AN ANALYSIS OF MENDEL'S TWO HYBRIDIST THEORIES AND THEIR INTERTHEORETICAL RELATIONSHIPS*

PABLO LORENZANO
Center of Studies in Philosophy and History of Science (CEFHIC)-National University of Quilmes (UNQ)/National Scientific and Technical Research Council (CONICET),
pablo.lorenzano@gmail.com

*ABSTRACT – Based on a statistical analysis of his experiments, which was a novelty for the tradition of "horticulturalists" (or "plant breeders") as well as for the tradition of "hybridists", and seeking a "generally applicable law governing the formation and development of hybrids" (MENDEL 1865: 3), Mendel states "the law of development/evolution found for Pisum" (MENDEL 1865: 32). When he tries to provide the "foundation and explanation" (MENDEL 1865: 32) of the law of formation and development of hybrids, he does it in terms of the production and behavior of egg cells and pollen cells, and, ultimately, in terms of the nature and behavior of what he calls "elements" (MENDEL 1865: 41) or "cell elements" (MENDEL 1865: 42). Moreover, Mendel recognizes the existence not just of hybrids that behave like those of Pisum – i.e., of "variable hybrids" – but also of hybrids that "remain perfectly like the hybrid and continue constant in their offspring" (MENDEL 1865: 38) and "acquire the status of new species" (MENDEL 1865: 40) – i.e., of "constant hybrids" (MENDEL 1869: 27–28, 31). The law that would govern the behavior of constant hybrids would also find its foundation and explanation in terms of the nature and behavior of elements (or cell elements). Mendel's hybridism consists of two theories: a theory that moves on a more "empirical" level, according to Schleiden's first "special guiding maxim", the "Maxim of the history of development/evolution" (SCHLEIDEN 1849: 141, 142, 146), which can be called "Mendel's theory of the development/evolution of hybrids" (**DEH**), and a theory that moves on a more "theoretical" level, according to Schleiden's second "special guiding maxim", the "Maxim of the autonomy of cells in plants" (SCHLEIDEN 1849: 146, 148), which can be called "Mendel's theory of the cellular foundation of the development/evolution of hybrids" (**CFH**).*
The paper aims to present an analysis of these two theories and their intertheoretical relationships, carried out within the framework of the so-called Metatheoretical Structuralism (BALZER, MOULINES & SNEED 1987).

INTRODUCTION

According to the most popular version of the history of genetics (the so-called "traditional account", OLBY 1979, "orthodox image", Bowler 1989, or "official story of genetics", LORENZANO 1995),[1] Johann (Gregor) Mendel (1822–1884) – in his "Versuche über Pflanzenhybriden" ["Experiments in Plant Hybridization"] read in 1865 at the

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Natural History Society of Brünn and published in its *Proceedings* in 1866 –, when, in trying to solve the problem of inheritance, he introduces the fundamental concepts and the laws later called in his honor "Mendel's Laws": the "Law of Segregation" (or "Mendel's First Law") the "Law of Independent Assortment" (or "Mendel's Second Law") and sets the foundations of the theory later called "classical", "formal" or "Mendelian" genetics. However, reading his original works carefully and trying to place his research in the context of 19th century biology might suggest a different picture.

For at least five decades there have been historiographical controversies concerning the figure of Mendel in the following aspects:

(1) Personal-biographical (e.g., Was he an amateur working in the solitude of the Augustinian monastery of Alt-Brünn? Was his relationship with Nägeli fatal for his aims?)

(2) Experimental (e.g., Were his results "too good to be true"? Does his account of the order and sequence of his experiments correspond to the actual order and sequence in which he carried them out?)

(3) Erotetic and theoretical-conceptual (e.g., What problem he was trying to solve? Were his basic concepts the same as those of Classical Genetics? Were the laws he proposed identical to the so-called "Mendelian Laws"? Was "the" theory presented by Mendel identical to the one later attributed to him under the name of "Mendelian Genetics")?[2]

The aim of this paper is to discuss some of the third type.[3] In particular, it will be discussed here what problem Mendel was trying to solve and whether he introduced the fundamental concepts, laws, and theory later labeled "Mendelian Genetics". And, if not, what were the concepts, laws, and theories he introduced?

We will distinguish two hybridist theories proposed by Mendel with their concepts and laws. A first theory that moves on a more "empirical" or "phenomenological" level, according to Schleiden's "Maxim of the history of development/evolution [*Entwicklungsgeschichte*]"[4] (Schleiden 1849: 141–146), which can be called "Mendel's theory of the development/evolution of hybrids" (**DEH**), and a second theory that moves on a level more "theoretical" one, according to Schleiden's "Maxim of the autonomy of cells in plants" (Schleiden 1849: 146–148), which can be called "Mendel's theory of the cellular foundation of the development/evolution of hybrids" (**CFH**).

Next, an analysis of these two theories and their intertheoretical relationships will be presented and carried out within the framework of the so-called Metatheoretical Structuralism (Balzer, Moulines & Sneed 1987). This metatheory will be used throughout the paper, both informally and semi-formally. We will present some technical clarifications in the Appendix, which complements the analysis contained in the article.

