TECHNOLOGY, CULTURE AND INNOVATION

MIGUEL ANGEL QUINTANILLA

SCIENCE AND TECHNOLOGY STUDIES INSTITUTE

UNIVERSITY OF SALAMANCA

It is widely acknowledged that the different modes of technological development are tightly linked to the cultural configurations of the various societies; that there is a certain coherence between the technologies that a society is able to create or assimilate and the rest of the cultural traits characterizing that society. Ortega y Gasset (1939) discussed this in his work "*Meditación de la Técnica*" when he attempted to explain the different technological styles of the West and of the East and when he contrasted the cultural models of the "*Hidalgo*" and the "*Gentleman*". More recently, debates about "appropriate technologies" for Third World countries and the controversies about alternative models of economic development have also highlighted the importance of cultural factors for the purposes of explaining or directing technical change. In fact, in reports aimed primarily at decision-making in scientific policy, and in the management of scientific innovation, increasing importance is being granted to cultural factors (COTEC, 1998). My aim in this paper is to address the bases of a general theory of technical culture that might serve to construct specific models for the analysis of the interactions between technology, culture, and innovation in certain specific cases. To accomplish this, I base my thoughts on the notion of technical system that I have developed elsewhere (Quintanilla, 1989, 1993.94, 1993 (96), 2004), on the philosophy of culture of Jesús Mosterín (1993)[1] and on the systems theory of Mario Bunge (1979).

To begin, I shall summarize some basic notions of the philosophy of technique such as those of technical systems, technique and technology. I shall then propose a theory of technical culture and, finally, a scheme for the analysis of the incidence of cultural factors on technological development and technological innovation

[1] This text was compiled integrating other previously published ones; in particular, Quintanilla (1998, 2002 and 2004).

First, note should be taken of the existence of systematic ambiguity in the use of the terms "technique" and "technology", "technological artefact", "technical knowledge" and "technical system".

In principle, the term *technique* is understood as a *set of skills and knowledge serving to solve practical problems.* A specific type of technique is *productive techniques*; i.e., techniques involving the transformation and manipulation of specific objects to deliberately create other objects, states, or processes. The results of applying these productive techniques are what we call *artefacts*, some of which, such as *tools* and *machines*, are in turn known as *technical instruments*. Techniques, in general, and especially productive techniques, are thus a *form of knowledge, with a practical nature*[2].

By technology, we understand a body of knowledge with a scientific basis that allows technical solutions to be described, explained, designed and applied to practical problems in a systematic and rational way[3]. The importance of a scientifically based technology to be able to design and produce certain types of technical artefacts explains the use of notions such as technological artefact, technological industry, advanced technology, etc., with respect to certain productive techniques characteristic of current industry. In all cases, reference is made to a type of technique or artefacts and industries whose development and application have been possible thanks to the existence of a body of technical knowledge with a scientific basis. In comparison, and to distinguish between them, it is possible to talk of empirical, artisanal or pre-technological technique to refer to the techniques that are based exclusively on practical experience and not on the systematic application of scientific knowledge to solve problems.

One rule that we shall use here, and that indeed should always be followed to avoid confusion, is that the concept of technique, in expressions such as *philosophy of technique, history of technique*, etc, will always be used in the *generic sense*, keeping the term *empirical technique, or artisanal technique,* for productive techniques that are not based on science, and we shall reserve the term *technology* to refer to productive techniques (or at least those of economic relevance) based on science.

We shall also distinguish between techniques, artefacts and technical systems. Techniques are cultural entities (Mosterin, 1993) or forms of knowledge; something that can be learnt and transmitted through different learning processes, as any other cultural information is transmitted. In contrast, artefacts are specific, material entities that can be manipulated, used, built, and destroyed and yet, except in the figurative or metaphorical sense, they cannot be learnt, encoded or interpreted. (Bunge, 1970, Vol. III). Like artefacts, *technical*

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[2] I include *skills* as forms of practical knowledge. In Quintanilla (1991) this issue is addressed and was later published as a part of Quintanilla (1993-94). See also Vega (1996).

[3] The meaning of the term "technology" is not stabilized either in Spanish or in other languages, such as English or French, on which the use of the Spanish term depends. Mitcham (1994) makes an exhaustive analysis of the meaning of "technology", and readers are referred to this. Of the different definitions commented by Mitcham (p. 153), the ones closest to what we are proposing here are those of Galbraith (1971): "the systematic application of scientific knowledge, or other forms of organized knowledge to practical tasks; and Rosenber (1982): "knowledge of techniques".

systems, as we shall see below, are specific entities, but in this case they include, as components the intentional agents that use, design, or control artefacts.

Thus, it is possible to distinguish three main directions or approaches in theories about technique and technology. We shall call these the cognitive, instrumental and systemic approaches[4]. For the *cognitive approach*, empirical techniques are forms of practical knowledge; technologies are *science applied to the solving of practical problems*, and technical change consists of the progress of knowledge and its applications, its main sources being technical invention and the development and application of scientific knowledge[5].

Table 1: Three approaches in the theory of technique

		Most relevant characteristics		
		Empirical technique is	**Technology is (mainly)**	**Fundamental factor of technological development**
Approaches	**Cognitive**	Practical knowledge Skill	Applied scientific knowledge	Invention and R&D
	Instrumental	Tools, machines and artisanal technical artefacts	Industrial artefacts	The diffusion of innovation
	Systemic	Systems of artefacts+materials+energy+ users/operators based on empirical techniques	Technical systems that include industrial artefacts and operators with special training, based on scientific technologies	Social and cultural innovation

[4] Mitcham (1994) makes a similar distinction, speaking of the different "forms of manifestation" of technology, as knowledge, as activity (production and use) and as objects (artefacts), also adding a manifestation "as volition" (one could say, as a source of power).

[5] Bunge (1966) is a classic reference for the cognitive approach, although Bunge (1985) offers a more complete and systemic philosophy of technology. Also, the work of Agassi (1985) fits in with the cognitive approach, but goes beyond it, addressing the social and political aspects of technology.

For the approach that we refer to as *instrumental*, techniques are identified with *artefacts*, the instruments and products resulting from technical activity or knowledge. This is applied to both empirical techniques (such as when we speak of the tools found in a deposit from the Upper Palaeolithic or the construction techniques used in ancient Egypt) and modern scientific technologies: aerospace technology is the set of devices used for space navigation; people say that a new *technology* has been implemented in a production plant, when in fact what has been done is to add a new machine or group of machines etc.

