Empirical Adequacy and Scientific Discovery

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Abstract

This paper aims to show that Bas van Fraassen's constructive empiricism, such as it is expounded in The Scientific Image, *ends up in considerable difficulties in the philosophy of science. The main problem would be the exclusion of mathematics from the conception of science, given its clear absence of empirical adequacy, which is the most important requirement of his formulation. In this sense, it is suggested a more inclusive formulation of scientific theory, aroused from the notion of Da Costa's (1999)* simple structure, *considering the notion of scientific discovery in a strict sense, and the validity limit of a theory and the formalism used in a temporal context.*

> Le physicien qui vient de renoncer à une de ses hypothèses devrait être (...) plein de joie car il vient de trouver une occasion inespérée de découverte. Son hypothèse, j'imagine, n'avait pas été adoptée à la légère ; elle tenait compte de tous les facteurs connus qui semblaient pouvoir intervenir dans le phénomène. Si la vérification ne se fait pas, c'est qu'il y a quelque chose d'inattendu, d'extraordinaire ; c'est qu'on va trouver de l'inconnu et du nouveau.
>
> Henri Poincaré, *La science et l'hypothèse*.

1. Introduction

Bas van Fraassen's empirical constructivism belongs to a traditional philosophy line known by the pursuit of "saving the phenomena" or "saving the appearances". Geminus (first century BC) seems to have been the first thinker to put forward this thesis as regards to a specific scientific domain, namely Astronomy. According to Simplicius (1913), Geminus observed the existence of two approaches in the study of celestial phenomena. The first one is the physicist's, who deduces the celestial bodies' movement from their *essential nature*. The second one is the astronomer's, who draws the celestial bodies' motions from the mathematical shapes and movements. So, according to Geminus, astronomers are not interested in knowing what there is by its nature, but in formulating hypotheses according to which bodies either move or keep still, and following to that they consider whether the hypotheses explain what has been observed.

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Andreas Osiander's instrumentalism belongs to the latter line, since he claims that Copernicus' calculations, employed in his world system, are liable to substitution without affecting what is observed. George Berkeley's criticisms to Newtonian physics, defending the supremacy of equations over "obscure hypotheses", produced elements for Ernst Mach to deepen those criticisms and to propose, perhaps for the first time in the philosophy of science, the notions of *refutation* as well as *confirmation*, as scientific ideals. This conception also took him to consider, somehow following Hume, function as a much more mature notion than cause. As is well known, Logical Empiricism inherited part of Mach's ideas, and the criticisms they put against metaphysics boosted non-realistic theses about the so-called theoretical terms or "unobservables".[1]

As a result, the novelty of van Fraassen's Constructive Empiricism lies in his use of the semantic conception of scientific theories, particularly the notions of structure and isomorphism, stating the latter in the geometric sense, fundamentally in order to hold that scientific theories "save the appearances".

The main goal of this paper is to show that this conception — saving the appearances — seems inadequate as regards three aspects. First, because Constructive Empiricism does not take discoveries as important in the elaboration of scientific theories. Secondly, but as well importantly, the constructive empiricism's conception of scientific theory, as stated by van Fraassen in *Scientific Image*, does not include mathematics, being restricted to empirical sciences. Last, in part as a consequence of the first aspect, scientific realism is rejected, and the "cosmic coincidence" argument (Smart 1968) is considered in a pragmatic way, which will be discussed later on.

It is important here to make a distinction that will clarify what we take to be some difficulties in Empirical Constructivism, bearing in mind that in our criticism we favour a notion of discovery that some authors call *invention* (Paty 2001). In this way, *invention*, which comes out of a "human creation" act, as Einstein[2] (1949) used to call it, is an initial conjecture of a theory, which conveys to definitions and/or principles, and which corresponds to "empirical substructures" (it carries out the empirical adequacy, to use van Fraassen's terminology). However, by way of improving a notion we have already developed before (Simon 2005), we restrict the term "discovery" to the *necessary* results (quantitative or in strictly theoretical terms — chiefly mathematical), bearing in mind the initial assumptions adopted. Consequently, the expression "scientific discovery" will be here understood as a result in which concepts *necessarily* originated from certain theoretical statements become constitutive of the theory. There are countless examples of this in many scientific domains, including mathematics — that is why the second critical aspect pointed out above — and we will come back to this later on.

