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CHARACTERISTICS AND THEORY OF KNOWLEDGE

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ABSTRACT

In the course of history the research about the nature of human knowledge, its characteristics and limitations has produced a huge amount of theories and philosophical systems. General topics such as the reality of the objects of knowledge, the relation between the objects of knowledge and their models, the possibility of a definitive foundation for knowledge have been differently interpreted by different philosophers and scientists, and they are schematically reviewed here.

KNOWLEDGE LISTING

1. THE PROBLEM OF KNOWLEDGE

Human beings know but do not definitely know what knowledge is: traditions, prejudices, expectations, and projections are more or less always part of knowledge and make it a combination of objectivity and subjectivity. Rationality allows some critical control on knowledge, but rational is the recognition of the limitations to which human knowledge is subject.

The interest in theorizing about knowledge arises from the observation that different persons have different beliefs, and ultimately that beliefs and facts are distinct: «theory of knowledge is a product of doubt», as Bertrand Russell wrote. In the history of both western and eastern culture such a doubt has stimulated an impressive amount of research, ideas, and philosophical systems, and nevertheless very different positions have been maintained and still remain on the nature of knowledge and its object (it is reasonable to hypothesize that, more than from the plethora of such positions, the complexity of the topic derives from its inherent reflexivity, due to the fact that the object of the analysis coincides with the tool by means of which the analysis is performed: to know knowledge only knowledge can be employed). A basic dichotomy can be identified, whose elements play the role of competing attractors for an ideal continuum of positions: *objectivism* assumes that a world external to the subject exists independently of him and has predefined properties, existing as such before they are acquired by the perceptive-cognitive system of the subject, whose aim is to reconstruct them; on the other hand, *solipsism* asserts that the cognitive system of the subject projects his own world out of him, and the reality of such a world is just an image of the laws internal to the system.

The position currently supported by the majority of scientists and engineers can be plausibly characterized as a kind of "pragmatic realism", close to but not coincident with objectivism, according to which the conjoint efforts of science and technology are aimed at reaching, and actually guarantee, better and better, i.e., more and more objective, knowledge of the world whose properties are therefore progressively discovered.

Measurement plays a crucial role in supporting this realism.

2. THE STATUS OF REALISM

In acquiring and processing information from the world human beings constantly *produce models* (and sometimes theories: we will not emphasize here the distinction between models and theories, grounded on formal logic) of the world they observe, thus generating knowledge on it.

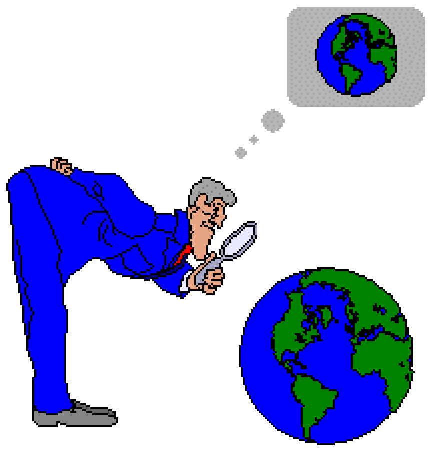

Figure 1 – Human beings produce modes of the world they observe

Such knowledge results from the relations among the three interacting entities, the subject, the world, and the model, so that the relation between the world and its models is not direct, but always mediated by the subject who produced the models themselves.

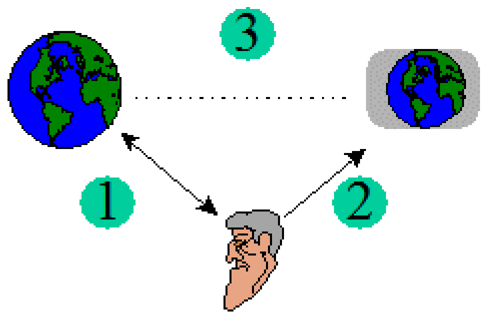

Figure 2 – The relations among subjects, world, and models

Whenever it remains individual, knowledge is just tacit and usually implicit and as such it reduces to personal experience that can be communicated only by person-to-person means, as imitation.