Finally, the approach we call *systemic* consists of considering that the units of analysis used to study the properties of a technique or to construct a theory of technological development are not sets of knowledge or sets of artefacts, but *technical systems*. The underlying intuitive idea in this approach is that a *technical system* is a complex unit formed by artefacts, materials and energy, for whose transformation the artefacts, and intentional agents (users and operators) that perform those *actions* of transformation are used. For example, a domestic washing machine is an artefact; dirty clothes, water, detergent and electrical energy are the inputs required for the device to work, but it is necessary to put the clothes etc. in the machine with the detergent and select the appropriate program for the machine to work as a technical system. The *artefact + materials + energy + user* set is the *technical system*. The definition is applicable both to artisanal systems based on empirical techniques and to technological systems. The differences lies in the complexity of the corresponding structures and the type of knowledge and skills required to design, construct and, sometimes, use the system.

The consequences derived from using one or the other approach in an analysis of technique are not unimportant. For example, if they adopt a *cognitive approach*, technique theorists will focus their attention on issues relating to the development of knowledge and applied investigation, but they will have difficulties in weaving into their theory issues relating to the diffusion of innovations. Policies of technological development based on *expanding the offer* (enhancing R & D) are usually inspired by a cognitive view of technology, and in them the main factor of innovation is the *invention* of new artefacts, but they usually find problems in understanding the difficulty involved in transferring the knowledge acquired in the R & D activities to activities involving production and commercialization by companies.

Further, if an *instrumental approach* is used, it will be easy to identify the different technologies and their properties, both functional and economic, and from them it will be possible to understand certain aspects of the processes of *innovation* and *development*, but it will be difficult to understand the *origin* of the innovations and the influence that *social and cultural factors* have on technological development. Many of the economic models of technical change tend to adopt this approach that we call instrumental.

For us, the *systemic* approach seems to be more realistic and comprehensive. Using this approach, we oblige ourselves to include within the theory of innovation and technical development not only cognitive or economic but also social, organizational, and cultural elements. For example, the introduction of an innovation into the market is now seen as a complex process that involves not only work in the R & D, production and sale of an artefact (a product), but also logistic processes involving the supply of materials, the organization of distribution networks, staff and user training etc., something that we can summarize in the idea of *social innovation* associated with technical innovation.

Many current approaches to economy (Dosi *et al*. (eds), 1982), sociology (Bijker *et al.* (eds), 1987) and, to a certain extent, technology policy[6] share the basic features of the systemic approach, although they do not always have a precise and coherent notion of a technical system.

THE STRUCTURE OF TECHNICAL SYSTEMS

Hughes (1983) uses the notion of technological system to refer to complex systems in which the social and organizational aspects may be as important as the physical artefacts themselves. The system of the generation and distribution of electrical energy invented and put into practice by Edison is a technological system in this sense. To understand how it works, it is necessary to bear in mind not only the properties of the electrical devices themselves but also Edison's organizational prowess and the changes in customs that occurred as a result of the industrial and domestic use of electricity. In fact, however, any given technical system, regardless of its magnitude and complexity, has that dual dimension (physical and social, artefacts and organization) that is easier to notice in large technological systems. A PC considered in isolation is a simple artefact incapable of doing anything; a computer coupled to a user is a technical system that can solve calculations, control machinery, etc.

We can define a technical system as a complex device composed of physical entities and human agents, whose function is to transform something, in an efficient way, in order to obtain certain result characteristics of the system[7].

Table 2: Characterization of technical systems

Inputs	Raw materials
	Energy

[6] The *Oslo manual* of the OECD for the collection of information on technological innovation policies to a large extent responds to this approach.

[7] In Quintanilla (1989), I proposed the following definition: "A technical system is a system of actions that is intentionally oriented to the transformation of specific objects to efficiently obtain a result considered to be of value" and I formally developed the concepts involved in this definition from Mario Bunge's ontology of systems.

- **Components**
  - Material (parts)
  - Agents
    - Operators
    - Users
    - Managers
- **Structure**
  - Transforming actions
    - Material processes
    - Manipulative actions
  - Management actions
    - Monitoring
    - Systems control
  - Intentional objectives ($o_1, \ldots o_n$)
- **Outputs (results obtained)**
  - Intended
  - Not intended

A car factory is a technical system. But a washing machine, with all its components, together with the user, the detergent, the clothes and water and the electricity consumed, also constitutes a technical system characterized by certain aims and results. Table 2 summarizes all the elements characterizing a technical system.

Inputs: These are the *raw materials* that are used and are transformed in the technical system (the clothes, detergent, water (in the case of a washing machine), enriched uranium (in a nuclear power plant) etc, and the *energy* used to operate the system.

Material components: The “parts” or “*equipment*”; i.e., the technical components of the system itself (the nuclear reactor, the surrounding buildings; the parts. Motors, mechanisms, electronic controllers, valves, etc. of the washing machine; the processor and the memory chips of the PC, etc).

Intentional components or agents: The main difference between an artefact and a technical system is that the latter requires the involvement of intentional agents: a washing machine without a user, a nuclear power plant without operators and engineers to run it and control its functioning, or a PC with nobody to program it are not technical systems; they are pieces for a museum that represent part of a technical system. The agents of a technical system are generally human beings, characterized by their *knowledge,* *skills* and *values* (for their *culture,* see below), who act within the system either as *users*, or as *manual operators* or as *controllers* or *managers* of the system. In complex systems these functions may be carried out by different individuals, although it is possible that several of such functions may be handled by the same person, and it is even possible that some of them could be transferred to mechanisms of automatic control.

The structure of the system: This is defined by the relationships or interactions that occur among the components of the system. We distinguish two types: *transformational relationships* and *management relationships*. Among the former, it is necessary to distinguish the *physical processes* that are produced in the material components of the system, on one hand, and the actions of *manipulation* carried out by the intentional agents on the other. In a nuclear reactor, the processes of the fission of the atomic nucleus belong to the first group, while the processes involving the manipulation, loading and unloading of the fuel rods belong to the second group. *Management relationships* are also relationships among the components of the system, but in these what matters is not the material transformations that are produced among the components but the flow of *information* that allows the control and overall management of the system: the action of the *monitoring* devices (which provide information about the status of the system), and of automatic *control* (the washing machine program, alarm and safety devices at the nuclear power plant) or manual control (starting up and shutting down the device, the power plant etc) are part of the structure of any technical system. In complex systems, management may require hundreds of people (from those in charge of the plant to the engineering team of an industrial factory) and millions of technical elements (electronic processors, automatic control systems, sensors, etc). It is also possible that the management of the system can be completely automated (with a computer program) or that all the functions of control may be carried out at the same time by the same agent (in simple or highly automated systems, where the management operations are reduced to observing alarm indicators and shutting the system off or starting it up manually).