We would like to emphasize that what we call scientific discovery includes Lakatos' *new facts*, Frederico Enriques' theory *extension*, Philipp Frank's theory *dynamics* and Kurt Gödel's *verifiable consequences* (referring to mathematics). In other words, discovery[3] derives from some structures (postulates, interpretations, and relationships among objects of a domain) and, as it consolidates the theory it also becomes one of the decisive elements in the theory's definition itself. It is worth remembering that discovery may be associated to certain empirical measures or even only to strictly theoretical concepts, although in science, as is widely accepted today, an empirical data is also theoretical.

Some examples might clarify our point of view. The electro-magnetic field, discovered after Maxwell's theory; the notions of spatial contraction and temporal expansion, which follow from the Restricted Relativity Theory postulates and from the definition of simultaneity; the infinitude of prime numbers, a theorem originated from the properties of these numbers; the genetic code, among many other concepts and relations, result from scientific theories and do not seem to be consequence of empirical adequacy, in the sense employed by van Fraassen.[4]

Thus, it follows from scientific discovery a process of theory construction — which is admitted by van Fraassen.[5] but not as the result of a process of discovery — that falls in two aspects: the domain of the theory's validity redefines it at the same time as occurs a refinement of language or its formalism (in the natural sciences case). We will come back to the problem of validity domain later on. As regards the theory language or its formalism, we should note that it results from a development of certain theories, which bring about new theories by the incorporation of concepts, often in various domains of a science.[6] If, on the one hand, formalism is situated in a period of "normal science" in its origins, it can be incorporated to another domain in a posterior moment. A good example of this is the Hamiltonian formulation, which is useful both in classical and quantum mechanics, but which was originated from developments of the former, particularly from the particles classical theory. In other words, formalism may increase the empirical basis of theories and also enable new discoveries.

A last comment regarding van Fraassen's formulation concerning Constructive Empiricism. In his proposition, "scientific activity is one of construction rather discovery: construction of models that must be adequate to he phenomena, and not discovery of truth concerning unobservable" (van Fraassen 1980, p. 5). The meaning of empirical adequacy for van Fraassen is that the theory "has some model such that all appearances are isomorphic to the empirical substructures of that model" (p. 64). In other words, scientific activity is the activity of model construction, which aims to empirical adequacy (and "not discovery of truth concerning the unobservable"). In our view, this proposition should be reformulated as follows: empirical science aims to the adequacy among the theory's models and the empirical substructures (since only empirical science admits empirical adequacy). This formulation makes more evident the definition's limitation, since mathematics is not included, which shows the need of a definition of science's aims. We also consider inadequate the expression "scientific activity", for it may involve other elements, sociological for example, and not only those associated to justification, as van Fraassen means.

Lastly, we are not going to examine the troubling question of whether van Fraassen's definition of scientific activity is true…

In this article, by means of employing a simple structural conception of scientific theory (Da Costa 1999) and the notion of theoretical incorporation (Moulines 1997) we aim to show that:

(1) A scientific theory cannot be mixed up with a scientific domain;
(2) It seems to be needed, for a complete definition of scientific theory, to incorporate to it either an axiomatic part or its statements;
(3) In the definition of theory, in order to complete it, one should to incorporate *scientific discovery*.
(4) One may say then that a scientific theory is given by a structure, its validity domain, its axioms and theorems; in other words, discoveries originated from axioms in a certain validity domain are given from the inside of some structure.

2. Definition of Scientific Theory

Starting from the definition of simple structural theory given by Da Costa[7] (1999, p. 169), we define as a scientific theory the triplet $T = \langle \Gamma, \mathcal{U}, \Delta \rangle$,[8] in which Γ is a set of propositions, $\mathcal{U}$ is the structure that satisfies those propositions, and Δ is the validity domain of the theory.[9] The inclusion of Γ in the definition comes to be necessary, because semantic conceptions often consider the axiomatizable part of relationships in $\mathcal{U}$, but they do not spell it out enough (Suppes 1957, cap. 12).

