TECHNICAL SYSTEMS AND TECHNICAL PROGRESS: A CONCEPTUAL FRAMEWORK

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THEORIES OF SCIENTIFIC PROGRESS

After more than twenty years, discussions on the truthlikeness of scientific theories, initiated in the seventies, have not, in my opinion, arrived at final conclusions; but they have contributed positively to improving our comprehension of scientific progress. Niiniluoto's (1984) contribution is especially useful to define what we may call *the kernel of the current standard view of scientific progress*. This can be summarized in the following thesis:

1) The goal of science is the enlargement of scientific knowledge.
2) Scientific knowledge is characterized by a double dimension: information content and truth value.
3) In order to characterize scientific progress as increase in knowledge, a good strategy is to define some truthlikeness or "similarity to the truth" function—including both dimensions, information content and truth value.

On this common basis, very different theories of scientific progress can be defined. The differences affect the epistemic or objective construction of truth and truthlikeness concepts, the realist or instrumentalist view of scientific theories, and the global or local character of scientific progress.

Niiniluoto's (1984) theory is an objective, realist, and local theory of scientific progress. Quintanilla's (1982) proposal has a more methodological or epistemic character, but it is consistent with a realist construction of the truth concept and with a global conception of scientific progress. Zamora's (1996) theory has the same features, and he offers a formalization of truthlikeness that is, in my opinion, one of the most promising proposals made from a methodological point of view.

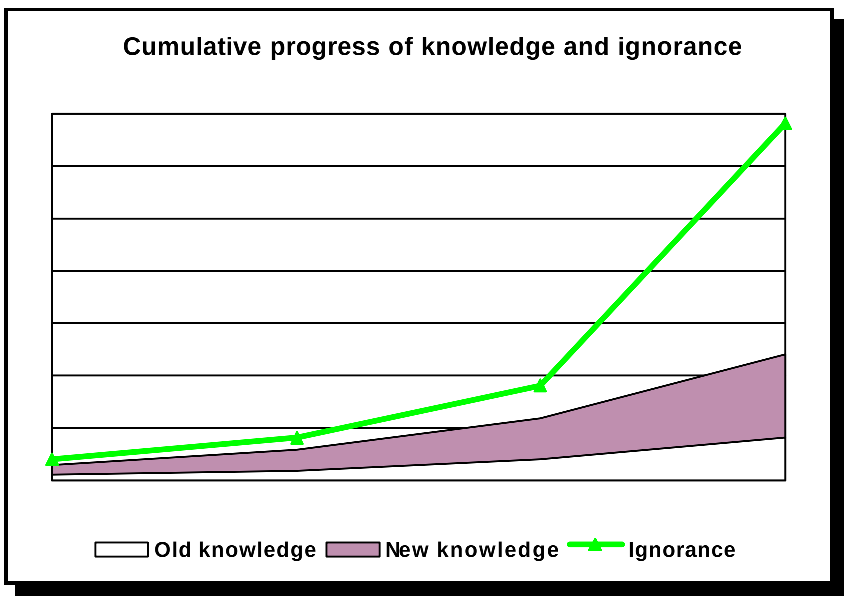
In discussions on truthlikeness and scientific progress, there is an issue that has not always been emphasized, though, in my opinion, it is very important. It is the distinction between two possible approaches to the concept of progress: the purely cumulative approach and the teleological one.

A process in a system is characterized by a change in the value of at least one proper variable, and it is defined as progressive if the variation of that variable is a monotonically increasing function of time (Bunge, 1977). If a process is teleologically progressive, then the time function describing it will have a limit. Therefore we will say that a process is cumulatively but not teleologically progressive if the time function describing it does not have a definite limit.

In Quintanilla (1982) I suggested that one of the problems affecting many formalizations of truthlikeness is that they are inspired by a teleological view of scientific progress.