Objectives: Objectives are part of the structure of the system because they are crucial for intentional actions. It is assumed that a technical system is designed and used to achieve certain objectives or to perform certain functions; a washing machine can be used as a table, but this is not what it was designed for. To characterize a technical system it is very important to define exactly what its objectives are with great precision, if possible in accurate and quantifiable terms, such that the user or operator of the system will know what his or her duties are, and what can be expected from the system.

Output or results: In general, the result of an intentional action does not completely match the aims of the action: it may happen that some of the aims are not achieved (or at least do not meet the anticipated aims) and also that unexpected results are found. Accordingly, to characterize and evaluate any technical system it is important to distinguish between the objectives foreseen and the results actually achieved (and, within these, those coinciding with the results anticipated and those that differ from them). Two nuclear power plants may have the same aims as regards the production of electricity, the same power capacity, etc., but they will be very different if one of them generates radioactive residues and the other does not, or if one is subject to more frequent escapes of radioactive material into the environment than the other, etc.

Our definition of technical systems is a solid basis for the construction of a theory of the structure and dynamics of technology. First, since the structure and dynamics of technical systems is well defined it is possible to define, with great precision, important notions such as those of technical subsystems, variants of techniques, the adaptation of techniques for alternative purposes, the composition of techniques, technological complexity, etc. It also allows us to establish systematic classifications of techniques and technologies and offer a precise meaning for ambiguous notions such as the distinction between soft and hard technologies, appropriate technologies, alternative technologies and alternative uses of a technology, as proposed by Quintanilla (1989, 2004). Second, the differentiation between material and social components (or agents) allows the complexity of technical systems to be pinpointed without reducing them to opaque conglomerates or networks of "actors", in which it is assumed that people, words, artefacts and raw materials, employing anthropomorphic metaphors extracted from linguistics (Calon, 1986, Latour, 1987), all have the same causal efficacy.

Third, the notion of technical system allows us to position the role of technical knowledge and of other cultural factors, such as values (see Broncano, 1997), in the development of techniques.

TECHNICAL CULTURE

Here we shall use the proposal of Mosterín (1993), according to which *culture is the information transmitted by social learning among animals of the same species.* This information may be of three types: representational (information about the characteristics and properties of the environment; practical (information about how to act) and value-related (information about which states of affairs are preferable, suitable or useful). As stated by Mosterín, this conception of culture covers, and precisely so, the essential content of the concept of culture used in scientific anthropology and ethology. The culture of a social group will be formed by a set of cultural traits (representations, beliefs, rules and guidelines for behaviour, systems of preferences and values) existing in the members of that group. Moreover, the set of all cultural traits forming the culture of a social group can be classified within several specific cultures, as a function of the contents of those cultural traits: thus, we speak of religious, political, scientific, sports, business, employment, academic, etc., culture. Within this framework of ideas, the term *technical culture* may have two meanings. On one hand it may refer to the set of techniques (as practical knowledge) of a given social group (technique forms part of the culture), and -on the other- it may refer to a set of cultural traits (representations, rules and values) related to techniques. Here, we shall focus on the second, broader, sense of technical culture.

In fact, technical systems are actually hybrid *sociotechnical* systems. They thus incorporate cultural, economic and organizational or political elements and, also, they function and are developed within an environment formed by broader social systems that both affect them and are affected by them. Part of the social environment of any technical system is a *cultural system*, which includes scientific and technological knowledge, although also other cultural components related to values, skills, representations, beliefs, etc. The situation can be encapsulated in the following way: *Culture forms part of technical systems and techniques form part of culture*.

In light of the foregoing, we can define the technical culture of a social group as a specific culture, formed by all the cultural traits (descriptive, practical and value-related information) that refer to, or are in some way related to, technical systems. Accordingly, the main components of technical culture are[8]:

Knowledge, beliefs and conceptual or symbolic representations about techniques and technical systems. We shall call this *the symbolic or representational content of technical culture.*

The rules and guidelines for behaviour, skills, and operational knowledge as referred to technical systems. We shall refer to these as *the practical component of technical culture.*

The aims, values and preferences relative to the design, acquisition, use, etc., of technical systems and technical knowledge. This will be referred to as the *value-related or axiological component of technical culture.*

These components of technical culture may be presented in two modes: those that *are incorporated* into technical systems, and those that, although still part of the technical culture of a social group, *are not incorporated* into any technical system. In the first case, we shall speak in terms of *incorporated* technical culture and in the second of *non-incorporated* technical culture.

INCORPORATED TECHNICAL CULTURE.

Indeed, technical systems incorporate many cultural components. A technical system is in part made up of human agents who act intentionally (operators, managers or users of the system). To act in the technical system, these agents need a certain amount of *information* that forms part of their own culture; in particular:

- The *knowledge, beliefs* or *representations* they have about the components, the structure, and the functioning of the system.
- The *practical skills* and *rules of action* that they are able to implement to operate with the system or to design and build it.
- The *values referring specifically to the intentional aims and results* of each action of the agents, as well as those of the overall system and the relationship between the two.

All these cultural elements can be considered to be incorporated within each technical system through its human operators and builders. The cultural content of each particular technical system may be (and generally will be) different, since the culture of the different human agents is also different.

[8] Our proposal differs, although not incompatibly so, with that of other authors who have addressed in depth the cultural aspects of technology. For example, Pacey (1983) distinguishes three *aspects* in *technological practice*: the purely technological, the organizational, and the cultural aspects. The latter includes the objectives, values, and beliefs about the technique (such as belief in progress, etc).

The set of cultural contents embodied in all members of a class of systems representative of a given technique is the cultural content of that technique in the strict sense (incorporated technical culture).

For example, currently the technology for individual transport in cars includes a true "car culture", with many variants. There is, nevertheless, a minimum cultural content that must be incorporated into each of the individual transport systems that are effectively functioning. In this case, that minimum cultural content of technological culture is usually set forth in traffic legislation and is the object of specialized teaching and controls by exams that drivers must pass in order to obtain a driving license.