2. AN ANALYSIS OF MENDEL'S *VERSUCHE* (1865)

Two main parts, or levels, can be distinguished in Mendel (1865). They are connected to the special guiding maxims ("specielle leitende Maximen") that appear in the "Methodological Introduction" – written "As Instructions for the Study of Plants" – to Schleiden's 1849 text (Schleiden 1849: 1–162). This text was recommended to Mendel by Franz Unger,[5] his professor during his studies at the University of Vienna, and was adopted by him to practice botany according to the methodological standards of his time.

The co-founder of cell theory and founder of the cell theory of plants, Matthias Jakob Schleiden (1804–1881), following the so-called "Kantian-Friesian natural philosophy" founded by Jakob Friedrich Fries (1773–1843) in Jena, reformulated Fries' general guiding maxims for the research of nature – according to which inductions and hypotheses are oriented, evaluated and justified – especially for botany which is considered to be an "inductive science" (Schleiden 1849).[6]

In the first main part, or level, of Mendel (1865), he intends to find a "generally applicable law governing the formation and evolution of hybrids" (1865: 3[21][7]), i.e., to find the way in which the hybrids develop/evolve, by carrying out a statistical analysis of his experiments, basically performed with *Pisum*. This was considered by Mendel a previous step in order to try to solve a problem that was for him a central problem in "the history of the evolution of organic forms" (1865: 4[22]). Mendel does not explicitly formulate this "question whose significance [...] should not be underestimated" (1865: 4[22]) but presupposes it as implicitly understood by the readers to whom his text is addressed. This is the problem posed by one of the two schools or traditions of research that it is common to note used the method of breeding toward the end of the 18th century and in the first half of the 19th century (Mayr 1982: 641), namely that of *species hybridizers*, or simply "hybridists" ("Hybridisten"). The other school or tradition is that of *animal and plant breeders* ("Tier- und Pflanzenzüchtern"), also called "horticulturalists".[8] Hybridists possessed an academic background and, starting from the problem of the sexuality of plants, engaged the question raised in the 18th century of whether new species could be created by *crossing – hybridizing – preexisting ones*.[9] This problem may be called *the problem of speciation by hybridization*.[10]

Of breeders we might say that they were practical men that wanted to know how new and economically useful varieties could be created and fixed in offspring; thus, trying to improve the productivity of the plants they grew (or animals they bred) – for instance, their resistance to cold, the color of their flowers or the quality of the wool or meat obtained from them – and to produce new varieties by *crossing already existing varieties* that differed in a few characteristics. Among them we might mention Thomas Andrew Knight (1799, 1824), Alexander Seton (1824), John Goss (1824) and Augustin Sageret (1826), all of whom provided examples of the phenomena known today by the name 'dominance' and 'segregation' without having determined their numerical relations (the first three even worked on genus *Pisum*, the very same Mendel would later work on, who, in turn, was apparently familiar with their results).[11]

It is worth noting here that, on the one hand, some breeders were explicit on the role played by hybrids in the generation of new species and, on the other hand, hybridists also reported what happened in their crossing experiments with individual traits – thus blurring the original distinction (or, at least, some of the terms in which it is formulated) –, in addition to the circumstance that Mendel, unlike his more conspicuous hybridist predecessors, such as Kölreuter and Gärtner, does not establish *any* distinction between varieties and species, because he considered it only a matter of degree, nor between hybrids of varieties and hybrids of species.

So, the fact that, "[t]he positions, however, which may be assigned to them in a classificatory system are quite immaterial for the purposes of the experiments in question" (Mendel 1865: 7[24]) is what allowed Mendel to face the problem of hybridists (raised in relation to species) with the breeders' techniques (used on what are accepted as varieties). Besides, if we take what Mendel regards as "the strictest determination of a species, according to which only those individuals belong to a species which under precisely the same circumstances display precisely similar characteristics, no two of these varieties could be referred to one species" (Mendel 1865: 6[24]),[12] either this is not the case, since though the plants he used don't meet the stipulated requirement, systematic botanists ("experts") claim that "the majority belong to the species *Pisum sativum*; while the rest are regarded and classed, some as sub-species of *sativum*, and some as independent species, such as *quadratum*, *saccharatum*, and *umbellatum*" (Mendel 1865: 6[24]), or rather, if we apply it to one or a few traits of individuals, we may hold that individuals that satisfy it belong to (or constitute) the same species. This latter option is what would justify Mendel's terminology of referring throughout his work to his varieties of peas as different "species" (*Arten*).[13] In that sense, we may consider Mendel himself as a hybrid between the two afore-mentioned schools or traditions. Mendel, encouraged by crossings of the kind performed by *plant breeders* or *horticulturists* (crossings performed in order to obtain desirable modifications in individual traits), directed his attention to a problem related to *hybridists* – such as Kölreuter, Gärtner, Herbert, Lecoq and Wichura –, namely, to find a "generally applicable law governing the formation and development of hybrids" on the basis of a statistical analysis of his experiments.[14] Additionally, he explicitly establishes a relation between that problem and an issue only mentioned in the introduction to Mendel (1865) and mostly taken for granted, which is the problem raised by hybridists of whether new species can be produced by crossing (or hybridization of) pre-existing ones.

