally the way by which our societies are framing our societal life in all aspects, it might be interesting to see how ICT have challenged, even in a crucial way, our legal environment, concepts, structure and put at risks our human liberties, fundament of the legal order. This article is devoted to these questions which definitively are still open in that tremendously evolving environment and calls for a better dialogue between Law and Technology if we want to keep alive our democratic societies.

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Table of content We start with an eye-bird overview of the evolution of the ICT context (Section "About the ICT Context"), before analysing the challenges faced by the Law both as regards its traditional fundaments like territory and supremacy of the legal order but also more challenging as regards the legal concepts deeply challenged by ICT (Section "The Law Put into Question by ICT Technologies"). The following chapter (Section "Creation and Application of the Law Facing ICT") is dedicated to the transformation of the legal normativity and a comparison between legal order and technological normativity. At the end (Section "Liberties Within the Internet World"), we propose some reflections about our liberties within an Internet world. To conclude, we propose certain ideas as regards a new approach of the relationships between Law and ICT.

About the ICT Context

A rapid chronology Certain dates and facts might be recalled. The Internet's birth is dated from the famous US military initiative: ARPANET, launched in 1967, only 50 years ago as a way to decentralise the information in case of a Russian military attack. The TCP/IP protocol has been proposed in 1973 by Vint CERF, as a way to ensure an international language permitting to all computers to enter into dialogue. Initially, the use of the Internet has been reserved to restrained circles, mostly universities' people, regulating themselves and dominated by the dogma of freedom (free exchange of ideas) but rapidly, with the creation of the WEB (BERNERS LEE and CAILLAU) in 1990, as a collection of pages in HTML format, mixing together pages, images and sounds and having an URL address, so being accessible through the HTTP protocol, we did assist to a progressive transformation of this fair to ideas into a commercial fair used by the companies in order to extend their market and the management of their activities. The globalisation of the Internet is now a fact: in 2014, a milliard of online sites and three milliards of Internet users. In 2025, one forecasts 100 milliards of IP addresses.

ICT's infinite capacities Our digital universe is growing and growing, from Giga, Tera, Peta, Zetta ($10^2$3 octets) and tomorrow Yotta bytes: today, we evaluate it to 1200 milliards $\times$ milliards octets (44 zettabytes in 2020).[1] In that context, three Laws are evocated: Moore Law, as regards the multiplication by two each 18 months of the processing capacities; Nielsen Law, as regards the multiplication by two each 21 months of the transmission capacities and Kryder Law, as regards the multiplication by two each 13 months of the storage capacities. Definitively we are entered in the **Big Data** era.

[1]Report EMC-IDC Digital Universe, "Extracting value from Chaos", 2011. Already in 2010, E. Schmidt, Google CEO, asserted that we are producing each two days five exa-octets of information. At his opinion, it was more than the information produced between the first appearance of the human culture and 2003.

To this first phenomenon, we must add another movement: I mean the trend to **Nano technologies** going from ambient intelligence (the 'Internet of things' or 'Smart dust': 150 milliards of connected objects mainly with RFID technologies)[2] to the present discoveries of the bioengineering which create the possibilities to intervene in the repair and modification of our ADN. So the technologies are everywhere in our homes, pockets, glasses, stores, streets and definitively embedded in our bodies and genes, conducting more and more our behaviour and what we are becoming.

… a deep modification The combination of these two phenomenon (Big data and Nano) leads to three fundamental modifications in the use of data.

a. The first deals with the **data collected, stored and processed**: due to the reduction of the costs of their storage, processing and transmission, Big Data is now a common activities of a large number of companies and administrations around the world. The data collected, stored and processed are more and more diverse (location, surfing or consumers habits, …) coming from different sources and a lot of them appear as trivial data even if their unpredictable combination might reveal very personal and sensitive information.
b. Precisely, as regards now the **applications** now available or envisaged at short time, through the use of meta data (Tag number, IP number, location identification, cookies, …), the collecting companies or administration are able to connect the data collected through different sources and therefore to **profile** people in such a way to have a very precise image of each Internet user and to act a priori vis à vis them. Two other kinds of applications must also be underlined: **affective computing** it means the possibility for data responsible to induce from different data (e.g. facial movements) in real time the emotion or sensitivity of person and to decide an action against him or her and **Brain–Computer Interfaces** which might act directly on the action or capacities of the human (like to increase his or her memory or to supply a deficient human organism).[3]
c. **Cloud computing**,[4] as a new way of data and application storage, and its different facets might be considered as a revolution. Data and software applications are no more stored or lodged on my laptop or mobile device and, for most of the companies, on their IT infrastructure but somewhere in the clouds. This reality raises the question of my or their master-ship of the data I or they are generating or building up. Where are these data located and for which uses?
d. Finally, as regards the **actors**, one pinpoints, beyond the traditional dichotomist presentation between the data subjects, from one part, and the data responsible

[2]G. Riva, "*The psychology of Ambien Intelligence: Activity, Situation and Presence*", Ambient Intelligence, IOS Press, 2005.

