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Natural classification and Pierre's Duhem historical work: Which relationships?

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1. Introduction

The concept of natural classification is a constitutive part of Pierre Duhem's philosophy of physics, as seen by the fact that he considers it to be the aim of physical theory, or, in the words of Vuillemin, a form which the "physical theory *strives* for" (Duhem, 1991 [1906], p. xviii) (my italics).[1] For Duhem, physical theory is a system written in the language of mathematics whose aim is to organize experimental laws. As a mere classification of experimental laws, theory is restricted to the sphere of the phenomenon, and any explicative power in the sense of explanation of causes is denied to it. Yet, with natural classification, Duhem proposes an endpoint for the historical evolution of physical theories whose status differs radically from the status of their present form: the physical theory "will end by being an image of *the ontological order* of things", "a sort of image and reflection of *the true order* according to which the realities escaping us are organized" (1991 [1906], p. 31) (my italics).

As a matter of fact, natural classification presents itself as a goal which is ideal in both senses of being the best possible theory and unachievable, since, for Duhem, access to essences lies beyond the capabilities of human nature: "such a theory, like everything that is perfect, infinitely surpasses the scope of human mind" (Duhem, 1996 [1893], p. 68). This ideal is described solely as a *limit* to the physical theory and, like the mathematical notion of limit, the physical theory *tends* towards natural classification without actually ever reaching it.

This qualification, however, does not change the fact that an ideal theory goes beyond the domain of an organization or a classification and has ontological status. To regard physical theories as aiming at natural classification and at the same time as being the mere product and working tool for the theoretical physicist exposes a certain duality in their status: metaphysical/ontological in the first case, simply formal in the second. Taken separately, as disconnected from each other or representing different periods in Duhem's career, for example, these contrasting views could very well be thought of just in terms of the debate between realism and antirealism in science, and a number of scholars have looked at them from this angle.[2]

The difficulty, though, lies precisely in the fact that Duhem holds both views *jointly*: current theory as mere organization of experimental laws, without true value, and ideal theory as faithful representation of the transcendental order. We are thus presented with a situation where two opposite philosophical perspectives coexist, a contrast that seems to jeopardize the coherence of Duhem's system. Further investigation into this problem will involve examining his more general views about the nature of physical theory in order to identify the reasons behind the postulation of natural classification; as we will emphasize, this includes history. From this investigation the principle of unity of the physical theory will emerge as a central pillar of natural classification.

The presence of history in Duhem's philosophical thought is beyond question. In spite of that, natural classification is not even mentioned in his historical work. Although one may not expect an

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[1] For Maiocchi, without the idea of natural classification "all of Duhem's scientific work would be meaningless" (1990, p. 389); Martin stresses the importance of this concept as "a permanent feature of his thinking" (1991, p. 31). These are views with which we certainly agree, especially on account of the reassurances about the relevance of natural classification made by Duhem himself in 1915 (Duhem, 1915, p. 84), when most of his historical work had already been published. We consequently disagree with De Broglie, who minimizes its role in Duhem's philosophy by referring to natural classification as a mere expedient "to *mitigate the rigor* of his scientific positivism" (Duhem, 1991 [1906], p. ix) (my italics). On the other hand, his reckoning of Duhem's position as being "a very personal one" (Duhem, 1991 [1906], p. x) can only reinforce the need to understand the meaning and significance of natural classification in his works.

[2] Some scholars sought to place Duhem's ideas at different intermediate positions in the realism/antirealism debate. McMullin (1990), for example, classifies him as structural realist, Lugg (1990) as convergent realist, and Needham (1998) as moderate realist. Niiniluoto (1999), on the other hand, sees Duhem at one extreme of the debate and considers his "To Save the Phenomena" as "part of his own campaign for instrumentalism" (1999, p. 146), incidentally, without making any reference to natural classification.

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epistemological/metaphysical concept to be part of a historical analysis, or that a historical reconstruction offers irrefutable proof of certain epistemology, the silence here is intriguing. In fact, this concept, fundamental for Duhem's epistemology, carries an implicit historical character since it is taken as the aim of the evolutive process of any physical theory.