Critical is therefore the *objectivity*, i.e., the independence from the subject, of the relation between the world and its models. Realism assumes two operative reasons for justifying the possibility of some objective knowledge:

- *intersubjectivity*: were knowledge only subjective, mutual understanding would be an exception more than a rule;

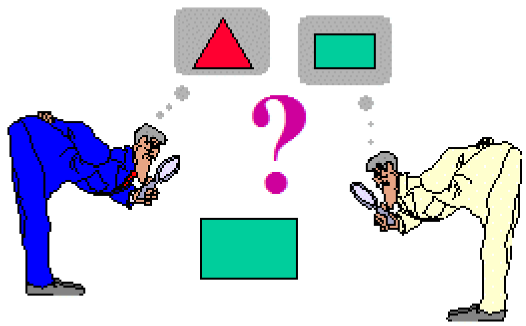

Figure 3 – A justification for realism: mutual understanding

- *pragmatics*: were knowledge only subjective, our ability to effectively operate on the world would be an exception more than a rule.

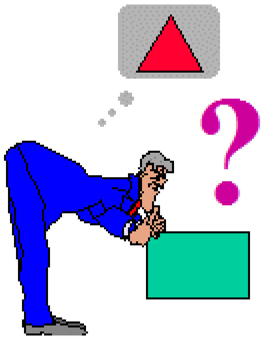

Figure 4 – A justification for realism: effectiveness

Realism can be then interpreted as a weak form of objectivism: world (exists independently of us and both intersubjective and pragmatic experiences lead us to assume that it) cannot be too different from our models of it.

On the other hand, to generate knowledge that can be shared subjective models must be expressed in some socially understandable and usable form, such as statements in a natural language or mathematical laws. This points out a further, basic, issue on knowledge: «how can it be that mathematics, a product of human thought independent of experience, is so admirably adapted to the objects of reality?», in the words of Albert Einstein.

Philosophers and scientists have formulated different opinions at this regard, more or less explicitly in reference to a basic dichotomy: either "scientific laws faithfully describe how the world is" or "scientific laws are just synthetic means to express information about events in an aggregate way". The former position implies a *metaphysical* hypothesis on the nature of the world, classically stated as «numbers are in the world» (Kepler) or by assuming that «the great book of nature» cannot be understood «but by learning its language and knowing the characters in which it is written: it is written in mathematical terms» (Galileo); in contrast, the latter position suggests the *economic* nature of science: since «in Nature the law of refraction does not exist at all, but only different cases of refraction», by means of such a law «we do not have to keep in mind the countless phenomena of refraction in the various compositions of matter and under the various incidence angles, but only the rule that we call “law of refraction”, a much easier thing» (Mach).

Measurement has been often adopted to justify the former position.

3. SEMIOTICS OF KNOWLEDGE

Knowledge can be *about* physical world but it is not *part of* it. Given the realistic assumption of the independence of the physical world from the subject, both subjective and objective knowledge can be interpreted in an evolutionary context as the results of mankind to adapt to his (firstly only physical and then also social) environment. At this regard Karl Popper has suggestively proposed to identify «some stages of the cosmic evolution» as organized in three “worlds”, as follows:

World 1

0. Hydrogen and helium
1. Heavier elements; liquids and crystals
2. Living organisms

World 2

3. Sensitivity (animal conscience)
4. Conscience of self and death

World 3

5. Human language; theories of self and death
6. Products of art, technology, and science

In this framework knowledge (whose object can belong to either Worlds, and finally could even become knowledge itself…) is a rather advanced entity, appearing initially within World 2, in the form of subjective experiences, and then fully evolving in the context of World 3. The transition from World 2 to World 3 corresponds to the social ability to communicate, and therefore to share, experience: that is why the availability of a (textual or non-textual) language is considered the first step within World 3. Furthermore, the usage of a language gives knowledge a syntax and make it a semiotic entity (see also mm_113, mm_135).