[3]M. Nicolelis, "*Beyond Boundaries, The Neuroscience of connecting Brains with Machines and How it will change our Lives*", New York, Times Books, 2011.

[4]M. Dikaiakos and others, "*Cloud Computing: Distributing Internet for IT and Scientific Research*", IEE Internet Computing 13 (5), 2009.

from the other part, the increasing importance of both, from one side, the ICT producers whose technology (e.g. the Androïd software) renders possible these applications and, from the other side, the omnipresence of what we call the 'Gatekeepers', it means the companies whose activities are necessary to get access to the information and communication services available through the Internet like social networks, search engines, music platforms, etc. All these services must be considered today as 'essential services' within our modern Information Society. These 'essential services' are no more offered by public authorities but are monopolised by a few number of private companies, the so-called GAFAM (Google, Amazon, Facebook, Apple, Microsoft) which progressively through a strategy of merger and acquisitions are dominating the global flow of information. The Google example (Google Map, Androïd, Double click, YouTube, Google news, Google search engine, …) might be quoted on that point. Their economic power goes beyond most of the States' power[5] and creates a big risk for our democracies.

The Law Put into Question by ICT Technologies

The multiple challenges It is obvious that the Internet is dismantling the main fundaments of the law. The Internet is without borders and shakes even erase considerably the territorial limits of our States and thus the basis of their sovereignty (A) Traditionally, the unique source of the regulation is coming from the States or by delegation from International Public organisations like EU, UN and its subsidiaries (WTO, ITU, WIPO). With the Internet development, new private organisations have been set up and the concept of self-regulation has been considerably entered into force instead of that unique source (B) More important, certain fundamental legal concepts have been either revised, either deeply reinterpreted in such a way that they have loosen their initial meaning in order to consecrate new interests (C) Fourth, the legal actors are facing in their activities new challenges which raise questions about the principles of their action and competences (D) Finally, we pinpoint that ICT technology, through its 'ubiquitarian' characteristics and its indefinite capacities of control, puts into danger our liberties and freedoms, fundament of our democratic societies even if, in the same time, ICT technology enlarges them, as we will see it (infra).

[5]In that perspective we might understand the recent announcement of the Danish Government to open a Embassy for Google in Denmark, putting therefore on a same footing a private company and a State. Already in 1995, the NORA MINC Report to the French government underlined that IBM's economic power was equivalent to the French Republic.

The Disappearance of the States' Boundaries

Territory and Sovereignty It is common sense to assert that the Internet more and more ignores the national frontiers. The borders' control are no more operated within the territory of the State of destination but through the use of databases operated directly in the country of origin (see for instance the PNR system). The domestic flows of information are crossing different States (40% of the intra-European flows are circulating on the US telecom infrastructure) might be captured by foreign States through satellites or other techniques of wiretapping (see the recent Merkel's case and the famous ECHELON case revealed in 2000), which permit to US, UK, Australia to spy the communications exchanges throughout the world). 10 of the thirteen Internet root servers are located in the US. In all these points, the US predominance might be pinpointed even if EU authorities have tried to challenge that predominance by multiplying legislative initiatives and by creating an EU legal environment for the Internet and to impose the EU solutions. So the Regulation on applicable law to Contractual obligations (called Rome I, 2008) has imposed the concept of 'overriding mandatory rules' which refer to national rules which are deemed so crucial for the protection of a national political, social or economic order that they must be applied as a matter of course. The General data Protection Directive (2016) has clearly extended the application of the EU legal order to controllers not established in the EU when they are offering goods or services to data subjects established in the EU or monitors their behaviour. Recently, the EU Court of Justice (2015) in the SCHREMS case has challenged the EU Safe Harbour decision which authorised the trans-border data flows between EU and US companies for not complying with the constitutional requirement of the EU since US permits, to a too large extent, wiretapping and surveillance by US public Intelligence services. Other countries like China but also Arab countries have decided to have their own national Intranet network connected to the Global Internet network by a gateway in order to forbid any not controlled intrusion from outside.

The Internet Regulation Beyond the Traditional Legal Order

Technical standardisation and private organisations The principle of the State as a unique or at least main source of national applicable regulation and the International treaties conclude within Public international organisations as the main source of the international mode of governance has always been considered as a dogma by lawyers in our democratic countries. The Internet is deeply challenging that principle. The 1993 Gore's (US vice president) for a self-regulation of the Internet, it means a regulation by the private actors themselves was the point of departure of this movement justified not only by the global, technical and evolutionary characteristics of the Internet but also by the will of the US government to keep a certain control on the Internet through these private bodies, instead of losing any power in case of International public bodies' competence. The multiplication of private bodies without any constitutional status but regulating globally our information society, beyond their competence on the technical aspects and their societal impacts, is henceforth a fact. So ICANN, a Californian non-profit organisation but having signed a memorandum of understanding (MoU) with the US department of Commerce, has taken the leadership as regards the regulation of TCP/IP and web addresses including the disputes on these topics.[6] It has to be underlined that this private organisation has mandated the International Public organisation, the WIPO for proposing an 'Uniform Domain-Name Resolution Policy' (the UDRP), a strange revolution where a private organisation dictated its law to a public organisation. IETF and W3C are ensuring the technical standardisation of the infrastructure, terminals and the web applications through expert's meetings and, at the end of a procedure founded on what they call a 'row' consensus, their decisions: the famous not well called 'request for comments'. As said, these private bodies are regulating indirectly economic and societal aspects of our life, so for instance when the IETF has decided to define the technical norms permitting the existence and functions of the cookies or when W3C has developed the P3P system (infra).

