Essays in Philosophy
A Biannual Journal

Vol. 6, No. 1, January 2005

The Many Faces of Science and Technology Relationships

Abstract

In this paper, the different theories about science and technology relationships are analyzed. All of them have some virtues, but also one main defect: these theories do not take into account other well-founded possible relationships. The origin of this problem is the narrow view about science and technology. In this paper another characterization about technology based on Ronald Giere's perspective is suggested. In the light of this new description, six different relationships between science and technology arise. Some of these relations had been explained in the before analyzed theories, but others emerge from the new portrayal.

0. Introduction.

One of the most popular problems in the area of philosophy of technology is the characterization of science?technology relationships. Various models try to explain these relations from different points of view. Some of these descriptions talk about either an application from scientific knowledge to technological innovation, or from new technological artifacts to new scientific discoveries. This application model was once a largely widespread opinion among historians and philosophers, but criticisms from economics, sociology and history have exposed good reasons for reconsideration. The critics have given rise to new interpretations and models, which extend from those which consider science and technology to be two different systems, to others that uphold that there are no significant differences between science and technology.

The first task of this paper is to show a brief review of the different models which have tried to explain the science-technology relationships. Section 1 looks at hierarchical models—in both directions, from science to technology, and from technology to science. Section 2 takes up non-hierarchical models. Section 3 suggests a reconsideration about the characteristics of science and technology in the light of Ronald Giere's perspective. This new explanation has the distinct merit of allowing a wider comprehension of the possible science- technology relations. At the end of this section, a general outline about the six different identified relationships is propounded.

1. The hierarchical model.

In this section it is possible to characterize two versions of the same idea: there is a relationship of subordination between science and technology. Without some developments in one area there is no possibility for the other to develop. There are two different versions: one maintains that technology is the outcome of the application of new scientific knowledge. The other one holds that without a special technological infrastructure there is no new scientific knowledge. In this first section, both linear models (and their critics) are discussed.

1. 1. Technology as the application of basic scientific knowledge.

This idea has been maintained by both scientists and engineers. The famous report of Vannevar Bush (an engineer in the Manhattan Project) came to the conclusion that basic research leads to new knowledge, and this creates the fund from which the practical applications of knowledge must be drawn (Bush, 1945, p. 13). Without basic research there is no possibility of technological progress. This linear or hierarchical model has its roots in economic and prestige factors. Scientists, for fear of technological outcomes over?shadowing scientific research, wanted to establish a linear dependence between scientific discoveries and technological innovation. On the other hand, engineers were happy to obtain status: the reputation of applied scientist was better than technician.

The most sophisticated version of this thesis in philosophy was produced by Mario Bunge (Bunge, 1966). Bunge defined technology as applied science: “The method and the theories of science can be applied either to increasing our knowledge of the external and the internal reality or to enhancing our welfare and power. If the goal is purely cognitive, pure science is obtained; if primarily practical, applied science” (Bunge, 1966, p. 329). There are two ways for applying science to produce technology: (i) in substantive theories, which are applications of scientific theories to nearly real situations—for example, the theory of flight as an application of fluid dynamics. The other possibility is (ii) in operative technological theories, which apply the scientific method. The primary objective of technology here is to establish “stable norms of successful human behavior, that is, rules” (Bunge, 1966, p. 338). These rules ought to be based on scientific laws to warrant their efficiency. A law, a nomological statement, is translated into a nomopragmatic statement, which provides the basis for a pair of rules. These rules prescribe a course of action and indicate “how one should proceed in order to achieve a predetermined goal” (Bunge, 1966, p. 338).

There were many critics in economics, sociology, history and philosophy, opposed to these ideas. The first reactions against the linear model were published in the late 60's and early 70's in two studies initiated with the aim of showing the economic benefits of scientific research: TRACES (produced by the Illinois Institute of Technology Research Institute, 1968); and Hindsight (see Isenson, 1969), and both concluded that “we cannot see that it is possible in any systematic way to trace important industrial applications of science back to basic work of the kind that the Research Councils support in a way which could help in determining how much support is justified” (see Gibbons and Johnston, 1974, p. 220). These two studies had in common one methodological assumption: that “innovation could be considered as composed of a series of specifiable events in research and development”, so that “the contribution of science to technology could be assessed by tracing the origin of these events” (Gibbons and Johnston, 1974, p. 222). However, they concluded that the transfer from new knowledge to new artifacts is an extremely complex process; the relationship between the academy and industrial research is not obvious nor direct, and innovation demands knowledge from internal and external sources. Similar studies to those produced by Michael Gibbons and C. Johnston were published by W. Faulkner, J. Senker, and L. Velho (1995). The conclusions were similar: the great majority of knowledge used in innovation originates within technological sources and is associated with design and R&D activities. The main external source comes from the public sector.

These economic studies proved, on the one hand, that the relationship between science and technology is different from direct application, and on the other, that technological knowledge plays a more important role in technological development than scientific discoveries. Researches carried out within industry account for technological innovation more effectively than remote scientific theories.

Along with these economic and sociological criticisms came historical criticisms. Derek S. Price in (1965) suggested one of the first historical reactions against the idea of technology as applied science. In this article he carried out a bibliometric study of science and technology, analyzing the differences in technological and scientific literature, “paying attention to the way in which the papers and the men related to each other, the journals in which the papers are published, and several indicators of the quality and scientific importance of papers, men, and journal” (Price, 1965, p. 555). If technology and science have the hierarchical relationship, their references should be related, too. Nevertheless, Price concluded that “the greater part of technology. . . does not seem to have such strong links with any particular portion of scientific literature” (Price, 1965, p. 563).

Other historical criticisms explored the reasons for the spread of the linear model among scientists and technologists. Edwin T. Layton (1976a) describes three ideologies about the science?technology relationships that arose during the nineteenth and twentieth centuries in the United States. Nathan Rosenberg and Richard Nelson (1994) focus on the real relations between academic and industrial fields from the seventeenth to the twentieth century in North America. Finally, Ronald Kline (1995) analyzes how, between 1880 and 1945, significant engineers and scientists proclaimed the relationship in conferences and articles. In a nutshell, both Layton and Rosenberg, Nelson and Kline concluded that the alleged reasons were spurious rather than epistemological ones. Scientists, for instance, were worried about the increasing prestige of technological innovation and tried to recover an earlier level of capital investment in their areas. Thus, if we want technological innovation, they argued, it is necessary to develop new basic (or “pure”) scientific research.

Another argument was raised from history, this time concerned with some technological developments, which happened to have no scientific explanation. The best known case is that of the steam engine and the laws of thermodynamics. The scientist Sadi Carnot set out to explain the behavior of a very efficient machine that had been created more or less half a century earlier by an engineer: James Watt. These sorts of examples are incompatible with the linear model: a scientific explanation came after and not before technological innovation. Which scientific theories were technologists applying in such cases?