In the first part or level of his most well-known paper, Mendel states "the law of development/evolution found for *Pisum*" (1865: 32[50]), which decomposes in "the law of simple combination of characteristics" (1865: 32[50]), and its generalization, "the law of combination of the differing characteristics" (1865: 32[49]).

This part moves on a, let's say, more "empirical" or "phenomenological" level, according to Schleiden's first "special guiding maxim", the *maxim of the history of development/evolution*, that reads as follows:

> *A*. Maxim of the history of development/evolution [*Entwicklungsgeschichte*]. [...] the *only* chance of reaching a scientific understanding in botany, and so, the only and inescapable instrument self-originated in the nature of the object, is the study of the *history of development/evolution*. [...] every *hypothesis, every induction in botany that is not oriented by the history of development/evolution must be rejected unconditionally*. (Schleiden 1849: 141, 142, 146; Schleiden's emphasis)

In order to give an answer to the question "How do hybrids develop/evolve?" – which would lead to making a decision on the question of whether new species can be generated by hybridizing (crossing) preexisting species–, Mendel proposes the "theory of the development/evolution of hybrids" (**DEH**).

On the other hand, in the second part or level of Mendel (1865), he intends *to lay the foundations and to explain* "the law of development/evolution found for *Pisum*" that rules the behavior of the "*variable* hybrids", but also the law that would govern the behavior of the "*constant* hybrids". After Mendel (1865), examples of them are the following hybrids: *Aquilegia atropurpureo-canadensis*, *Lavatera pseudolbio-thuringiaca*, *Geum urbano-rivale*, some of *Dianthus*, and those of the Willow family, and, according to Mendel (1869), also those of *Hieracium*.

In this second part or level of Mendel (1865), he relates the production and behavior of egg cells and pollen cells to the production and behavior of constant forms (characteristics), and, ultimately, on the nature and behavior ("material composition and arrangement") of what he calls "elements" (1865: 41[58]) or "cell elements" (1865: 42[60]), being either a *temporary association* of the *differing* cell *elements* for explaining the *behavior* of the *variable* hybrids or a *permanent association* of the *differing* cell *elements* for explaining the *existence* of the *constant* hybrids (1865: 42[60]).

This part moves on a, let's say, more "theoretical" or "underlying" level, according to Schleiden's second "special guiding maxim", the *maxim of the autonomy of cells in plants*:

> *B.* Maxim of the autonomy of cells in plants. [...] essentially the life of plants must be contained in the life of cells [...] *every hypothesis, every induction that does not purport to explain the processes that occur in the plant as a result of the changes that take place in individual cells must be rejected unconditionally.* (Schleiden 1849: 146, 148; Schleiden's emphasis)

In order to give an answer to the question "Why do hybrids develop/evolve in the way they do?", Mendel proposes, though only hypothetically, the "theory of the cellular foundation of the development/evolution of hybrids" (**CFH**).

3. SOME METATHEORETICAL NOTIONS

It could be said that concepts – which enable us to articulate knowledge – are the smallest meaningful units in science. *What concepts are* is one of the most difficult subjects in philosophy, which has been very much discussed – at least since Plato's time, and in general, related to the so-called *problem of universals* –, and which is still being discussed, with the contribution of other disciplines, like linguistics and psychology. The variety of theories about concepts is impressive, including those positions which *deny* the existence of concepts.

Yet, we will neither present the different theories here nor attempt to mediate the debate among them. Assuming *there are concepts*, for the sake of argument, and they are *different* from the *words* and *things* they designate, denote, or refer to and are closely related to both of them, their kinds, classifications, and functions are also very much discussed in the literature.

In the analysis of empirical science, one distinction is usually made between logico-mathematical and descriptive concepts. The latter are frequently classified in different ways, according to the criterion chosen. According to their formal structure, descriptive concepts are classified as qualitative (or classificatory), comparative (or topological), and quantitative (or metric). If we look at their relationships in a system of concepts, they will be classified into primitive and defined. If we do so according to their set-theoretical type, they are differentiated into those that denote domains of objects, relations, or functions. And if what is relevant is the function they fulfill in the theory they occur, descriptive concepts are divided into those specific to the theory in question and those coming from "outside". (In the terminology of Metatheoretical Structuralism, the first kind of concepts, which can *only be* determined by applying the theory's laws, are called "**T**-theoretical" concepts, whereas the second kind of concepts, which are typically determined by the laws of other "underlying" theories, are called "**T**-non-theoretical" concepts).[15]

However, both in science and in daily discourse, language is used primarily to make *assertions* (statements or claims), i.e., to say that certain things are a certain way. Concepts are essential for this use, but it is not enough to consider them in isolation, since they do not constitute assertoric units on their own. The smallest assertoric units are the so-called *propositions* or, in linguistic terms, *statements* or *sentences*.

A special kind of scientific statements are the so-called *laws*. At least as of 1930, the problem of what a (scientific) law is had been discussed. That is, the problem of finding the necessary and sufficient criteria or conditions that a statement should satisfy in order to be considered or in order to function as a (scientific) law, or the necessary but not sufficient conditions; or the sufficient but not necessary conditions; or the disjunction of conditions neither necessary nor sufficient, but whose instances of application share a certain "family resemblance" (Wittgenstein), or a cluster of criteria associated with it, of which only the majority must be satisfied by any instance (prototype theory), even though these conditions or criteria may change historically.

