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Demarcating Technology from Science: Problems and Problem Solving in Technology

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Zusammenfassung

Es wird eine Unterscheidung zwischen für eine einzelne Wissenschaft (z. B. Physik, Chemie) eigentümlichen Problemen und technologischen Problemen vorgeschlagen. Dieser Unterscheidung liegt eine Auffassung zugrunde, nach welcher jede Wissenschaft einen speziellen Ausblick auf die Welt erarbeitet, einen Ausblick, der nur diejenigen Aspekte eines wirklichen Vorgangs heraussucht und sich aneignet, welche für diese Wissenschaft eigentümlich sind. Im Gegensatz dazu erfaßt die Technologie Vorgänge in der Gesamtheit ihrer Aspekte. Auf der Grundlage dieser Unterscheidung werden die Grundzüge des Verfahrens, welches zur Lösung von technologischen Problemen führt (Mittel zur Lösung, Natur des Verfahrens, besondere Kennzeichen der erzielten Lösungen), diskutiert.

INTRODUCTION

In its usual usage, the term "technology" embraces: (1) material artifacts (objects, devices, processes etc) as well as the knowledge concerning these artifacts, and (2) the activity aiming at the satisfaction of particular human and social needs through devising appropriate artifacts as well as the knowledge concerning this activity.[1] Accordingly, just like science, technology refers both to an activity (i.e. "the way in which...") and to the end product of this activity. Now, since all human activities are goal-oriented, the question of demarcating science from technology appears to gain a simple from: one distinguishes an activity by its purpose and an artifact by its use (Agassi, 1980, p. 84). We can say, therefore, that science aims at increasing and rationalizing knowledge by establishing better and better theories. The purpose of scientific research is increased understanding. On the other hand, technology aims at satisfying human and social needs (i.e. realizing desired states of affairs) through devising material artifacts which are appropriate and as effective as possible. The purpose of technological research is usefulness.[2]

Although demarcating science from technology according to their respective aims cannot be rejected out of hand, the corresponding distinction is neither sufficient nor satisfactory. Today science and technology often endorse each other's aims, while there exist several research disciplines in which both scien-

[1] For this "definition" see Walentynowicz (1968, p. 586).

[2] The problem of demarcating science from technology has been widely discussed. The formulation presented here conforms to the views of many philosophers who hold that such a demarcation is possible and significant (J. Agassi, J.K. Feibleman, H. Skolimowski, B. Walentynowicz, G. Radnitzky). Such an agreement, however, concerns the issue at its most general level. On a finer analysis many points of disagreement would appear.

Zeitschrift für allgemeine Wissenschaftstheorie XX/2 (1989)

tific and technological concerns interfere.[3] The difference between science and technology cannot be just a matter of different objectives. If demarcating the two is to have any philosophical import it has to take into account a variety of epistemological and methodological issues. More specifically, the cognitive aspects of technology should be asessed[4], the distinguishing features of a technological problem should be examined and contrasted with those of a scientific problem, the normative aspects and the modes of development of technology should be analysed and contrasted with those of science. The present paper proposes to face such questions. But first a short introduction to the various issues involved is in order.

As a matter of historical fact, technology has followed a course independent from science for milleniums and, accordingly, the question of distinguishing the two has become meaningful only very recently. Until the Renaissance, all the major technological achievements (fermentation, the use of quinine in medical practice, etc) were brought about by *craft technologies* without the slightest contribution from science. A craft technology may be roughly characterized as follows: It is based on practical knowledge and empirical observations of factual correlations and it employs techniques and methods (trial and error, analogies etc) which are justified only by their success in bringing about the desired state of affairs (i.e. solving the corresponding technological problem). There are no well defined criteria determining the circumstances under which a particular craft technology could solve different, yet intuitively similar, problems. Thus each solution is essentially unique while the domain of its applicability remains unknown. From the point of view of scientific knowledge, the process realizing the desired state of affairs by solving the corresponding technological problem may be regarded as a "black box". To give a very simple example, one may know in practice how to build a two-storied building with the particular means and materials available; moreover, one may intuitively recognize that he/she cannot build a twenty-five storied building with these means and materials. But he/she knows neither which is the maximum number of floors that the available means and materials enable him/her to build nor what one could build with some other means and materials. In contradistinction, the process of solving such a problem on the basis of Engineering Mechanics not only delimits the applicability domain of the achieved solution, but it also determines the allowed ways of progressing from one technological problem to another. In this sense, scientifically attested solutions to technological problems acquire some repeatability

[3] Consider the example of Plasma Physics given by Agassi (1980, pp. 96–97).

[4] The conception of technical knowledge as a mere "know-how", as opposed to the scientific (theoretical) "know-that", is oversimplified and hence misleading. Technical know-how is a sort of know-that since it tells us what actually works in this world. (For the function of the so-called "working hypotheses" in science and in technology see Agassi, 1980, p. 98). Following a different line of reasoning, based on the assumptions that (1) "The community is the arbiter of knowledge" and "action is its criterion", and (2) "knowledge is a tool we use to get around in the world", Pitt (1983) argues that no valid distinction is to be drawn between the two allegedly different types of knowledge.

features where the criteria restraining such repeatability are provided by the corresponding scientific theories (in the present case of Classical Mechanics).[5] Solutions to technological problems based on scientific theories give rise to what we may call *scientifically attested technologies* (Radnitzky, 1978, p. 1012).