Other kinds of criticisms came from the field of philosophy. The most important problem is the characterization of the application process. There is no explanation about how a new scientific discovery is transformed into a new technological device. It is, in fact, very difficult to explain how an idealized scientific law can be used in a specific technological situation (see Christine Shrader-Frechette, 1989). Scientific laws are idealized because they have to explain the phenomena in a generalized way, and these laws must be applicable to many different situations. However, these laws, when applied to real situations, give rise to errors: “The greater the inaccuracy of the idealization, the less desirable a particular application” (Shrader-Frechette, 1989, p. 348). If the application of a scientific law to a technological situation is so difficult, how could we, in general, use science to obtain new technology?

Despite the weakness of the linear model, it remains a very popular idea, and scientists and engineers still believe in it today. It is difficult to overcome such a widespread proposal, and that is a good reason to reconsider its weak points—and alternatives.

1. 2. Technology creates new scientific possibilities.

The hierarchical model also moves in another direction, one from technological innovation to scientific discoveries. For instance, Derek de Solla Price (1984) argues that there are some technological innovations (arising within normal technological evolution) that yield new scientific possibilities. Price gives as an example the development of the telescope by Galileo. Galileo was able to change the cosmology of his time thanks to telescopic observations. This new instrument led to the acquisition of new data, which made possible new scientific knowledge. Such relationships between science and technology occur in the field of experimentation. There is not a path from science to technology, through applied science; instead, basic and applied research are linked to technology by instrumentality. "Thus, the dominant pattern of science/technology interaction turns out to be that both the scientific and the technological innovation may proceed from the same adventitious invention of a new instrumentality. In science the typical result of such a major change is a breakthrough or shift of paradigm. In technology one has a significant innovation and the possibility of products that were not around to be sold last year" (Price, 1984, p. 15). Nowadays, research laboratories are trying to bring to light new techniques which reproduce this same phenomena of instrumentality.

In the same vein is the theory of Joseph Pitt (1995, 2000), who enlarges the ideas of Price about the direction of development of science and technology. Instead of instrumentalities, Pitt expounds the concept of infrastructure, something more complex than the habitual meaning of technology. A technological infrastructure is "a complex set of mutually supporting individuals, artifacts, networks, and structures, physical and social, which enable human activity and which foster inquiry and action" (Pitt, 1998. See too: Pitt 2000, p. 24). Science is one of the components of a technological infrastructure, but without other activities science would be impossible. Scientific change is the outcome of changes in the technological infrastructure where scientific explanation is generated. Every development in scientific knowledge must be explained in terms of a specific historical context—to be exact, in terms of a technological infrastructure.

Both Price and Pitt come to the conclusion that some kind of technology (an instrumentality for Price, an infrastructure for Pitt) is necessary to make possible a scientific development, and changes in these technologies are responsible for new science. The relationship between science and technology is not a matter of subordination, going from technology to science any more than from science to technology. However, it is worth remarking that there are some technological devices that would not have been possible if some scientific investigations had not been done before. Another important problem is related to the role of technological knowledge in scientific development. In the interpretation of the science?technology relationship of Price and Pitt, technology is always an artifact or a set of artifacts, in which technology gives rise to some kinds of knowledge that could be an influence on scientific development. This is to say that, this version of the hierarchical model, no more than the other one, is not complex enough to explain the entirety of science?technology relationships.

2. Non-hierarchical models.

2. 1. Technology and science as different and separate systems.

Some philosophers and historians try to provide a more accurate explanation of these relationships, avoiding any kind of subordination while explaining the complex features of science and technology. Their theories can be seen as reactions against the hierarchical model, but are more than this. These authors wanted to go beyond, to look for a new characterization of technology, such as Edwin Layton's "mirror-image twins" (1971). Science and technology are very similar communities, but with differences. Each of them has its own goals, languages, values and social controls. Engineers place "doing" in front of "knowing," a very important condition for values, languages and knowledge structures. Between these two communities there are a variety of relationships: they are like two different organisms which "live together in a mutually beneficial relationship." Therefore, even though technology and science are independent, they are still related.

The problem with this conception is that it does not explain where and how the relationships between scientists and engineers take place. If science and technology are so different it is difficult to imagine which the terms of this relation are. Which kinds of scientists are connected with engineers? Which kinds of engineers are in this relation? Moreover, science can be interpreted both as research activities or as a set of theories, laws and methodologies; that is, as a process or as a result. Likewise, the same can be said for technology, which is both a set of technological devices and the complex process for producing them – again, a process or a result. The relationships in the conception of technology and science as different and separated systems do not mention any of these distinctions. Without them it is difficult to understand the kinds of relationships that exist between science and technology. To say that the relation is symbiotic is not to say much that is specific.

2. 2. The absence of differences: the continuum model.

While preceding proposals share the consideration about science and technology as two different and distinguishable areas, constructivists propose the idea that it is not possible to distinguish between them[1] . Regarding the constructivists model, science and technology are not separate communities, but a single entity, named the "science?technology complex," or "technoscience." Whether in former times science and technology were able to develop separately, after the Industrial Revolution they merged into a single complex.[2]

There are some differences between all the perspectives comprised under the name of constructivism. The Social Construction of Technology (SCOT) approach, as well as the work of Collins and Woolgar, maintain the "symmetry principle", avoiding any explanation of real features of technology (see, for instance, Bijker, Hughes and Pinch, 1987, p. 17). Technology is a social construction and can be only explained by reference to the social elements (actors and social groups) that have produced its stabilization. The "social shaping" approach (see, for instance, MacKenzie & Wajcman, 1985, or MacKenzie, 1990) distinguishes between different categories: natural, social, and technical. The authors who belong to this group are interested in how social factors shape technology. Nevertheless, these sociologists recognize the role of nonsocial factors in technological change, and are less reluctant to accept that technology has properties and effects, even though the properties and effects are relative to a particular social context. Finally, there is another group of researchers interested in science and technology problems: those in the actor-

[3]

network theory , who claim that technological and scientific objects are consequences of the work of actor networks (not only human actors, but also natural and technical phenomena).

The thesis of a single and indistinguishable science and technology complex is fostered by some sociologists as Pinch. When these sociologists try to understand technological problems they prefer to consider technology to be similar to science. From this view, the desire to distinguish science from technology is due to an idealized perspective on science. Since actual science is very similar to traditional technology, scientists do not observe a set of methodological rules, as philosophers have claimed. Instead, scientific activities are influenced by socio?historical circumstances, just as in technological activities. Any distinction between what it is done in science and what it is done in technology is based on an idea taken for granted: that science is only related to the production of knowledge, especially theories. Nonetheless, science is involved in the development of instruments and sets of practices. Whether some kind of distinction could be established between science and technology, it would be to consider them as two different and socially built cultures; but this does not mean that any real division exists. Some sociologists, e.g., Hughes and Callon, go further when they claim that technology, science and the economy are a seamless web (see Hughes, 1988); or a system in which all elements are constructed, with no limits between them.

