THE TRANSFORMATION OF TECHNOLOGY BY SCIENCE — IMPLICATIONS AND INTERROGATIONS

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In the past and during millennia, through a long and slow transformation process, technology always emerged from existent artifacts and devices as a mature construction, tested and verified in the framework of the prevailing technical culture. It was in the course of everyday life that new ideas were suggested, a slow procedure, similar to an accumulation of knowledge about the usage of the forces and substances of nature. It was like this until the introduction of the railways, and up to a certain extent, of the telegraph.

However, in the course of the 20th century, the mechanism of technological creation was drastically altered.

The industrial research activities grew stronger with the development of new industries in the sectors of rubber, oil, glass, metallurgy, transportation and instrumentation; and science left the relative isolation in which it lived until then in its laboratories, academies and universities, when it was summoned during the Second World War to develop technologies with direct and immediate military application. The effort of the post-war alignment propelled the national budgets for scientific and technological research to values, which had never been attained before. With the appearance of the first artificial satellites at the end of the fifties, the public character of science and its technological applications was definitely established. (Caraça, 1999).

The emergence of industries of high technological intensity in the second half of our century, such as aerospace, semiconductors and computers, and more recently the pharmaceutical and biotechnological ones, reveals the critical importance of science applications in the societies of the industrialized world. Business and societal practices now strongly depend on new ideas which have an origin intimately related to the scientific effort, i.e., that does not derive from natural language or from common knowledge. This procedural change is not straightforward; it implies transformation and deep institutional reorganization in the societies, which assume it.

It is necessary to change, but, most of all, it is necessary to know what and how to change. This means that we should not attempt at changing everything, because then, everything would remain the same. And this is the central difficulty of innovation, in the times that we live in. To change where, how, and by how much?

The advanced societies adopted structured processes of transformation where innovation is envisaged as the only answer to economic survival in the framework of fierce and omnipresent competition. This transformation has in the new science-based technological creation process a powerful driving force that no innovation effort can remain indifferent to.

The process of development that was established in western societies since the middle of the 20th century has a scientific base that prompts significant changes in the behavior and in the way the institutions are organized. Naturally, the structure of economic activity is also changing, forcing the emergence of a new innovation system based on science. This is the way our brave new world now functions; for lack of a better world, we call it "globalization".

It is, for this reason, important to reflect on the changes that took place during this transformation.

The first consequence of the new process of technological creation originated in the 20th century was the emergence of new sectors in the manufacturing industry. These sectors, the "hi-tech" or high technological intensity ones, all have a high added value associated to them. New enterprises were created in these sectors, which generated powerful multinationals enterprises, in order to manage the new wealth that these industries generated. The world, today, would not be possible without its products: airplanes, missiles, satellites, space vehicles, computers, lasers, antennas, electronic networks, genetically modified products …

The second consequence was the emergence of a new discipline within the social sciences: science policy. Originally conceived as a means of organizing the framework of scientific activity as to be able to direct it towards the production of technology — a new science-based technology — its success led it to be a template for a series of new policies, which appeared later in the 20th century, such as innovation policies and knowledge policies. Scientific and technological policy is today an established and assumed discipline in the university structure.

The third consequence was the creation of a new political need: to diffuse to the public the great issues that science is confronted with. This need of the public diffusion of science, of enlarging the scientific culture of the citizens, of massively introducing experimental teaching of the sciences, is related to the fact of science directly influencing everyday life, through new technological products that the citizens consume. It is necessary that they understand the value and effort that these innovations allow.

The fourth consequence was the introduction of a new concept: "science and technology" or "S&T", when in the middle of the last century just "science", or "technology" were mentioned, and seldom their interactions. The need to closely link science with technology only arises when the new essential function of modern science becomes evident: to produce technology. The term "R&D" also dates back to this period, legitimating the unity of a creative scientific process, which now offers countless commercial advantages.