The presence of Δ in the definition and the explicit character of central axioms are evidence of the theory's historicity, bearing in mind that the validity domains are progressively incorporated, after their original formulation — where the axioms are present, not always by means of equations —, and they turn out to be the fundamental part of the theory. The inclusion of the validity domain in the definition is also very decisive, and is a great deal entailed by *scientific discoveries*, — often given by new theories that impose the old theory's validity region — and do not result exclusively from a process of *empirical adequacy*. Although van Fraassen claims that previsions — where we could include discoveries —, result from a competition among theories, this formulation seems too narrow for two reasons. First, because it is excluded from the scientific domain, bearing in mind the restriction of empirical adequacy[10], *as we said above*. Second, because, as we will see, van Fraassen produces a feeble argument for the existence of previsions (or discoveries, as we prefer). We will return to the problem of mathematics shortly. Let us go back to Suppes' semantic conception.

Suppes (1957) proposes the following formulation for the "Classical Particles Mechanics": the basic structure of this "theory" is axiomatized by defining, through theoretical tools provided by logic and set theory, the MCP predicate. The defining conditions of this predicate are what normally are considered the axioms of the theory. This way, MCP(x) if and only if P, T, s, m, f, such that:

(1) $x = \langle P, T, s, m, f \rangle$.
(2) P is a finite non-empty set (that represents a set of physical particles).
(3) T is a closed interval of real numbers (that represents the time interval during which the particles are considered).
(4) s is a function of the Cartesian product $P \times T$ in vectorial space R^3, two times distinguishable in T (s represents the function that determines the position in the space of each particle in each instant).
(5) m is a function of P in real positive numbers (that represents each particles' mass).
(6) f is a function $P \times T$ in R^3 (that represents the resulting force that acts on each particle in each instant).
(7) For all p in P and for all t in T, we have:

$$m(p).D_t^2(p,t) = f(p,t)$$

Some remarks may be made to Suppes' proposal. First, we observe that expression (7) is, evidently, Newton's second law. The Newtonian statement is present at MCP(x) predicate, but according to a formalization adopted after Newton's original work. In other words, Suppes keeps the Newtonian axiom, but does so in a modern version, enouncing its equation. It gets clear then that the predicate expressed by Suppes conveys the formalism of a certain moment. The theory is then expressed beyond its axioms — an idea that is not always presented by a semantic conception such as van Fraassen's — in a formalism that incorporated the interpretation and other elements that were shown to be historically important. We would like to insist on that propositions seem to us determinant in theories that have their origins or enhancements through principles. In this sense, we argue that theories may be expressed in spaces of states, as van Fraassen (1980, p. 196) hold, but these are determined in time trajectories, which have *selected* the logically possible sequences. However, this solution is given historically, taking into account scientific discovery.

Given the formalization enounced above, we would like to propose the following definition and formalization for a scientific theory, taking into account the historical dimension: a scientific theory is given by $T(t_1) = \langle \Gamma, \mathcal{U}, \Delta \rangle_{t_1}$, being t_1 its creation moment. Considering van Fraassen's proposal, we could say that a theory would be given by $T(t_i) = \langle \Gamma, \mathcal{U}, \Delta \rangle_{t_i}$, where t_i is the historical moment taken, including the admitted formalization, such that T would run the state spaces $t_1, t_2, \ldots, t_n$, until having its validity limit definitely stipulated. In the former Suppes' example there is a value t_i such that the validity domain has been determined, in the case of classical particles theory, at the moment when the Relativity Theory showed that this theory is valid to $v \ll c$. This way, $t_i = 1905$; that is, Δ expresses the upper limit for particles motion (or the mass center for bodies in general).

The possibility of continually improving a formalism implies that there is not a limit for n inside the theory itself, and that only the negation of certain axioms will lead to new theories. It is worth noting that the formalism itself may suggest new unifications that will lead to new scientific areas, such as Lagrange's and Hamilton's formalisms, which permit the incorporation of systems where energy or potentials may be considered.