Duhem's historiography is continuist; it does not allow for leaps or ruptures. Although the principle of historical continuity may be one methodological choice among others, we begin with the assumption that it provides necessary support to the concept of natural classification. Nonetheless, like Agassi, who finds it necessary to narrow the question "is the history of science continuous?" down to the more specific question "in which respects is it, in which not?" (1973, p. 625), this paper also discusses the meanings of historical continuity for Duhem.

The first meaning is the one peculiar to Duhem, namely, continuity of structure, which will be briefly revisited in this paper. However, given the fact that physical theories rely on concepts to convey their empirical meaning, conceptual continuity and rupture along history also need to be addressed. We do not intend to make a comprehensive analysis of Duhem's historiographical work here. Instead we will analyze conceptual continuity by means of an example, one that formed the "main axis" of the Duhemian investigation into medieval science (Brenner, 1990, p. 200), namely, the idea of impetus in the context of its connections with the concepts of inertia and force, within which there is a conceptual leap that poses a problem for the thesis of historical continuity. Inspired by Friedman (2001, 2008), we propose the idea of "continuous transformation" as a way to also give some kind of continuity to concepts and therefore preserve the place of natural classification in Duhem's system.

Starting with these two methodological principles, once they are made sufficiently clear, this paper will suggest a certain articulation between them as a way out of the apparent incoherence in Duhem's thought mentioned above. We will see that the subsidiary role played by natural classification in his historical narrative justifies its conspicuous absence from it. We will also see that the keeping of a tradition along history, if seen as a process of "additions of natural classification", preserves the analogical relationship between theory and reality and, therefore, makes the gap between a theory in progress and its aim a false problem.

2. The thesis of natural classification: context and justification

Duhem regards physical theory as a grouping of experimental laws. The goal of physical theories is to interconnect and classify the pieces of knowledge obtained through the experimental method: a physical theory is "a system of mathematical propositions, deduced from a small number of principles, which aim to represent as simply, as completely, and as exactly as possible a set of experimental laws" (1991 [1906], p.19).

Physical theory as a representation does not derive from experience; it is an invention, "an artificial construction manufactured with the aid of mathematical magnitudes" (ibid., p. 277) which were made to correspond to certain qualities without these magnitudes themselves stemming from observation. Therefore, it does not necessarily employ inductive reasoning: "physical theory is neither a metaphysical explanation nor a set of general laws whose truth is established by experiment and induction" (ibid., p. 277). Theoretical systems develop through rational procedures that involve correction, generalization and analogy. To these ingredients two complementary requirements are added: logical coherence, preventing contradictory theories to mix, and the principle of unity of the physical theory, which, far from just satisfying the principle of non-contradiction, considers "to coordinate a set of experimental laws in the midst of a single theory" to be "better" and "more perfect" (1996 [1893], p. 67).

Duhem denies the kind of mechanicism of the English school.[3] As a method, mechanicism allows different models to represent the same group of laws; these models are not required to be interconnected, although they represent the same phenomena. For him, since each model "is developed in isolation, with no concern for the preceding one, covering again a part of the field already covered by the preceding model" (Duhem, 1996 [1893], p. 63), the physics thus constructed results in an "incoherent collection of incompatible theories" (ibid., p. 67).

The fact that mechanicism fails to satisfy the principle of logical coherence does not make it absurd. The justification for denying mechanical theories, therefore, needs a stronger criterion going beyond the required internal coherence of each theory. This criterion is given by the postulate of the logical unity of physical theory: "logical *unity* is imposed on physical theory as an ideal to which it tends constantly" (1991 [1906], p. 294) (my italics). This principle is consistent with the ideal of logical coherence but surpasses its characteristic requirement of non-contradiction by assuming the unity of physical theory in the sense of *singularity* or *uniqueness*. Duhem is an ontological realist: for him, the entities and structures of the world are real, they exist apart from the observer. And, given the fact that the world is ontologically singular, its representation would not admit different, even if logically coherent theories; on the contrary, it requires the theory to show a uniqueness capable of mirroring the unity of the world, a feature which then becomes a condition of natural classification.