The main difficulty with this perspective is its exclusive sociological point of view, in which it is difficult to find differences between science and technology, because the perspective only focuses on social similarities. Philosophers of technology have no problem accepting that technological artifacts, as scientific theories, are the result of human actions. However, it could be useful to differentiate the objectives of the two communities. The main goal of scientists is to increase the state of knowledge, and the main goal of technologists is the improvement of an artifact or the invention of a new one. This statement does not mean that in achieving these objectives other sub?objectives cannot be involved —practical sub?objectives in science and epistemic sub?objectives in technology. The principal aim in both cases, however, decides the structure of science and technology, their separate knowledge, activities, and practitioners.

Another widespread commonplace within the non?differentiation perspective is a focus on “know how” in science, the most characteristic aspect of technological knowledge. This idea, however, is not appropriate in accounting for the existence of a science?technology system; it rests on the confusion between “know how” and technological knowledge. As a matter of fact, there are kinds of knowledge involved in technology others than “know how.”[4] The argument of a continuous science?technology complex based on the use by scientists of know-how is not suitable. Technologists use every kind of knowledge, and the same could be said for scientists. The differences between them, as it will be shown in this paper, lie in part in their objectives. When a community has the goal of knowing the age of the universe, it develops activities and sets of knowledge different from another community which tries to build a long and strong bridge. Of course, the first community needs a powerful telescope built by technologists. Similarly, the technological community could need some knowledge developed by scientists about hydrology or physics. The reason for these connections is not that they are the same system, though they are related systems. Sociological, or even epistemic similarities, are not enough to prove a continuum because there are important differences among these communities, especially the objectives scientists and technologists try to achieve.

Nowadays, there are some mixed communities, where scientists and technologists collaborate on special projects. Michael Gibbons (1994) describes two different ways to create knowledge: one is more traditional, where problems are solved in an interest-directed context. Some of the interests are academic, related to a specialized community, hierarchically organized, and the principal aim is to obtain cognitive outcomes. The other way of doing science is carried out in an application context, with different scientists and technologists collaborating and joined together temporarily with the aim of obtaining useful outcomes. This explanation is useful for these new mixed projects, even though the scientists and technologists who work together have different objectives. In addition to traditional ways of doing science and technology there is this new one. However, this does not mean that the traditional ways are no longer useful; it is still possible to find "pure" scientific and technological projects.

3. The relationships between science and technology in a new light.

The absence of a consensus among the different characterizations of the science?technology relationship could drive us to despair. Perhaps their relationships are so complex that it is impossible to achieve consensus. However, we should not give up on the aim. It is possible to consider all the attempts to be partial characterizations. That is to say, most of them propose some kind of existing relationships. The problem is that each of these perspectives considers one explanation as the only possible relationship. It is true, for example, that some technological developments would not have been possible without some previous scientific discoveries. In the same way, technological infrastructures are determinant of modern science —so there are symbiotic relationships between them. Nonetheless, a new understanding of science and technology relationships has to take into account a deeper view of the complex systems that science and technology are.

3. 1. A more complex characterization of science and technology.

Science, in general, can be described as a complex system of actions and agents, whose general objective is the production of models in order to represent the reality, in the same vein as Ronald Giere has propounded (Giere, 1988, 1992, 1993, 1994, 1999a, 1999b, 2002, forthcoming (1), and forthcoming (2)). At the same time, it is reasonable to defend that technology is a complex system of actions performed by human agents whose final objective is to build an artifact or a technological process. In both cases, several activities are displayed, and different objectives and kinds of knowledge[5] are involved.

Giere's view is commonly framed in the so-called "semantic view of theories", in which other well known philosophers such as Patrick Suppes, Frederick Suppe, and Bas van Fraasen have made important contributions (for a historical review: Frederick Suppe, 1989). The semantic view was conceived as an alternative to the "syntactic approach" of the received view. Instead of sets of true propositions about the world, theories are now better understood as sets or clusters of models. It is generally considered that the relationship between models and the world must be an *isomorphic* one. Nevertheless, Giere considers more accurately to say that the relations between models and the world are *similarity relationships*. There are no true theories but catalogues of cases in which models "fit" well enough with systems of the world (Giere, 1988, p. 92). These models are generated by scientists using general principles and specific conditions (Giere, 2003, p. 5). General principles —which in other perspectives are scientific laws— are not universal truths, but at best truths consensually agreed by scientists for a specific model or cluster of models.[6] The degree of similarity will depend on pragmatic issues and not just on ontological and epistemological ones. Considering general principles from pragmatical, as well as ontological and epistemological perspectives, it supports Giere's realistic constructive perspective. Giere has pointed out (Giere, 1999b) that it is possible to distinguish between different types of representational models: (i) *material models*, which include maps, diagrams, and scale models; (ii) *abstract models*, such as pure mathematical models, applied mathematical models, and theoretical models built with theoretical principles (such as Newton's laws, Schroedinger's equation for quantum mechanics, Darwin's theory of natural selection, and Mendel's laws of genetics).

Another interesting feature of Giere's realism is the incorporation of some constructivist elements generally considered contrary to the traditional realism. He maintains that science is made by human beings: scientists. They are intentional agents, and use models in order to represent some aspects of the world with determined purposes. From the very beginning some values are involved in the election of the best model, the most important being to choose a model that provides the most accurate potential representation. The scientific community will help to reach a consensus regarding validity of reasons.[7]

Nevertheless, Giere's approach does not imply any relativism from the ontological point of view. Scientists choose those aspects of phenomena they are going to deal with, that is to say, the properties they consider relevant to their purposes, while ignoring others (Giere, 1999, p. 180). This is not to say that scientists "invent" reality, the position which a more radical constructivist could defend, but rather that the world is complex enough so as to admit different models about the same phenomena without necessarily implying that one of them has to be the right one.[8] It all depends on the purposes for which the models are devised.

Technological activities have not been so well described as scientific activities, nor they have received the same amount of philosophical efforts. As a result, the consideration of technology as a set of artifacts is now a widespread definition. Of course, technological artifacts are a very important element of the complex system, but not the only one. These artifacts are possible because some agents carried out different activities. Researching, designing, and manufacturing could be an attempt for categorizing the three main types, although within these sets more specialized activities are developed. During manufacturing processes, technologists construct real artifacts with the use of tools and machinery. In the designing phase, technologists are involved in the process of creating a new device or some improvement on an old one. Likewise, within the designing processes there are different sub?activities[9] .

3. 2. The engineering sciences.

