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You make experiments and I make theories.

Do you know the difference?

A theory is something nobody believes except the person who made it, while an experiment is something everybody believes except the person who made it.

Albert Einstein

## 0. Introduction

One of the important goals of scientific and technological research is the construction of theories. A theory is a system  $\underline{T} = \langle \underline{P}, \underline{Q}, \underline{R}, \vdash \rangle$ , where  $\underline{P}$  is a set of theorems,  $\underline{Q}$  the set of all predicates occurring in  $\underline{P}$ ,  $\underline{R}$  the set of referents of the predicates in  $\underline{Q}$ , and ' $\vdash$ ' the relation of logical consequence (or entailment). A theory then is a hypothetico-deductive system composed of infinitely many propositions generated by the use of logic from a finite set of hypotheses or axioms. A theory is formal if all the referents of the members of the set  $\underline{Q}$  are conceptual and factual if some of them are concrete, namely material or real.

Scientific and technological theories form part of the system of factual knowledge, which is composed of ordinary knowledge, arts, crafts, factual science, and technology (1).

It is worth mentioning that the formal/factual distinction leads to two different notions of truth: formal truth and factual truth or as Leibniz put it truth of reason and truth of facts. Henceforth we need a coherence theory to elucidate the notion of formal truth, and a correspondence theory (adequatio ad rem) to explicate that of factual truth.

Looking at Einstein's quotation (Woolf 1980, p. 57), in our approach to scientific and technological theories we submit that no reasoning can replace experiment, no experiment can replace reasoning: every experiment is designed and interpreted rationally. Reasoning and experiment are mutually complementary. Whereas according to the positivist view (i) theories are confirmed by their true

observational consequences, and (ii) theories are true if all their observational consequences are true, we claim that no theory by itself has observational consequences. We must adjoin observational data, and even specific theories most of the time. Furthermore, the "observational consequences" after this operation lead not to totally true statements but to partially true ones (Tobar-Arbulu 1983). Despite some new empiricists (Popper 1974, p. 971; van Fraassen 1980), experimental data do not have the last word.

#### 1. Formal truth. Factual (partial) truth

In factual sciences and technology we need classical logic (propositional calculus with identity) to save consistency, not to guarantee truth. This classical predicate calculus joined to set theory will allow us to work in mathematics, which in turn is the basis or better the tool used in science and technology.

In mathematics we use the notion of formal truth with values 0 (total falsity) and 1 (total truth). In factual science and technology we need, however, another notion of truth, i. e., the notion of partial (factual) truth for our task -as scientists or technologists- is the construction of theories that are true or approximately true most of the time.

While the notion of formal truth is common to all sciences and technologies because of their use of traditional mathematics and consistent reasoning, so is the notion of partial truth but with a difference. While scientists seek deep theories in all cognitive problems concerning the real world, technologists are concerned, mainly, with problems of design and operation where usually no deep knowledge is required. Technology aims at the design of producing more and more artifacts with increasing diversified features in a more and more efficient way (Tobar-Arbulu 1984a, Ch. 3). Thus, while the kernel of technology lies in increasing effectiveness in the design of objects of any kind, the kernel of science lies in building theories of increasing depth in order to understand the world. In a nutshell, science aims at enlarging our knowledge by developing better and deeper theories; technology aims at creating new artifacts of increasing effectiveness. Thus, the aims and means of each are different (2).

It has been said that both in science and in technology we use the coherence theory of formal truth, and the correspondence theory of (partial) factual truth.

While in science we investigate reality, in technology we create a reality according to our designs and plans, which is the technological reality or man-made reality. This fact has important consequences for the notion of truth. The partial (factual) notion of truth in science means a correspondence between a given reality outside us and its description. In technology, on the other hand, we have the knowledge of scientific laws that yield among things and concrete or material systems -physical, chemical, biological, or social- and by their use we develop designs or plans to create a new "reality", the things that are created and produced according to our designs. So, reality for technologists is the total sum of resources (natural and human), artifacts (inanimate or alive), and waste products. In technology we presuppose the same notion of (partial) factual truth as in science (as far as technology is based on scientific knowledge (Tobar-Arbulu 1984b)) but we add the notion of efficiency and usefulness, as well as the notion of possibility.