A way to appreciate the differences between cumulative and teleological views of scientific progress is to declare what we are expected to accept, in each case, if we claim that a given scientific contribution means progress. Indeed, in scientific research, when a new theory is appraised as a valuable contribution, as true progress in scientific knowledge, what is assumed is either that, after having accepted it, we know somewhat more than we knew before, or that we know it better (with more depth, etc.). At the same time, we also accept that, as a result of this new contribution, new problems will emerge—but also new possibilities to study and find solutions for those problems. So all scientific progress generates at the same time an increase of both our knowledge and our ignorance, as Popper (1963) claimed. But nobody should be worried by this: after every step in the development of our knowledge, we learn that our ignorance is larger than we believed it to be, but we also learn that we now know something new that was not known before. This is exactly what (cumulative) progress of knowledge means. In order to accept that our knowledge is now larger than before, we do not need to assume that we are closer to the final and complete truth. In fact, we do not even need to assume that such a complete truth exists. (It would be the Gods eye point of view of metaphysical realism defined by Putnam.) Truthlikeness functions, like Niiniluoto's, have only local limits (determined by the complexity of the language in each moment); they do not have a global limit, since the language of science is neither globally fixed nor finite.

We may illustrate our view of cumulative progress by the graphic below. In it, the upper line represents the growth of our ignorance; the larger shadow area represents the growth of our knowledge; and the grey area represents the number of old beliefs refuted by our new scientific knowledge. All three sets grow at different rates and without limits.



In what way can this model of scientific progress help us to enhance our understanding of technological progress?

The notion of technological progress is somewhat more complex than that of scientific progress. First, it is not clear what the units of technological change are. Second, the notion of technological progress generally incorporates not only descriptive but also evaluative elements. Finally, it is not clear how a function of technological change can be defined that gives an accurate meaning for the concept of progress in this field.

In what follows we will try to improve the situation and to build up the kernel of a possible standard theory of technological progress.

2. PROBLEMS IN THE CONCEPT OF TECHNOLOGICAL PROGRESS

There are three possible views in philosophy of technology. We will call them cognitive, instrumental, and praxiological views.

According to the *cognitive view*, technology is a form of science-based practical knowledge that allows us to design efficient artifacts to solve practical problems. Technological change is mainly produced through applied scientific research and the improvement of technological knowledge. Technical progress consists in the increase of technological knowledge and depends, to a large extent, on scientific progress.

According to the *instrumental view*, technology is a set of artifacts intentionally designed and produced to perform some definite functions and to satisfy some human necessities. Technological change consists in the increase of the quantity and variety of artifacts, and technological progress is defined as a function of the quantity and importance of the human necessities that can be satisfied by the available technological equipment.

According to the so-called *praxiological approach*, the basic technological entities are neither knowledge systems nor sets of artifacts, but some kind of complex systems formed by the artifacts plus their users or intentional operators. We can characterize technological systems as *action systems intentionally oriented toward transforming concrete objects in order to obtain, in an efficient way, a valuable result*. Technological change consists in the design and production of new technical systems and in the improvement of their efficiency. Technological progress may be interpreted as an increment of human power to control reality: new and more efficient technical systems applied to new and larger parts of reality mean higher capacity to adapt reality to human desires (Quintanilla, 1996).

In the last chapter of Niiniluoto (1984), he proposes some interesting ideas on technological progress—integrating, in some ways, the three views of the philosophy of technology. Indeed, following an idea of Skolimowski (1966), Niiniluoto compares scientific and technological progress in these terms:

> Activities can be appraised by evaluating how "good" results they produce. Therefore, *scientific progress* has to be defined by the increase that new theories contribute to human knowledge—how much new information they give and how close to the true this information is. *Technological progress* has to be defined by the ability of new tools to perform effectively their intended function or use. While scientific progress is measured by *epistemic utilities* (such as truth, information content, truthlikeness, explanatory power, simplicity), technological progress is measured by *technological utilities* (effectiveness relative to a given practical purpose (p. 260).

Then Niiniluoto points out the fact that, in different technological areas, there may be different standards of technical efficiency, and that different groups of persons can give different weight to the different technological values or utilities. This could explain the existence of "alternative technologies" and phenomena of inconmensurability (*à la* Kuhn) in the area of technology:

> Given a set of technological utilities and their weights, we may speak of an unambiguous sense of progress in the development of farm tractors, locomotives, semiconductors, computers, etc. However, when two groups of people disagree on these utilities (e.g., on the weight given to sideeffects that are harmful to the natural and social environment), their evaluations become "incommensurable." Thus the conflict between "alternative technologies" can be reduced to the existence of rival frameworks or "paradigms" in the Kuhnian sense (p. 261).