On the basis of the above, the reasons why modern technology strives to achieve scientific attestation become obvious. In fact, it was Sir Francis Bacon who first formulated clearly the philosophical grounds of those reasons. Since science unearths truth, it forms a better tool for technology than mere guess-work and rules of thumb (Agassi, 1980, pp. 87–89). But this advice had to wait a long time before coming to fruition. Even such advanced innovations (widely implemented by the end of the 19th century) as Bessemer's steel-producing technology or Solvay's process for the production of soda had been developed by craftmanship alone (Radnitzky, 1978, p. 1013 and Buchholz, 19179, p. 39). It is only in our century that technology became connected to science in the way we are actually experiencing.

The tendency of contemporary technology to achieve scientific attestation is manifested mainly in two ways. On the one hand, theoretical models (based on the relevant parts of the natural sciences) of the various technological processes are elaborated. Such models tend to bridge the gap between what a scientific theory accounts for and what a particular technology aims to bring about and thus they implement a strong reductionist orientation: the ultimate reduction of all technology to science is being actively and explicitly pursued. On the other hand, there still exist many technological processes which cannot be so modelled. In such cases a "black box" approach remains the only option. But this deficiency in scientific attestation is considered as more or less compensated by the mathematical sophistication of the methods and techniques employed (e. g. correlation and regression analysis).[6] Furthermore, the selection of the relevant variables is often based – at least partly – on criteria provided by the sciences while the reliability of the extrapolations from the given data is checked by Probability Theory and Statistics.

If one adds to the above that a distinct kind of research-usually called basic or fundamental research-has been instituted within the overlap of science and technology[7], one cannot help admitting that, in our time and despite the different histories of the two enterprises, the boundaries between science and technology have become blurred.[8] Such fuzziness has led some philosophers to

[5] An interesting discussion of the notions of uniqueness and repeatability with respect to art, science and technology is included in Agassi (1983). In Agassi's words (1983, p. 63): "...technology is, and will remain, both science and art".

[6] According to Buchholz (1979, p. 51), regression analysis and creation of physical – deterministic models are the two fundamental methodological procedures used in research and development in Verfahrenstechnik (Chemical Engineering).

[7] A discussion of basic or fundamental research as an overlap between science and technology may be found in Agassi (1980).

[8] An amusing example of the fuzziness of the boundaries between science and technology is the following: Graines (1976, p. 624) notes that even the specialists may not be able to decide

hold that a clear-cut distinction between science and technology is theoretically impossible, misleading or insignificant.[9]

As it is evident, the question whether technology can or cannot be demarcated from science depends upon the particular metascientific approach or theory one espouses. For example, an instrumentalist conception of science, which regards scientific thoeries as mere tools or calculating devices for deriving predictions from observational data and which considers statements and theories as effective or ineffective (and not as true or false), is unable to draw any distinction between science and technology. Or, to take another example, Agassi, realizing the challenge that technology presents to philosophy of science, tried to examine the problem of this demarcation within the context of his own variant of Popperianism. In Agassi's view (1968, 1980), the demarcation between science and technology is to be founded on the different role of positive evidence (corroboration) in each one of them. Or again, within the context of the pragmatic epistemology championed by Pitt (1983), both science and technology are seen as input/output transformation processes, and technology is conceived in such a broad sense so as to include science.

For us, technology cannot be equated to science. As we have said, present-day technology still contains parts which cannot be firmly based on scientific theories and therefore it still continues to be a "mixture" of craft and scientifically attested technologies, even if the latter predominate over the former. At the very least, we can say that the equation technology-science has not been realized as yet. But we have reasons to believe that there is more than this. As we will try to show in the present paper, such a "mixture" constitutes an essential feature of technology, a feature that will continue to characterize it despite all the eventual successes of the reductionist programs. Moreover, as we will also try to show, not even the "scientific" part of this "mixture" can be equated to science without further ado. Scientific technology relates to science in a way that forbids the collapse of the one on the other.

Of course, as we have just noted, our arguments cannot but depend on our

conclusively whether a given paper belongs to a technological or a scientific discipline by considering the paper's content. His illustration (which is an instance of the sorites or falacros paradox) is as follows: "...consider a study in control engineering; it clearly remains one if we replace the actual plant controlled with a computer model of that plant. It clearly remains so if we consider the plant model as a set of numeric equations. It continues to remain so if we consider the general algebraic form of these equations. And so on each step in itself is a small enough change that we agree that the content of the paper cannot have crossed a borderline between "control engineering" and "not control engineering". Yet when the final paper appears (called "Residues of contraction mappings in Banach spaces"!), few control engineers will recognize it as belonging to their discipline".