The notion of possibility, and impossibility, deserves special attention in technology. An object may be logically impossible, that is, contradictory (e. g., a square copula) in which case no amount of technology will enable us to construct it. The object may be physically impossible, that is, one which defies the laws of science (e. g., a spacecraft faster than the speed of light). The object may be technically impossible, that is, one which defies existing technical means. It is this realm of technical possibility that is constantly expanded. "The history of technology is the history of the constant expansion of the scope of the possible and the constant decrease of the realm of the impossible"(Skolimowski 1968, p. 555)(3). So, in technology we extend the sphere of the possible, while in science each new theory attempts to go deeper grasping reality.

One of the characteristics of modern technology is that it attempts to make possible the prototype that has been designed, and tested in the laboratory. The study of feasibility, optimization and design of an artifact leads to a prototype that later on has to be produced taking into account economic, political, and social factors of the production itself (Tobar-Arbulu 1984a, Ch. 3). (This last programming of production, not the production itself, is another task for technologists.) However, there are projects that cannot be put into practice. They are considered as technologically unpracticable, for though they may be scientifically possible technically they have failures for one reason or another. "In the museums of science and technology there are numerous prototypes of

machines and inventions which never left the workshops of their inventors because they were unpracticable" (Skolimowski 1968, p. 557).

So, in technology we validate our theories with efficiency, where the pragmatic aspect is of great importance. Therefore, the critical realism of technology (Tobar-Arbulu 1984a) is tempered and distorted by a strong instrumentalism or pragmatic attitude. This pragmatic attitude is reflected in the way the technologist deals with the notion of truth: Although in practice she adopts the correspondence notion of truth as adequacy of the intellect to the thing, she will care for true data, hypotheses, and theories only as long as they are conducive to the desired goals.

Technological programs, on the other hand, are programs for action and therefore praxiological programs. Praxiology, or action theory, is concerned with studying human action in general. Technopraxiology would be the study of human action guided by technology, granted that technology is a field of knowledge.

## 2. Scientific truth

We characterize factual science as a field of knowledge (2). We disregard the consensus view (according to which science is characterized by a certain lack of controversy, aiming at attaining consensus), the empirical view (that holds that science only involves empirical data and inductive generalizations from them), the success view (as in James (1907) for whom the main feature of science is success), the formalist view (that defines a body of knowledge as scientific if it has been thoroughly mathematized), the refutationist view (mainly due to Popper, which maintains that the mark of science is refutability or falsifiability), the methodist view (that holds that the sole requisite for science is the adoption of the scientific method). (Note that the pragmatist view, or success view fails to distinguish science from technology.)

Our approach to science as a field of knowledge includes a general world view (ontology, epistemology, and ethics), some body of background knowledge, a domain, a problematics, a set of aims, and a methodics (2).

Let us have a look at two different approaches in the literature so that our own conception of scientific truth can be elucidated and clarified: one against realism (van Fraassen's), another supporting it (Einstein's).

## 2.1. Constructive empiricism

Van Fraasen (1980) agrees with Carnap (1959) that the primary philosophical tools are formal, logical, or mathematical methods. According to him, we should expand our formal tools with the resources of semantics and pragmatics (4). For him, modern mathematical physics is best seen as an instrument for describing the observable part of the world, although it is certainly not reducible to a description of the mere observable. This neo-empiricist approach is opposed to scientific realism (5). For van Fraasen, a physical theory is a class of models, and it is empirically adequate if what it says about the observable of its world picture is true: "...the theory is empirically adequate if it has some model such that all appearances are isomorphic to empirical substructures of the model" (van Fraasen 1980, p. 64). What he calls 'constructive empiricism' is the belief in the empirical adequacy of the theory, though, to be sure, the "observable" is "theory-laden" (van Fraasen 1980, pp. 56-59, 80-83, 152). So van Fraasen does not take sides about the unobservable part of the world described by the theory. He correctly criticizes the trend of scientific realists that maintains in turn (i) correctly that a physical theory is a hypothetico-deductive system in the logical sense, and (ii) incorrectly that a theory is said to be empirically adequate if its logical consequences within the set of observation sentences are true (6). However, we don't agree with him because for van Fraasen (1981, p. 674) the central aim of science is not the search for truth but "empirical adequacy": "...the central aim of science is to provide us with empirically adequate theories. This certainly implies truth for part of the theory: what it says solely about what is observable must be true".