In addition to those activities, there is another technological activity which needs to be defended against the point of view of those who think that the most sophisticated technological knowledge comes from scientific research. More than a few authors, among whom are Mario Bunge (Bunge, 1966, 1967), Edwin Layton (Layton, 1971, 1974, 1976b, 1979, 1988), Ladislav Tondl (Tondl, 1973), Joseph Agassi (Agassi, 1980, 1985), Fredrich Rapp (Rapp, 1981), Walter Vincenti (Vincenti, 1990, 2001), and Ilkaa Niiniluoto (Niiniluoto, 1995)[10] , suggested that technologists themselves are able to develop theoretical knowledge. All of these authors distinguished a group of sciences not included in the more habitual classifications, and agreed these special sciences share a good deal of features. As sciences, they require experimental research and mathematical language (Rapp); they deal with the same laws of nature as the rest of sciences (Bunge, Rapp, and Vincenti); they are both descriptive (Rapp and Niiniluoto) and predictive (Rapp and Bunge); their outcomes are shared and taught in similar ways of communication and training as the other sciences have been (Layton and Vincenti); they are a result of the division of labor (Tondl, Layton, and Vincenti); and the development of their knowledge is accumulative (Layton and Vincenti[11]). In spite of many discrepancies among these authors, all of them agreed on this: the practical goal that directs these sciences is what makes them different from the others. Engineering scientists work with the aim of solving engineering problems and helping during the production of artifacts (while current scientists build up their theories so as to get a better comprehension of observable phenomena).

These contributions made it possible to question the simplistic idea that all theoretical knowledge comes from natural sciences and then is applied to technology. Obviously, this idea is still widely accepted.[12] For instance, in the cases of Bunge and Rapp, there still remains the tendency to consider this knowledge the result of certain processes of transformation (never adequately explained[13]) of previous knowledge developed by natural scientists. This tendency is derived from the privileged relationship some philosophers consider to exist between scientific knowledge and reality: scientific theories provide accurate knowledge about the world (realism), and the artifacts created based on that knowledge supposedly validates this thesis.[14]

This idea is only partially correct. First, it is not plausible that all natural scientific theories must be applied in order to design a technological device. Second, in order to explain the highly sophisticated knowledge involved in designing and manufacturing technological artifacts, certain scientific theories are necessary. However, in many cases current scientific theories cannot adequately solve every problem emerging during technological processes, and technologists themselves must face up to the task of developing their own theoretical knowledge. Artifacts manufactured through such a process work effectively, though with limitations.

Engineering sciences, as the other sciences, can be analyzed with resources provided by Ronald Giere’s constructive realism. However, in the case of engineering sciences, Giere’s constructive realism may be interpreted as having instrumentalist characteristics. This claim may be controversial, because some philosophers tend to think of instrumentalism as a kind of relativism (non compatible with realism). Nevertheless, this is not the case, at least for engineering sciences. Whether something works in the world effectively is not a relative matter, nor to choose the most adequate model for achieving that goal.

Strength of materials can be a good example of one of these engineering sciences. This theory provides models about the relationships between external loads applied to a body and effects of the loads in the internal structure of that body. The engineers who develop this theory produce those models on the basis of general principles, as the Hooke’s law or the Saint Venant’s principle. These engineers abstract and idealize different characteristics of bodies interesting for the purposes of the theory. For instance, properties of homogeneity, isotropy, continuity of the matter or elasticity are assumed in strength of materials. From the point of view of other related sciences, as theoretical mechanics, those properties are false. The traditional explanation about scientific theories would say that these assumptions are false, since in more consolidated theories (such as Physics) matter has quite different properties (matter is neither homogeneous nor continuous, and just is isotropic in some cases). In contrast, from the perspective of model based and representational theories, it is possible to say that strength of materials proposes representational models about some systems of the world, and that systems can be considered to bear the properties of homogeneity, continuity, and isomorphism. That is to say, different purposes can bring about the generation of different models. Margaret Morrison (Morrison, 1999) and Paul Teller (Teller, 2001) have studied the case of water: how water can be considered to be either a collection of molecules (when the diffusion of a drop of ink in a glass of water is analyzed); or a fluid (if the objective is the characterization of the behavior of water circulating in pipes). In other words, there can be multiple models dealing with the same phenomena, if those models deal with different properties of phenomena, and the purposes for analyzing are also different. Reality is too complex to be grasped with only one theory (for instance Giere, 1999, p. 180). Theories are sets of models that search for characterizations or explanations of the behavior of some systems, that are nothing but partial aspects of reality. In this sense, strength of materials is doing nothing different. The only difference has to do with the purposes aiming the research.[15] In this way, the most similar models for the scientists-engineers are those models that allow to build, in the most efficient way, an artifact. From the point of view of other scientific theories, such as Newtonian mechanics, the conclusions achieved by strength of materials can be false, but from the point of view of the purposes of the engineers who develop and use strength of materials theory, these conclusions are satisfactory enough. If the main objective in natural sciences is “to know how the things are”, for engineering sciences, as strength of materials, it is necessary to add another objective: “in order to make other things work”.

Technological knowledge can be limited neither to know-how or skills, nor to the application of natural scientific theories. Sometimes, the most developed formal, natural, or social sciences cannot supply the necessary knowledge for some technological problems. In such a case, technologists can develop their own theoretical knowledge.

It is obvious that these engineering sciences are going to play an important role in the characterization of science-technology relationships. As any other scientific development, engineering sciences could influence and be influenced by other sciences. Moreover, the model based perspective about sciences allows a better comprehension of different roles that technological artifacts may play in their relation with scientific development.

Given these reconsiderations of science and technology, the time has come to introduce a wider explanation about the relationships between scientific and technological systems.

3. 3. How many relationships?

This papers defends the idea that science is a complex system for producing representational models (in the general sense of models), and that technology is a complex system for producing artifacts. Nevertheless, the production of scientific representational models is a process that requires different activities. On the other hand, technologists need some theoretical models that can sometimes be developed by themselves, in order to achieve their goal. Consequently, the elements that are going to be part of the relationships between science and technology are, fundamentally, models. These models can be physical models or theoretical. If we uphold the stated definitions about science and technology, then the physical models are the outcome of a technological process, and the theoretical models are the result of a scientific process. With this distinction in mind, it is possible to identify six kinds of relationships:

Science-technology relationships	**Science as an outcome: Scientific theoretical models**	**Science as a process: Research activities**
Technology as artifacts	(1) Exemplary relationship: Technological artifacts are used as examples for scientific theories.	(2) Instrumental relationship: Technological artifacts are involved in: (a) Experimentations (b) Measurements (c) Observations (3) 1st kind of heuristic relationship: Technological machines or processes inspire the development of a new scientific explanation (4) 2nd kind of heuristic relationship: Scientists request physical models for researching purposes
Technological theoretical models	(5) Technological theoretical models can use some parts of well founded scientific theoretical models.	(6) Scientific theoretical models can use some parts of well founded technological theoretical models.