[9] This trend in philosophy of technology is represented (among others) by M. Bunge, M. Jonas, and J. Ellul. They share the view that modern technology is substantially different from old-time technology, because it is completely attached to science. Therefore only a distinction between modern and old-time science (e.g. between the aristotelian and the baconian conception of science according to Jonas, 1966) or between modern and old-time technology (e.g. between the technology prevailing in the west until the 18th century and that which succeeded it during the 19th century on Ellul's (1954) view) may gain philosophical importance.

own conception of science. Such a conception has been developed elsewhere for the particular case of Physics (Baltas 1986a and b). Accordingly, and independently of the light it might throw on the issue in question, the present paper constitutes for us a kind of "test" for this conception. We are here also trying to examine, that is, to what extent the ideas developed in that different context manage to capture the distinction between science and technology in a way that does justice to both without being at odds with our experience of either.

SCIENTIFIC VERSUS TECHNOLOGICAL PROBLEMS

We start our discussion by trying to pinpoint the difference between a scientific and a technological problem. To do this in a philosophically responsible manner, however, we have to present first a brief overview of the conception of science on which this difference is predicated.

In a nuthsell this conception is as follows.[10]

Each science carves out a particular perspective on the world. What this perspective "sees" are the real phenomena that this science can cognitively account for, while this "seeing" is nothing but this accounting for. But through this perspective these real phenomena are not "seen" as they are given to our experience[11] but ony as they are apprehended by the "way of looking" peculiar to that science. Now, this "way of looking" is complex because it involves bootstrapping or feedback loops among three elements which, in their interrelations, define the perspective in question: (1) The conceptual system of the science (the system of concepts and relations making up its theories). This system picks out the particular real phenomena for which the science in question can cognitively account (and which we may call the object of that science), and "dresses" them with the "clothes" (the concepts and relations) that make up this system. The perspective defining a science "sees" real phenomena only so "dressed". (2) The thus picked out phenomena (the object of the science). These impose various constrains and limitations on the conceptual system itself because they resist their "dressing" by "clothes" that do not "fit" them. (3) The experimental procedures specific to the science in question. These check and thereby make manifest the resistance that phenomena may pose to their being "dressed" by and "seen" through inappropriate "clothes". This conceptual system, this object and these experimental procedures make up what we may call the three constitutive elements of the science in question.

[10] This conception constitutes a "structuralist" approach to science in the sense that the interrelations among what we call the three constitutive elements of each science are highlighted. It is an approach inspired by the works of Louis Althusser, of Joseph D. Sneed and of their respective followers and it is developed in Baltas (1986, a, b and c). A concise summary of it is to be found in Baltas (1987).

[11] This does not imply that phenomena are given to our experience "in the raw", as they "really are". Before a given science appropriates them, phenomena are given to our experience through what Althusser calls the interplay of practical and theoretical ideologies. For details see Baltas (1986b).

These three elements are not constituted independently of each other and they are not established once and for all. Each is what it is and performs the epistemic function that it performs only on the basis of the relations it entertains with the other two. It is these constitutive interrelations which determine what the given science can or cannot subsume under its cognitive jurisdiction, what it accepts as true or approximately true and what it rejects as false, what the rigour specific to that science amounts to. Moreover it its these interrelations which determine the ways in which this science develops.

For the purposes of the present paper, what we mean in saying that the relation which a given science bears to the world is that of carving out a particular perspective on it, can be spelled out roughly as follows (Baltas, 1986a). Through the interplay of its three constitutive elements, this science singles out the one particular – idiosyncratic to that science – aspect of the real phenomenon which the science is in the process of cognitively appropriating: It "sees" this aspect exclusively through the "eyes" of its own conceptual system (which, in the very same process, is being established or further elaborated); it completely wipes out of its "visual field" all other aspects of the real phenomenon; it totally reduces the real phenomenon to just that aspect identifying the whole phenomenon with it. To take a simple example, Physics "sees" a real apple falling not as a fruit, not as something having shape, colour, taste, kernel, seeds etc but only as "a material point (or body) moving in space because of gravitational attraction". Physics (or, for that matter, any science) becomes constituted by, precisely, reducing away all aspects of the real phenomenon which are not what the interplay among the corresponding three constitutive elements determines as idiosyncratic to this interplay. Of course the thus eliminated aspects of the real phenomenon are not completely "lost". They may be or become parts of the object of other sciences or scientific disciplines. However, no science can overstep the limits of the perspective defining it. Each science sees *only* the things which are *exclusively* determined in the way *specific* to that science.

The perspective defining a science does not constitute, in fact, a simple point of view, just a way of *looking* at the world. In some essential respects, the metaphor of vision is not appropriate here. For a perspective defining a science necessarily involves those *material* operations, those manipulations, in which the experimental procedures specific to that science consist. To stay with the same example, Physics can cognitively appropriate the fall of an apple only to the extent that it can verify that this fall actually obeys the law that the conceptual system of that science claims to hold for it (namely $S = gt^2/2$). And for this to be shown, a material procedure measuring time intervals and involving a material device which is qualified to do just that has to be effectuated. However, on the present conception, this procedure remains in its entirety within the perspective defining Physics. The device in question is, let us say, a pendulum clock. But a pendulum clock is nothing but the "materialization" of a phenomenon which Physics has *already appropriated*: The test in question is strictly meaningless unless we *already know* that the (small) oscillations of the pendulum *are isochronous*, that is that the pendulum obeys the law (T =

$2\pi\sqrt{(l/g)}$. The perspective defining a science is not just a way of viewing things and does not involve only concepts; it is a complex affair relating concepts, real phenomena and material procedures in ways that this perspective alone determines by itself.