Self-regulation—Towards a global and complete normative system Beyond that emergence of private global standardisation organisations, there are another trends. First, the global companies, like but not only the GAFAMs, are developing their own privacy policies, codes of conduct, terms of Agreement, all these mechanisms often conceived in their content independently of any reference to national legislation. Recently, Facebook, Twitter, Microsoft and YouTube have published on countering illegal hate speech online (May 31, 2016) and more recently, they developed together the Hash-sharing initiative, which provides a unique digital fingerprints identifying terrorist content and preventing any apparition of the content elsewhere.[7] Second, at a large scale we see flourishing codes of conduct, codes of deontology, labelling systems and alternative (alternative to the national public jurisdictions) online dispute resolution (ODR) mechanisms, which are offering more rapid and effective sanctions (like blacklist, loss of label, …). To explain the ODR success, we pinpoint the globalisation of operations caused by the Internet and the relative inefficiency of international private Law to solve them. To conclude, we see, on the fringe of our traditional legal order, the increasing development of global and complete self-regulatory systems, since the adoption of normative rules, setting-up of controlling methods, ad hoc jurisdictions and proper sanctions.

From WSIS to the EU approach—Multi-stakeholders and/or co-regulatory approaches Against that trend to a global privatisation of the Internet regulation, international public authorities have reacted. The UN General Secretary launched in

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[6]As regards the Internet of things, EPC (Electronic Product Code) Global (a joint venture between private bodies) is regulating the world of connected things, having created the Object Name service in parallel with the Domain Name service operated by the ICANN and defining different protocols for connecting and interconnecting the different objects and their producers.

[7]This code of conduct has been evaluated by the EU Commission at the end of 2016.

2003 (Geneva) the first World Summit of the Information Society (WSIS), followed in 2008 by another Summit at Tunis. The final 'Declaration of Principles' looks like a sort of Constitution of the Global Information Society. It asserts the fact that Internet is a '*global public resource*' and introduces the absolute need to set up a '*multi-stakeholder Governance*', it means '*the drafting and implementation by the States, the private sector and the Civil Society, each of them in the limits of their respective competences, of the norms, rules, procedures, decisions making and common programmes appropriate to the modelling of the evolution and usage of the Internet*.' Despite this clear assertion, we have to recognise that International Public authorities have not been successful in asserting their place. The fact that different organiations might be competent for the same problem might explain their weakness and the fact that they are acting in different ways. So as regards the regulation of the Intellectual Property, UNESCO, WIPO and WTO have not obviously the same point of view and contradictory approaches might be expressed by each of them. The tentative to set up a public Internet regulatory body has been clearly rejected by US authorities, only an Internet Governance forum, without any regulatory competence but simple discussion forum, 'guarantees' the survival of the 'multi-stakeholder' governance asserted by the WSIS.[8]

The attitude of the EU definitively vis-à-vis the Internet self-regulation has to be underlined. On different themes, EU clearly has pleaded for a coregulatory system, asserting the predominance of the public regulation without excluding the private regulation but fixing the limits of it. Co-regulation means the mechanism, whereby a legislative Act entrusts the attainment of the objectives fixed by this Act to parties (NGO, Consumers' representatives, Companies' associations).[9] So in different domains, like Data Protection Regulation (1995 and 2016), Freedom of expression, Electronic commerce (2000), Services in the Internet Market (2006), Copyright issues (in course of debates), Racism and xenophobia (2008 within 2016, the conclusion between EU Commission and Facebook, Microsoft, Twitter and YouTube of a code of conduct on countering illegal hate speech), the EU Directives or Regulation are referring to more specific provisions (codes of conduct, Codes of deontology) or mechanisms (labelling systems, certification or accreditation procedures, technical means) which are defined by the actors themselves. The EU claims for transparent and effective mechanisms of private regulation including all the concerned stakeholders. This approach seems to offer an added value to both pure self-regulatory and public regulatory system since it combines the fundamental legislative choices with a better effectiveness and evolution of the norms, in the hands of the private sectors after discussion with organisations representing other interests and under control of the public bodies.

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[8]It must also be noted that ICANN has created the 'Governmental Advisory Committee' within its complex organization.

[9]That co-regulation system might be considered as a 'top down' approach, compared with a 'bottom up' co-regulatory approach where in a first step, private actors are defining themselves their self-regulation before in a second step to approach the legislators in order to enact and give a legal enforcement or accreditation to their practices.