Given the complexity of the concept of knowledge and its fuzzy characterization, rather than trying a definition of it we suggest that the (possible) presence and the relative importance of the semiotic components, {syntax}, {semantics}, and {pragmatics}, can be adopted as a criterion to distinguish among the different entities that are commonly deemed to be (related to) knowledge. In particular:

- the exclusive availability of *pragmatic* information ("to know how to do"), such as the competence shown by many craftsmen, appears to be a limited kind of knowledge, if knowledge at all;
- the exclusive availability of *syntactical* information and the ability of purely symbolic (i.e., only syntactical) processing, as performed by most automatic devices, appears to be a limited kind of knowledge, if knowledge at all.

The designation of "knowledge-based" for the systems operating on the basis of an explicit semantics is a further argument to support the hypothesis that meanings are critical for the emergence of "proper" knowledge, and therefore that socially communicable knowledge ("World 3 knowledge") is an entity spanning all the semiotic components.

4. PRAGMATIC CLASSIFICATION OF MODELS

If the pragmatic component is taken into account, different purposes for knowledge can be recognized: models can be adopted for {description}, {explanation}, {prevision}, {prescription}.

It is usual that the first stages of the development of a new field of knowledge are devoted to the production of models aimed at the *description* of the system under analysis. Typical outcomes of this work are the identification of properties relevant to describe the system and their evaluation to classify the system itself into more or less rough categories.

To overcome the conventionality of taxonomies and whenever the available knowledge allows it, some relations among properties are identified, so that each property is embedded in a network of dependencies. In such cases the relational information that is (explicitly or implicitly) conveyed by properties can be referred to in order to obtain an *explanation* of the system state / behavior: the value of the property x_1 is v_1 because x_1 is connected to the properties $x_2,\ldots,x_n$ by the relation R, and the properties $x_2,\ldots,x_n$ have values $v_2,\ldots,v_n$ respectively, and $R(x_1,\ldots,x_n)$.

Sometimes models can be further enhanced to include relations connecting properties with an explicit functional time dependence, $\forall i = 1,\ldots n, x_i = x_i(t)$, for example in the form (known as {*canonic representation*}, or *local state transition* in System Theory):

$$\frac{dx_i(t)}{dt} = f_i(x_1(t),\ldots,x_n(t)) \tag{1}$$

for time-continuous models, and:

$$x_i(t+\Delta t) = x_i(t) + f_i(x_1(t),\ldots,x_n(t))\Delta t \tag{2}$$

for time-discrete models. Models can be then used also for *prevision*, in particular if the integral / time-global versions of the canonic representations is taken into account:

$$x_i(t) = x_i(t_0) + \int_{t_0}^{t} f_i(x_1(\tau),\dots,x_n(\tau))d\tau \qquad (3)$$

$$x_i(t_n) = x_i(t_0) + \sum_{j=0}^{n-1} f_i(x_1(t_j),\dots,x_n(t_j))\Delta t \qquad (4)$$

allowing to compute the system state $< x_1(t),\dots,x_n(t) >$ at a generic (future or past) time t from a reference, initial state $< x_1(t_0),\dots,x_n(t_0) >$ and by means of the state transitions $< f_1,\dots,f_n >$.

Finally, if an external intervention is possible on the system, its spontaneous dynamics can be controlled to let the system evolve toward a required target. In this case, models are then aimed at *prescription*: given a generalized version of the local state transition function including in its domain both the current state and the user input, models specify how to provide such an input, and therefore become decision-making tools.

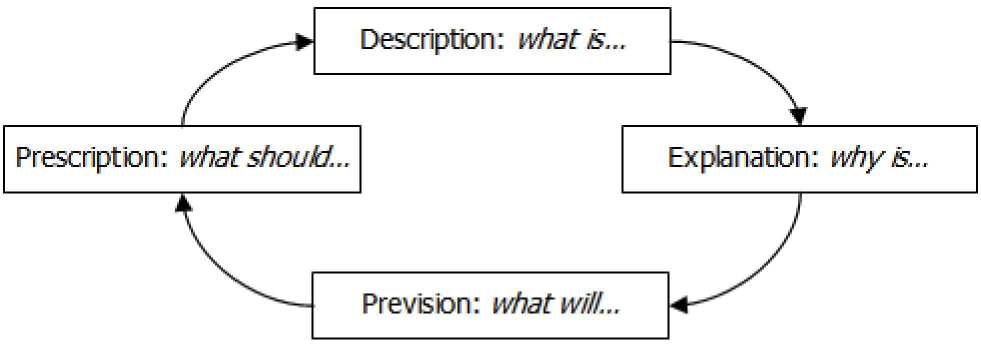

Figure 5 – The knowledge loop among the four kinds of models

According to the traditional paradigm of science and its relations with technology, by repeatedly following this *knowledge loop* the quality of knowledge itself and the effectiveness of system control can be always enhanced.