Despite successive and renewed efforts, a generally accepted solution does not seem to have been found. Nevertheless, this does not mean that, although we do not yet have at our disposal a totally satisfactory explication of the concept of scientific law, everything done up to the present moment in this sense has been in vain or that now we do not "know more" than before what a (scientific) law is and how it functions.

Nevertheless, there are philosophers who denied the existence of laws in biology. The main reasons provided for such a view are the locality or non-universality of generalizations in biology (Smart 1963) and their alleged contingency (Beatty 1995). We must distinguish the claim that there are no laws of any kind in biology, which goes against the use by biologists who give the label "law" to many different sentences, and the claim that there are no fundamental and/or general nomological principles in biology (see Lorenzano 2006, 2007, for a discussion).

As for the non-universality of biological generalizations, we contend that universality is too demanding a condition. What matters is not strict universality but rather the existence of at least non-accidental, counterfactual-supporting generalizations, whose presence in biology we think is hardly deniable, though generally they are more domain restricted and ceteris paribus dependent than in other scientific areas such as physics.

Many philosophers of biology, and of physics as well, accept a broader sense of lawhood that does not require non-accidental generalizations to be universal and exceptionless in order to qualify as laws (Carrier 1995, Mitchell 1997, Lange 1995, 2000, Dorato 2005, 2012, Craver & Kaiser 2013, Lorenzano 2014). Our minimal characterization of laws as *counterfactual-supporting regularities* is similar to the one defended in Dorato (2012), and it is also compatible with some proposals about laws in biology in particular, such as the "paradigmatic" (Carrier 1995) and "pragmatic" (Mitchell 1997) ones.

On the other hand, it is worth noting that there are usually many distinct laws with different levels of generality formulated within the same conceptual framework. This distinction between two types of laws with different degrees of generality was explicated in the classical philosophy of science, especially in the Hempelian proposal, with the distinction between fundamental laws and derivative laws (Hempel & Oppenheim 1948). Comparably, in the historical philosophy of science, in the Kuhnian version, it was explicated with the distinction between the symbolic generalizations – "generalization-sketches" (Kuhn 1974), "schematic forms" (Kuhn 1974), "law sketches" (Kuhn 1970, 1974) or "law-schema" (Kuhn 1970) – and their "particular symbolic forms" (Kuhn 1974) adopted for application to particular problems in a detailed way.

Metatheoretical Structuralism elaborates the classical and the Kuhnian distinctions in a different way. It draws a distinction between the so-called *fundamental laws* (or *guiding principles*) and the so-called *special laws*. Briefly, fundamental laws are those laws having *cluster or synoptic character* – i.e., including every fundamental concept –, *applicability to every intended application* – i.e., their universal applicability is relativized to the phenomena/applications intended by the theory's users: the set of intended applications of the theory –, *quasi-vacuous character* – i.e., being highly abstract and schematic, and contain essential occurrences of **T**-theoretical terms whose extension can only be determined through the application of a theory's fundamental law(s) so that they can resist possible refutations, but which nevertheless acquire specific refutable empirical content through the (non-deductive) process of specialization –, *systematizing* or *unifying role* – i.e., allowing to include diverse applications within the same theory since they provide a guide to and a conceptual frame for the formulation of other laws (the so-called 'special laws'), which are introduced to impose restrictions on the fundamental laws and thus for them to apply to particular empirical systems –, and *modal import* – i.e., expressing non-accidental regularities, and being able to give support to counterfactual statements (if they are taken together with their specializations within a theory-net), even when they are context sensitive and have a domain of local application, they are necessary in their area of application. Fundamental laws/guiding principles are thus "programmatic" or heuristic in the sense that they tell us the kind of things we should look for when we want to explain a specific phenomenon. But, as mentioned before, taken in isolation, without their specializations, empirically they say very little. They can be considered, when considered alone, "empirically non-restricted" in the sense that in order to be tested/applied they have to be specialized ("specified"). On the other hand, the so-called "special laws" are these specific forms adopted by the fundamental laws. The relationship established between laws of different levels of generality is *not* one of implication or derivation, but of *specialization* in the structuralist sense: bottom laws are specific versions of top ones, i.e., they specify some functional dependencies (concepts) that are left partially open in the laws above. That is the reason why they are called "*special* laws" instead of "*derivative* laws" like in the classical view of laws, according to which the laws with a more restricted or limited scope are assumed to be logically derived or deduced from the fundamental laws. Actually, "special laws" *are not derived* or *deduced literally* from the fundamental laws (at least are not derived or deduced *only* from them) without considering some additional premises.

In the same way that in the case of law discussed above there has long been the problem of establishing the nature and structure of a scientific theory. After decades of discussion, different conceptions coexist, often at odds, of what a theory is, how it is articulated, and how it works.