Evidently, the technique of driving cars is not the same as that used to manufacture them. The car that leaves the factory incorporates many more cultural elements in the design and manufacturing processes than what went into actually producing it. Some such elements will be transparent for the user, but others will not. For the system to function adequately, the cultural repertoire of the eventual users must include at least part of the contents incorporated by the designer and the maker, but not necessarily all of them, or only those contents. The members of a society can use cars even though they do not know how to make them. They can even build technical systems with them with properties other than those foreseen by the original designer. For example, in a poor country, an old, but very powerful, car can be used as a truck instead of being scrapped.

Naturally, not all cultural contents can be equally incorporated into any technical system, and neither does the same technical system function in the same way in different cultural contents. For instance, when the first automatic washing machines began to spread to domestic use, some users took some time in understanding the function of the programmer in the new machines, and instead of using it to select a pre-established program they tended to use it as a means to give successive instructions to the machine along the washing cycle manually, such that in practice they were suppressing the automatic nature of the new machines and reducing their performance to a considerable extent. The new system required a new culture from the user; a culture in which the notion of program could be included, as well as other novel notions, all within the context of domestic technology.

There are many other phenomena that can be seen in processes of technological change and of technological transfer that highlight the importance of cultural contents *incorporated* into technical systems. For example, along the history of technique it may be seen that nearly all innovations, however radical, are initially seen as variants of pre-existing technical systems: the first steam engines were conceived as substitutes of the water-wheels that were used to extract water from mines; the first cars were made by trying to put a motor on a horse-drawn cart, and the first computers installed in offices were conceived as a replacement for the traditional typewriters, not as a powerful tool for dealing with management tasks, as they tend to be considered today[9].

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[9] Currently, the huge efforts being made to fit Internet technology into the cultural schemes of traditional information media (television, multimedia) and communications media (personal and business telephony) offer a good example of this "procrustean" drift (the new must fit in with the old) of technological culture.

We also know of other problems encountered in the transfer of advanced technologies to developing countries. Most of these problems stem from a *cultural gap* between the context in which the technology was originally developed and the new context into which it is being transferred. This gap may affect not only the level of technical knowledge and of the skills or the users, operators and managers of the new system, but even the preferences and valuations with respect to the intended aims of the system. See the ICPS report (1992) for the UNESCO.

This notion of incorporated technological culture can be used to give a precise content to the idea of the *interpretative flexibility of artefacts* used by Bijker (1994) to explain the processes of the social configuration of technologies. For example, as explained by Bijker, the first bicycles were seen by some (especially women) as an instrument to move placidly from one place to another, while others (especially males) considered them artefacts for sport and competition. The different interpretations also give rise to different valuations regarding the available technological alternatives (the different models of bicycle) and, finally, the *stabilization* of a given model is achieved when one of the social groups involved manages to impose its own interpretation (generally after having modified it to allow the *inclusion* of other groups within a single *technological framework*). It is clear that the notion of incorporated technological culture has much to do with the "interpretative flexibility of artefacts", However, the following differences and nuances should be borne in mind.

Firstly, what Bijker metaphorically refers to as the *interpretation* of an artefact is actually, according to our thesis, a part of the *cultural content incorporated* into each technical system, through the culture of its users and operators. This cultural content can be analyzed through its three main components: *knowledge* or *representations* of the artefact and of its context; *skills* and *rules* of operation, and *preferences* or *valuations* with respect to the aims and results of the system. From here it is possible to define -and precisely so- the *cultural content incorporated into a class of technical systems* (a model of bicycle, for example) as the set of cultural contents *shared* by all the members of that class. In Bijker's model, this would be the same as something like a *common core* to all interpretations compatible with the same artefact, which it would be necessary to define.

One consequence of the foregoing is that the set of cultural contents (interpretations, in the terms of Bijker) that can be incorporated into a technical system is not unlimited: *there are restrictions imposed by the very structure of the system*. In other words, although all artefacts admit different interpretations, not all interpretations that are logically possible are technically compatible with any given artefact. For example, a bicycle can be seen as a means of transport or for competitive purposes, but it would not be technically viable to see it as an instrument for frying potatoes, for writing letters, or for baking apples. Again, the reason for these limitations cannot be found in the social and cultural conditions that contribute to configuring a technology, but in the internal structure of the technical system.

Moreover, Bijker's theory allows no room for analyzing the different role in technological development of the *interpretations* that are embodied in technical systems and those outside it, but that may be of great transcendence in their development and social configuration. For instance, the interpretation of the various techniques of birth control as "the devil's instruments" may prevent their diffusion (without having to convert them into an "alternative technology"), whereas the extension of ecological awareness may lead to important technical innovations as regards the replacement of the polluting gases from some industries by other less harmful ones.

Finally, the distinction between incorporated and non-incorporated cultural contents or *interpretations* is a useful tool for explaining the cases of alternative interpretations (different social uses) of the same artefact. Bijker explains this phenomenon through the mechanism of the "inclusion" of groups of users with different interpretations within the dominant paradigm of an artefact. In our model, this phenomenon is completely natural: on the basis of a cultural content incorporated in an artefact, which must be shared by all user groups, there are "non-incorporated cultures" that may be characteristic of each particular group. One could thus explain the success of a given model or artefact or technical system (for example the model of the modern bicycle analyzed by Bijker: large wheels, with pneumatic tyres and chain-driven transmission) owing to its intrinsic efficiency and its compatibility with a set of cultural elements (easy to understand and use and useful for personal transport) widely shared by many social groups, each of which, too, was able to include the new artefact within its own differentiated cultural profile (as sports people, as consumers of fashion, as workers who need easy and cheap transport, etc). Hence the importance of the elements of cultural technology *lato sensu*, i.e. not incorporated in technical systems.

TECHNICAL CULTURE LATO SENSU

Indeed, one could also mention *technical-cultural contents of a social group not incorporated into any technical system*. Technical systems develop in a broader social context, with which they interact in different ways. In the social context of a technical system there may be individuals who may or may not be agents or users of that system but whose culture includes representations, rules and valuations of those technical systems. For example, such individuals may have scientific knowledge that is potentially applicable to the design and construction of technical systems, they may have a deterministic philosophy about the technique, or a linear and teleological conception of technical development, or may defend an anti-technological or, by contrast, technocratic ideology; they may have religious or moral ideas about the value of certain technical aims (*in vitro* fecundation, thermoelectric/nuclear power plants, etc) or rules that forbid them to use certain techniques (birth control, blood transfusions, for example) or ideological representations of certain techniques as perverse or beneficial elements for society (for example, the different representations of the effects of technological innovations concerning employment, or the role of communications technologies in the democratic organization of society, etc). In sum, they may simply have interests or whims (economic, political, aesthetic, religious values, etc) in favour or not of a given technique or indeed all techniques. All these cultural traits can also be considered part of the *technical culture of a social group* *lato sensu*, some of them may eventually form part of the technical culture embodied in some class of technical system, but others may be an important part of the technical culture even though they never form part of the cultural content of any technical system proper.