On the other hand, in many situations prescriptions are required even when predictive, explanatory, and sometimes even socially agreed descriptive models lack (let us quote the crucial examples of medicine and business administration). In these cases experiences and expectations (i.e., World 2 knowledge) still play a critical role.

5. THE EVALUATON OF QUALITY OF KNOWLEDGE

Given the combination of subjectivity and objectivity so usually present in knowledge, it is not amazing that the evaluation of the quality of knowledge represents a basic issue in the process of acquisition of candidate items for their integration in an existing body of knowledge.

The quality of a model can only be evaluated in reference to the goals for which the model itself has been produced: the general criterion for this quality evaluation is therefore the *adequacy to goals*. Truth, traditionally thought of as "correspondence to facts", is regarded as a specific case of adequacy, applicable whenever correspondence to facts is indeed considered an important issue (note how this position radically differs from the pragmatist definition of truth, according to which «a sentence may be taken as a law of behavior in any environment containing certain characteristics; it will be "true" if the behavior leads to results satisfactory to the person concerned, and otherwise it will be "false"» (Russell)).

While adequacy is hardly object of a general treatment, the possibility of evaluating the truth of a model has been widely debated and is surely one of the most critical topics of Philosophy of Science. Following Karl Popper, it can be suggested that the controversy is specifically related to two basic Problems:

1. how to compare (the statements of) competing models?

2. how to evaluate (the truth of) a model?

(see also mm_89, mm_603) in reference to which three standpoints can be identified:

- *{verificationism}*, typical of classical science and brought to its extreme consequences by the Neo-Positivistic school: the Problem 2 admits a solution (and therefore the truth of a model can be determined), from which a solution to the Problem 1 is derived: the reference to truth is the foundation allowing the advancement of science;
- *{falsificationism}*, also called "critical rationalism", as advocated by Popper himself: the Problem 1 admits a solution (in presence of competing models the one is chosen that is not falsified and has the greater empirical content), but a solution to the Problem 2 cannot be derived from it: by means of conjectures and confutations truth is approximated; the preference of a model over a competing one can be rationally motivated, but a model cannot be justified in itself;
- *{epistemic relativism}*, also called "irrationalism", supported by philosophers such as Thomas Kuhn and, in its extreme consequences, Paul Feyerabend: the Problem 2 does not admit a solution («the only principle that does not inhibit progress is: anything goes. For example, we may use hypotheses that contradict well-confirmed theories and/or well-established experimental results. We may advance science by proceeding counter-inductively» (Feyerabend)), and therefore also the Problem 1 cannot be solved: no criterion / method that is absolutely valid holds in scientific research.

6. DATA AND INFERENCE IN KNOWLEDGE

We get an insight into knowledge by considering its operational side of being a *faculty to solve problems*, and in particular to modify the state of systems according to given goals. As human beings we constitutively have the ability to operate state transitions on the systems with which we interact by means of a “World 2 strategy”: we acquire data on the current state through our sensorial apparatus; by means of brain we perform inference on such data, and finally we use the data resulting from this process to drive our motor apparatus whose activity actually carries out the required state transition (this three steps correspond to the tripartite structure of the neural system: *sensorium*, brain, and *motorium*; note that more than 99% of the about 10^{10} neurons of human beings are part of the brain). In many cases this strategy is manifestly both more efficient and more effective than a blind “try-and-error” approach, although far more complex than it.