On the basis of the above, two consequences can be drawn which have a direct bearing on the issue under discussion:

(1) A science can treat and cognitively appropriate the only aspect of a phenomenon which this science picks out as idiosyncratic to it. All other aspects of the real phenomenon get excluded from that science's visual field. And this exclusion is definitive. In fact a given science is *defined* by such an exclusion.[12]

(2) A science treats the particular aspect of the real phenomenon which is idiosyncratic to that science in an autonomous way.[13] A science progresses only through the deployment of the interplay among its three constitutive elements, a deployment which elaborates these elements and their interrelations giving thus rise to that science's cognitive effets. The cognitive effects of a science depend *exclusively* on this interplay.

Now, if, in very general terms, we define a scientific problem as a demand for the further elaboration of some of the constitutive elements of a given science and/or of their interrelations – an elaboration aiming at furthering the cognitive appropriation of the one particular aspect of the real phenomenon which the science in question treats- it follows that a problem can be called scientific only if it is a problem *proper to a particular science*. This is to say that a scientific problem concerns only such a particular aspect of the real phenomenon and that this problem can become formulated and eventually solved only within the confines of the corresponding science and only through and only by the interplay of that science's three constitutive elements. Since it is such an interplay alone which always does the job, we can say that scientific problems get formulated in a "subjectless" manner[14] and without reference to any need external to the science in question. (Omiting, of course, the need to further knowledge which concerns by definition all the sciences in their entirety).

On the other hand, at the same level of generality, we can define a technological problem as a demand for the production of a material artifact that will realize a particular desired state of affairs. With this definition the differences between a scientific and a technological problem become apparent: (1)

[12] This does not imply that hitherto untreated aspects of a phenomenon cannot come under the jurisdiction of a given science. But which aspects these are as well as the way they become cognitively appropriated are *exclusively* determined by the interplay among the given science's three constitutive elements.

[13] The characteristics of this autonomy are analysed and discussed in Baltas (1986b).

[14] This, of course, does not imply that it is not always scientists who formualte and solve scientific problems. It means, roughly, only that the demand for furthering knowledge that a given scientific problem manifests is independent of any scientist's beliefs, desires etc and, accordingly, that it transcends such beliefs and desires imposing itself upon scientists. This is one of the fundamental tenets of Althusser's approach. For details see Pêcheux (1975).

The production of a material artifact, the artifact itself as well as the state of affairs this artifact realizes obviously involve the relevant real phenomena in a multitude of their aspects. Not only properties belonging to the subject matter of different sciences but also feasibility, suitability, reliability etc considerations are necessarily involved. And since each science can treat only the one particular aspect of a real phenomenon which is idiosyncratic to it, a technological problem lies outside the jurisdiction of any single science. Moreover, as each science gets defined by excluding from its field of vision *all* the aspects of the real phenomena which are not idiosyncratic to it, on the basis of what we have said so far, there appears to be *no scientific* way by which a technological problem can be tackled. (2) A *desired* state of affairs implies that somebody (an individual, a group of people, an institution etc) is the subject of this desire as well as that this state of affairs is desired because it is considered as satisfying some human or social need (of a biological and/or economical and/or cultural etc character). Accordingly, in contradistinction to what happens with the sciences, a technological problem is a problem which is always posed by a particular subject or agent in response to a particular need which is shaped by socially and/or historically determined concerns.

These differences between scientific and technological problems do not imply that there cannot exist an intimate relationship between science and technology. For example, the stage of development that a given science has reached may implement the realization of a particular artifact and thus lead to the demand for the satisfaction (or even to the creation *ex nihilo* and the subsequent satisfaction) of a certain need. But more importantly, science and technology become intimately related in either (or both) of the following two ways:

(1) A need may be raised *in the interior* of a given science appealing to the realization of a particular artifact (e.g. a device or an apparatus) so as to implement its experimental procedures and assure its own development. This does not contradict what we have said so far to the extent that we realize that a device or an apparatus enters in a scientific experiment *only* as a "materialization" of a phenomenon that the science in question has already cognitively appropriated. This is to say that the particular nature of the device or apparatus and most of its various material properties and features have no bearing at all on the epistemic function of the experiment. Those that do have such a bearing are totally controlled by the corresponding conceptual system: they become translated by it into the parameters determining the limits within which the experiment can indeed perform the epistemic function that the science in question asks of it.