The fifth consequence is the advent of direct relations between industry and universities. That is, between the industries of high technological intensity and the universities where the research is done at the frontier, of course. Why? Because there are now a considerable number of scientific researchers in the new productive sectors who communicate with their colleagues in the other activity sectors of the scientific community. This means that, the industry-university relationship does not take place at the level of the C.E.O. or the Dean (even though it is not excluded), but between the researchers in the firms laboratories and the university centers that speak the same language and share the basic knowledge of the same subjects.

The sixth consequence was the emergence of a new structure in the economic activity: the "scientific and technological system" (or STS). This system corresponds to the functioning and interaction of the entities and institutions involved in the process of technological creation from a scientific base. It is this system that allows, in the economies of developed countries, the creation of an innovation mechanism directly linked to the research at the frontiers of scientific knowledge.

The seventh consequence was the birth of a new type of university: the "research university" that functions as a central link of the communicating and interactive process that generates the technological innovations in the sectors of high technological intensity. It is that university in which the research activity is organized in institutes and projects, and where the post-graduation assumes a central role in the financing and stability of the university system. It isn't surprising that this university model emerged in the United States after World War II, as the American national effort of response to the cold war. In this model, the total number of post-graduate students is the same as the undergraduate students, and the quality of the scientific production is such a sensitive evaluation parameter as the competences of the bachelor degrees who are educated there.

The eighth consequence was the creation of a new academic degree: the "research Ph.D" or "research doctorate", this is, a doctorate that is taken at the beginning of active life, as an entry qualification for scientific activity, and not a degree that is obtained as a certificate of the Ph.D.'s ability to teach in other universities (as it was in the past).

The ninth consequence was the appearance of a new profession: the scientific researcher. Until then, scientific research was the work of inquisitive, highly gifted geniuses or university professors. The creation of national research laboratories, and of research centers in the enterprises and supported by philanthropic foundations, brought the notion of "full time scientific researcher", as well as that of a scientific "career".

The tenth consequence was the appearance of a new craft or skill — "technology management", due to the need of managing new economic organizations, where a high percentage of its staff (e.g. 50%) has a high level of formal education: bachelors, masters of science, and doctors. Clearly, these companies must adopt procedures which do not classify under the classical rules of business strategy, either in the decision making process or in their relations with other external entities.

The eleventh consequence was the emergence of the "two cultures" issue, the humanistic-literary and the scientific-technological, and their dispute in advanced societies. There was some apprehension at the time (in the 1960's) about the enlargement of the gap between the two cultures, because it could destroy the base and the cohesion of the advanced societies (Caraça, 2001). Today, evidently, with the emergence of the phenomena of market globalization and social exclusion, we can see that a need is being generated to comprehend and put reality in perspective, which goes, by far, beyond the differences between the two cultures and its disciplinary conflicts.

The twelfth consequence was the recognition of the existence of a mode of creating knowledge different from the mode which was based on the disciplinary research: "Mode 2" — the "new" applied, transdisciplinary and reflexive mode of knowledge production proposed by Gibbons, Limoges, Nowotny, Schwartzman, Scott and Trow in 1994. It is through this framework that thematic research, performed by means of projects of interdisciplinary nature, obtains a statute of legitimacy.

The world has changed, and innovation emerged, triumphant, during the decade of 1970's. The systems which create, diffuse, finance, manage and support innovation are based on a group of social, organizational and technological changes brought by the new process of producing technology from a science base, introduced in the middle of the last century. These changes make part of today's reality, with its networks of intense and enlarged communication that support everyday life.

But apart from new institutions and new opportunities, new challenges and new worries arise: global markets induce the notion of global commons, but also of global greed. And instability brings along the need to understand and manage risk, together with the threat of a new social stratification due to the "commodization" of knowledge.

Thus, we must be aware of what is worth — and what is not worth — changing. Of what must be preserved of the past and what is necessary to change in order to originate a better future. This is, in essence, what should be meant by "innovation".

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