To explain and exemplify all these relationships:

(1) Scientists often use technological artifacts as replicas, scale models and analogue machines[16] . Some of these artifacts are used as exemplars, i.e., machines that can be used for explaining an excessively complex idea. An orrery, or any of the instruments that are nowadays in the science museums, is a good instance. These technological artifacts are very useful in the experience of learning and spreading scientific concepts, otherwise difficult or obscure. In this case, the relationship between technological artifacts and scientific theories is *exemplary*.[17]

(2) Scientists need to use different technological artifacts in the course of performing their work. They need precise artifacts for measuring, experimenting, and observing. These artifacts are made by technologists, and can be considered to be part of technological systems, in the same way as Pitt has propounded. This kind of technological artifacts are sometimes created on the basis of older technological artifacts, which had a different purpose. For instance, before the invention of the telescope, there were lenses used for correcting some defects in eyesight. When Hans Lippershey, a manufacturer of eyeglasses, built the first telescope in 1608 he did not revolutionize the science of his time. One year later, Galileo did, when he found a new utility for the device. Another example

that illustrates this point is the relationship between chaos theory and computers. Chaos theory was developed out of what computers made possible in mathematics and physics. Nowadays, most technological artifacts used during scientific work are built by technologists following specifications from scientists. In this sense, the way of doing science in laboratories involves the work of technologists. Despite the fact that these devices are used by scientists, we must not forget that they still are technological artifacts created by technologists using special knowledge and skills. In this case, the relationship between science and technology is instrumental and the function of the technological artifacts is integrated into the scientific activity.

(3) Another relationship between scientific models and technological artifacts arises when a technological artifact inspires the development of a new scientific explanation. The most famous example here is the steam engine and thermodynamics. In this kind of case, the artifact is not instrumental, but rather an artifact that works even without a good explanation suggested by any scientific theory. When Sadi Carnot later made his proposal, he was trying to give a scientific explanation of the processes that occur inside a steam engine. Instead of explaining the behavior of only one machine, his theory was intended to be useful for any machine or similar process. Lord Kelvin substituted the caloric theory, the most accepted view at that time, for thermodynamics when he made Sadi Carnot’s results compatible with Joule’s conclusions about energy. These relationships have been very common in the history of science. Actually, some historians (as Paolo Rossi in 1970) have suggested that all of modern science in the seventeen century was originated in a similar process. We call this the *first kind of heuristic* relationships.

(4) The physical models can have also another heuristic purpose. Sometimes it can be very difficult, or even impossible, to analyze directly the properties of a system. In those cases, the simplest method for researching the properties of the real system may be to build a replica or an analogue. The Lorenzian waterwheel and its relationships with chaos theory is a good example of this kind of interaction. Between analogue models of this kind and real systems there is a *second kind of heuristic* relationship.

(5) It is possible to consider another kind of relationship between scientific models and technology: when a new scientific theory creates new technological possibilities. These relationships are explained in the linear model, above. Technology applies those theories developed by sciences in the production of new artifacts. However, the process of application is not simple.

First, the recognition by a technologist of some interesting or useful scientific knowledge is necessary. It is important to point out that the theoretical models provided by scientists are usually far away from practical technological problems. During the construction of these models, scientists need to: (a) compose and decompose, (b) weight or emphasize, (c) order, (d) delete and supplement, and (e) deform reality.[18] Scientists apply these procedures for the sake of research. This theoretical aim is the main reason why scientific theoretical models cannot be directly applied to solve technological problems, and the possibilities of applying directly these idealized and abstract models to technological problems are limited. General and abstract models provided by scientists contain general principles that have to be transformed into more particular principles. When some general principles coming from theoretical models are used by technologists, they need to add some margin of error, more precise examples, or more accurate physical models. The model as a whole cannot be applied to solve technological problems.[19]

During this "specification process," the relation between the general model provided by conventional sciences, and the new model in engineering sciences, is not a mere process of application. It is necessary to develop new research in order to obtain a technological-theoretical model. Nathan Rosenberg and Richard Nelson (1994) have analyzed the example of chemical engineering. They have pointed out that knowledge provided by chemistry is not enough to develop industrial chemical processes. In order to generate new products on an industrial scale, engineering processes are necessary. Some of the general principles from the chemistry models can be used in the models required for industrial production, but the models are not the same. The new technological-theoretical models provide an interpretation of reality (an epistemological goal), but these models have also to answer to design questions (a practical objective). Some well known examples are those suggested by Bunge about fluid mechanics and the theory of flight (Bunge, 1966, p. 338).[20]

(6) To end, there is another relationship between science and technology that is not commonly recognized. In the reverse way, technologists may use some elements from formal, natural, and social sciences theoretical models for producing technological-theoretical models. These models in the realm of engineering science have the same function as models in the generation of the formal, natural or social sciences.

One example that can illustrate this relationship is the connection some theoretical ideas from between strength of materials and explanations using the luminiferous ether. The ether theory was suggested to explain the deformative behavior of light waves. If there is a material substrate in which light can move, planets and stars can also move in the same material. However, to accept this idea led to problems in the explanation of the movements of these bodies in space. If there is such a material, then it has to slow down planetary and stars movements, but this is not the case. For these reasons, some scientists during the nineteen century used other ideas from strength of materials, namely elasticity. James McCullagh proposed a rotational elastic medium, and Cauchy propounded an unusual property for the ether: negative compression. George Gabriel Stokes in his work *On the Dynamical Theory of Diffraction* (Mathematical and Physical Papers, Vol. 1, 1845) considered the ether as a non-crystal and elastic medium, or in other words, an elastic solid, a property of matter explained in strength of materials.

A more current instance is the development of the computer and its influence in the cognitive sciences. This example is different than others considered before in (3) and (4). During World War II computers were developed as general machines to process symbols. Some scientists, as Allen Newell and Herbert A. Simon (1957), Noam Chomsky (1957) and George A. Miller, Eugene Galanter and Karl H. Pribram (1960) did not agree with the behaviorist's perspective and put forward a new approach: an information-processing model of psychology. They realized that computers could help in the understanding of human thought processes. Like the computer, humans take in information (from the senses), process it, and produce an output.[21] In the computer case, the hardware is the physical machine and the software is the programs that run on it. In the human case, the hardware is the brain and the software is the mental processes. When perceiving, people are parallel processors encoding different information, and when thinking, people are serial processors, who do one thing after another. As Herbert Simon has maintained: "If you test your programs not merely by what they can accomplish, but how they accomplish it, then you are really doing cognitive science; you are using AI to understand the human mind". Some of them even said, it is possible to predict the behavior of one person if we know: (i) the goal that the person is striving towards, (ii) the internal representation of a problem, and (iii) the invariant mechanism, i.e. hardware (memory, capacity, speed of processing etc.). Therefore, those models provided by computer sciences were (and are) useful in the development of theoretical models about human psychology.