Three main philosophical conceptions about scientific theories have been developed during the twentieth and the twenty-first century so far: the "classical (or received)" view, the "historical (or historicist)" view and the "semantic (or model-theoretic)" view. The classical conception (or "received view") was developed in the classical phase of philosophy of science, from approximately the end of 1920 to the end of 1950, initiated mainly in Central Europe and continued mostly in the United States, following the arrival in that country of European philosophers of science (such as Rudolf Carnap and Carl G. Hempel). The historical (or "historicist") conception was developed in the historicist phase of philosophy of science, which was initiated approximately between the end of the 1950s and the beginning of the 1960s and dominant during the 1970s and early 1980s, thanks to the work of those who were once called "new philosophers of science" (such as Thomas S. Kuhn and Imre Lakatos). And the semantic (or "model-theoretic") conception that, even when with previous developments, is consolidated towards the end of the 1970s and during the 1980s as an alternative to the classical and historicist views.

In the above-mentioned metatheoretical conceptions, we can distinguish three general aspects in the explication of the concept of theory: one referring to the (more) "theoretical" (or "formal") part, another to the (more) "empirical" ("applicative" or "testing") part, and the last referring to the relationship between both parts, between the "theoretical" and the "empirical", between the "theory" and the "experience".

One of the main differences between these conceptions lies in the central basic ideas they have about the general way of conceiving each of these aspects.

Regarding the *classical view* it could be said that, although all classical philosophers of science considered theories to be sets of statements organized deductively or axiomatically, not all agreed on the specific way in which this should be understood and clarified.

Central to the *historicist view* was the idea that scientific theories – which the historicist philosophers refer to with different terms, e.g. *paradigms* or *disciplinary matrices* for Kuhn, *research programmes* for Lakatos, *research traditions* for Larry Laudan – are not sentences or sentence sequences, and in a proper sense they cannot be described as true or false (although true or false empirical claims are certainly made with them), but they are highly complex and ductile entities, susceptible of evolving in time without losing their identity.

The distinctive feature of the semantic conception is the centrality models play in the philosophical analysis of the concept of theory. According to the semantic conception the most fundamental, and essential, component for the identity of a scientific theory is a class (set, population, collection, family) of models.[16] Consequently, the strong conviction of the semantic conception is that concepts relative to models are much more fruitful for the philosophical analysis of theories, their nature and function, than concepts relative to linguistic expressions or propositions.[17]

Metatheoretical Structuralism is a version, variant or approach of the semantic conception. We will use it only informally or semi-formally, without going into technicalities (for some of them, see the Appendix), but retaining some of its basic ideas. On the one hand, the idea of different kinds of concepts that make up the conceptual framework of a theory. On the other hand, the distinction between fundamental laws and special laws of a theory. And, finally, the resulting structure of a theory, which could be represented, in a simplified form, as a net, where the nodes are given by the conceptual framework of a theory and the laws with different levels of generality – with the fundamental law(s) that characterize(s) the basic node at the top –, and the links represent different relations of specialization.

In this presentation of Metatheoretical Structuralism, the (more) "theoretical" (or "formal") part of a theory **T** would be constituted by the (whole) conceptual framework of the theory conceived as a structure containing **T**-theoretical and **T**-non-theoretical concepts and by the (fundamental as well as special) laws; the (more) "empirical" ("applicative" or "testing") part of a theory by the "phenomena" or intended applications conceived as systems expressed through the **T**-non-theoretical concepts; and bearing in mind that the "theoretical" and the "empirical" parts are conceived as systems or structures of a certain type, the relationship between both would be of a sort of morphism, generally weaker than isomorphism, such as homomorphism – or isomorphism but between the systems or

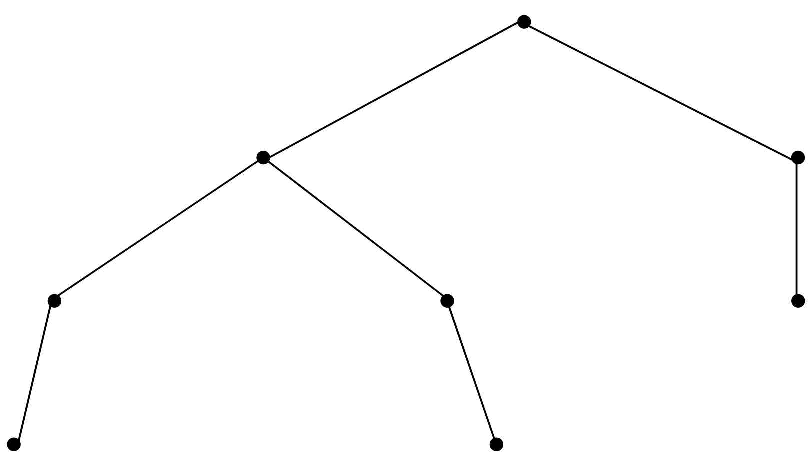

Fig. 1. A graphic representation of a theory-net.

structures that represent the "phenomena" and a part of the systems or structures that represent the formal part of the theory (either a partial structure or substructure or even a partial substructure of them)[18] – a relationship that is often called "embedding".