(2) A need may be raised outside a given science in various quarters and for various reasons and appeal to that science for its satisfaction. For example, the completion of a technological artifact may require of a given science to solve a particular scientific problem or set or problems. Such externally raised demands induce a particular branching out of the sciences to which these demands are addressed and give rise to the different branches of *applied sci-*

ence. But the existence of such hybrid disciplines[15] does not contradict what we have said. In order to be tackled by a given science, a demand raised outside of it should necessarily be formulated as a scientific problem proper to that science and handed over to the exclusive juirisdiction of that science's three constitutive elements. Such externally posed demands may well influence the division of labour of the corresponding scientific community by making a part of it specialize in answering them. A particular branch of applied science is thereby institutionalized. Such demands may also have important effects on the outlook of the community as regards the priority it attaches to the different problems that it is each time facing. But these factors do not in any way impair the distinction between scientific and technological problems that we propose. A given science is in the position to translate an externally raised demand to a problem proper to itself to the exact same extent that it is in the position to arrive at this problem exclusively by its own means, i.e. through the interplay of its three constitutive elements.[16]

SOLVING TECHNOLOGICAL PROBLEMS – THE MEANS

As we have said, a technological problem can be defined as a demand for the production of a material artifact that will realize a particular desired state of affairs. On the basis of this definition, a technological problem was shown to possess the following characteristics:

(1) A technological problem is posed by an agent (an individual, a group, an institution etc), the agent who expresses that demand and who is the subject of that desire. (2) A technological problem is posed in response to a particular human or social need (of a biological and/or economical and/or cultural etc character), need which, in general, is shaped by socially and/or historically determined concerns. (3) A technological problem involves the relevant real phenomena in a multitude of their aspects.

These characteristics impose a set of important constraints on the whole process of solving a technological problem as well as on what can count as its solution. First, the state of affairs that the solution of the technological problem will realize is, by definition, desired by a *particular* agent in response to a *particular* need. Other agents may not have this need, they may not consider this state of affairs as desirable or even they may be strongly hostile to it. Accordingly, the solution of a technological problem may encounter important social (and political) resistance and thus involve important social (and political) costs. Second, since a technological problem involves real

[15] Several illustrative examples on the distinction between pure and applied science are included in Feibleman (1961).

[16] This idea is shared by Kuhn (1970, p. 30) who maintains that the problems of applied science (e.g. the manufacture of astronomical ephemerides or the computation of lens characteristics) are merely some of the problems that normal science is confronted with.

phenomena in a multitude of their aspects, a single well-defined criterion determining the satisfaction status of the attained solution does not, in general, exist. Conflicting criteria of appraisal are usually involved (e.g. a construction should be firm and safe but also not expensive) and the attained solution is considered acceptable only if it satisfies a complex function of those. Third, as no single science is in the position to take into account and control all aspects of the phenomena involved in the solution of a technological problem, adverse side-effects (technological accidents, environmental hazards etc) may come about which are unintended and, on the basis of the existing knowledge, unpredictable. The process of solving a technological problem should take into account such risks as well. We can lump all these considerations together into the notion of *effectiveness* and say that the solution of a technological problem is accepted to the extent that it is effective, i.e. to the extent that the various sorts of costs involved in this solution remain below the level that the agent who has posed the problem and ordered its solution is willing to pay. In this sense the norm of technology is effectiveness.

From what we have said it follows that no single science is in the position to face effectiveness and tackle by itself a technological problem. Nevertheless the sciences can be used as *means* towards such a solution. For this to be possible the major aspects of the real phenomena involved have to belong to the objects of established sciences. Scientifically attested technologies are precisely the technologies that are based on the sciences in this way, that is those that use the sciences as means for solving the corresponding technological problems.[17] The particular ways in which this is done are examined in what follows.

The different aspects of the real phenomena involved in a technological problem are mutually exclusive in the sense that each one belongs to the object of a different science while each science can treat such an aspect only if it totally excludes from its field of vision all the others.[18] Accordingly, if different sciences are to collaborate for the solution of a technological problem, links have to be established among the collaborating sciences: links which cannot but be *external* to the sciences involved and imposed only be the technological problem itself. We can call such links *interscientific* or, more generaly, *interdisciplinary relations*.

[17] As a matter of fact, the success of scientifically attested technologies has given rise to an ideological overestimation of the role of science in solving technological problems. A scientifically attested solution to a technological problem is *ipso facto* considered as providing a satisfactory degree of social assurance – or, at least, a socially acceptable degree of responsibility (cf. Agassi, 1968, pp. 485–487 and 1983, pp. 58–59) – while, on a closer look, this is hardly justifiable.

[18] To this may be objected that there exist cases where this does not happen. For example, Physics apparently does not exlude from its field of vision chemical phenomena. On the contrary, are not chemical phenomena, in the last analysis, reducible to Physics? To this we reply that the "last analysis" clause has to be taken seriously here. Although, after the discovery of the periodic table and of the quantum physics of the atom all chemical phenomena have become indeed in principle reducible to Physics, this "in principle" has never become "in fact". Physics and Chemistry have conserved their independence from each other while the establishment of a determinate interface between the two, far from collapsing the one on the other, *has itself acquired structure* through the development of *new scientific disciplines* (e. g. Phyiscal Chemistry).