The EU attitude followed by certain countries like Japan, Latin American countries, even to a certain extent Canada, represents another model than the US one. It leads to a difficult coexistence of these two models in certain areas like especially the domain of Privacy or Freedom of expression. As regards Privacy, the OECD self-regulatory Guidelines are promoting self-regulation in the same time when Council of Europe and EU are adopting the legislative approach.

Legal Concepts Facing the Internet Context

The legal order has been construed on different concepts which have been defined in a societal context quite different from today and were taking into account a certain equilibrium between different legitimate but contradictory interests in that context. Technology is radically affecting this context and might affect sometimes deeply the actors' powers in a positive or negative way. ICT is transforming our social relationships and the way the technology is interacting with us. Considering that new reality, the law has either to reconsider the concepts developed in the traditional world and to maintain the traditional equilibrium embedded within the legislation, either to give the traditional concept another significance or to create a new concept. I take an example: the concept of advertisement or publicity was defined as a communication to the public in order to promote the selling of a good or service. Today with the development of the one-to-one marketing and the possibility for website to deliver, without any additional costs, large quantity of information looking like objective information, it was needed [see the EU Directive on e-commerce (2000)] to propose a new concept, that of '*commercial communications' which is defined as 'any form of communication designed to promote directly or indirectly the goods, services or image of company, organisation or person pursuing a commercial, industrial or craft activity or exercising a regulated profession* and to regulate it in an appropriate manner. In the Internet age, the extension of the 'press' notion has to be reviewed in a deeper way since anybody might through his or her blog or through other electronic means deliver a message and so influence the general opinion. This radical extension raises questions: to what extent the legal regulation including administrative and fiscal ones available for the traditional press actors and institutions have to be applied to these new actors? Can we consider Facebook or others social networks' operators as editors? The last example: the traditional concept of 'swindle' linked with a human behaviour aimed at deceiving another human being has to be rethought when the deceptive behaviour is committed vis-à-vis a technical device.

We might multiply the examples but in the following paragraphs, we would like to amplify a general principle. We do enunciate it as follows: the Law has to welcome the development represented by the technological innovation but according to what we call the principle of **technological neutrality** (see, infra, n° 13). This principle has a dual nature. It might be considered as positive since we have to see how through technological means the traditional functions and equilibrium embedded in the traditional legal concepts might be ensured: therefore, we have to host the technological means according to the respect of these functions and equilibrium. At the contrary, the legal system has to fight against technological means which modify the balance of interests enshrined in legal regimes and concepts (infra, n° 13) or to accept the risk to create through the legislative procedure new concepts.

From the non-discrimination principle to the principle of functional equivalence: the Law of Evidence and of the Electronic Signature As regards the technological neutrality, the main idea is to prevent the Law from considering a barrier to technological development (non-discrimination principle). In the same time, it cannot be question of subtracting technological developments from the substantial requirements established by the traditional legislation but at the same time (positive aspect) it must be required that these developments are complying with them (functional equivalency): the state of technology has a legal and judicial value equal to the one conferred to the traditional state, provided that it demonstrates its capacity to realise the same functionalities as the traditional state. Two EU directives about, the first, electronic signatures and, the second, the electronic commerce illustrate these two sub-principles. So, the 1999 Directive on electronic signature enunciates: '*Member states shall ensure that an electronic signature is not denied legal effectiveness solely on the grounds that it is in electronic form…*' but requires for being recognised as equivalent to a handwritten signature, that guarantees of identification, authentication and not revocability are met. On a parallel way, the e-commerce directive requires the Member States to remove any legal obstacles which hamper the use of online contracts. This means that a contract cannot be deprived of legal validity on the ground that it has been made by electronic means. So the e-commerce Directive recognise as its duty the welcoming of technological developments that substitute traditional conclusion, the process of execution and archiving of contracts when these developments guarantee the respect of functional requirements, which originally justified the recognition of traditional processes.

ICT and Copyright The history of the copyright facing the ICT illustrates the importance of the dialogue between Law and Technology. How the legal concepts might be deformed in other to protect ICT products and services and how the technology might give to legal protection an extension beyond the equilibrium put into place by the legislator.

As regards the first assertion, the origin of the software protection by copyright might be recalled. It is quite clear, according to the specialists of copyright that this concept was not fit for a not artistic work, that the concept of originality might qualify only rare software and that the requirement about the access to the work and not only to the functioning of the work was not met. Notwithstanding these objections, the lobbies and finally the legislators have chosen to use the inappropriate concept of copyright in order to get the benefits of its universal legal protection.