When one wants to analyze a theory, the first thing to distinguish informally is what the theory (or the theory's user) intends to explain, on the one hand, and how the theory (or the theory's user) explains it, on the other. In general, "what the theory intends to explain" is formulated in the non-theoretical vocabulary of the theory, i.e., with the **T**-non-theoretical terms or concepts of the theory **T**. Whereas "how the theory explains it" appeals to the theoretical concepts for the theory **T** and to the laws of the theory by extending the **T**-non-theoretically described systems with the **T**-theoretical concepts in such a way that the laws are satisfied.

Let us now apply these metatheoretical ideas to the analysis of both Mendel's hybridist theories – the theory of the development/evolution of hybrids (**DEH**) and the theory of the cellular foundation of the development/evolution of hybrids (**CFH**) –, beginning with the first of them.

4. MENDEL'S THEORY OF THE DEVELOPMENT/EVOLUTION OF HYBRIDS (DEH)

The theory of the development/evolution of hybrids (**DEH**) intends to explain the formation and evolution of hybrids. This is represented through crossings of individuals with constant differing characteristics – that part corresponds to the "formation of hybrids" – and their subsequent distribution in the offspring of such crossings – that part corresponds to the "evolution of hybrids".

On the other hand, **DEH** explains the formation and evolution of hybrids by postulating the formation of hybrid characteristics (or forms), which are in a dominance/recessivity relationship, and which are transmitted (or distributed) in a certain way in the offspring so that the distribution of constant differing characteristics "matches/fits" with the "series of development/evolution of the hybrids" – i.e., with the distribution of constant differing characteristics (dominant and recessive) and of hybrid characteristics (forms) in the offspring –, given the dominance/recessivity relationship.

Let us now present the conceptual framework of Mendel's **DEH** in more detail, which can be represented by structures as the following one:

$\langle I, (C_i)_{i \leq k}, (H_i)_{i \leq k}, APP, DOM, REC, MAT, DIST, SER \rangle$.

There,

- I represents the set of *individuals* (parents and progeny), which constitute populations linked by kinship relations.
- $(C_i)_{i \leq k}$ the set of types of *constant differing characteristics* (where each set C_i should be considered as a characteristic and the members $c_i \in C_i$ as traits or expressions of that characteristic; Mendel only considers two traits per characteristic, or two cases of each type of characteristic; they are the "observed" characteristics).
- $(H_i)_{i \leq k}$ is the set of *hybrid forms* or *characteristics*, constituted by a set of pairs of constant differing characteristics symbolized by $\langle c_i, c_i' \rangle$ or simpler by $c_i c_i'$ (where each type i of the set H corresponds to type i of the set C from which it originates).
- *APP* represents a *function that assigns their traits or characteristics of a certain type or appearance to individuals* ("what is observed").
- *DOM* is a dyadic relation in which are (some of) the traits or cases of characteristics of a certain type C_i, namely, the hybrid characteristics. The relation of *dominance*, or

its converse of *recessivity*: $REC =_{def} DOM^{-1}$, sorts out the *dominant* constant differing characteristics from the *recessive* ones).[19]

- *MAT* is a *function of mating that assigns their progeny to any two parents*.
- *DIST* is a *function that represents the ratios or relative frequencies of the traits or characteristics of a certain type observed in the progeny*.
- And *SER* is a *function that represents the transition of parental dominant or recessive constant differing characteristics and hybrid characteristics to their distribution in the progeny* or a *series for the formation of hybrids and of the evolution for the progeny of the hybrids*.[20]

If we use these concepts to represent what **DEH** intends to explain, i.e., the formation and evolution of hybrids, we would use some but not all of them. In particular, we would use the **T**-non-theoretical concepts of **DEH**.[21] They are the concepts of (the set of) individuals (I), of (the set of types of) constant differing characteristics ($(C_i)_{i \leq k}$), of appearance (*APP*), of mating (*MAT*), and of distribution of characteristics of a certain type in the progeny (given in terms of ratios or relative frequencies) (*DIST*).

If we put together these concepts, we obtain structures as the following one:

$\langle I, (C_i)_{i \leq k}, APP, MAT, DIST \rangle$.

Structures of this logical type, which can be used to represent the "phenomena", the "(empirical) systems" to which the theory intends to apply, are partial substructures[22] of those containing the totality of **DEH**'s concepts.

On the other hand, the whole conceptual framework of **DEH** is used to express "the law found in *Pisum*", i.e., the law valid for the development/evolution of the variable hybrids of *Pisum*, and, therefore, by generalizing it, the law valid for the development/evolution of variable hybrids. By means of this law – containing the function *SER* as well as of the other **DEH**-theoretical concepts $(H_i)_{i \leq k}$, *DOM* and *REC* – the formation of hybrids and the distributions of the constant differing characteristics in the progeny – which constitute the intended applications of **DEH**, and whose representations only use the **DEH**-non-theoretical concepts I, $(C_i)_{i \leq k}$, *APP*, *MAT*, *DIST* – can be explained. For this reason, we may also assume that these same concepts can be used to express the law that would be valid for the development/evolution of constant hybrids, as well as for the "generally applicable law governing the formation and evolution of hybrids". However, Mendel admits that "we do not possess a complete theory of hybridization" (Mendel 1869: 28[67]).[23]

From the theory-net that makes up such a theory, he came to propose in a developed way only one of the nodes, namely, that that represents the line of specialization corresponding to the development/evolution of the variable hybrids (**DEHV**), given by the whole conceptual framework of the theory and the law restricted to variable hybrids.