Such interscientific or interdisciplinary relations are not shaped *ad hoc* for each particular technological problem. The development of the collaborating sciences themselves as well as the resemblances, analogies etc which characterize various technological problems lead to the distribution of such problems into different families, and to the constitution of a more or less permanent group of sciences tied by interdisciplinary links and clustering around each family of technological problems. An interdisciplinary basis is thus established, which is oriented towards a more or less sharply defined family of technological problems and which, in the long run, acquires permanence, distinctness and a characteristic rigour. The various specialties of engineering (Chemical Engineering, Civil Engineering, Electrical Engineeering, etc) are interdisciplinary branches institutionalized through such processes of problem – induced hybridization. Accordingly, we can say that engineering disciplines are *problem-based specialties*.[19] The various communities of engineers are primarily characterized by their central concern in solving a more or less precisely defined type of technological problems.

The curriculum of an engineering school constitutes an excellent reflection of the heterogeneous basis of an engineering discipline. Besides the genuinely scientific courses, we find also there bundles of courses which correspond to the so-called *theories of engineering*. Following Walentynowicz (1968, p. 588) we can classify the theories of engineering by their content, and draw a distinction between *factual theories* and *operational theories* of engineering.

The factual theories of engineering deal with the various phenomena and effects involved in the structure and the function of technologically significant artifacts and they incorporate – or they are externally articulated with – appropriate methods for analyzing and controlling these phenomena and effects. In general, the factual theories of engineering try to understand and to explain such phenomena and effects on the basis of a coherent conceptual system which is considered as, at least in principle, reducible to the conceptual system of a particular science or of a scientific discipline. Because of the high degree of complexity of the phenomena they deal with, the factual theories of engineering – or at least their application-oriented parts – are frequently obliged to remain at a phenomenological (descriptive) level.

To illustrate these considerations let us briefly examine the example of Chemical Engineering. The factual theories of Chemical Engineering include Applied Thermodynamics, Transport Phenomena, Unit Operations, Kinetics and Catalysis of Processes in Technical Reactors, and Material "Science" (mechanical properties of materials, corrosion, etc). These theories are articulated with appropriate methods of analyzing the various phenomena (e.g. regression analysis, demensional analysis, mathematical modelling of processes, simulation, scale-up methods etc) as well a with methods of controlling them (e.g. automatic process control). Some of these methods do not depend upon the factual theories in question but come from distinct disciplines (e.g. Mathematics, Statistics, Computer Science, Cybernetics etc).

[19] We adopt here a terminology first proposed by Law (see Buchholz, 1979, p. 37).

The factual theories of Chemical Engineering have been reduced to the sciences in various degrees. For instance, Transport Phenomena are founded on Physics (and partly on Physical Chemistry) while the study of corosion is nowadays part and parcel of Applied Electrochemistry. On the other hand, hierarchy relations have been established among several factual theories of Chemical Engineering in the sense that some of them depend upon "more fundamental" ones. (E.g. the study of unit operations is substantially based on Transport Phenomena and Equilibrium Thermodynamics). However, despite such reductionist features, all factual theories of Chemical Engineering involve (especially in their application instances) phenomenological approaches because of the complexity of the problems they are confronted with. An appropriate example here is Fluid Dynamics. Although Fluid Dynamics is a proper part of Physics in the sense that we can formally derive the relevant general equations within the conceptual system of that science, these equations, in almost all significant cases, are so complicated that their analytic mathematical (or even numerical) solution is not feasible (a least in practice). For this reason, certain convenient quantities (e.g. Reynolds number, friction factors, etc) are introduced and several empirical or semiempirical equations and charts are widely used enabling us to calculate easily and with sufficient accuracy the numerical values of the important parameters occuring in many classes of problems.

In contradistinction to the factual theories of engineering which try to understand and to explain phenomena and effects, the operational theories of engineering are essentially practice-oriented: Their objective is to formulate the rules for the optimal course of action in the process of technological realization. Despite their sophistication, the operational theories (e.g. optimization theory, decision theory, cost-benefit analysis etc) are completely subjected to the social determinations of the engineering activity, reflecting there the corresponding social values. These theories try to theorize human and social needs, demands and costs so as to make them amenable to a mathematical treatment and aim at giving an exact shape to the image of the "technological ideal" as this image is conceived by the agent who has posed the technological problem and ordered its solution. Concomitantly, these theories are supposed to show the ways in which the solution of the technological problem conforms to this "technological ideal". Of course, it goes without saying that the image of the "technological ideal" is variable, and subjected to historical evolution and social change.[20]

Both the factual and the operational theories of an engineering discipline, together with the appropriate methods and techniques as well as with the

[20] It is a historical fact that the conception of the "technological ideal" has undergone several alterations over the centuries. Indeed, effectiveness as we have discussed it constitutes only the "technological ideal" that was recently adopted by modern western societies. The technology of the Roman period, for example, was not subject to any limitations as concerns saving materials, energy or human labor. The Romans used to build bridges strong enough to support weights much heavier than what could possibly pass over them.

corresponding background sciences, are integrated into a structured whole which constitutes the conceptual and methodological[21] framework specific to that engineering discipline. The framework of an engineering discipline is purported[22] to be theoretically and methodologically compatible with the general scientific framework, that is the "framework" constituted by the different sciences. This compatibility has been attained – with some minor discrepancies[23] and of course, as regards only the correspoding factual theories – for all the presently existing engineering disciplines. The framework specific to an engineering discipline provides all the means for a scientifically attested solution to a technological problem proper to that discipline.