Against this new fashion of empiricism -and against Popper's own empiricism (7)- we say that in order to qualify as scientific a statement, or a set of statements (in particular a theory), it should be conceptually testable, i. e., it should be possible to check it against other items of formal or factual science. Conceptual testability is only a necessary condition. In fact, some further conditions must be added: a hypothesis should be empirically confirmable, in however an indirect manner; a specific theory should have components which are both empirically confirmable and refutable when enriched with empirical data; a generic theory should be susceptible of becoming a specific scientific theory upon the adjunction of subsidiary assumptions and empirical data constituting a model object.

Against the widespread belief that every theory faces its empirical jury, we submit that (i) in order to describe specific observable facts, a theory must be adjoined some information, a definite model, and a bunch of hypotheses linking unobservables to observables (a fact that distinguishes our approach from van Fraassen's), and (ii) the empirical jury is itself backed up by a body of theory, a further model (of empirical set-up), and some bridge hypotheses (8).

As consequence, there can hardly be any conclusive evidence for or against a scientific theory. While agreement between theory and experience confirms the former, it does not point with certainty to the truth of the theory: it may indicate that both theory and data are sloppy. And disagreement between theory and experience cannot always be interpreted as a clear refutation of the former either.

Constructive empiricism (van Fraassen) and refutationist empiricism (Popper) are both inadequate. We submit that some of our theories have at least a grain of truth, hence the need of a theory of partial (factual) truth.

## 2.2. Einstein's "Epistemological Credo"

Perhaps the most concise formulation of Einstein's model for constructing a theory can be found in a letter to Solovine in 1952 (9). It reads as follows:

"I see the matter schematically like this:

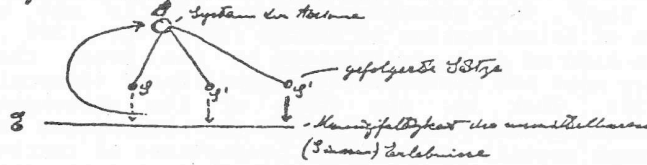
(1) The E (direct experiences) are given to us (which refers to the horizontal line at the bottom of Figure 1 and can be better read as "totality of empirical facts" (Einstein 1981a, p. 264)).

(2) A are the axioms, from which we draw consequences. Psychologically the A rest on the E. But there exist no logical path leading from E to A, only intuitive (psychological) connection, which is always merely 'until further motive' (i. e., the axioms have to be postulated).

(3) From the A are deduced by a logical path, particular assertions S that claim to be exact (theory as hypothetico-deductive system: if A, then S should follow).

(4) The S are brought into relation (are referred or related) with E (testing experience)".

Mit der Erkenntnis - Theoretischen Sätze haben Sie nicht geistliche  
 nichtbestanden; unbeständiger habe ich nicht alle  
 angedeutet. Ich sehe die Sätze schematisch so



(1) Die <sup>(Sinn-) Erlebnisse</sup> ~~Erlebnisse~~ sind nicht gegeben.

- A: System of Axioms
- E: Resultant propositions
- E: Variety of immediate sense-experience

Fig. 1. (From P. A. French 1979, p. 270)

Einstein adds (in P. A. French 1979, p. 272) the following: "This procedure belongs also to the extra-logical (intuitive) sphere, because the connection(s) between the concepts appearing in S and the immediate experiences E are not of logical nature. But this relationship between the S and the E is (pragmatically) much less uncertain than the relation of the A to the E".

Elsewhere Einstein (1981b, pp. 18-19) wrote: "If an experiment agrees with a theory it means for the latter "Maybe", and if it does not agree it means "No".