The ongoing tendency of physical theory to unity suggests that, if it organizes experimental laws progressively, if it should move towards a single theory rather than a divergent group of theories, its aim must be an exact classification of these laws. A theoretical system of this sort would be in a relation of positive analogy with the empirical world, it would classify experimental laws "in an order which would be the very expression of the metaphysical relations that the essences that cause the laws have among themselves" (Duhem, 1996 [1893], p. 68), namely, natural classification.

Natural classification appears then in a context where mechanicism is denied and the postulate of logical unity of theory provides the ground for its proposition. "Logical unity is a characteristic without which physical theory cannot claim this rank of natural classification" (Duhem, 1991 [1905], p. 297); Duhem's concept of natural classification is formulated "to justify the tendency of theory toward logical unity" (ibid., p. 297). In other words, natural classification is objectively a consequence of the principle of logical unity being accepted.[4] As a principle, it does not require formal justification; it is a truth admitted by all, and it is "imposed" upon us.

For natural classification to be accepted, criteria such as "perfection of form", "simplicity", and "beauty" are added to the principle of logical unity (Duhem, 1996 [1893], p. 67). These are concepts alien to the sphere of rationality; Duhem himself

[3] By mechanicism we mean here the method of employing models, either material or ideal ones, as a way to imitate the phenomenon and to represent the structure and properties of matter such as rigidity, elasticity, compressibility, etc. For Duhem, in a mechanical theory, "all physical magnitudes are composed by means of geometrical and mechanical elements of a certain fictional system" (1996 [1892], p. 12) and to mechanical explanations "understanding the nature of material things will be the same thing as imagining a mechanism that will represent or simulate the properties of bodies by its action" (1996 [1893], p. 55).

[4] For Maiocchi, instead, this relationship takes place in the opposite direction: "coherence *was sustainable and justifiable* only by admitting that theories … are also capable of reflecting an ever-perfectible and always 'more perfect' real arrangement" (1990, p. 388) (my italics).

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concedes that justifying natural classification is not a question of rational proof *stricto sensu*, given that the physicist only has the data from observation to work with, and these "cannot *prove* that the order established among experimental laws reflects an order transcending experience", (1991 [1906], p. 27) (my italics), since such order lies beyond experience.

Perhaps, the closest one finds to a rational criterion that justifies natural classification in methodological terms is the requirement that it has predictive power: "… the highest test, therefore, of our holding a classification as a natural one is to ask it to indicate in advance things which the future alone will reveal" (1991 [1906], p. 28). For Ivanova (2010), natural classification is the solution that Duhem finds in order to tackle the predictive power of theories. Our interpretation inverts this relationship: we understand that Duhem takes predictive power as *evidence* instead of *cause* of natural classification.

However, once its consequences are corroborated by experience, which guarantee does one have that such is a case of natural classification? "If, …, we recognize in the theory a natural classification, if we *feel* that its principles express profound and real relations among things, we shall not be surprised to see its consequences anticipating experience …" (ibid., p. 28) (my italics). In the last resort, the guarantee one has of holding a natural classification comes from intuition: "… this ideal state is not given in a plain and indisputable manner; it is hinted to us by an infinitely delicate and volatile intuition" (ibid., p. 305) (my italics).[5]

In classifying experimental laws, bringing analogous phenomena together, the physicist finds in intuition the means to formulate hypotheses that keep the theory on track of natural classification. Somehow the physicist must be able to foresee history, even if only concerning the immediate future of a theory. This possibility is envisaged by Duhem in his epistemological work and is coherent with his reading of history, what takes us to another question. Would Duhem have developed a historiography to support his epistemological theses? This is the question examined in the next section.

3. The relationship between history and philosophy in Duhem's works

The chronology of Duhem's writings reveals an unequivocal direction in his dedication to history and philosophy: the methodological/philosophical papers predate the historical/philosophical ones, which, in turn, come before his eminently historical research where he looks directly into some authors' original texts.[6] This order is not enough, however, to state conclusively that Duhem composed a history of physics in order to support his philosophical theses. Analysis of the relevant literature shows a number of different interpretations concerning the direction of mutual influence between these two fields in his works.