In closing the present section,it is very important to note that the conceptual and methodological framework of an engineering discipline, once formed, engenders its own dynamics which becomes partly disconnected from external needs and demands. The engineering discipline acquires thus its "inner" research front and its "internal" problem generating process which are independent, to some extent at least, from the discipline's vocation to respond to externally raised demands. Obviously, this aspect of the engineering activity makes it resemble to that of a science: they both enjoy a relative autonomy from external determinations, they both have an eye to the elaboration of their own conceptual and experimental tools as well as to the extension of their domains of application, etc. However, there remain substantial differences between the two. The "internal" dynamics of an engineering discipline generates sequences of problems which may not be directly technological; but they are not properly scientific either. These are problems concerning the systematization of the processes of solving technological problems.[24] In order to avoid terminological confusion, we will call "technological problems" only the type of problems we have been discussing throughout this and the previous section while we will adopt the term "*engineering problems*" to refer to the problems generated by the "internal" dynamics of an engineering discipline. In the sense described above, we may say that technological problems are the first-order problems and engineering problems are the second-order problems of technological research. As it is evident, engineering problems (like technological problems) involve the real phenomena in a multitude of their aspects.

[21] We use "methodology" here only to refer to the particular methods, skills and techniques employed by the working scientist or engineer.

[22] Only purported: we do not consider that the corresponding operational theories can be unqualifiedly called "scientific".

[23] Such discrepancies continue to give rise to "black box" approaches. As a result, and as we noted in the introduction, craft technologies continue to be employed.

[24] A typical example here are the Chemical Engineering research problems related to the study of unit operations. The notion of unit operations arose from the observed fact that a number of particular operations in various industrial processes (in other words, in processes involving different technological problems) are similar (distilation, filtration, mixing, crushing and grinding etc). The study of unit operations systematizes the process of solving such technological problems. See Buchholz (1979, pp. 42–43).

SOLVING TECHNOLOGICAL PROBLEMS – THE PROCESS

A technological problem is posed when a particular agent (or collective of agents) proposes to produce (or only to finance the production of) a particular material artifact that will realize a particular state of affairs he/she desires. The agent considers the state of affairs in question as desirable only to the extent that the various costs (social, political, economical, environmental etc) involved in the production and in the operation of the artifact remain within the limits of acceptability determined by the agent himself/herself; i.e. only if the expected effectiveness of this artifact is high enough. The agent determines this "height" on the basis of his/her social economical etc situation and usually in conformity with the dominant "technological ideal".

The expected effectiveness of the artifact becomes precisely assessed through a *feasibility study*. The relevant information is gathered, the different functions and general characterisitcs of the artifact are determined, different alternatives leading to substantially the same desired state of affairs are examined, all in conjunction with their various projected costs. The feasibility study is carried out on the basis of the relevant operational theories and its outcome consists in a precise "weighing" of the alternatives examined, where the "weight" of each alternative is calculated in reference to the "technological ideal" through "comparing" its relative advantages with its estimated costs. The precision in question is the precision characterizing the operational theories used. Given that both advantages and costs are usually highly heterogeneous, the "weighing" in question makes sense only on the basis of the uniformization of needs, demands, costs etc "achieved" by the operatational theories. On the basis of the feasibility study, the agent who has posed the technological problem will select the particular artifact that will realize the state of affairs he/she desires as well as the particular way of producing it.

Once this choice has been made, the stage of *designing* the artifact and the way to produce it is conducted. This stage is usually divided into three distinct steps. (1) A preliminiary study of the particular system selected (artifact plus its manner of production) is carried out whereby its various functions, characterisitcs, costs etc are examined in detail and in view of that system's immediate realization. (2) On the basis of the relevant factual theories, the design proper of the system is performed. The technological problem is analyzed into different partial problems and these become solved on paper and/or in the laboratory. (3) On the basis of the solutions obtained on paper and/or in the laboratory, the problems that are expected to be encountered in the *in situ* construction and/or installation of the system are tackled and a strategy towards solving them is developed.