The last example of how engineering models can generate new models in other sciences is the case of robotics. Ulrich Nehmzow, a professor in the Department of Computer Science in the University of Manchester, and one of the most important experts in robotics nowadays, has suggested that it is necessary to apply "quantitative methods in mobile robotics, in order to change the discipline from an empirical one to a more precise science" (Nehmzow, 2001, p. 1, see also Nehmzow 2003). Mobile robotics in the present day provides models for the behavior of robots in a very particularized way. There is no general explanation, no general model that recounts the common characteristics that robots have to fulfill. The new models fall somewhere between natural sciences and social sciences. Some aspects of the robot's activity (speed, acceleration, or the characteristics of electronic circuits) can be measured quantitatively, but other aspects of the robot behavior are characterized by qualitative descriptions. We will see in future years the development of this new theory.

4. Conclusions

This paper has tried to show the different explanations propounded by philosophers, historians, sociologists, and economists, about the possible relationships between science and technology. All these positions have some virtues, but most of them exclude other equally valid possibilities. Here it has been suggested that this problem could be fixed with a less restricted definition of science and technology. The new definitions are based on the constructive realism of Giere. For him, scientists are devoted to the production of representational models which fit real systems in different degrees. However, the restricted idea of technology as a set of artifacts is not accurate. Technology is not only artifacts, it implies the work of different technologists and different kinds of knowledge. In addition, technologists do not merely apply scientific theories for technological solutions. Engineers can develop their own theoretical models about real systems. Those models are, in important senses, different from the theoretical models offered in other sciences. These differences are due to their respective main objectives. In the case of traditional sciences, the main goal is to provide general and correct models of some real systems. These systems and models have to be similar. In the case of technological theoretical models, the main goal is to offer models that help in the solution of problems that arise when designing and manufacturing artifacts. The relationship between the models and the real systems is also a similarity relation, but the degree of similarity depends on the efficiency of these models. Even when technologists use models which come from formal, natural or social sciences, they need to introduce some changes in the models in order to use them.

With this new characterization of science and technology, a fresh perspective about the relationships between these two fields has been suggested. It is possible to distinguish, at least, between six different kinds of relationships. Technological artifacts may be exemplar models for other sciences. In other cases, technological artifacts are instruments for the development of scientific activities. In addition, technological artifacts can have two heuristic functions for scientific development of models: as inspirations for new scientific explanations, or as models that help in seeking new properties of reality. Furthermore, parts of theoretical models coming from formal, natural or social sciences can be used (with some prior changes) in the solution of technological problems. Similarly, some technological theoretical models can have an analogous effect within formal, natural or social sciences.

This new description of the relations between different kinds of models implies a new perspective about sciences. The standard idea of the unity of science maintains that "the laws and concepts of every scientific domain (psychology, sociology, economics, history, biology, chemistry) are reducible to those of a more fundamental domain, all arranged in a hierarchy, till we reach physics at the pinnacle".[22] This characterization is not valid any more. Instead, if we accept the definition of scientific theories as families or clusters of models, then it is possible to describe the relations between different scientific disciplines as sharing some models or fundamental principles. Sometimes, the relationship is not of sharing models, but of finding inspiration for new explanations in one scientific area that come from another area.[23] Given these considerations, it is not surprising that the characterization maintained by supporters of these traditional views of science and technology could be described as excessively simplistic. Science and technology are made by human beings and, on some occasions, to distinguish between them is far from easy. Nevertheless, it is possible to differentiate between them on the basis of the different purposes that scientists and engineers can have during the development of their activities. Scientists' main purpose is "to know how things are", whereas engineers' main purpose is "to build an effective artifact".

All the different relationships suggest, as well, another conclusion. If the idea of technology as applied science is too narrow, and there are other relationships between science and technology (in both directions), then it is necessary to reconsider the justifications for investments in basic research. There is no guarantee that large investments in an area will produce practical benefits. Sometimes, technological opportunities are more side effects than applications of scientific knowledge. The deterministic perspective, that connects scientific research with technological development, is no longer valid. Harmful technologies can also be consequence of scientific advancement. Saying this does not imply the Dr. Frankenstein myth, however. In our modern societies, technologists sometimes cause misfortune but often also create success. We need to be more certain about the of nature of our technologies if the effects of their development on society or on the environment will be irreversible.[**]

Ana Cuevas
University of Delaware

Bibliography

Agassi, Joseph. 1980. "Between Science and Technology." *Philosophy of Science*, 47: 82-99.

Agassi, Joseph. 1985. *Technology: Philosophical and Social Aspect*. Dordrecht: Kluwer.

Bijker, Wiebe E., Huges, Thomas. P. and Pinch, Trevor. 1987. *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*. Cambridge Mass.: The MIT Press.

Brey, Philip. 1997. "Philosophy of Technology Meets Social Constructivism." *Techné*, 3-4.

Bunge, Mario. 1966. “Technology as Applied Science.” *Technology and Culture*, 3: 329-347.

Bunge, Mario. 1967. *Scientific Research*. New York: Springer-Verlag.

Bush, Vanevar. 1945. *Science, The Endless Frontier: A Report to the President*. Washington DC.

Bynum, W. F., E. J. Browne, and R. Porter. 1981. *Dictionary of the History of Science*, Princeton, NJ: Princeton University Press.

Callon, M., Law, J. & Rip, A. (Eds.). 1986. *Mapping the Dynamics of Science and Technology*. London: MacMillan Press.

Callon, M., and Latour, B. 1992. “Don’t Throw the Baby Out with the Bath School! A Reply to Collins and Yearley.” In A. Pickering (Ed.). *Science as Practice and Culture*. Chicago: Univ. of Chicago Press.

Cartwright, Nancy. 1983. *How the Laws of Physics Lie*. Oxford: Clarendon Press.

Cartwright, N. 1999. *The Dappled World. A Study of the Boundaries of Science*. Cambridge: Cambridge Univ. Press.

Collins H. M.. 1985. *Changing Order: Replication and Induction in Scientific Practice*. Chicago: Univ. of Chicago Press.

Constant, Edward W. II. 1980. *The Origins of the Turbojet Revolution*. Baltimore: The Johns Hopkins Univ. Press.

Faulkner, Wendy, Jacqueline Senker, and Léa Velho. 1995. *Knowledge Frontiers: Public Sector Research and Industrial Innovation in Biotechnology*. New York: Oxford University Press.

Gibbons, M., and R. Johnston. 1974. "The Role of Science in Technological Innovation." *Research Policy*, 3: 220?242.

Gibbons, M., et al. 1994. *The New Production of Knowledge*. London: Sage.

Giere, Ronald N. 1988. *Explaining Science: A Cognitive Approach*. Chicago: Univ. of Chicago Press.

Giere, Ronald N. 1992. “Cognitive Construction of Scientific Knowledge.” *Social Studies of Science*, 22: 95-107.

Giere, Ronald N. 1993. “Science and Technology Studies: Prospects for an Enlightened Post-Modern Synthesis.” *Science, Technology, and Human Values*, 18: 102-112.