Maiocchi and Stoffel reckon that Duhem's historical work not only underwent the influence of his epistemology but seems to have been purposely directed to defend or even validate it. The former affirms that "the whole of his epistemology *and his historical work* was an effort to sustain this notion" (1990, p. 389) (my italics), namely, natural classification, the metaphysical concept associated with his epistemology. For the latter, Duhem seeks "on the one hand, to establish, at the historical level, the validity of his phenomenalism" (2001, p. 766), while Boudot is of the opinion that Duhem would really reveal himself as a historian only after he already had an epistemology in its final form (Brenner, 1990, pp. 16, 17).

For Lugg, instead, the influence between these two areas took place in the opposite direction: Duhem's commitment to a certain historiographical approach, namely, the principle of historical continuity, seems to have formed the grounds for his views on natural classification as the goal of physical theory: "… given his commitment to the principle of historical continuity, there is nothing particularly remarkable about his rejection of the view that physical theories are artificial classifications in favour of the view that they are becoming increasingly natural" (Lugg, 1990, p. 411).

Objecting to the latter point of view, Patapievici believes that only *a posteriori* Duhem embraced the thesis of historical continuity as a philosophical principle, "… as a result of the discovery he had made, and not *a priori*, as a result of the identification of a philosophical principle that lies beyond experience and is independent of it …" (2015, pp. 215–216). And Ivanova argues that the purpose behind the development of the concept of natural classification was to tackle *a posteriori* the historical lesson that new theories "usually build on old ones, evolve from old ones …" (2010, p. 59).

Let us then look into Duhem's own position. Although the context of the following passage is not about supporting natural classification, his words seem coherent with the chronology of his published work, i.e., with the idea that his historical work was written in the light of certain pre-existing epistemological principles taken as background for the selection and organization of facts: "Thus, the history of the development of physics *has come to confirm* what the logical analysis of the methods used by that science had taught us" (1996 [1913], p. 250) (my italics).

According to Duhem, the process of developing a theory requires an assessment of its tendency, "the goal toward which it is directed" (1991 [1906], p. 303); this assessment is made by means of "the knowledge of the road it has already covered" (ibid., p. 303). In other words, Duhem proposes to extrapolate the present status of a theory by turning to the history of its successful steps. As in the case of a moving tennis ball whose forthcoming trajectory is possible to predict from the course it already travelled, "so the history of physics let us *suspect* a few traits of the ideal theory to which scientific progress tends, that is, the natural classification …" (ibid., p. 303) (my italics).

Thus, the development of theories in a state of approximation to natural classification cannot dispense with history; classifications that propose to be in a relation of analogy with reality should be "guided by a profound knowledge of theory *and its history*" (ibid., p. 305) (my italics). Intuition, referred to in section 2 above, takes the role of mediator between history and the logical procedures that characterize the job of a theoretical physicist (Dion, 2013, p. 17).

In the metaphor of the moving tennis ball, the ability to predict its trajectory is given by a mathematical equation, which points to both past and future indifferently in a continuous way. The other term of the analogy, i.e., the formulation of hypotheses, requires the perception of the continuous trajectory of the theory; to do so, it is necessary to find a guiding line that plays the role of "mathematical equation" and thus allows conjectures about the future to be made which eventually show themselves empirically successful; such guiding line is given by the whole of structures preserved along history. There are, therefore, justified grounds for the interaction

[5] His defense of intuition as an argument for natural classification draws on Pascal's ideas: "yielding to an intuition which Pascal would have recognized as one of those reasons of the heart 'that reason does not know', he [the physicist] asserts his faith in a real order reflected in his theories more clearly and more faithfully as time goes on" (1991 [1906], p. 27).

[6] While his writings on philosophy of physics begin in 1892 and last until 1894, with a second period triggered by the publication of "The Aim and Structure of Physical Theory" (1904–1906), his first paper on the interface between philosophy and history, "Les Théories de l'Optique" dates from 1894; his first historical work properly speaking, "Les Origines de la Statique", comes out in 1903. "Études sur Léonard de Vinci. Ceux qu'il a lu et ceux qui l'ont lu" begins to be published in 1905, and "Le Système du Monde. Histoire des doctrines cosmologiques de Platon à Copernic" is published from 1913 on.

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between history and philosophy in Duhem's work, and also, the other way round, between philosophy and history.