In this sense, a space of states that are logically and historically taken could be given (approximately) by the following sequence for the Newtonian theory of particles:

$T(t_i) = \langle \Gamma, \mathcal{U}, \Delta \rangle_{t_i}$, where, for $t_1 = 1687$, we have the original Newtonian formulation; for $t_2 = 1743$, D'Alembert's formulation; for $t_3 = 1744$ Euler's formulation; $t_4 = 1788$, Lagrange's formulation; for $t_5 = 1835$, Hamilton's formulation, and so on. Each of these formulations allows a theory expansion, which is different from the original theory. This way, a theory T in t_1, incorporating discoveries or only the *invention* (*creation*), which will be present in $\mathcal{U}$ and Δ, will take to the following sequence: $T(t_1) \to T(t_2) \to \ldots \to T(t_n)$.

As a result, the adoption of the theory in a given moment depends not only on its logical consistency, but also on the possibility of discoveries that are either new experimental ones or merely theoretical. It is in the latter case that mathematics is included.

3. Empirical Adequacy and Mathematics

The difficulty to van Fraassen's formulation pointed out above, that is, the exclusion of mathematics from the scientific domain looks serious to us. In order to include it, a new unifying criterion is necessary. It is in this sense that the notion of discovery or conceptual expansion or "verifiable consequences", as Gödel suggests, can be more adequate as a criterion for the acceptance of a scientific theory. For Gödel, there could be axioms

> So plentiful in their verifiable consequences, that cast so much light on a whole discipline, and that furnished so powerful methods for solving problems (...) that, no matter its intrinsic necessity, they would have to be assumed at least in the sense of any well succeeded physical theory. (Gödel 1947, apud Lakatos 1978, p. 26)

An attempt to sort this acknowledged difficulty out, and adopting van Fraassen's constructive empiricist program is developed by Bueno (1999a, p. 158ss and 289ss; 1999b, S482). However, the author looks for an approximation between constructive empiricism in empirical sciences and mathematics. In a first moment, Bueno (1999a, p. 158) insists in defending the theory and starts from the notion of pragmatic truth, as developed by Da Costa (1999, p. 170), transposing it by analogy to a coherence sense of truth. However, we see problems in this formulation, for the normal structures employed by him bear the requirement of "saving the appearances" in their origin, as formulated by Da Costa.

In a second moment, Bueno (1999b, S482) tries an axiological formulation of the constructive empiricist proposal, eliminating the notion of truth in both cases. In other words, like empirical sciences, mathematics would be in search of truth, but of a quasi-truth. However, the author poses a too strong constraint. Starting from Hartry Field's (1980, 1989) notion of *conservativeness*, and adapting the nominalist strategy, Bueno proposes that a mathematical theory M is weakly conservative "if it is quasi-true in a partial structure with respect to a consistent body *N* of nominalistic claims". (Bueno 1999b, p. S482). And concludes that "M is weakly conservative iff M is consistent with some internally consistent body of claims about the physical word" (ibid.).[11]

It looks to us that, in both cases, the requirements are too strong. We hold that the emphasis on discoveries, as occurs in empirical sciences, satisfies mathematical theories, since the validity domain will be given by discoveries (now mathematical) that come out from the theory itself and by the restrictions (validity limits) imposed by the new theories. Euclidean and non-Euclidean geometries are good examples of theoretical evolution in mathematics (for space properties, in the case at issue) and the above formulation is able to satisfy it. For example: if the addition of a triangle's angles is equal to two straight angles we are in an Euclidean regimen, otherwise we are in non-Euclidean regimens.

4. Empirical Adequacy, Success and Scientific Realism

Let us return to the problem of the relationship between empirical adequacy and discovery. For van Fraassen, prevision results from a competition among theories instead of a discovery process. Let us examine an example given by him, although it has nothing to do with the one from Particles Classical Theory we have treated so far. This analysis shows us that van Fraassen looks for an *a posteriori* instance, hence taken from the *history of science*, for a *pragmatic* foundation, which is important as a complement of his *logical* argument. The reason is as follows: in order to reply the criticisms against his proposal that the problem of prevision has not been properly dealt with, the antirealist position of constructive empiricism opts for the pragmatic aspect of the theory. In other words, the theory that surpasses its rival is the one that becomes the most successful. Now, this does not occur very often in the history of science and the example above has shown that the case was of evolution, formalism enhancement and discoveries instead of competition.