As regards the second concern, the easy and not controllable plagiarism of works and images on the Internet and the difficulty to fight against illegal reproduction and dissemination has been denunciated as the 'Death of Copyright'. The use of technological means (Watermarking, Anti-copying software, Digital Rights Management Systems (DRMS), …) did represent a technological answer to that risk. These devices enable the control of not only the initial access but also are fixing the conditions of the use of the work (restriction as regards the support or the duplication, the price and its payment). Others might detect automatically the plagiarism and denunciate it. The Law has been solicited to support these technologies in order to prevent their circumvention and recognise their legal value. Doing that, it must be recognised that the Law is going beyond the traditional limit of copyright. First, they might protect works which are not deign of copyrightability; second, in a lot of cases, these systems undermined the possibility of taking advantage of specific exceptions to the author's exploitation right which were precisely granted by the legislator in order to promote intellectual creation. Third, certain of these devices authorises to protect any part of the work even if so partial that they do not represent the essence of the work. Finally, we pinpoint the fact that they constitutes a sort of reversal of the *onus probandi*: traditionally, the proof of the existence of a copyright is at the charge of the person who pretends to the protection. The technical measures give to this person a sort of presumption, not easily rebuttable, that he (or she) benefits of the protection. To what extent, this alliance between technology and law is in conformity with the system of intellectual property designed to promote intellectual freedom and the plurality of expressions and ideas what impose to take into consideration the conditions of public access and the use of the intellectual goods. To define through technology a perfect control of the use of the intellectual creations does not respect that essential equilibrium at the core of the copyright regime. Definitively, at the contrary, with the movement of 'open document' or 'open access', based also on the recognition of the author's moral rights, technology might also be used as a way to disseminate these intellectual creation at the benefit of a maximum of users and in the same time to respect adequately the moral and if asked the patrimonial author's right.

Creation and Application of the Law Facing ICT

The legislative time schedule the evolution of technology leads to multiply the intervention of the regulators in order to face these continuous innovations and their impacts on the society. That leads to a shortening of the legislative process as regards their adoption but also their modifications. So it is frequent to see legislation adopted with a process of evaluation after 2 or 3 years ('sunset clause'), where yesterday the legislation was written for the eternity. It might be of interest to underline that more and more pubic authorities, especially international public organisations (notably, Council of Europe, WIPO, CNUDCI, European Union, UNCITRAL…), are intervening no more through hard law it means legislation but through soft law it means more supple methods not requiring the long legislative process and in certain cases issued by group of experts like recommendations, resolutions, decisions. These new methods of regulation rapidly adopted are effective since judges might more and more inclined to afford to that soft law a real effectiveness. The last point, sometimes large delegations are given to independent administrative authorities in charge of the interpretation and often of application of the law. We might quote that phenomenon in audio–visual, media and telecommunication sectors and in domains, like data protection or freedom of expression.

The use of ICT in the application of the Law Different remarks might be addressed on this point? ICT have not only invaded our Courts and tribunals but also the offices of the auxiliaries of the Justice like solicitors' offices. They facilitate the constitution of files, their transmission and the notification of the judgment and their archiving in databases easily exploitable. That phenomenon has a great impact on the way the lawyers are working. So we see new practices developed by solicitors as regards the way they are communicating between us and with their clients and the Courts and Tribunals, obliging to modify the ancestral rules and deontology as regards their conduct. Their conclusions are more and more exploiting large databases and give more importance to the case law and to the comparative law than before.

Artificial intelligence is supporting more and more their opinions, identifying according to the facts and the psychology of the judges, the good case law, the appropriate arguments and the interpretation to be given to the legal provisions with the risks to have more and more a sort of normalised case law. The fact that not all the lawyers might have access to these information services and facilities creates another risk: the risk of discrimination between lawyers and therefore between citizens in their legal defence.

The phenomenon of ADR and ODR the point has already been stressed (supra). If the phenomenon has started within the US, EU has followed the same trend to encourage the creation of EU ODR platforms to solve contractual disputes that stem from domestic or cross-border online purchases between consumers resident in EU and traders established in EU (B2C). A directive and a regulation have been issued in 2013 and enunciate rules to be followed by these entities. They provide the obligation for these platforms to offer services effective, transparent (all the details of the procedure must be published on the website), easily accessible, without the need of legal representatives and submitted to the control of a competent authority designated by the member states to monitor their functioning and development. Consumer and trader must agree on that way to solve the problem. The consumer submits his or her complaint by filling a complaint form through the ODR platform. However, nothing is said about the quality of the 'mediators' which are dealing the disputes and the obligation to provide a solution in conformity with the legislation available. Normally (except for complex questions), the solution must be provided within the 90 days of the reception of the complaint.

ICT and Law Enforcement Authorities at the service of public security and fight against illegal activities All our behaviours including our criminal activities are leaving electronic traces, it might be the simple possession in your pocket of a mobile which reveals your presence at a certain place, it might be a message stored in a computer or transmitted through a network, it might be a video-surveillance detecting your behaviour or movements. Numerous legislation are offering new possibilities for Law Enforcement Authorities to collect these data from their own initiative including by penetrating in the personal computers of suspected people but overall to collect data processed by information or communication services, including social networks operators. Moreover, they impose to these private companies the obligation to cooperate with them and to denunciate criminal infringements.