The brief summary presented here shows that, although there is no conclusive evidence that Duhem developed his historiography to support epistemological theses, these two facets of his work are coherent. In dealing with this coherence, however, the literature has not seen natural classification as a guiding concept to analyze Duhem's epistemology and/or historiography. This paper, on the contrary, places natural classification at the center of his epistemology and accordingly examines its influence on his historical work. This influence deserves investigation especially for the reasons mentioned above: the epistemological relevance of natural classification and the absence of any explicit reference to it in Duhem's historical work.

As we see it, the fundamental link between history and philosophy in Duhem's thought is given by the argument of historical continuity, which is required by natural classification. On the other hand, from the perspective of the historical narrative, this thesis may be regarded as just one among other ways of selecting and analyzing facts. It is then necessary to explain this thesis in Duhem's own terms and discuss to what extent it can support natural classification as the aim of physical theory. This discussion will take place in the following two sections.

4. History and the continuity of structure of physical theories

Duhem divides physical theory in two distinct parts: the set of mathematical structures gathered along history, the "representative" part, and the statements with ontological content that make assertions about entities existing in the world, the "explanatory" part. For him, structures are the parts that remain throughout theoretical changes[7]:

When the progress of experimental physics goes counter to a theory and compels it to be modified or transformed, the purely representative part enters nearly whole in the new theory, bringing to it the inheritance of all the valuable possessions of the old theory, whereas the explanatory part falls out in order to give way to another explanation (1991 [1906], p. 32).[8]

The evolution of the representative part defines a tradition in which "we see created across the ages a constantly more ample and more precise mathematical representation of the inanimate world disclosed to us by experiment" (ibid., p. 306). This tradition denies that physics can be deduced from metaphysics and that true assertions about entities of reality are possible, revealing itself as the guiding line through which "each theory passes on to the one that follows it a share of the natural classification it was able to construct" (ibid., pp. 32, 33)[9]. There is, therefore, a relationship of direct dependency between the development of hypotheses and the history of a theory, if the aim is natural classification.

In fact, the formulation of successful hypotheses depends not only on the present state of a theory but also on grasping tradition, which requires turning to history. The guarantee that one has grasped a "share of the natural classification" is given by a theory's past, its history of logical unity and the power of prediction that it could amass. We elaborate here on Maiocchi (1990) views. For him, "the historical context, in which every scientist moves, guides the choice of hypotheses" (1990, p. 394). However, while his context is the present stage of a theory, "the concrete influences that every stage of development of the historically determined scientific thought exerts upon the researches" (ibid., p. 394), we emphasize *its past* as the defining factor behind its continuous trajectory.

As in the metaphor of the tennis ball, therefore, a continuous tradition is required if history is going to be able to support the formulation of hypotheses and provide the theoretical conditions to predict the next step in its trajectory. So, intuition, allied with this kind of tradition as guiding line, preserves the search for natural classification by physical theories. However, even setting aside the explanatory part, one ought to take into consideration the fact that physical theories are not made of empty forms and cannot do without concepts that give them empirical content. Like Chakravartty in his defense of semirealism, when he affirms that the "separation of truth where relations are concerned from truth with respect to relata is unintelligible" (1998, p. 402), we consider the separation between form and content regarding physical theories to be "unintelligible" too.

In his historical work, Duhem deals explicitly with the continuity of the representative tradition, in which physical theory makes itself present through mathematical symbols, with no objective existence. But what about his epistemological work? Although supported there, continuity of tradition, as mentioned above, is now joined by the epistemological idea of *gradual additions of natural classification*. These "additions" of natural classification refer to the way in which reality is effectively organized. Since we are now dealing with the real world, the theory needs to be able to connect mind and sense experiences, a link given by concepts. Thus, although Duhem's analysis focuses on the form, the mathematical structure of a theory, about which he explicitly defends the thesis of continuity, we also have to take into account the contents of a theory when we consider the gradual construction of natural classification.

In sum, to suggest a continuity of structures does not dispense with the need to examine the problem of conceptual continuity and rupture in the history of theories. We do not intend to make an extensive analysis of Duhem's historical work here. This issue will be dealt with instead through a case study, namely, the idea of impetus, whose relevance in Duhem's historical studies as the "main axis" of his investigation on the "Parisian dynamics" is well known. The following analysis looks into the connections between impetus and the modern concepts of inertia and force, a history that at first seems to be an example of rupture.