The frontiers between incorporated and non-incorporated technical culture are permeable. The development and diffusion of technologies have a dual effect: on one hand they broaden the spectrum of cultural contents that are *incorporated into* technical systems; on the other, they give rise to the appearance of new technical-cultural traits *lato* *sensu*. A celebrated example of the former is the incorporation of certain cultural traits of Japanese society into the organization of production processes in the automobile industry. An example of the second type is the extension to the public at large of technological controversies surrounding the suitability, the risks, the environmental impact and the social consequences of certain technological systems or projects.

There are objective limits to these processes of cultural transfer. There are cultural traits that are not compatible with the functioning of certain technical systems: a Jehovah's Witness, at least for the time being, cannot be an efficient surgeon; an illiterate person cannot manage a complicated control system, just as a blind person cannot drive a car. And there are technical systems that cannot be disseminated in a society in which certain cultural traits predominate: a high valuation of the hierarchical organization may impede the introduction of new production techniques that leave a large part of the management of the system in the operator's hands; the engineers of a factory cannot be replaced by tribal shamans.

One of the biggest problems faced when reflecting upon the history of technique is precisely how to understand how the cultural traits characteristic of different societies are related to the different lines of technological development. An especially striking case is that of the different fate in China and in the West of certain very significant inventions (gunpowder, the printing press), whose technological potentials were never developed to their full extent by the culture that generated them. Another interesting case, although in the opposite sense, is the development of firearms in Japan; first they were accepted (16th century) and indeed a significant industry was forged, but then they were relegated to a lower position with a view to preserving the weapons and military technology typical of traditional Japanese culture. Finally, they were re-incorporated after Japan opened up to the outside (1876), until a powerful military industry was developed that rapidly converted Japan into a modern power in the first third of the 20th century (Basalla, 1988).

With the above in mind, we should ask ourselves what the true role of cultural elements is in the development and diffusion of technologies. Chinese culture enabled the invention of gunpowder and the printing press, but it did not facilitate the further development of these inventions or their dissemination, as occurred in the West. Traditional Japanese culture was an obstacle (through a political decision) to the diffusion of western weapons technology; however, after another political decision that culture did allow its rapid incorporation and development. Which factors were brought into play in each case and how did they work?

One way of answering these questions lies in analyzing the mechanisms responsible for the transfer of cultural contents from technical systems to social systems and vice-versa in greater detail.

The technical culture of a society at a given moment is characterized by the following traits:

1. The *technical culture incorporated into* the technical systems available to that society. This includes:

    a. *Cognitive components*, representational or symbolic: Applied technical and scientific knowledge.

b. *Practical or operational components*: rules of operation, technical design skills, production and use of artefacts.

c. *Value-related components*: objectives incorporated in technical systems and valuations of the results, attitudes as regards risks, uncertainty, the necessary social change associated with the different technical systems, etc.

2. *Technical culture not incorporated* into technical systems, although referred to them or relevant for their production. This includes:

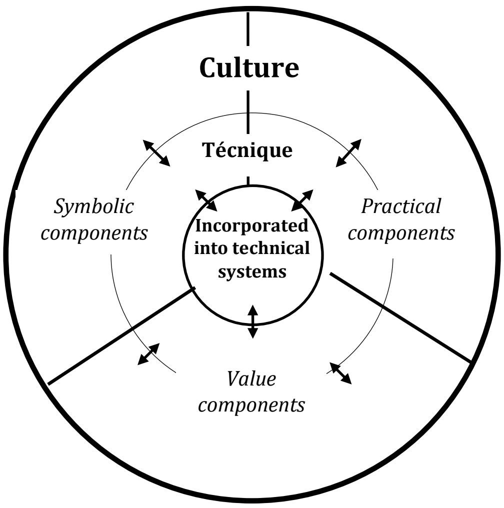
    a. *Basic knowledge* (*scientific*, in the case of technological culture), not incorporated into technical systems, but with potential technical applications. *Symbolic representations* of reality, especially of technical systems and their relationships with society. *Technological myths* (or anti-technological ones, etc).

    b. Rules of *action* of social, moral, religious, political, economic etc. nature that may be significant for behaviour related to the use and development of technical systems.

    c. *Values and significant preferences for the use and development of technical systems*. For example, the valuation of life may affect the development of medical techniques; the preference for stability against change may hamper technological innovations, etc.

Technical culture changes and evolves like the rest of culture: individuals are nearly always creating and testing new cultural traits, some of which are successful, become consolidated, are taught to other members of the society in question, and are learned (and possibly modified) by these latter, etc. What is specific about the dynamics of technical culture is the importance in it of the transfer of cultural contents between the technical systems and the rest of the culture.

Illustration 1: Components of technical culture



For example, many ancestral *myths* of Western culture are the result of a transfer of cultural elements that were originated by the development of technical systems and that have become generalized to the rest of the culture in the form of myths. The most significant of these is the *myth of Prometheus* (chastised for having handed fire to humans and with it the Arts and industrial techniques). Among the technological myths of modern culture, one of the most significant is that of *Frankenstein*, strongly linked to the development of bio-medical techniques and the discovery of electromagnetic properties and phenomena.

Also well known is the influence of *artisanal technical experience* in the birth of modern science (Bacon, Galileo, etc) and in the philosophical representations of modern culture: the machine animal of the Cartesians, for example.

The influence of *more advanced technologies* in today's culture is also easy to perceive: post-industrial society, the information society, the knowledge society – all are representations of social reality inspired by communications and information technology (Mazlish, 1993).