He also suggests how does the specialized node that would represent the line of specialization corresponding to the development/evolution of the constant hybrids (**DEHC**) look like, given by the conceptual framework of the theory and the law restricted to constant hybrids.

And he just suggests the existence of the basic node ($\mathbf{DEH}_0$), which would contain, besides the whole conceptual framework of the theory, "a higher, general, law" (Mendel 1870: 1270), the "generally applicable law governing the formation and evolution of hybrids", which would be *the fundamental law of* **DEH**, but that Mendel never came to formulate:

> On this occasion I cannot resist remarking how striking it is that the hybrids of *Hieracium* show a behavior exactly opposite to those of *Pisum*. Evidently, we are

> here dealing only with individual phenomena, which are the manifestation of a higher, more fundamental, law. (MENDEL 1870: 1270)

Imagine that someone would give that step that Mendel never did. She might formulate a part of this "higher, general, law" – *the* "law governing the formation and evolution of hybrids" –, in its highest generality, as claiming something like "that types of parental either constant or hybrid differing characteristics are distributed in a certain way (given by *SER*) in the progeny".

This would be what we consider the theoretical part of the *fundamental law* of **DEH**, but not the complete law. This is because it is centered on the **DEH**-theoretical distributions of either constant or hybrid differing characteristics, leaving aside the matching/fitting relationship between the **DEH**-theoretical distributions (given by *SER*) and the **DEH**-non-theoretical distributions of constant differing characteristics observed in the progeny (given by *DIST*).

And let us remember that the distribution of either constant or hybrid parental differing characteristics (given by *SER*), together with the relation of dominance (given by *DOM* and by its converse of recessivity *REC*), is what explains the constant differing characteristics observed in the progeny (given by *DIST*). A complete formulation of the *fundamental law* of **DEH** should take this into account. And if one would want to take this path, the basic, fundamental law of Mendel's **DEH** would claim that

(I) For any given parental pair that mates and produces offspring, the distributions of dominant or recessive constant differing characteristics and of hybrid forms – given by *SER* – and of differing characteristics – given by *DIST* – in the progeny of this pair *ideally* match or fit – through *DOM* (and REC) – with each other.

On the other hand, the special laws of this theory would say just the particular way in which the considered types of characteristics are distributed, i.e., they would establish the specific form adopted by *SER* for such types of characteristics.

"The law found in *Pisum*" (for variable hybrids) decomposes in "the law of simple combination of characteristics" (MENDEL 1865: 32[50]) – first for monohybrids, then for dihybrids and finally for trihybrids –, and its generalization, "the law of combination of differing characteristics" (MENDEL 1865: 32[50]). Inasmuch as they establish the specific form adopted by *SER* for the number of types of characteristics considered, they can be regarded as special laws of **DEH**.

Nevertheless, as said before, we should consider the theory of the development/evolution of hybrids, as Mendel himself consider it, as an incipient theory, in its initial stages of development, i.e., as an incomplete theory.

But the incompleteness of this theory is not that which could be found in the initial formulations of other empirical theories, such as those found in *Philosophić Naturalis Principia Mathematica* (NEWTON 1687) for classical particle mechanics or in *On the Origin of Species by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life* (DARWIN 1859) for the theory of natural selection.

In these cases, the theories were presented – or, at least, they were intended to be presented – in a more or less precise and explicit way. These presentations would allow for the identification of an initial theory-net – with its conceptual framework, its fundamental law(s), and some of its special laws as well as some successful applications. And some of these applications became "paradigmatic" for the theory in its later development. This development is what Kuhn called "normal science" (KUHN 1970), and Metatheoretical Structuralism, "theory-evolution" (BALZER, MOULINES & SNEED 1987).

Though, the incompleteness of the theory that we refer to in **DEH** is different. It lies in the fact that it does not contain that initial theory-net. And that for the reasons mentioned above: in Mendel's texts, one does not find the "universally valid law on the formation and evolution of hybrids" at the top of the theory-net, and from which one would obtain, as two lines of specialization of this, the "law valid for *Pisum* (and other variable hybrids)", which he does formulate, on the one hand, and the "law valid for *Hieracium* and other constant hybrids", which he only suggests, on the other.