The same conditions, the availability of data and the ability to deal with them by means of inference, are also characteristic of the “World 3 strategy” to problem solving:

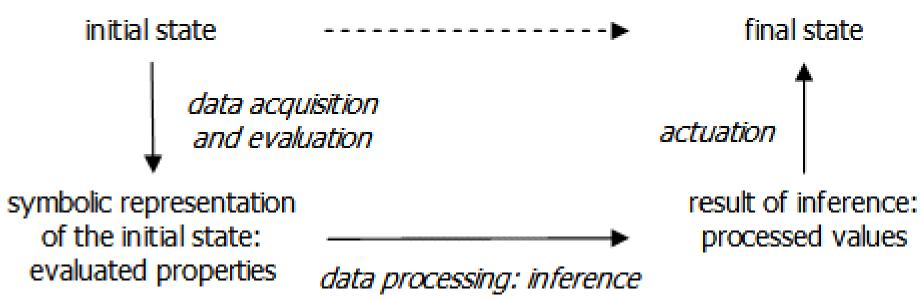

Figure 6 – The “World 3 strategy” to problem solving

This scheme highlight the complementary role of data and inference in knowledge (see also mm_61).

Data, i.e., evaluated properties, are aimed at being *faithful representative* of the observed state, as obtained by either subjective or inter-subjective and objective procedures, and can be expressed by means of either an informal or a formal language. The fundamental operation to empirically get formal data by means of an inter-subjective and objective procedure is measurement: according to the representational point of view to measurement theory (see also mm_59), such a faithfulness is formalized by requiring that the mapping from empirical states to symbols be a homomorphism for the scale type in which states are measured; the existence of monomorphisms for the measurement scale type (i.e., admissible scale transformations) manifests the residual presence of conventionality in the selection of symbols. It is at this regard that one could wonder about *the truth* of symbols and the related sentences.

Inference is an operation aimed at obtaining new data ("conclusions") from the processing of the given inputs ("premises"). To understand the structure of inferential processes the fundamental distinction between *singular* and *universal assertions* (sometimes called *facts* and *laws* respectively) must kept into account. In set-theoretical terms, $a \in P$ (the element a belongs to the set P; the property P holds the element a) is singular, whereas $P \subset Q$ (P is a subset of Q; for all elements x, if the property P holds for x then also the property Q holds for it) is universal (it should be clear therefore that data obtained by means of measurement are singular).

Two kinds of inference are then traditionally considered, that in their simplest forms are as follows:

- from the singular $a \in P$ and the universal $P \subset Q$ by *{deduction}* the singular $a \in Q$ is obtained; deduction is a truth-preserving inference that, strictly speaking, *does not lead to new knowledge*;

- from a collection of singular $a \in P$ and $a \in Q$ by *{induction}* the universal $P \subset Q$ can be obtained; induction is a hypothetical inference that *does not lead to conclusive knowledge*.

The problem of foundation of empirical knowledge is traditionally ascribed to this circularity: deduction leads to true conclusions, but only if the truth of its (both singular and universal) premises can be assumed; induction is the only means to obtain new universal knowledge, but the truth of such a knowledge cannot be definitely assumed.

7. NON-EXACTNESS OF KNOWLEDGE AND MEASUREMENT

We have already noted the relevance of language for World 3 knowledge: truth is a property of sentences (actually: of declarative ones), and «science, though it seeks traits of reality independent of language, can neither get on without language nor aspire to linguistic neutrality. To some degree, nevertheless, the scientist can enhance objectivity and diminish the interference of language, by the very choice of language» (Quine). That is why formalization (i.e., the expression of knowledge in a form such that inferential processes can be entirely performed on the basis of the syntactical component of data) is often regarded as a critical requirement for scientific knowledge. On the other hand, formalized languages can be (and in many cases actually are) far too precise for expressing empirical knowledge: «there are certain human activities which apparently have perfect sharpness. The realm of mathematics and of logic is such a realm, par excellence. Here we have yes-no sharpness. But (...) this yes-no sharpness is found only in the realm of things *we say*, as distinguished from the realm of things *we do*. (…) Nothing that happens in the laboratory corresponds to the statement that a given point is either on a given line or it is not» (Bridgman).

Hence the same empirical knowledge can be expressed in sentences by balancing two basic components: *{certainty}* (a term for some aspects more general than truth) and *{precision}* (see also mm_12) (also called specificity or, at the opposite, vagueness). Therefore «all knowledge is more or less uncertain and more or less vague. These are, in a sense, opposing characters: vague knowledge has more likelihood of truth than precise knowledge, but is less useful. One of the aims of science is to increase precision without diminishing certainty» (Russell).