The influence of some *behavioural guidelines* linked to the functioning of certain technical systems on the rest of society is also well known. One of the most striking is the influence of mechanical clocks in the organization of the life of the whole of western society as from the end of the Middle Ages (Mumford, 1934; Pacey, 1974). The idea of a uniform and constant time with equally identical periods could only be spread after mechanical clocks of sufficient reliability and precision had become available. Until the 14th century, social life had been able to function with systems for measuring time that were not very precise and that depended on the variable duration of the day and the night, in turn depending on the season. We can gain an idea of the magnitude of the cultural change that this afforded if we stop to think how modern society could survive if all clocks and watches suddenly stopped working. In the case of computers, the famous *2000 eff*ect (the alteration of internal calendars of many large information technology devices, which would return to year zero when the year 2000 arrived) and the headaches it gave for months is a poor reflection of what our world would be like if the *culture of uniform time* ceased to exist, this having been achieved with the first mediaeval mechanical clocks.

There are also *values* of technological origin, which have become generalized to the rest of culture. Educated people of the 18th century held the notions of technological progress and happiness and moral progress to be almost identical. Even today we identify wellbeing, as an objective in life, with comfort and the availability of efficient and reliable technological artefacts. However, this requires special attention. In Western technological culture there are two values that play a central role. These are *efficiency* and *innovation*. In my opinion, here we are dealing with strictly technical values whose generalization to the rest of culture has contributed to configuring the nucleus of what is today considered to be modern Western society (Quintanilla, 1996(93)) and they are inseparable from the notion of technological progress.

CULTURAL FACTORS OF TECHNICAL CHANGE

Despite the considerable advances made in our knowledge of the processes of technical change, we are still far from discovering a comprehensive theory, sufficiently based on empirical data. Nevertheless, study of the social dimensions of technology now allows us to understand that the processes of technical change are far more complex than previously thought.

Returning to the three approaches in the study of technology summarized in Table 1, we see that each of them emphasizes one of the possible dimensions of technical change: processes of invention, of diffusion, and of social innovation. In fact, an integrated theory of technical change must take into account all three dimensions and its aim should be to articulate the set of factors that are brought into play in this complex process.

Table 3 offers some examples of the incidence of the different factors within the three dimensions of technical change. The cultural factors are distributed in three groups, according to the three main components (cognitive, practical and value-related) of technical culture.

TABLE 3 FACTORS OF TECHNICAL CHANGE

	Cultural factors			**Social and institutional factors**	**Economic factors**
	Cognitive	**Practical**	**Values**		
Inventions	Scientific and technical training	Practical and efficient *Know how*	Efficacy Efficiency Innovation	Institutions of R+D, Patent regulations	R&D Project funding
Diffusion of innovations	Level and capacity of communication and of access to information	Production and consumption trends	Risks and environmental impact assessment	Technological centres Standardisation systems	Support for innovation in companies
Social changes	Self-awarenessof society Technological myths	Customs Life styles	Evaluation of the social consequences of technological development	Training policies Institutions for the evaluation of technologies	Industrial, financial etc. policies

Certainly, there is no set of social conditions that will guarantee a strong production of viable technical inventions. However, it can be said that certain cultural factors facilitate, while others hinder, the *appearance of new, practical, efficient and useful ideas*. A society with a high level of scientific and technical training will have greater possibilities of designing new technical applications for the knowledge available and of using its cognitive resources to solve practical problems in an innovative way. Naturally, this is not sufficient, but it does improve the situation if there is also a good repertoire of technical practices and there is a predominance in that society of behavioural directives and values guided by the principles of efficacy and efficiency and, also, it is a culture open to innovation in which creativity is highly valued. In any historical period or social environment in which it is possible to find a high concentration of technical innovation we shall nearly always find a strong presence of all these cultural components.

The processes of *innovation and diffusion of such innovations* are more directly governed by economic and social factors than strictly cultural ones. Notwithstanding, these latter also play an important role. First, the speed and intensity of the diffusion of technological novelties to a large extent depends on access to information by the agents involved in technical change; i.e., users, technologists, business people, etc. In a closed society, with a technical culture based on industrial secrecy, it would be harder to diffuse innovations than in a society in which technical information is able to flow freely[10].: most technical innovations arise from the imitation and adaptation of other innovations. Second, some attitudes and behavioural guidelines related to the production and distribution of technological goods may also govern the diffusion of technological innovations. For example, the distrust of domestic industrial products (or, in contrast, of those coming from outside a country) may hinder or facilitate the diffusion of innovations from one or the other origin. Finally, the influence of certain values with respect to safety, risk, harm to the environment, etc., may act as sturdy bastions of resistance to certain technical innovations or, by contrast, they may act as the driving force behind technical change. In fact, one of the most characteristic phenomena of current technological culture in developed countries consists of the generalization of public debate about the suitability, or lack thereof, of certain technological projects that are perceived as threats to safety, health, the environment, etc.

In our model, *social and institutional change* is a dimension inherent to technical change. Naturally, here we are not referring to reintroducing technological determinism but to recognizing – following the model of Pérez (1983) and that of Freeman and Pérez (1988)- that technological development is inseparable from social and institutional change. Thus, at this level there is also an evident effect of cultural factors. First, the very idea that a society has of itself and of technology may have decisive influence on technical change. For example, a society that conceives of itself as something fixed and unchangeable will not have the same success in adopting the changes accompanying technological development as one that sees itself as open and changeable. It would also be interesting to analyze to what extent the technophobic myths of our times (the "hypermachine", the rebellion of "thinking machines", etc) govern contemporary social transformations. Customs, trends and life styles are also important factors when attempting to explain certain movements of adaptation and the reactions of society to technological changes. As we see from the different stages of the Industrial revolution of the 18th and 19th centuries, the introduction of new ways of using tools and machines in the production process, of new labour relations or of new management practices, does not occur equally in agrarian societies as in industrial ones. Finally, a cumulus of moral, religious, political etc. values that affect the mechanism of the generation of consensus concerning the large long-term projects of a given society may have important repercussions in the processes of social and technological innovation at all levels. Debates about military technology during the Cold War years or current debates about the long-term repercussions of genetic engineering may be important for the orientation of technological development and the transformation of society.

Naturally, together with this very broad repertoire of cultural factors one should not overlook, on one hand, the effect of economic and social factors and, on the other, the importance of previous technological trajectories. The technical changes occurring at a given moment in time are not independent from those that have been produced earlier; regardless of the innovative and creative spirit present in the culture of a society, few technological innovations can be made if the previously accumulated technological equipment is absent or negligible. Processes of innovation have considerable inertia, or *impetus* in the terminology of Hughes (1987): in a society with a strong tradition of innovation the tendency to introduce technological innovations will continue well beyond the time at which the cultural, economic and social conditions that led to the first steps along the pathway of innovation have disappeared. And, by contrast, a society without a tradition of technological innovation will take years and will require huge efforts if it is to "take off", as it were, in the field of innovation. Let us look at this aspect in greater detail.