So far Einstein. He knew pretty well that there is no such a thing as final verification or confirmation by experiment or observation. In fact, when Einstein threw down the gauntlet to the experimentalists asking whether or not light was bent by gravity as it passed near the sun, he was far away from sense-experience, even from astronomic experiments. He was in possession of a theory. As Clark (1972, p. 222) asserts: "Only Einstein the philosopher could have convinced Einstein the scientist that if the evidence did not agree with the theory, the evidence must be faulty". (Actually the new event predicted by Einstein was confirmed later on by English astronomers in 1919.)

How can then we understand the relation between the S and the E?

How are the S related to the E?

Einstein (1949, p. 201) refers to "external validation" as "concerned with the validation of the theoretical foundation by means of the material experience lying at hand". This assertion, in our view, is not a principle of falsification as Holton (1979, p. 122) thinks, but a kind of weak verification in the sense that "the theory must not contradict empirical fact" (Einstein 1949, p. 20). That is, the value of the statement which expresses S when testing with the techniques at hand -through specific theories or assumptions of testing- will be between 0 (total falsity) and 1 (total truth). That means that our statements, either at the S level following Einstein or at another level after having being translated into new statement T -through specific theories of measurement and data- will be partially true.

For Einstein (1981a, p. 264) it was clear that "the two inseparable components of our knowledge (are) the empirical and the rational". Moreover, he opposed naive realism (10). For us, the confrontation of theory with experience is never vis-à-vis, nor as Carnap thought, namely that an isolated hypothesis is directly confronted with pure empirical evidence. Neither as the neo-empiricists claim. For theories often refer not to observed objects (as van Fraassen thinks) but to idealized ones (i. e., quanta, quarks) whose existence we assume to be real. Hence, they cannot be tested directly. Different subsidiary assumptions are necessary to obtain new forms of theories that are closer to experience. Only in this way may the the theories be tested. However, this is not enough. Experimental data are usually unfit for confrontation. They must be translated into the language of the tested theory; here, again, and when treating with social systems (including societies) and their planning. If we submit that technological theories are scientific theories of action, namely applications of theories and methods of science to practical action where the rules of pre-scientific crafts have been replaced by scientific laws which explain or account for their effectiveness, then technological theories are the foundation of a system of rules prescribing the course of optimal action. In this context we can say that technology is both 'technical science' -in as much as it is the application of scientific theories and the scientific method most of the time- and 'action or technical praxis'. So we have, in general, two kinds of technological theories: substantive technological theories, which are applications of pre-existing scientific theories, and operative technological theories which employ the scientific method and are theories of action. So operations research, systems engineering, and systems analysis, all of which



provide grounded rules for rational actions (11) are not limited to what "may or does, did or will happen" but also include "what ought to be done" (12) to manipulate the environment to obtain a predetermined end. (So, in the technological field, the philosophy of action or technopraxiology -the study of technology-guided actions- is linked to axiology or value theory, and in particular to technoaxiology -the study of the valuations performed by technologists in their activities.)

The use of scientific theories for practical purposes involves the way the theories must be prepared or worked out in order to be applied to the deliberate production or prevention of some practical outcomes. This problem is related to, but different from, the problem of the preparation of a theory for its empirical test: as in the case of practical applications we need subsidiary assumptions and even auxiliary theories, but here we look for maximum efficiency rather than maximum truth. This will influence the actual choice of the theory: for practical purposes, one may prefer the theory that is easier to handle, or one involving the lowest cost, or one that optimizes constraints in a very different way from the search of truth in scientific theories. (See Dixon 1966 and Wilde 1978 for some different optimizations within some constraints. The pragmatic attitude of modern technologists, once without the pragmatist prejudice against the theory itself, enables us to understand better the interactions between theorizing and doing.)

### 3. Technopraxiology as rational action

The study of rational actions belongs to some disciplines, namely human engineering, operations research, management science, military strategy, game theory, and decision theory among others. Technopraxiology can be considered as the philosophical study of human action guided by technology. While the problem of planning action, e. g. the specific problem of building a city, is a task for technological experts (city planners, architects, civil engineers, geologists, geographers, sociologists, public health experts) technopraxiology is a question of approaching philosophically the study of technological projects as well as their implementation.