5. The continuity of concepts: the case of the idea of impetus

Duhem places the concept of impetus within the historical trajectory leading to modern physics: "… if we wanted to draw a precise line separating the period of ancient science from the period of modern science, we would have to draw it at the instant when Jean Buridan conceived this theory …" (1996 [1913], p. 246). For him, Buridan's major contribution to the impetus theory was to do away with the need for things in motion to be physically accompanied by their movers. Impetus is, in this sense, a permanent quality; the idea of permanence associated with it brought

[7] Duhem's adherence to this kind of continuity is consensual in the literature. According to Martin, his belief in continuity is "beyond question" (1990, p. 339). See also Ariew and Barker (1990, p. 180); Brenner (1990, p. 332); Lugg (1990, p. 411); Maiocchi (1990, p. 395); Ivanova (2010, p. 59); Patapievici (2015, pp. 215–216).

[8] The notion of "preserving structure" suggested here considers former equations to be limit cases of their successors. This does not imply Duhem is a structural realist. In classifying Duhem as realist, of whatever flavor, one must take into account the fact that his is a peculiar kind of realism, which the current categories cannot grasp entirely since it relies on his very personal notion of historical tradition.

[9] The heir *par excellence* of the representative tradition would be thermodynamics, whose principles "are propositions relative to certain mathematical signs stripped of all objective existence" (1991 [1906], p. 285). Through continuous progress, the different branches of physics should be brought together and ordered under the aegis of this science, resulting in the "generalized thermodynamics" or "energetics", "representative" in the sense that it "claims to explain nothing … simply gives general rules of which the laws observed by the experimentalist are particular cases" (1996 [1913], p. 233).

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this concept close to the notion of inertia in the sense of motion that remains in spite of any action from an external force.

However, as Drake points out, permanence in this sense "is hardly reconcilable" with the corruption clause advanced by Buridan himself: "terrestrial projectiles were always undergoing a reduction of impetus that would eventually bring them to rest, even in the absence of external resistances" (Drake, 1975, p. 34, p. 34)[10]. Since, "*unlike inertia*, impetus – though distinct from the motion – behaves just like the motion and is weakened or destroyed along with it" (Drake, 1975, p. 33) (my italics), one at first may not see continuity between these two concepts. Also, impetus cannot be identified with the concept of force in the Newtonian sense of the term: impetus is an "*intrinsic* property of a body", or something "acquired", while force is interaction, an action external to the objects, not requiring them to be in contact. Moreover, impetus is a cause that sustains motion; force, instead, causes its variation.

These differences would suggest that the historical process from impetus to inertia and force is a case of rupture. Nonetheless, according to Duhem, "the role that impetus played in Buridan's dynamics is exactly the one that Galileo attributed to *impeto* or *momento*" (1996 [1913], p. 245) (author's italics). In fact, this statement may be acceptable in a certain sense, as Galileo's mechanics carries traces of the medieval conception of impetus: "he did, for example, think in terms of impressed forces and the impetus acquired in descent, and he continued to speak of intrinsic motions, both of which were banished from inertial mechanics" (Hooper, 1998, p. 147) and he "did not regard gravity as an external force but always regarded it as an intrinsic property of a body" (ibid., p. 153).

However, the comparison that Duhem proposes between the Parisian physics and the views of Galileo is not restricted to these aspects. Consider the way he describes the use of the concept of impetus to explain free fall: "gravity creates, in equal periods, a new and uniform impetus which, added to that already acquired, causes the total impetus to increase in arithmetical progression according to the time occupied in the fall; hence, the velocity of the falling body" (Duhem, 1996 [1911], p. 191). From this, he concludes: "this argument … *leads to our modern law*: A constant force produces uniformly accelerated motion" (ibid., p. 191) (my italics), a conclusion that brings about an idea of conceptual continuity in a sense stronger than the one mentioned above.