Giere, Ronald N. 1994. “Cognitive Structure of Scientific Theories.” *Philosophy of Science*, 61: 276-96.

Giere, Ronald N. 1999a. *Science without Laws*. Chicago: Univ. of Chicago Press.

Giere, Ronald N. 1999b. “Using Models to Represent Reality.” In L. Magnani, N. J. Nersessiand & P. Thagard (Eds.). *Model-Based Reasoning and Scientific Discovery*. New York: Kluwer/Plenum.

Giere, Ronald N. 2002. “Discussion Note: Distributed Cognition in Epistemic Cultures.” *Philosophy of Science*, 69: 637-644.

Giere, Ronald N. Forthcoming (1). “How Models Are Used to Represent Reality.” *Philosophy of Science*. Giere, Ronald N. Forthcoming (2). “Perspectival Pluralism.” *Minnesota Studies in Philosophy of Science*, vol. 19.

Goodman, Nelson. 1978. *Ways of Worldmaking*. Cambridge: Hackett Pub. Comp.

Hesse, Mary. 1966. *Models and Analogies in Science*. Notre Dame: Notre Dame Univ. Press.

Hughes, T. P. 1988. "The Seamless Web: Technology, Science, et cetera, et cetera." In B. Elliot, (Ed.). *Technology and Social Process*. Edinburgh: University of Edinburgh Press. Pp. 9?19.

Illinois Institute of Technology Research Institute. 1968. *Technology in Retrospect and Critical Events in Science*. Washington, DC: National Science Foundation.

Isenson, Raymond S. 1969. “Project Hindsight: An Empirical Study of the Sources of Ideas Utilized in Operational Weapons Systems.” In W. Gruber and D. Marquis, (Eds.). *Factors in the Transfer of Technology*. Cambridge, MA: MIT Press.: 155-176.

Kline, Ronald. 1995. "Constructing ‘Technology’ as ‘Applied Science’: Public Rhetoric of Scientists and Engineers in the United States." *Isis*, 86: 194?221.

Latour, Bruno. 1987. *Science in Action*. Cambridge Mass.: Harvard Univ. Press.

Layton, Edwin T. 1971. “Mirror Image Twins: The Communities of Science and Technology in 19th Century America.” *Technology and Culture*, 19: 562-580.

Layton, E. T. 1974. “Technology as Knowledge.” *Technology and Culture*, 15: 31-41.

Layton, E. T. 1976a. “American Ideologies of Science and Engineering.” *Technology and Culture*, 17: 688?701.

Layton, E. T. 1976b. “Technology and Science or ‘Vive la Petite Diference ’.” *PSA*, 2: 173-184.

Layton, E. T. 1979: “Scientific Technology, 1845-1900: The Hydraulic Turbine and the Origins of American Industrial Research.” *Technology and Culture*, 20: 64-89.

Layton, E. T. 1987. “Through the Looking Glass, or News from Lake Mirror Image.” *Technology and Culture*, 28: 594-607.

Layton, E. T. 1988. “Science as a Form of Action: The Role of the Engineering Sciences.” *Technology and Culture*, 29: 82-97.

MacKenzie, Donald. 1990. *Inventing Accuracy: A Historical Sociology of Nuclear Missile Guidance*. Cambridge, Mass.: MIT Press.

MacKenzie, D. and Wajcman, J. (Eds.). 1985. *The Social Shaping of Technology*. Milton Keynes: Open Univ. Press.

Miller, George A., Galanter, Eugene & Pribram, Karl H. 1960. *Plans and the Structure of Behavior*. New York: Holt, Rinehart & Winston.

Morrison, Margaret. 1999. *Models as Mediators: Perspectives on Natural and Social Sciences*. Cambridge: Cambridge Univ. Press.

Nagel, Ernest. 1961. *The Structure of Science*. New York: Harcourt, Brace & World Inc.

Niiniluoto, Ilkaa. 1995. “Approximation in Applied Science.” In M. Kuokkanen ed. *Structuralism, Approximation, and Idealization*. Poznan Studies in the Philosophy of the Sciences and the Humanities, Vol. 42: 127-139.

Nehmozov, Ulrich. 2001. “Mobile robotics: Research, Applications, and Challenges.” *Proc. Future Trends in Robotics, London: Institution of Mechanical Engineers*.

Nehmozov, U. 2003. “Qualitative Analysis of Robot-Environment Interaction: Towards ‘Scientific Mobile Robotics’.” *Journal of Robotics and Autonomous Systems*, 44: 55-68.

Pitt, Joseph C. (Ed.). 1995. *New Directions in the Philosophy of Technology*. Dordrecht: Kluwer.

Pitt, J. C. 1998. “Explaining Change in Science.” *Society for Philosophy and Technology Electronic Journal*, 3: 36-46.

Pitt, J. C. 2000. *Thinking about Technology. Foundations of the Philosophy of Technology*. New York: Seven Bridges Press.

Pitt, J. C. 2001. “What Engineers Know.” *Techné: Journal of the Society for Philosophy and Technology*, 5, nº 3.

Price, Derek S. 1965. “Is Technology Historically Independent of Science? A Study in Statistical Historiography.” *Technology and Culture*, 6: 553?568.

Price, D. S. 1984. “The Science/Technology Relationship, the Craft of Experimental Science, and Policy for the Improvement of High Technology Innovation.” *Research Policy*; 13: 1: 3?20.

Putnam, Hilary. 1975. *Mathematics, Matter, and Method*. New York: Cambridge Univ. Press.

Quintanilla, Miguel A. 1996. “The Incompleteness of Technics.” In G. Munévar, (Ed.). *Spanish Studies in the Philosophy of Science*. Dordrecht: Kluwer. Pp. 89?102.

Radder, Hans. 1992. “Normative Reflexions on Cosntructivists Approaches to Science and Technology.” *Social Studies of Science*, 22: 141-173.

Radder, H. 1996. *In and About the World. Philosophical Studies of Science and Technology*. New York: State University of New York Press.

Rapp, Friedrich. 1981. *Analytical Philosophy of Technology*. Dordrecht: Boston Studies in Philosophy of Science, vol. 63.

Rosenberg, N. and Richard Nelson. 1994. "American Universities and Technical Advance in Industry." *Research Policy*, 23: 323?348.

Rossi, Paolo. 1970. *Philosophy, and the Arts in the Early Modern Era*. New York: Harper & Row.

Shrader-Frechette, Christine 1989. "Idealized Laws, Antirealism, and Applied Science: A Case in Hydrogeology." *Synthese*, 81: 329?352.

Smart, John Jamieson C. 1963. *Philosophy and Scientific Realism*. New York, Humanities Press.

Suppe, Frederick. 1989. *The Semantic Conception of Theories and Scientific Realism*. Chicago: Univ. of Illinois Press.