The fact that the length of the diagonal of a physical 1 m side square *cannot* be $\sqrt{2}$ m is an important consequence of metrological thinking: the information conveyed by real numbers (and the related concepts of continuity / differentiability) is too specific to be applicable, as is, to physical systems. By progressively enhancing the resolution of the measuring systems, and therefore by increasing the specificity of the measurement results, their uncertainty consequently grows, until the object of measurement itself becomes uncertain (in the previous example, at the atomic scale the concept of "physical square" is meaningless), and an "intrinsic uncertainty" (also called "model uncertainty") is reached.

This reflects a basic feature of the relation that by means of knowledge it is established between World 1 (to which the object of knowledge belongs) and World 3 (to which the sentence that expresses knowledge belongs): if symbols are not generally so specific to univocally denote (properties of) things (2+2=4 holds for both apples and aircraft carriers), at the same time things are too complex to be fully described by means of symbols.

8. (NON-)FOUNDATIONS OF KNOWLEDGE

Philosophy of Knowledge (and Philosophy of Science in particular) has always quested for a *foundation* of knowledge, i.e., the elements on which the "building of knowledge" can be firmly erected. In the course of history such a foundation has been found in natural elements (for example Thales of Miletus affirmed that the principle that causes all the things is water, while Heraclitus of Ephesus found it in fire), in physical or conceptual structures (atoms according to Democritus of Abdera, numbers in the conception of Pythagoric school), in metaphysical principles (such as the hypothesis that Nature is simple), in methodological assumptions (in particular the postulation that any empirical knowledge cannot derive but from sense data). The usage of the metaphor of foundations is not conceptually neutral: the architectural image of "foundations" reveals the hypothesis that scientific research can make knowledge incrementally grow from its bases, where measurement has been traditionally recognized as the operation able to produce the objective data playing the role of such bases.

In the last decades this confidence on the progressive development of scientific knowledge has been questioned by concentric objections, all emphasizing that definitive foundations are beyond the reach of the means human beings adopt to know. Complementary to the above mentioned philosophical positions of epistemic relativism (according to which raw sense data do not exist because data are always theory-laden), an important area of scientific research is currently devoted to the systems that exhibit relevant *structural complexity*, a characteristic that makes such systems irreducible to the classical paradigm of reduction to simplicity through the hypotheses of linearity, principle of superposition of effects, …

Knowledge is recognized to be an always evolving process, where «there is never an absolute beginning. We can never get back to the point where we can say, "Here is the very beginning of logical structures."» (Piaget). More than the actual availability of data, knowledge is recognized to be a potentiality (what is "stored" in our brain is how to compute multiplications, not the results of operations such as 1234×5678), information always under reconfiguration.

The role assigned to measurement is paradigmatic of the shift towards what could be called *reticular* (and therefore without foundations) knowledge. Indeed, according to the current standpoints of philosophy of measurement:

- since measurement results depend on standards through a traceability chain, standards themselves could be thought of as "realizations of true values", then playing the role of actual foundations for measurement; on the other hand, standards must be indeed "realized" by primary laboratories, who maintain their quality by means inter-laboratory comparisons: therefore this claimed "path towards foundations" cannot but include a component of conventionality;
- any measurement result depends for its evaluation on the previous measurement of a set of influence quantities, in their turn being new measurands so that in principle such a dependence should be recursively applied, with the consequence that a "well founded measurement" would be impossible to be completed; the usual operative choice to assume that the quantities influencing the initial measurand are not influenced by other quantities, and therefore that they can be "directly measured", highlights the conceptual approximation inherent to any measurement;

- while the adequacy of empirical models is controlled by means of measurement, the quality of measurement results depends on the quality of mathematical models used for designing measuring systems.

This complexity makes knowledge the most versatile tool available to human beings and a fascinating object for knowledge itself.

REFERENCES

The scientific literature devoted to this topic is so wide that any selection of items is partial. What follows is a (short and subjectively selected) list of general references to the issues covered here.

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