The example examined by van Fraassen is von Neumann's study of hidden variables formulation. Von Neumann has established that observable quantities are represented by operators A, B,..., each of them is associated to an infinite matrix (A_i) and also a function $\langle A\rangle$, which gives the expected value $\langle A\rangle_\phi$ in any state ϕ. According to van Fraassen (1980, p. 53), when von Neumann formulated his own theory, he could have chosen one of the following principles regarding the combination of observable quantities in order to serve as an axiom:

1. $\langle aA + bB\rangle_\phi = a\langle A\rangle_\phi + b\langle B\rangle_\phi$
2. $(aA + bB)_{ij} = a(A)_{ij} + b(B)_{ij}$

Van Fraassen argues that, depending on the choice, von Neumann could have concluded for the existence or not of hidden variables. His choice took him to the denial of these variables, being pragmatic then:

> Such pragmatic superiorities of one theory over another are of course very important for the progress of science. But since they can appear even between different formulations of the same theory and also may only show up in actual defeat, they are no reflection on what the theory itself says about what is observables. (Van Fraassen 1980, p. 53)

This conclusion is directly linked to two other theses by him presented at the beginning of this paper: the difference between observables and unobservables, on the one hand, and between belief in the truth of a theory and empirical adequacy, on the other hand. For van Fraassen, there is no ontology — or realism — possible to be affirmed about the unobservable entities of a theory, but only its empirical adequacy.

Van Fraassen is clearly an antirealist and his conception of empirical adequacy makes a sharp distinction between an exclusive belief in adequacy, instead of unobservable entities or in the so-called theoretical terms. However, as some authors observe (cf. Moulines 2006, p. 127), the unobservability criterion is not clear in van Fraassen' thought, for what is unobservable today may not to be so later; there is no need in pointing out all the innumerable examples of this in the history of science. In this matter, these authors are right and the Constructive Empiricism's antirealist argument loses much of its force.

Returning to the example of hidden variables chosen by van Fraassen, it is doubtful the assertion that von Neumann's choice is pragmatic in a strict sense. Even if we consider discovery as a pragmatic criterion — which could have been invoked in the above example — it is founded in the discovery of entities taken in a realistic context. This is because the novelty lies not in empirical adequacy, but in the existence of those new entities, which were unknown before. An unobservable associated to a new phenomenon is not merely a matter of empirical adequacy, since "adequacy" itself comes up with and after the unobservable, even in Quantum Mechanics. The examples in physics and even in mathematics are plentiful enough and some of them have been pointed out here.

5. Conclusion

The possibility of incorporating mathematics in a definition of scientific theory arises as the most considerable advantage of the formulation here proposed by us.

Having his source in the need of incorporating scientific discovery, as historically given, in the definition of scientific theory, this definition of scientific theory seem more inclusive than the one proposed by Van Fraassen.

The notion of empirical adequacy, a central issue in the criticism directed to scientific realism, is *logically* unimpeachable when we refer to empirical sciences, but it excludes formal sciences. Moreover, the theory's pragmatic virtue defense as a solution for the "cosmic coincidence" problem, that is, the thesis that competition among theories takes to the fittest in a given moment. Besides, it is also limited as a reply to realists. It is not always that a scientific theory competes with other ones, as it occurred in the Newtonian case.[12] In fact, it was a theoretical improvement, on the one hand, and the restrictions in its validity domain, on the other hand, which took the classical particles theory to a mature formulation. The conceptualization here proposed makes clearer the distinction between a "scientific domain", like classical mechanics, and the various theories of which it is composed, such as elasticity theory, gravitation theory and so on. What van Fraassen calls theory models are often other theories, which should satisfy a theory specific criterion, and not a general criterion, which mixes up the notions of scientific domain and scientific theory.

The incorporation of scientific discovery to the definition of theory may help to clarify an old problem in the philosophy of science, namely, inter-theoretical change, according to Moulines' terminology (1997, p. 449). Inter-theoretical change should take into account formalism improvement, but above the discoveries that come out of these new formalisms or even of new concepts' incorporation that are absent from the original formulation. However, when one refers to a theory, one should, in our view, to refer to the formulation at issue, because the novelties in a theory depend on which moment in history we are referring to. This certainly does not mean relativism, since former determinations, either experimental or strictly theoretical, are preserved in posterior formulations.