We find implicit here an idea of continuity that goes beyond the structural domain of a theory. However, how can such continuity be sustained given the fact that the concepts of impetus, on the one hand, and force and inertia, on the other, are not equivalent? We have here an important difficult that must be addressed since the continuity thesis is fundamental for Duhem's epistemology. A solution would be to interpret Duhem's assertion from a strictly linguistic angle: instead of saying that the theory of impetus "led to" the law according to which "a constant force produces uniformly accelerated motion", we could affirm that the old concept "led up to" the idea of force in the sense of having only prepared its way.[11]

We propose to expand this linguistic solution as a way to give some kind of continuity to concepts and therefore preserve natural classification. According to Duhem, "… the *so-called* intellectual revolutions consisted, in most cases, of nothing but an *evolution* developing over long periods of time" (Duhem, 1905-1906 [1903–1906], p. 3) (my italics). Since, regarding concepts, simple addition and generalization do not apply to continuity, we offer a solution by associating "evolution" with "preparing the way": we suggest that "evolution" is understood as "continuous transformation", a kind of change throughout which some elements key to defining concepts are retained. This suggestion is inspired by Friedman (2001), who applied the terms with which Kant analyzes the regulative use of reason to what the latter called constitutive domain (the domain of principles like the ones in Newton's mathematical physics).[12]

Like Kant, who saw the evolution of science as moving towards "an ideal state of completion", in the sense of the regulative use of reason, "our present constitutive principles represent one stage of a convergent process … in that they can be viewed as approximations to more general and adequate constitutive principles that will only be articulated at a later stage" (2001, p. 64). Taking evolution as a series of approximations, "we can exhibit the historical evolution by which the new concepts and principles *gradually emerge through successive transformations* of the old concepts and principles" (Friedman, 2001, p. 60) (my italics); "we thereby find a natural and continuous *transformation* of concepts" (Friedman, 2008, p. 129) (my italics).

As in the mathematical notion of limit, the physical theory comes gradually closer to natural classification through a process of "addition", without actually reaching it. From the perspective of evolution as "continuous transformation", although impetus and the modern concepts of inertia and force are not equivalent, there is an element of continuity or addition in the fact that all of them break with metaphysics-based explanations, and have the status of rationality in common. Besides, the notion of impetus allowed a certain degree of mathematization, a legacy which eventually was fully developed since Galileo. Bringing Friedman's framework into this context, we notice in this case a "natural and continuous route from one space of conceptual possibilities to the other" (2008, p. 12, note 12). Or, in Duhemian terms, "by virtue of a continuous tradition each theory passes on to the one that follows it *a share of* the natural classification it was able to construct" (1991, p. 32) (my italics), a process involving not only the structure but also the concepts of the theory.

In sum, the history of impetus is particularly relevant because it shows elements of continuity amidst rupture even in the extreme case of a concept already abandoned by modern science. Looking into this history through the principle of "continuous transformation" proved to be crucial as it allowed us to understand, to a certain extent, revolutions as evolutions and, as a consequence, to give the evolution of concepts a certain degree of continuity amidst rupture and therefore preserve the place of natural classification in Duhem's system.[13] There remains, however, the question of which guarantees can be found in Duhem's work that natural classification will eventually be the outcome of this evolutive process involving the structure and contents of theories.

[10] A suitable example here would be a heavy object thrown vertically upwards whose impetus would be weakened by the contrary inclination given by its "gravity", an inner tendency to move downwards, i.e., to the center of the world according to a strictly Aristotelian point of view.

[11] Another solution would be to consider the Correspondence to: take place between the concepts of impetus and kinetic energy, which, as opposed to force, is a magnitude that remains throughout motion without requiring a force to keep it (as long as the motion does not undergo contrary actions). Duhem seems to be aware of this view as, referring to projectile motion, he says that "John Philoponus declared that the arrow continues to move without any motor applied to it because the string of the bow has given it an *energy* that plays the role of motive virtue" (1996 [1913], p. 244) (my italics).

[12] We only say "inspired by" Friedmann because he makes it clear that this notion "need not imply a second and further conception of convergence, according to which successive scientific theories are viewed as ever better approximations to a radically external world existing entirely independently of the scientific enterprise itself" (2001, p. 67), which is precisely how Duhem conceives of it.