Artifacts can obey natural laws, though they themselves are not natural (Tobar-Arbulu 1985), or social ones in the case of social artifacts (from schools to societies). Artificial social systems obey some laws -in fact, the task of social technologists is to apply the knowledge of social sciences to achieve some goal or

other- and follow certain social trends. Since technological research is the pursuit of effectiveness in practical purposes, the development of efficient technologies depends upon the development of deeper scientific theories. The better we know (physical, chemical, biological, and social) laws the more reliable, controllable, and efficient artifacts we can build (13).

Since technology is action-oriented knowledge, its rules, unlike the laws of nature, can be obeyed or broken. Therefore, the side-effects of applying technological knowledge can be avoided either by not applying this specific knowledge or by studying the problem through science (hence deeper and better knowledge) in order to get rid of prejudicial side-effects. The first solution can lead to the stagnation of our knowledge and the worsening of the initial problem if the problem we have to face is not faced. The second one leads us to the need of more science (therefore more basic research in the R&D budgets) not only because of the sake of knowing but also because of the magnitude of the problems that beset present-day society (Tobar-Arbulu 1984c).

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#### NOTES

(1) The following types of knowledge can be distinguished by looking at their referents:

<u>Type</u>	<u>Referent(s)</u>	<u>Field(s)</u>
Formal	Constructs	Logic, Mathematics.
Factual	Things, Facts	Ordinary knowledge, Arts, Crafts, Factual Science, Technology.

Empirical	Experience	Ordinary Knowledge, Arts, Crafts.
Moral	Right Conduct	Ethics, Sociology, Art.
Epistemological	Knowledge	Epistemology.

(2) If we stipulate (Tobar-Arbulu 1984a,b) that a field of knowledge can be represented as an eleven-tuple  $E = \langle C, S, D, G, F, B, P, K, V, A, M \rangle$ , then we list the main differences, and similarities, between science and technology as follows:

<u>Component</u>	<u>Science</u>	<u>Technology</u>
C, Community	Research community.	Technological community.
S, Society	Any modern society.	Any modern society.
D, Domain	The entire world.	The manipulable world.
G, General outlook	Naturalistic ontology, realistic epistemology, ethics of free search for truth.	Naturalistic ontology, opportunistic epistemo- logy, utilitarian ethics.
F, Formal back- ground	Logic and Mathematics.	Logic and Mathematics
B, Specific back- ground	As needed.	As needed.
P, Problematics	All cognitive problems concerning the world.	Problems of design and operation.
F, Fund of know- ledge	Growing body of test- factual knowledge, in particular laws.	Growing body of practi- cal knowledge.
V, Value system	Exactness, logical con- sistency, maximal truth, testability.	Exactness, logical con- sistency, truth, test- ability, reliability, practical applicability, efficiency.
A, Aims	Understanding and pre- dicting with the help of laws.	Control.
M, Methodics	Scientific method and scrutable techniques.	Scientific method and scrutable techniques.

(3) Skolimowski (1968, p. 556) remarks that "we shall never know whether we design something that is impossible for all possible technological worlds, or simply something that is not possible in our technological world... Thus in technology we never invalidate our projects with finality; they are demonstrated to be impossible only tentatively for the time being".

(4) As Friedman (1982, p. 282) points out: "The problem is not that positivistic methods are limited and inadequate; it is that explanation, confirmation, etc. are not formal notions. More generally when the syntax of language is an appropriate subject for purely formal study... the semantics and pragmatics of language are not."

(5) For us scientific realism is a family of epistemologies which assume that (i) the world exists independently of the knowing subject, (ii) the task of science is to produce maximally true conceptual models of reality (Tobar-Arbulu 1984a).

(6) As one example of this incorrect view: "A realist (with respect to a given theory of discourse) holds that (1) sentences of that theory are true or false; and (2) that what makes them true or false is something external... that is to say, it is not (in general) our sense data" (Putnam 1975, p. 60 f.).

(7) Popper (1974, p. 971): "I was, and still am, an empiricist of sorts, though certainly not a naive empiricist who believes that 'all knowledge stems from our perceptions or sense data'. My empiricism consisted in the view that, though all experience was theory-impregnated, it was experience which in the end could decide the fate of a theory, by knocking it out; and also in the view that only such theories which in principle were capable of being thus refuted merited to be counted among the theories of 'empirical science'."