After its design has been completed, the system gets constructed and/or installed in the way this design prescribes. Problems or discrepancies that may be encountered in this stage are faced with the aid of the relevant factual and operational theories; if these prove that they are not up to it, craftmanship and *ad hoc* solutions fill in the holes. Once the system has been constructed and/or installed, various performance tests are conducted. The technological problem has been solved once the produced artifact passes those tests successfully.[25]

The solution of a technological problem is not determined by purely intrascientific factors the way the solution of a scientific problem is. The solution of a technological problem may follow any one of the family of proposals that the corresponding feasability study delimits. The general pattern of these proposals is that of a *recommendation* (Radnitzky, 1978, p. 1012): To realize the state of affairs desired, the agent who has posed the technological problem is advised to choose a particular process of solution to the extent that he/she estimates the costs (of all sorts) therein involved as acceptable. Since the solution of a technological problem obeys the norm of effectiveness, the optimal solution among those proposed is the more effective. And effectiveness, as we have said, incorporates a "measure" of the costs involved, costs that reflect extrascientific and in general controversial needs, demands, interests, values, concerns etc. Moreover, even if one considers the "measure" of the relevant costs as fair or even objective,the optimality of a solution cannot often be itself objectively assessed. What is optimal for a given agent depends largely upon the particular situation (social, polititical, financial etc) this agent finds himself/herself in.

It is noteworthy that such a pattern does not concern only the stage of the feasibility study. In every stage of solving a technological problem different alternatives usually appear the relative merits of which are determined each time by the relevant operational theories. That is why the operational theories can never be completely separated from the factual ones. Such alternatives appear even within the stage of design in the narrow sense, requiring often important extrascientific decisions that involve costs of all sorts. In this way a *tree of solutions* arises calling on the agent who has posed the technological problem and ordered its solution to make at every juncture the corresponding decision. It may well be that in most cases the agent does not intervene "personally" in every such stage but delegates his/her power of decision to the engineer responsible; but the fact that, for this solution to proceed, an extrascientific agency is structurally required throughout the process, manifests clearly the limits that a scientifically attested solution to a technological problem cannot overstep. The solution to a technological problem is scientifically indeterminate in the sense that the factual theories of engineering – those providing scientific attestation – cannot pick out by themselves this solution; they can only delimit a domain, the domain of the scientifically possible. It is up to the agent who has posed the technological problem to select from this

[25] Needless to say that in some cases these stages may not be sharply distinguishable while, of course, the analysis of the stages themselves can be filled in with more detail (for example see Walentynowicz, 1968, p. 589). These details may be different for different engineering disciplines and for different types of technological problems. It is outside the scope of the present paper to enter into such details and to examine such differences.

domain the optimum (i.e. most effective) such solution, where the effectiveness or optimality criteria are, in the last analysis, subjectively determined by the agent himself/herself.

SOME REFLECTIONS ON THE DEVELOPMENT OF TECHNOLOGY

We just said that the factual theories of engineering can only delimit the domain of the scientifically possible solutions to a technological problem and cannot pick out by themselves the solution to be realized. This remark may serve as a point of departure for examining the notions of possibility and impossibility in technology and thereby for presenting some reflections on the way technology develops.

Following Skolimowsky (1968, p. 555–557), we can say that as far as technology is concerned, possibility is a matter of what can be produced, constructed, installed etc and not simply of what can occur (contingency of events) or of what may exist (contingency of entities). In this sense, an object or artifact may be (1) *logically possible* if it is not self-contradictory, that is if it can be intelligibly and coherently described, (2) *scientifically (or physically) possible* if it does not defy the laws of nature established by the existing sciences, (3) *technically possible* if it does not defy existing technical means, and (4) *technologically possible* if it can be effectively produced to realize a desired state of affairs. Let us now ponder for a moment the distinction between the technically and the technologically possible. If an artifact is technically possible, it follows that this artifact *can* be produced if only in the laboratory or the workshop. However, such a technical possibility may not constitute a technological possibility as long as the artifact in question does not conform to the existing norms of effectiveness. Technological possibility incorporates not only the technical but also the social, political, economic etc aspects and costs of the artifacts that technology can produce. For instance, the electric automobile does constitute a technical but not a technological possibility, at least for the time being.

In light of the above, we may say that technology develops by enlarging the scope of the technologically possible. In doing this, while remaining always confined within the scientifically possible, technology strives to expand the scope of the technically possible and to transform technical possibilities into technological ones. It follows that, as long as they remain scientifically possible, technological projects are never definitively invalidated: they may be demonstrably technically or technologically impossible only for the time being. Moreover, once a technological project has been realized, it has proved to be possible (and thence it has been validated) forever.

On this basis, the history of technology may be viewed as an accumulation of technological achievements. Unlike what happens in science, where a new theory may completely negate an older one, in technology the older achievements are never invalidated by the new ones. Even today we can successfully employ (and we sometimes actually do) techniques used in antiquity to solve a particular technological problem (e.g. to produce wine or build a boat). In this sense, the development of technology is cumulative.

However, there exist cases where technology does forgo its past. For example, we do not forge steel the way the Arabs used to several centuries ago. Such an abnegation results from transformations in the "technological ideal" and of what counts as effective. And these transformations, in their turn, follow from changes in the social framework within which technology functions. It is certain that, once something has been demonstrated to be technologically possible, it remains a *technical* possibility forever; but it may become a *technological* impossibility if the "technological ideal" and the effectiveness estimates have changed sufficiently. We can say therefore that the non-cumulative aspect of technology manifests the adaptation of technology to socio-economic conditions. It is the social framework which either invalidates or conserves past technological achievements.

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