Niiniluoto's point of view, in these texts, seems like a mixture of the two views that I have named instrumental and praxiological: the units of technological change are the artifacts, but the criterion of progress is their effectiveness, or efficiency, in performing their intended function. But the artifacts may have different functions, and their assessment depends on technological contexts and on the interests of different groups of users. Consequently, we could try to define, at best, a kind of local or contextual measure of progress but no measure of global technological progress.

It is easy to realize that the situation here is in some way similar to but worse than the case of scientific progress. Truthlikeness functions were context-dependent, but they could be defined in an objective and general way. In the case of technological progress, however, subjective value judgments seem to be unavoidable, so that any possible concept of technological progress will be not only local-context-dependent but also limited to subjective interests, and thus forever controversial.

I believe nevertheless that, if the praxiological point of view is consistently assumed, it may be possible to define an objective and general concept of technological progress, similar in nature to the concept of scientific progress that truthlikeness measures allow us to use. For this we will need a more precise notion of a technical system.

3. THE STRUCTURE OF TECHNICAL SYSTEMS

The intuitive idea underlying the notion of a technical system is that an artifact, together with its user and the materials whose transformation is intended, constitute a technical system. For example, a domestic washing machine is an artifact; the dirty clothes, the water, the soap and the electric energy are the inputs that are needed so that the machine operates; but there is also required at least one intentional agent (the user) to switch on the machine, to introduce the clothes and the soap into it, and to select the program to perform. The set—machine + materials + user—is this technical system.

A technical system, $ST = < C, A, O, R >$, is characterized by its components C, the set A of processes and interactions that constitute its structure, the objectives O intended for the system, and the results R that are effectively achieved. Among the components C there must be a subset of intentional agents (the users or operators of the system), that conceive of the set O of objectives and perform the subset of actions needed for the control and management of the system.

Each technical system is an individual specific entity. But a lot of equivalence relations among the objectives, components, structures, and results of technical systems can be defined. Any class of equivalent technical systems defines a technique in an extensional way: for example, the set of all the technical systems able to wash five kilos of dirty clothes using an electrical motor, a programmer, hot water and detergent would constitute the extension of the concept of a "domestic automatic washing technology."

The distinction between objectives and results of a technique is essential. We can define the objectives as the set of states of things that the operation of the system is intended to produce, and the results as the set of states of things that the operation of the system actually produces. For any technical system it is assumed that both sets can be defined and eventually measured in an objective and independent way. This means that their description does not depend on any subjective appraisal of their interest or importance for the user. In practice it is possible that different users give different importance to each one of the objectives and results of a technical system. For example it can be very important for one user that the washing machine use little water and little electrical energy, while for another user the most important thing will be that the clothes become thoroughly white, the quantity of water and soap needed remaining as secondary goals. But in any case both users can agree on the objective description (not the appraisal) of goals and results.

The fitness of goals and results of a system has to do with the two basic notions that we use to appraise technological progress: the notion of effectiveness or efficacy and the notion of efficiency.

4. EFFECTIVENESS AND EFFICIENCY

In spite of the importance that effectiveness and efficiency have for technology, it is not usual to find philosophical elucidations of these concepts. Bunge (1989) and Quintanilla (1989, 1996) are exceptions.