(8) As Stein (1964, p. 16) asserts, "there is no experiment without theory". Therefore, in measurement one needs "to identify these elements and to study the laws that govern their behavior and interaction" (Stein 1964, p. 7); and one will need criteria that would guide one in the collection of facts and data (Stein 1964, p. 13), as well as an analysis of the types of tests (Stein 1964, Section 2-2.0) and the checking of the different kinds of errors (Stein 1964, Section 2-4.3). Churchman (1961, p. 770) will speak about the need of a "theory of theory testing"; and Ackoff (1962, p. 205 f.) lists the following possible sources of error in measurement: error due to the observer, to the instrument used, to the environment, and to the thing observed.

(9) See the English translation in P. A. French (1979).

(10) In "Remarks on Bertrand Russell's Theory of Knowledge", Einstein (1981a, p. 30) wrote against "the plebeian illusion of naive realism, according to which things 'are' as they are perceived by us through our senses".

(11) The relation between well grounded rules and corresponding laws is as follows: Consider an elementary rule schema of the form "To attain G use M", or G per M for short, where G is a goal and M a means. We stipulate that this is well grounded if, and only if, there is a law according to which M brings about G. In other words, the rule is well confirmed only in the case there is a reasonable well-confirmed theory containing a statement of the form "If M then G", where 'M' and 'G' are interpreted, in the theory, as properties, states, or events. Technological rules lead to technological forecasting, which, in turn, differs from scientific prediction. The scientist attempts to model concrete (real) things in terms of

properties, trying to conceptualize such properties and their constant relation, i. e., the laws of physical objects. We distinguish laws from law-statements, that is, we distinguish concrete (physical, chemical, biological, social) properties from their mathematical representation. The propositions that represent the laws of concrete or material things or systems are called law-statements (i. e., the principle of conservation of energy). On the other hand, law-statements determine only possible values of magnitudes. The actual values depend on the actual circumstances and they must be found by measurement. Technological theories, from a practical point of view, are richer than scientific theories because they do not explain what has happened or may happen, but they give power to bring about what we want to happen or prevent from happening what we do not want to happen.

(12) According to Simon (1969, p. 5), "the engineer is concerned with how things ought to be".

(13) Pattern must be hypothesized -when we look for some constancy, trend or law- or imposed -when we enforce a rule for action. Trends are stable while they last, but they can stop or reverse. (Think of the trend of the increasing lethality of weapons and the nuclear arms race.) Law-statements or nomological statements can be translated into nomopractical statements for technological purposes. They are usually called rules. Unlike law-statements, rules do not describe, explain or forecast: they prescribe.

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#### RESUMEN

En este trabajo se reflexiona sobre el concepto de verdad en el marco de la filosofía de la tecnología y se contraponen las posiciones de tendencias empiristas recientes -especialmente la formulada por van Fraassen- al realismo epistemológico -cuyo modelo lo proporciona Einstein- como formas alternativas de desigual valor.

La noción de verdad adecuada a la tecnología y su filosofía es la de verdad parcial o factual. Aunque la tecnología adopta la noción de verdad como correspondencia del discurso científico con la realidad, lo hace en la medida en que los datos, hipótesis y teorías verdaderos conduzcan a los objetivos deseados. Ello se debe a que la eficacia es el criterio de la validez tecnológica de una teoría, que se añade a los criterios propiamente científicos.

Las teorías tecnológicas son teorías científicas de la acción, es decir, aplicaciones de las teorías y los métodos de la ciencia a la acción práctica con el fin de obtener, según reglas precisas, resultados óptimos. Esta finalidad práctica hace que la preparación de estas teorías, en orden a su aplicación, sea diferente del modo en que se prepara una teoría científica para su contrastación empírica -la última atiende a la verdad máxima; la primera a la eficacia máxima.

La tecnopraxiología es el estudio filosófico de la acción humana guiada por la tecnología y, como tal, está ligada a la axiología o teoría de los valores, porque las especialidades tecnológicas que suministran reglas para la acción no se limitan a lo que ocurre u ocurrió, puede o habrá de ocurrir, sino que tratan de lo que debe hacerse para manipular el ambiente en vista de un objetivo previamente establecido.