In an economic system, continual changes -of very different natures- are constantly taking place. Some of these changes stem from variations in available knowledge, either due to the creation of new knowledge or to the assimilation of knowledge established previously and its application to economic activity. The changes introduced into the production of wealth or social welfare generated through the creation or assimilation of knowledge and its application are referred to as **innovations**. Thus, in this context by **innovation** we understand **the process that consists of creating or assimilating knowledge and applying it to generate wealth or social welfare in a new way**. We may therefore consider innovation as a specific type of creative activity: an activity whose aim is the creation of wealth or social welfare.

In any innovation one can distinguish two fundamental moments: **access to knowledge** and its **transformation into wealth** or welfare. The access to knowledge that gives rise to innovation may occur through the **creation** of new knowledge or through the **assimilation** of knowledge created or discovered by others. In general, the knowledge involved in processes of innovation is of two kinds: representational (**knowing what**) and operational (**knowing how**) and they have different degrees of formalization, from the maximum level of tacit, implicit or informal knowledge to the maximum level of fully formalized and explicit knowledge that is encoded in language of a general or specialized nature, such as scientific language.

The transformation of knowledge into wealth occurs through many routes, thus defining the different types of innovation. For example, management experience and knowledge may lead to **organizational innovations** in a company that will allow a more rational deployment of its staff or material resources, with the subsequent increase in productivity and wealth. The organizational innovations introduced into the public health service or into the compulsory education system can improve social welfare. One type of innovation of great interest for business companies is that deriving from knowledge of the market, and it consists of the adaptation of the company's activity or its products to market demands. This group includes **commercial innovations**, which range from novelties introduced in the presentation of publicity for a product to the opening of new sales points or the invention of new commercialization systems, client financing, etc.

In absolute terms, the introduction of an innovation into an economic system means that something, with economic value, is done for the first time that has never been done anywhere else before. In practice, it is useful to differentiate between **universal innovations** and **local innovations**, relative to a given company, country or sector. For example the substitution of production lines by integrated production cells is an organizational innovation of absolute or universal nature that can be applied locally to many different factories. Every time this change is introduced into a given company a "local" innovation, relative to that company, is produced.

Of all the different types of company innovation, in the present context the only one that we are interested in is what is known as **technological innovation**. Technological innovations are characterized as follows: a) they are innovations based on **technological knowledge**, and b) they occur within the sphere of the **production** of goods and services, either because they consist of the creation of a new type of product or service (**product innovation**) or because they involve the introduction of a new way of producing a good or offering an already existing service (**process innovation**).

Accordingly, we may define technological innovation as that which consists of generating wealth or social welfare by means of the introduction into the economic system of new products, services or production processes based on the application of technological knowledge.

Along the evolution of humankind, many technical innovations have been produced. In fact, we use some of these innovations to mark out the main steps in human evolution. **One of the specific traits of current economic activity is the importance that technological innovations have acquired** (based on scientific knowledge and implemented in an industrial context) **as one of the main sources of wealth and welfare**.

For years it was believed that technological innovation was merely a linear process that begins with the conception of a new idea (invention) and ends in the social diffusion (commercialization) of a new product or process. Today we know that it is a highly complex process, in which continuous feedback and interactions with many factors of different types take place. In any case, however, as a key element to technological innovation there is still the fact that it is inseparable from the production or assimilation of **new technological knowledge** (i.e., with a scientific basis and systematic in nature) and from the design, production, commercialization and diffusion of **new products and processes**.

It is possible to distinguish **three major moments** in the process of technological innovation:

a. The **conception of a new idea**, product or process that is to be introduced into the market.

b. The **development** of that idea, to convert it into a technically, socially and economically viable product.

c. The **production** and **diffusion** of the new product or process resulting from the development of the original idea.

The whole process of innovation occurs within a dual context: the technological context (mainly characterized by the available technological knowledge plus the knowledge generated in the process itself) and the social context (represented mainly, but not only, by the market). The innovation process is influenced by both contexts, out of which flow elements of information that condition, enable, and direct the innovation. At the same time, the actual process receives feed-back in such a way that the results of each stage may have repercussions on the other stages and the overall process may modify the actual technological context, affording it new techniques, new knowledge, etc., and the social context, in which new needs, new demands and new opportunities appear.

As well as the flow of information, there are other processes and factors of very different kinds that **affect innovation causally**. For example, in a subsistence economy there are few possibilities of new ideas arising and even fewer of these becoming converted into viable products. It is thus feasible to surmise that a certain general level of economic development and labour division would be able to favour the appearance of new ideas that could give rise to innovations. Indeed, the prior existence of value added, together with the appearance of a minimum of social labour division that would allow technical specialization, seems to have been a constant throughout historical processes of innovation. This is also a condition that technological innovation shares with any other type of social innovation: the inhabitants of the caves of Altamira must surely have dedicated their time and efforts to painting the walls thanks to the surplus from a good day’s hunting and the fact that other tasks were carried out by other members of the clan. Other factors (some of them cultural; for example, the currency of certain values such as the expectation of obtaining wealth or welfare; the “effort to save effort” in the words of Ortega y Gasset, 1939) also seem to be necessary if we are to suitably understand the appearance of ideas that can give rise to technological innovations, unlike those leading to other processes of social innovation.

The process of the transformation of an idea into a technically, economically and socially viable product is the crucial core of the process of innovation. Again, we see multiple factors that will affect the process. On one hand it is necessary to have a suitable technical capacity to design the new system, check its performance, its reliability, etc., and, on the other, it is necessary to have adequate and sufficient means to accomplish this, which in turn may depend on the amount of resources available in terms of capital, raw materials, a qualified work force, etc.

The same can be said of the last stage of innovation: the production and commercialization of the new system (product, service or process). This involves factors of production engineering, together with financial strategies, marketing campaigns, the creation of post-sales technical help, etc. All this affects the success or failure of the innovation process.

Finally, it should be noted that the whole process receives feedback. The original idea undergoes dramatic modifications along the different steps involved in its design and development, which in turn are determined by the demands of the production process or by the results of preliminary market research, etc. Thus, the social and technological contexts themselves are altered to a greater or lesser extent as a result of innovation.

TECHNOLOGICAL CULTURE AND INNOVATION

Knowledge is an important part of culture. Accordingly, all innovations have an important cultural dimension. What we are interested in, however, is how the set of elements constituting the culture of a country, region, company or any other social group is articulated and how those cultural elements affect the process of technological innovation.