Discovery arises then as one of the main aims of science and allows theoretical novelty, particularly those of unobservables, namely, either as coherence inside a theory — as in mathematics — or as indirect experimental evidence — as in empirical sciences, or even taking to new connections, and so to new theories. It looks that it is possible to admit the concept of truth in sciences, namely the coherentist one in mathematics and the approximate correspondence one (in Tarski's sense), in empirical sciences. We may conclude that science, as an activity that searches for expressing theories about social and natural phenomena, apart from the strictly formal relations, also looks for the (approximated) truth of theoretical terms. This search may include the attempt of constructing certain *natural species* and, above all, their relations, keeping the notion of causal relation[13] among unorbservables.

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Resumo

O presente trabalho busca mostrar que o empirismo construtivo de Bas van Fraassen, segundo enunciado em sua obra The Scientific Image, *conduz a dificuldades consideráveis em filosofia da ciência. A principal dificuldade seria a exclusão da matemática dessa concepção, por sua clara ausência de adequação empírica, sendo essa a mais importante exigência da formulação de van Fraassen. Nesse sentido, é proposto uma formulação mais ampla de teoria científica, oriunda a noção de* estrutura simples *de Da Costa (1999), considerando a noção de descoberta científica num sentido estrito, o limite de validade da teoria e o formalismo utilizado, num contexto temporal.*

Palavras-chave
Adequação empírica, descoberta científica, teoria científica.

Notes

[1] We are not suggesting that the Vienna Circle members are all anti-realist. Their epistemological conceptions vary considerably as regards the problem of scientific realism. On this, see a conception of empirical realism such as Moritz Schlick's. Cf. Schlick 1932.
[2] In all his writings, Einstein emphasizes the role of experience and well established theories as guides in this act of creation.
[3] Always when we use the term "discovery" we mean "scientific discovery".
[4] It is worth noting that, in general, van Fraassen's criterion is very appropriate, both in a logical and in a historical sense. However, as we will see in the following, he holds

that the main belief of scientific activity appears in the search for empirical adequacy exclusively. It is this restriction that we disagree with.

[5] More rigorously, the construction of models, according to van Fraassen. See below.

[6] Paty examines the role of mathematics in its relationship with physics and classifies this process as *entraînement* — dragging — of the latter by the former. Paty 2002.

[7] According to Da Costa, a theory T may be identified to the triplet $A_T = \langle E, \Delta, R\rangle$, where E is a kind of structure, Δ is T's application domain, R is the set of techniques and processes that link T to experience.

[8] A more adequate formulation for T could be given by: $T = \langle \Gamma, \mathcal{U}, S, \Delta\rangle$, where S stands for the relationship of *satisfactibility* — in Tarski's terms (cf. Branquinho, Murcho and Gomes 2006, p. 797) — between Γ and $\mathcal{U}$.

[9] We consider more adequate the expression "theory validity domain" instead of "theory application domains" (Da Costa 1999, p. 169); we do not include in our formulation, as Da Costa does, the "set of techniques and processes" that link T to the experience.

[10] Bueno (1999b, 2000) keeps the empirical adequacy criterion, even in the mathematics' domain. However, as we will see, this proposal also looks problematic.

[11] In a third moment, Bueno presents a formulation a little more general, but still keeps the need of empirical "reference" for mathematics. Insisting in the notion of quasi-truth, he asserts: "If the aim of mathematics is quasi-truth, a mathematical theory does not need to map, in complete detail, every aspect of the domain to which it is applied. It suffices if it accommodates certain aspects of this domain". (Bueno 2000, p. 226). Now, it does not seem to be needed any reference of this type in order to define mathematical knowledge. It is in this sense that the notion of discovery looks more general to us.

[12] Berkeley's criticisms to infinitesimals in mathematics and the criticisms to Newtonian absolute space cannot be taken as an alternative theory, although the latter have become important in Mach's criticism to mechanics. Mach's criticism, as is known, was important to the edification of the Relativity Theory.

[13] A formulation that looks proper to us has recently been developed by Richard Corry. Improving Nancy Cartwright's (1999) notion of causation, this author defends a "causal realism" in science. "Causal realism allows to formulate laws of the form 'when a finite number of quite localized things hold at one time, there will be a causal influence directed toward some particular effect' " (Corry 2006, p. 273).