As regards that authorisation, we might regret that the concepts used in these legislations are often vague and that the list of criminal offences which might be subject to these cooperation's duty is extended constantly. Always about this searching methods, the procedure might be launched sometimes without the judicial control. Another problem to underline is the increasing use of big data services to detect potential suspected persons not only as regards terrorism but also as regards social or fiscal fraud. It means these often trivial data coming from different sources and combined through an unpredictable algorithm are not related logically with the pretended illegal activity. So the colour of your car, your moving, your surfing habits, your residence, etc. might from a statistical point of view reveals that you are belonging to potential raiders. That use leads to a reversal of the proof. Once again like with the use of DRMS (supra), the proof that you are honest will be on your shoulders.

Technological normativity versus legal normativity A lot of applications of technologies have a normative impact. This impact is not necessarily viewed as such by their users. I would like to take two examples. When an insurance company proposes to their customers to equip their vehicle with a sensor which automatically might record your infringements, you as a driver are committed to accept this automatic and at distance control of his or her car's driving. In exchange of an important reduction of your insurance's premium, you agree to be controlled each moment of your life. The insurance company is allowed to detect if your behaviour attested by the black box embedded in your car and connected directly with the information control system of the insurance company is conform to the circulation rules. In that context, it is quite clear that you are incited to obey to the legal prescriptions in a very efficient way. Another example, if you know that the network you use commonly is able to detect the use of certain words or sentences you will carefully avoid these terms. In these two examples, technology is used to force people to adopt consciously or not a behaviour conform to that expected by the society and operates as fixing a model making more effective the legal order—but also I will come back later thereon- in a not refutable way.

More generally, the opacity of the world surrounding you creates the feeling that you have to adopt the behaviour you estimate expected from you. That's what we call the ‘anticipatory conformity’, we mean the fact that, even without clear prescription about what you have to do, people are inclined to follow a certain line of conduct. In 1983, the German Constitutional Court declared illegal for insufficient transparency the Census Law adopted by the Parliament in the following terms: “*The possibility of inspection and of gaining influence have increased to hitherto unknown, and may influence the individuals’ behaviour by the psychological pressure exerted by public(or private) interests. Even in certain conditions of modern information processing technology, individual self-determination presupposes that the individuals left with the freedom of decision about actions to be taken or to be omitted, including the possibility to follow that decision in practice. If someone cannot predict with sufficiently certainty which information about himself in certain areas is known and cannot sufficiently estimate the knowledge of parties to whom communications may be possible,* ***he is crucially inhibited in his freedom to plan or to decide freely…This would not only impact his chances of development but would have also impact the common good because self-development is an elementary functional condition of a free democratic society based on its citizen’s capacity to act and cooperate***.”.

Finally, technology might also negatively prohibit certain behaviours or positively force people to adopt other ones. Normativity through technology deeply differs from legal normativity at least in our democratic countries in different ways. First, with the legal order, it is required that the legal texts will be published in due time in order to permit a certain forecast by the citizens who might anticipate the consequences of its non-respect. Second, technology offers apparently at least a perfect effectiveness of the norms, what is not the case with the legal order: all infringements are sanctioned positively or negatively (refusal of an advantage). Third, and this point is at my opinion the most important: as regards legal texts, their interpretation might always be disputed by people themselves before the Courts, that is what we call the ‘recursivity’ of the norm what means that the application of the legal texts are always subject to new interpretations at the light of the facts and by the judges taking into account the human beings’ arguments. Since the technology operates automatically and following a logic not transparent, the possibility to go before the Courts and to invoke another interpretation of the applied norm will be difficult even impossible. As Lessig asserts, technology constitutes a source of norms often more powerful than the legal ones.

Liberties Within the Internet World

Our liberties at stake the Internet has tremendously modified the exercise of our liberties, both in a positive way but also in a negative one. What concerns the freedom of expression or of mobility and the privacy, we underline different facts which clearly demonstrate this positive impact of all the ICT applications. The global characteristics of the Internet and its open character mean a man ‘without

borders', a man able to transcend the traditional social normativity: when I am surfing on the web or navigating on social networks, 'I feel free' since I am not identified a priori through my handicap, my job or my residence. Due to the interactivity of the web, I am able to act on my environment, to express my opinion, to refuse or at the contrary to share views, to select my 'friends' and the websites I want to get access. Moreover, ICT applications will increase my action, presence and capacities to master my environment, to use robots in order to facilitate my daily life, able through telemetry to control at distance my home, my children, to find my way within an unknown city. Tomorrow with brain–computer interfaces or telemetric at distance system, I will be able to be an 'increased' man more clever, more armed against health diseases or genetic problems. Perhaps, after tomorrow, I will be multiplied, having at disposal clones of myself.
In the same time, we have to confess that technology might affect quite deeply our liberties. More and more, we are tracked in our moving and choices, we are under surveillance without always being conscious of it and unable to know why and who is putting us under surveillance. Big data and the technologies of profiling already described are collecting more and more data about us and reducing us to our profile. That leads to a man more and more manipulated: as asserted by the Google CEO: "*it will become very difficult for people to see or consume something that has not in some sense been tailored for them.*". In the end, as the German Court noticed, the opaque ICT system surrounding us and its incredible capacities to collect, store without limits of time and to process all the data generated by my actions to control and manipulate us lead to a man more and more normalised.