To do so, we shall use the model of technological culture that we have compiled along the previous pages, distinguishing between technological culture **incorporated** and **not incorporated** in technical systems.

Let us assume that we have defined the rate of technological innovation of a social group, in acceptable terms, such as for example the amount of innovation that the group has produced over a given period of time, or the percentage of wealth generated due to technological innovation, or indeed any other effective measure of the level of technological innovation attained by the group. Our problem will then be to determine whether that measure of the level of innovation is correlated with some set of variables that represent the state or evolution of the technological culture of that social group.

At a first glance, an intuitive and quite feasible hypothesis would be articulated around the following points.

a. For any social group (company, country, region, etc.), its **level or rate of innovation** depends on two factors: **its capacity for innovation** and its **propensity to innovate.**

b. **The capacity for technological innovation** of a social group depends on the technologies available to it; that is, the **technological culture embodied** in technical systems and integrated in the culture of the group.

c. **The propensity to innovate within the sphere of technology** of a social group depends on certain representations, attitudes, values and guidelines for behaviour regarding the technology and technical systems (**non-incorporated technological culture**) shared by the members of the group.

Let us briefly explain the content of these hypotheses. The first is in fact a trivial hypothesis. It only suggests that the fact that a country or a business company has achieved or may achieve a high degree of success in technological innovation is on one hand related to the availability of resources or capacities to innovate and, on the other, to the decision to effectively use that capacity to perform technological innovations. However, we may assume that the capacity for innovation is a cumulative variable: the more we innovate, the more our capacities to innovate increase. This is due to two well known facts: the cumulative nature of technological development (the production of a technological innovation may open a new trajectory of technological development in which innovations proliferate) and the pervasive and compositional nature of many technologies (an innovation produced in one sector of the economy may "fertilize" many other sectors, giving rise to further innovations). Nevertheless, it is clear that it does not suffice merely to have capacities to innovate; it is also necessary to want to innovate; that is we must try to use such capacities effectively to produce new innovations. This is what is meant by the "propensity" to innovate.

Naturally, both the capacity and the propensity to innovate depend on many factors. Along the history of humankind we see, for example, that situations of extreme pressure, such as those occurring in a war or in a health crisis, etc., often contribute to increasing the propensity to innovate. Perhaps a group has a given technology but not the material resources to initiate the process of innovation, such that a change in the economic situation may have effects on the effective capacity for innovation or on the propensity to innovate (by varying the threshold of risk that the group is prepared to assume, for example).

However, what we are interested in is that, leaving aside other factors that may be relevant, both the capacity and the propensity to innovate depend directly on cultural factors. This is what we find in the second and third hypotheses.

Indeed, the second hypothesis makes technological capacity depend on **available technologies** and it identifies these as the incorporated technological culture of the social group in question. This means that for us to be able to consider that a technology forms part of the repertoire of technological capacities of a social group it is not sufficient that the groups should merely have technological systems based on that technology (for example, it is not sufficient that the group simply has the machinery or equipment based on that technology) but that it is necessary for the technological culture of the group to be really broadened with the cultural contents incorporated into such equipment. As we know, essentially these are on one hand the corresponding technologies (the technological knowledge used to design, manufacture, etc., such equipment or technical systems) and also other cultural components such as operating rules, the values incorporated into the system, etc. Were it possible to distinguish between the **level of availability** of technical systems and the **level of cultural assimilation** of those systems, our second hypothesis states that the technological capacities of a social group (of a business company, for example) lie in the latter, and not in the former. A company can acquire the most advanced technology, but it will not increase its technological capacity for innovation very much if it does not manage to integrate that technology into the company's culture (knowledge, customs and values). This is what our second hypothesis is about.

The third hypothesis is possibly more intuitive. It makes the **propensity to innovate** depend on certain representations, attitudes, and values shared by the members of the group; attitudes and values that correspond to what we have called the **non-incorporated technological culture**. The problem here lies in identifying what those attitudes are and how they affect, either positively or negatively, the propensity to innovate. A noteworthy example would be the **disposition to assume risks**. It seems evident that below a given threshold of risk the propensity to innovate almost vanishes: the innovator must know how to live with uncertainty and be able to assume the risk of failure. However, above a certain risk threshold it is possible that the rational effort to find practical and efficient solutions through technology will also tend to decrease: if we are not particularly worried about failing (because we give little value to what might be lost in the event of failure), we shall have a greater predisposition to engage in foolish endeavours, although it is unlikely that reliable and efficient technological innovations will arise from them. Thus, there are certain attitudes and values that are especially relevant for characterizing the propensity to innovate; for example, the following four: attitude in favour of **work done properly** (i.e., valuation of efficient actions), valuation of **creativity, confidence** in science and technology as means to solve practical problems or to generate wealth and welfare, an attitude towards **uncertainty**, and the predisposition to **assume risks**.

CONCLUSIONS

Much has been written about technique and culture and there is a widespread conviction that cultural factors (or the cultural dimension of technique) are decisive for understanding the phenomena involved in technological development. However, there is no widely shared precise and consistent theory of technical culture. This absence is due to the partiality of theoretical approaches to technique, especially within the fields of philosophy and the social sciences. The consideration of technique as a form of knowledge (practical knowledge, applied science, etc.) facilitates the identification of technique with culture, but it hampers the perception of the complex dimensions of technical culture. Further, the conception of techniques as "socially constructed artefacts" does allow us to give a more important role to the cultural factors involved in technological development, but at the price of almost completely reducing all the relevant aspects of technical change to social phenomena.

The conceptual framework that we have proposed rests on a rigorous notion of technical systems and on the scientific concept of culture and it affords, as a novelty, a distinction between technological culture *stricto sensu* and *lato sensu*. The strict sense of the technological culture of a social group is formed by sets of cultural elements *incorporated* into the technical systems available to that group. However, there are other elements, *not incorporated*, that may also form part of the technical culture of that group. The transfer of cultural elements of both types and their relationships with the rest of the culture are one of the basic mechanisms for understanding how cultural factors affect technical development.

An adequate theory of the dynamics of technique is also essential for understanding processes of innovation. These depend on two factors: the *capacity* to innovate and the *propensity* to innovate. In the case of technological innovations, the first factor seems to be related to the technological culture incorporated into the technical systems and the second one to technological culture in the broad, or non-incorporated, sense.

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