The effectiveness or efficacy of a technique can be understood as the degree to which the set O of intended goals is included in the set R of the actually obtained results. The degree of effectiveness can be measured therefore as the ratio of actually obtained to intended objectives, that is to say:

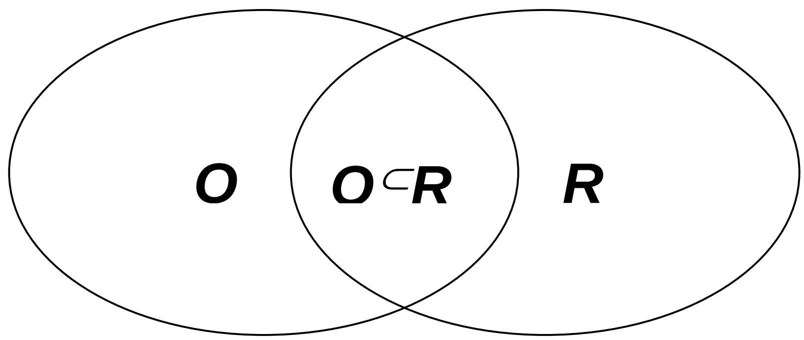
$$F = |O \subset R| / |O|.$$

However, an action can be extremely effective, but not very efficient. Usually efficiency is understood either in thermodynamic or in economic terms. The thermodynamic efficiency of an engine is defined as a ratio of the energy converted into useful work relative to the total amount of energy consumed. This concept of efficiency can not be directly generalized for any technical system, because—as Skolimowski and Niiniluoto note—the efficiency of a system is not always measured in terms of energy transformations.

The notion of economic efficiency seems to solve this problem. Indeed the economic efficiency of an action can be calculated as the ratio of the value of the results produced to the cost of the action carried out to produce them. The problem in this case is that, calculated this way, the efficiency of a technical system will depend on an economic value (for example, the market price of the production factors and of the produced goods) depending not on technology but on subjective appraisals or external conditions of a social or economic nature.

To solve these problems, we (Quintanilla, 1989) proposed the following concept of technical efficiency:

$$E = |O \subset R| / |O \cap R|.$$



Effectiveness

$$F = \frac{|O \subset R|}{|O|}$$

Efficiency

$$E = \frac{|O \subset R|}{|O \cap R|}$$

In this equation, a maximum effectiveness may be consistent with a low degree of efficiency. (Recall the expression “killing flies with sledgehammers." Other meaningful examples might be combating plagues with DDT, winning wars with atomic bombs, or maybe producing electric energy with nuclear power stations.) As a rule, the efficiency of a system will increase as its effectiveness does, but it will also increase if there is stricter agreement between its results and its intended objectives, and if superfluous or unwanted results decrease.

The main advantages of this definition are the following:

1. It can be applied to any type of objects and results of an action or system.

2. It allows us to compute the efficiency value of an action or a system, independent of values (economic, social, moral, etc.) assigned to its objectives or results.

3. It is possible to calculate the efficiency of actions or systems that are not thoroughly effective.

4. For a thoroughly effective system, if the cost of the actions is included in the value of unwanted results (*R* - *O*), the value of economic efficiency may be derived from that of technical efficiency.

5. For a thoroughly effective system, whose objectives and results are characterized only in terms of energy consumption and use, technical efficiency is equivalent to thermodynamic efficiency.

5. TWO DIMENSIONS OF TECHNOLOGICAL PROGRESS

In philosophy of technology, the concept of efficiency plays a role similar to that which the concept of truth plays in philosophy of science. We judge scientific theories by their truth value, and technological systems by their efficiency. In a given technological context, an increase in the efficiency of a technical system can easily be interpreted as an increase in the human capacity to ensure that the reality to which the system is applied behaves in agreement with human goals. Therefore a measure of the efficiency of technical systems could be interpreted as an objective, value free (although local-context-dependent) measure.

However, the interpretation of technical progress as an increase of human capacity to ensure that reality behaves in agreement with our desires—as is presented, for example, by Ortega y Gasset (1939) in his *Meditación de la técnica*—seems to go beyond the simple truth that, in any technological environment, it is always possible to obtain better and better results. In fact technical progress is related not only with the efficiency but also with the enlargement of technical systems.

There is here a parallelism with the notion of scientific progress as explained through the concept of verisimilitude: it means not only an increase of the truth value of our knowledge, but also of its information content, richness, and depth. Something similar happens with the notion of technological progress: it implies not only an increase in the efficiency of technical systems but also a continuous amplification of their extension. This second dimension of technological change is quite well represented by the notion of radical innovation.