Teller, Paul. 2001. "Twilight of the Perfect Model Model." *Erkenntnis*, 55: 393-415.

Timoshenko, Stephen P. 1953. *History of Strength of Materials*. New York: McGraw-Hill.

Todhunter, Issac. *A History of the Theory of Elasticity and the Strength of Materials. From Galileo to the Present*. London: Dover.

Tondl, Ladislav. 1973. *Scientific Procedures; a Contribution Concerning the Methodological Problems of Scientific Concepts and Scientific Explanation*. Boston: Dordrecht Reidel Pub.

Toynbee, Arnold J. 1962. *America and the World Revolution and Other Lectures*. New York: Oxford Univ. Press.

Vincenti, Walter G. 1984, "Technological Knowledge without Science: the Innovation of Flush Riveting in American Airplanes, ca. 1930-ca. 1950." *Technology and Culture*, 25: 540-576.

Vincenti, Walter G. 1990. *What Engineers Know and How They Know It. Analytical Studies of Aeronautical History*. Baltimore: The Johns Hopkins Univ. Press.

Vincenti, Walter G. 2001. "The Experimental Assessment of Engineering Theory as a Tool for Design." *Techné: Journal of the Society for Philosophy and Technology*, 5, nº 3.

Whitehead, Alfred N. 1932. *The Aims of Education*. London.

Woolgar, Steve. 1991. "The Turn to Technology in Social Studies of Science." *Science, Technology and Human Values*, 16: 20-50.

Notes

** This paper has been written with the support of a grant from the Spanish Department of Education and Culture. I am grateful to Paul T. Durbin and Oscar Martinez for their extremely helpful comments on an earlier version of this paper, and to Jack T. Chen for his help to improve my English. I am also very grateful to Fred Adams for his kindness and hospitality during my time as a research fellow in the Philosophy Department of the University of Delaware.

1. It is possible to distinguish several approaches considered as constructivism. In the first place, we find the Social Construction of Technology (SCOT), originally put forward by Wiebe E. Bijker , Thomas P. Huges and Trevor Pinch (1987). Related with this is the work of H. M. Collins (1985) and Steve Woolgar (1991). The constructivism also includes the "social shaping" approach of Donald MacKenzie (1990) and the actor-network approach of Bruno Latour (1987), Michael Callon (1986, 1992), and John Law (1986).

2. For a very good explanations about the relevance of the Constructivist point of view for the philosophy of technology see: Woolgar (1991); Radder (1992); Brey (1997).

3. Bruno Latour, Michael Callon, and John Law are the main authors in this group.

4. If we take into account the following schema (see Quintanilla, 1996), we will have four kinds of knowledge, and each one is found in technology.

	Representational	Operational
Explicit	Know that	Know how
Tacit	Intuition	Skill

5. See quotation number 4.

6. He deliberately says that the natural laws are not universal, nor necessaries, nor truth. (Giere, 1999, p. 90).

7. These ideas derive from pragmatism (Ronald Giere, 1999, p. 75). In philosophy of technology we could find something similar in (Joseph Pitt, 2000, p. 4).

8. He agrees with Nancy Cartwright (Cartwright, 1983, p. 11), "No single model serves all purposes best." (Also in p. 104 and 152).
"Imagine the universe as having a definite structure, but exceedingly complex, so complex that no models humans can devise could ever capture more than limited aspects of the total complexity. Nevertheless, some ways of constructing models of the world do provide resources for capturing some aspects of the world more or less well. Other ways may provide resources for capturing some aspects more or less well. Both ways, however, may capture some aspects of the reality and thus be candidates for a realistic understanding of the world. So here, in principle, is a solution to the problem of finding a picture of science that is both naturalistic and realistic." (Giere, 1999, p. 79).

9. First, to verify needs, either pulled by demand or pushed by the particular technology itself. Second, to analyze the requisites of the artifact and the available means within the firm. Third, to think up different solutions and choose the most adequate one. Fourth, to put to the test these different alternatives, then choose one and build a prototype. This prototype will be the base for

touching up possible mistakes before the definitive blueprint. Lastly, it is necessary to organize the manufacturing process.

10. We also could include here T. Kortabinski, H. Rumpf, G. Ropohl and others, but the cited authors are representative of the main ideas on the subject.

11. See Edward Constant (1980).

12. For instance, (Pitt, 2000, p. 9) says: “It is necessary to rethink the old assumption that technology is merely applied science and, as such, applied knowledge. This is not to deny the fact that from certain scientific discoveries we have been able to produce devices that make life easier. That is, *some technologies are the result of applying the knowledge that science produces*.” (The italics are mine).

13. For instance, Hans Radder says: “Much hard work is needed to transform a successfully realized scientific result and to incorporate it into a working technological system.” (Radder, 1996, p. 145). However, he does not make a deeper account of this “hard work”.

14. Just to mention a classic: “Science as an institutionalized art of inquiry has yielded varied fruit. Its currently best-published products are undoubtedly the technological skills that have been transforming traditional forms of human economy at an accelerating rate.” (Ernest Nagel, 1961, p. vii). In the same vein we could see too the “miracle argument” by John J. C. Smart (1963) and Hilary Putnam (1975).
A more recent contribution is Radder’s view: “Concerning experimental natural science as such, I think two legitimations play a fairly prominent and general role. The first is the claim that science is valuable because it delivers the truth about nature or, at least, promises to eventually give a true account of nature. The second major social legitimations is framed in the claim that experimental science is practically useful, that its results can often be fruitfully incorporated into all kinds of technological projects. (…) Actually, in present-day society, the “technological” legitimations seems to be the most influential.” (Radder, 1996, p. 40).

15. This idea is suggested by R. Giere, Margaret Morrison, and Paul Teller, although neither of them apply it to the case of engineering sciences.

16. Mary Hesse proposed this classification long time ago, in 1963. Nevertheless, it still remains useful for the purposes of this paper.

17. For some scientists is an habitual practice. Lord Kelvin said "I am never content until I have constructed a mechanical model of the subject I am studying. If I succeed in making one, I understand; otherwise I do not."

18. As Nelson Goodman (1978) has pointed out. This article does not uphold the ontological implications of Goodman’s view. Nevertheless, his characterization of the different actions that scientists may do during their work is very inspired.

19. “The margins of error rarely appear in the descriptions or calculations until one gets to the point of comparing theoretical predictions with actual measurements. This practice strongly supports

interpreting the original equations without explicit margins of error, as referring not to actual things but to abstract models of which they are true by definition" (Giere, 1999b, p. 6).

20. This example has been analyzed by Walter Vincenty in (2001). There he studies the case of a general theory: "The theory of supersonic wing" by Allen Puckett and how this theory had to be corrected by engineers for being applicable to real cases.

21. An Information Processing System has a processor, memory (short-term and long term), receptors and effectors.

22. Cartwright (1999), p. 6.

23. In a similar way, Cartwright (1999) following Neurath's theory.