[13] Friedman's principle could also be applied to a non-realist interpretation of physical theories. What this paper shows, however, and this is possibly a unique use of the principle, is that it can tackle the idea of progress of a theory characteristic of Duhem's historical views and for which the case of evolution of concepts cannot be ignored.

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6. Dependence between logical unity and historical continuity

As we have seen, for Duhem, "a coherent physical theory [is] more perfect than an incoherent collection of incompatible theories" (1996 [1893], p. 67). Physical theories "can and should tend toward perfection" (ibid., p. 68); "perfection", in this case, implies that "analogies brought to light by them would be not accidental agreement, but true relations, showing the connections that really exist among essences" (ibid., p. 67). There is here, in principle, a logical relationship being established between theory and reality by means of analogy.

The concept of analogy as an instrument of discovery relies on the existence of some similarity between a known domain and a domain being investigated: "an analogy may be said to exist between two objects in virtue of their common properties" (Hesse, 1966, p. 58). In the present case, these are similarities among structures, i.e., the mathematical structure of theories, on the one hand, and the way essences are organized, on the other. The latter, the material term of the analogy, presumes unity in the sense of singularity, since, from a realist point of view, there is only *one* reality outside the subject. Therefore, being similar requires unity from the theory in a sense that goes beyond the mere logical coherence – its ideal form does not allow competition; it must be *unique*.

Given this, one should look at history for facts that lead to unity, i.e., to the continuity of what have been successful. As we have seen, for Duhem, this continuity is guaranteed as far as the representative aspect of theories is concerned, with a relative continuity of concepts, as shown in the previous section. Continuity allows a certain degree of historical foresight regarding the formulation of hypotheses, and a theory grounded on historical development carries a relationship analogical in character with the structures of reality. However, although one cannot require that an analogy be true, from a Duhemian point of view, it can contain a certain degree of truth: the presence of truth is justified by its predictive power. Thus, the possibility of natural classification as singular theory is justified by the connection between logical unity in the sense of uniqueness and historical continuity in Duhem's terms.

7. Conclusion: rescuing coherence

We have seen that the possibility of natural classification rests on the requirement of logical unity and historical continuity. Duhem's historical work is devoted to providing evidence for a lasting tradition that leads to unity. As such, its lack of an explicit reference to natural classification does not represent an obstacle to the integrity of his work: itself a metaphysical concept, natural classification may not be explicitly mentioned there, however, it acts as a heuristic principle, at the same time subsidizing and being the end product of the historical narrative.

There is an analogy between physical theory and the organization of essences. Because of that, there is no change in status between a current theory and its ideal form, since the latter maintains an analogical relation with the structures of reality. This ideal form presents itself simply as a limit for the physical theory, and, as in the mathematical notion of limit, the physical theory comes gradually closer to natural classification through a process of "addition", without effectively ever reaching it. The continuous production of the natural classification, like in a continuous function, will inexorably lead to a limit which will ideally represent the effective form of reality.

No share of natural classification is achieved simply because one gives up denying that physics derives from metaphysics or adds explicative parts to a theory; it is rather intuited from history. Thus, the ideal theory will result from an infinite, therefore unending, process of additions of natural classification, and, being only a goal, its ontological nature does not represent a rupture with a theory in progress, since it is a continuous superposition of parts of natural classification over a structural base that persists along history.

In other words, Duhem's epistemological views involve a time-related aspect that cannot be ignored. It is simply not possible to understand his epistemology disconnected from his approach to history. Successful theories are always associated with traditions that, recorded by history, lean towards well-defined directions. We are presented with a kind of history that is intrinsic to the very development of theories, not in the sense of justifying their present, as the no-miracle argument does, but as a legacy left for their future evolution.

Like a function whose limit tends to an unreachable but unique value such as infinity and does so through a predetermined process, the tradition forged by history guarantees that the sum of partial truths ("sum" understood here by analogy with the process of mathematical limit) will result in a unique although only ideal theory, namely, natural classification. That is why Duhem's epistemology cannot be separated from the relationship between logical unity and historical continuity. Taken in this way, tradition preserves the analogical nature of the relationship between theory and reality and, therefore, makes the hiatus between a theory in progress and its goal a false problem that does not jeopardize the coherence of Duhem's thought.

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