New issues and the need to redefine the Privacy concept To summarise, these technical advances, even if from a certain point of view they are increasing our liberties, at the same time are creating huge risks for them and are raising fundamental questions other than the traditional ones concerning the protection of our intimacy. So new issues, more salient and crucial, are now entering the discussion like the question of justice as regards access to these technologies, the risk of a two-tier society, the question of democracy when we consider economic-technical, broadly non transparent, governmentality and the question of social justice in relation to the consequence of profiling applications rejecting a priori and without appeal certain categories of population. The question of dignity in the Kantian sense of the word is also to be raised since it is clear that, analysed through profiling techniques that use data collected from a large number of sources, the human definitively is not considered as an end as such but as a pure mean put at the service of marketing or security logic. 'Algorithmic governmentality'[10] operates without the possibility for the human beings, who are subject to it, to challenge the reasoning behind what is proposed as a truth, precluding any discussion, criticism or debate. How do we face these new challenges? Is privacy an adequate concept to

[10]According to the expression of Antoinette Rouvroy, "*The end(s) of a Critique: Data Behaviourism versus Due Process*", in Privacy, Due Process and the Computational Turn, the philosophy of Law meets the Philosophy of Technology, 2013, pp. 143–168.

answer to all these challenges and, if yes, with which meaning and how do we envisage the relationship between data protection and privacy, which are considered apparently as at least two separate human liberties by the EU Charter on fundamental rights (2000)?

Recently an author[11] suggests to better scrutinise the relationships between the Sen's or Nussbaum's theories of capabilities and privacy. Under Sen, capabilities encompass the conditions which enable the citizens to become '*fuller social persons, exercising their own volitions and to interact with—and influence- the world in which they live*'. The interest of bringing closer together the concepts of 'capabilities' and 'privacy' is twofold. First, it underlines the fact that the individual's mastery of his or her environment is not obvious and does not depend on his or her own volition but presupposes an active role of the State, which in a societal and economic context will enable this possibility of mastery. Arendt, as noted in the thesis, would have spoken about the possibility of an individual realising his or her 'virtuality', in other words to make valuable choices within an uncertain environment. It emphasises the fact that privacy is not a liberty among others but does constitute the conditions of these autonomic capabilities and is thus an instrument for the flourishing of our human fundamental rights and freedoms. The right to self-development within a given societal context is an adequate criterion to define the outlines of privacy requirements, considered as a tool for '*sustaining the uniquely human capacity for individual reflexive self-determination and for collective deliberative decision making regarding the rules of social cooperation*'. The author insists on the fact that the concept of privacy is evolving in its concrete meaning since it will refer to different means according to the evolution of the socio-economic, technological and cultural context wherein that human capacity will have to develop itself. If privacy could be limited to the protection of home, correspondence and sensitive data in 1950, the new technologies, the globalisation of our economy, the profiling activities,… oblige us to give to privacy another dimension and to recognise new subjective rights in order to achieve our capacity for self-determination.

Data Protection at the Big Data Age Data protection legislation appears in that perspective as a historical answer to the risks created for our self-development by an information society and thus is directly derived from the privacy concept. Legislation creates procedural guarantees (duty to inform, obligation to register and so on) and subjective rights (right to object, right to access,…) in order to leave '*space for individuals to choose the lives they have reason to value*'. Ambient intelligence and the profiling activities authorised by modern technologies oblige us to renew our legislation in different directions. The first one, definitively, is to draw our attention to the technology itself. Traditionally, Data Protection legislations consider only the relationship between data controllers and data subjects considered

[11]Luiz COSTA, *Virtuality and Capabilities in a world of Ambient Intelligence—New Challenges to Privacy and Data Protection*, Thesis, University of Namur, 2015, Law, Governance and Technology Series, 32, Springer, 2016.

as a liberal subject, the relationship submitted to the DPA (Data Protection Authorities) control. From now, we have to consider the technology itself insofar as the danger resides in the software algorithms, the infrastructure, the functioning of terminals. We have to take care of the potentialities of the technology, the design of the ICT systems, and the logic behind the algorithms. We have to consider that the individual consent as a way to legitimate data processing is no more appropriate since the data subject has no possibility to negotiate correctly as an isolated person. Collective consent and class action must be recognised. Moreover, with the author, we plead for a risk assessment of ICT technologies and for public debates about new applications and their societal impacts. The second point will be to underline the crucial role of the State which has to create this space for democratic discussion and to preserve the conditions of a public sphere where every citizen might, with confidence, express him or herself and develop his or her own personality.