In technical literature an innovation is the result of transforming a technical invention into a good with economic value. Two kinds of innovations are usually distinguished, according to their importance: incremental and radical. Another common distinction is that between product and process innovations (changes in the form of producing something and changes in the nature of the thing produced). The most radical innovations are usually product innovations. If they are successful, they give the most competitive advantage to the industrial firms that introduce them. They consist in creating a new type of technical product, which implies that they extend the sphere of technical intervention to a new part of reality.

I believe, then, that we should conceive technological development as a process that has a double dimension: efficiency and innovation. A normative theory of technological progress (something like a methodology for technological development) should include two principles: the principle of efficiency and the innovation principle. The principle of efficiency recommends getting progressively more efficient technical systems. The innovation principle recommends enlarging the realm of technical systems to cover ever more kinds and parts of reality.

There are in principle several possible ways to measure technological progress. We have already seen how an objective measure of technical efficiency can be built. The degree of innovation could also be measured as a distance between given states of things and intended states of things sought as a result of the application of the new technical system. Finally, here as in the case of truthlikeness, a measure of technological progress can be devised that combines both dimensions.

With all these elements,what we will call the kernel of a standard theory of technological progress could be defined. Its main theses would be the following:

1. The objective of a technology is to increase the human power to control and to create a reality.

2. Technological development is characterized by a double dimension: innovation and efficiency.

3. To characterize technical progress as an increase of human power over reality, a good strategy would consist in defining some function of technological progress that combines innovation and efficiency.

6. TECHNOLOGICAL AND MORAL PROGRESS

Contrary to the theory of scientific progress, the theory of technological progress can not avoid value questions—moral, economic, social, etc. The reason is very clear. On one hand, the selection of the objectives of a technical system is an essential component of its definition. On the other hand, the practical consequences of opting for some or other objectives will not only affect the innovation level and technical efficiency that we can reach, but the material conditions of human life a well.

In fact, this is one of the most radical differences between science and technology: science itself does not create moral problems, because it does not directly affect the life of people; but technology does. This is so because, as Vega (1997) points out, science consists in epistemic actions that do not alter the real world, while technology involves actions that do.

Now, in connection with the moral dimensions of technological development, there are two types of questions: questions relative to the influence of moral values on technological development; and questions relative to the influence of technological values on moral development.

Questions of the first type—for example, moral limits on the development of certain biological technologies—are generally most popular. However, questions of the second type are conceptually much more interesting and problematic. The increase of technological possibilities sometimes brings not only radical changes in the design of moral codes and criteria of evaluation, but also in such other value systems as the economy, art, and religion. The theory of technological progress should not be interpreted as a theory of moral progress, but if we advance in the understanding of technological progess, we will also understand the moral problems of technology better.

REFERENCES

Bunge, M. 1977. *Treatise on Basic Philosophy*, vol. 3: *The Furniture of the World*. Dordrecht: Reidel.

_______. 1989. *Treatise on Basic Philosophy*, vol. 8. Dordrecht: Reidel.

Niiniluoto, I. 1984. *Is science progressive?* Dordrecht: Reidel.

Ortega y Gasset, J. 1939. *Meditación de la Técnica*. Madrid: Revista de Occidente.

Popper, K. 1963. *Conjectures and Refutations*. New York: Basic Books.

Quintanilla, M. 1982. "La verosimilitud de las teorías." *Actas del Primer Congreso de Teoría y Metodología de las Ciencias*. Ovideo: Ediciones Pentalfa.

_______. 1989. *Tecnología: Un enfoque filosófico*. Madrid:FUNDESCO.

_______. 1996. "The Incompleteness of Technics." In G. Munévar, ed., *Spanish Studies in the Philosophy of Science*. Dordrecht: Kluwer. Pp. 89-102.

Skolimowski, H. 1966. "The Structure of Thinking in Technology." *Technology and Culture*, 7:371-383.

Vega, J. 1977. "¿Por qué es necesario distinguir entre ciencia y técnica?'" Philosophy Department, University of Salamanca.

Zamora, J. 1996. *Mentiras a Medias*. Madrid: Publicaciones de la Universidad Autónoma de Madrid.