Conclusions

Technology is the problem it might be also the solution the recent evolution shows that facing societal problems, technology might offer better than a legislation adequate solutions. It is quite usual to mention on that point the development by W3C, a private standardisation institution (see supra, n° 9) of the '*Platform for Privacy Preferences*' *(P3P)*, a tool that enables internet' users first to define his or her preferences as regards privacy but also sexual content, nudity or violence used by the websites, second, to exclude automatically any access to sites not respecting his or her preferences and third to engage, in that case, a dialogue with the website not fulfilling such preferences. This P3P is one of what we call *Privacy Enhancing Technological systems* (PETS). Besides PETS, different other technologies as already quoted are protecting the Intellectual Property (IPETS) certain are aimed to restrict access, others are preventing certain utilisations of the work (e.g. Digital Rights Management Systems (DRMS)), others are aimed to detect illegal use (e.g. watermarking). As regards consumer protection, certain Consumer Protection Enhancing Technologies are also developed. For instance, pop-up containing certain contractual provisions questionable from the perspective of the consumer protection might appear in order to request explicit agreement on them before to enter into the transaction. All these technologies might be supported even imposed by the legislation. So, for instance, the EU directive on Intellectual Property will forbid any circumvention of any DRMS and the EU Directive on e-commerce will impose the use of a symbol to distinguish clearly what might be called 'advertisement' from simple 'information'. To be short, technology assists law and its effectiveness, which itself in a sort of exchange of civilities, assists technology.

Recent legislations are going a bit further imposing the use of technology compliant with the legislative requirements. The example of the recent EU Global Data Protection Regulation (GDPR) adopted in 2016, by the EU Parliament is a good model of this new trend. It enumerates new principles, like the ‘Privacy by Design’ principle which requires to embed into the technological and organisational design of the information systems used by data controllers the privacy requirements, like the ‘Information Accountability’ principle which obliges the data controller to develop mechanisms to ensure the respect and the control of the Privacy Policies they are issuing. We might also mention the ‘data portability’ principle that requires the possibility for the data subject to transfer without any technical constraints from a data controller to another one (e.g. if I want to leave my present social network to another one).

Towards an environmentalist approach Another trend as regards the relationships between Law and Technology, Technology is reshaping our society and the relations between people within this society, especially affecting their respective powers. ICT are surrounding and influencing all our activities and do constitute an essential element of our environment. That is why we are of opinion that certain principles derived from the environmental law have to be implemented within Internet Law. Therefore, we are of opinion that the States have new roles to play in that context. First, through independent agencies, they must first alert about these modifications and the risks incurred by certain citizens. Second, they have to set up a multi-stakeholders’ dialogue in order to provide a ‘Technology Assessment’ in order not only to anticipate the developments of ICT innovations but also to follow the technological evolution, since these developments are often unpredictable (so cookies’ technology has been developed by IETF (supra) just for preventing the consequences of the disconnection of the communication with the website without assuming all the invasions of Privacy the evolution of the Web applications have since permitted; other example: RFID technology was created only for logistic reasons) and to have public discussions about the risks but also the advantages of that technologies. Third, we want to recall the precautionary principle available in environmental law, which must be applied each time certain technologies are putting into question or at risks fundamental values of our societies.

In the same perspective, it is noticeable to see that GDPR is requiring a Privacy assessment, prior to a data processing when the processing ‘*is likely to result in a high risk for the rights and freedoms of individuals*’, notably when they are undertaking profiling operations or before processing sensitive data on a large scale and in certain cases a prior consultation of the DPA.

The call for an inter-normative and interdisciplinary approach Facing the technology requires from the lawyers a double humility: the first one is to consider that the ICT regulation is no more ensured only by legal texts. As previously said ICT is also governed by technical standards by the market’s forces and definitively by self-regulatory documents. Moreover, the effectiveness of legal solutions is ensured better through other normative systems than by the legal systems themselves. All these facts oblige the lawyers to be humble and to dialogue with these other normative systems. Enter into dialogue with the tenants of these other systems in order to create complementarities between these different regulatory systems is mandatory. Assuming that, we plead however for preserving the essential role of the Law. First, it is quite clear that the Law is at the service of the investment's protection, the security of transaction (electronic signature or evidence) and of people (cybercrime). The Law has to take into account values like education, universal access and multicultural dimension of our world but above all, the liberties and the dignity of individuals are an absolute requirement as regards the development of our Information Societies not as an individualistic request but as a condition of our democracies.

As regards the second point, in order to provide the appropriate solutions, the lawyers must adopt a double **interdisciplinary** approach. First, most of the technological developments must be examined through different legal branches to be correctly regulated. To take an example, if you want to regulate DRMS, not only intellectual property problems have to be evoked but, beyond that, contractual issues, privacy questions, non-discrimination and other constitutional principles, competition rules, … must be addressed and solved in an international perspective. Second, in order to understand not the technology in itself but the human dimension of its usages, definitively the lawyer has to understand not only the very nature of the technology but confront his or her analysis with sociological, ethical, communication's specialists' opinions. We clearly plead for multidisciplinary teams beyond the traditional disciplinary walls.

At the Internet Age, the tasks of us lawyers is thus essential: with the complicity of all stakeholders and taking fully into account the merits and benefits but also the risks linked with the development of ICT regulate our always evolving information society in such a way to leave to anybody throughout the world a space to choose the lives they have reason to value.