If we had such a theory-net, and we symbolize its basic theory-element by $\mathbf{DEH}_0$, the line of specialization corresponding to the variable hybrids by **DEHV** (with the specializations presented in his 1865 text of "the law of the simple combination of characteristics" for monohybrids **DEHVM**, for dihybrids **DEHVD** and for trihybrids **DEHVT**) and the one that would represent the line of specialization corresponding to the constant hybrids by **DEHC**, we would graph it in the following way:

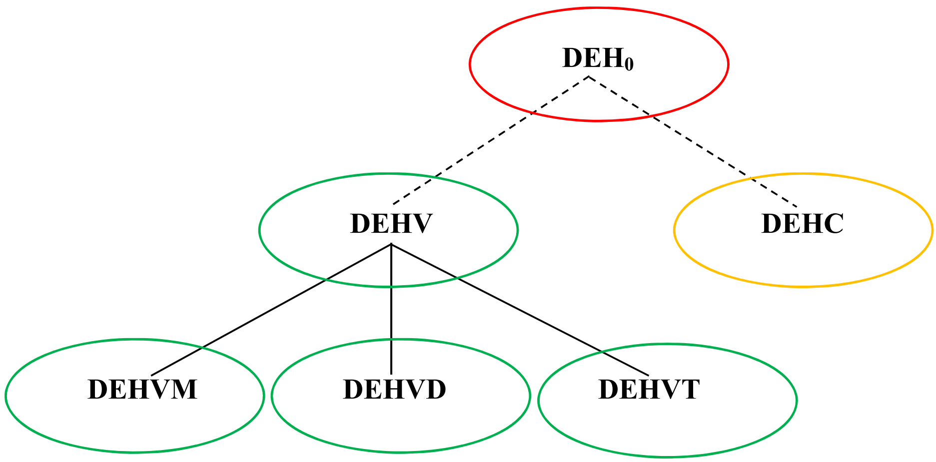

Fig. 2. The theory-net of DEH.

However, as we said, of that possible theory-net, intended by Mendel, he came to propose in a developed way only **DEHV**, suggested **DEHC**, and supposed that $\mathbf{DEH}_0$ must exist, but did not even give hints as to the form it would take.

5. MENDEL'S THEORY OF THE CELLULAR FOUNDATION OF THE DEVELOPMENT/EVOLUTION OF HYBRIDS (CFH)

The theory of the cellular foundation of the development/evolution of hybrids (**CFH**) intends to explain the law of development/evolution (formation and evolution) of hybrids. As we already saw, in order to express such a law, we use the whole conceptual framework of **DEH**, represented by structures of the following logical type:

$\langle I, (C_i)_{i\leq k}, (H_i)_{i\leq k}, APP, DOM, REC, MAT, DIST, SER\rangle$,

The symbols mean here the same as in the previous section.

Mendel proposed in a tentative way that the theory of the cellular foundation of the development/evolution of hybrids (**CFH**) explains the law of development/evolution (formation and evolution) of hybrids by an appeal to the underlying cellular level. In this explanation, a part of it is given by the cellular theory of sexual reproduction presupposed by Mendel – and presented in the section "Die Befruchtungszellen der Hybriden" (MENDEL 1865) –, and another part is tentatively proposed by Mendel – presented in the "Schlußbemerkungen" (MENDEL 1865).

CFH postulates, firstly, the existence of types of reproductive cells, which distribute in a certain way from parents to offspring, and relate to types of constant differing characteristics by a bijective mating function. Secondly, the existence of types of (cell) elements, which distribute in a certain way from parents to offspring, and relate to types of reproductive cells through another bijective function. And, thirdly, the existence of an operation of composition between the bijective functions, which relates types of constant differing characteristics to types of (cell) elements. Then, **CFH** hypothesizes what would be its "law" – how all concepts are articulated to "say something about 'the world'". It claims that there is a match/fit between the distribution of constant differing characteristics (dominant and recessive) and of hybrid characteristics (forms) in the offspring with the distribution of (cell) elements, given the composition of the bijective functions that relate types of reproductive cells with types of constant differing characteristics, on the one hand, and types of (cell) elements with types of reproductive cells, on the other hand.

If we now present the conceptual framework of Mendel's **CFH** in more detail, it can be represented by structures as the following one:

$\langle I, (C_i)_{i\leq k}, (H_i)_{i\leq k}, (R_i)_{i\leq k}, (E_i)_{i\leq k}, APP, DOM, REC, MAT, DIST, SER, DISTR, DISTE, MAP, MAP^*, COMP\rangle$.

There,

- I, $(C_i)_{i\leq k}$, $(H_i)_{i\leq k}$, *DOM*, *APP*, *MAT*, *DIST*, and *SER* represent the same as in the case of Mendel's **DEH**.
- $(R_i)_{i\leq k}$ represents the set of *types of reproductive cells*.
- $(E_i)_{i\leq k}$ represents the set of *types of* (*cell*) *elements*.
- *DISTR* a *function of distribution of types of reproductive cells* from parents to offspring.
- *DISTE* a *function of distribution of types of* (*cell*) *elements* from parents to offspring.
- *MAP* a *bijective function mapping reproductive cells of a certain type to constant differing characteristics of a certain type*.
- *MAP** a *bijective function mapping reproductive cells of a certain type to (cell) elements of a certain type.*
- And *COMP* a function produced by the composition of functions *MAP* and *MAP*,* thus relating *constant differing characteristics of a certain type with (cell) elements of a certain type.*[24]

If we now use these concepts to represent what **CFH** intends to explain, i.e., the law of formation and evolution of hybrids, we would use some but not all of them. In particular, we would use the whole conceptual framework of **DEH**. Structures with the logical type of $\langle I, (C_i)_{i\leq k}, (H_i)_{i\leq k}, APP, DOM, REC, MAT, DIST, SER\rangle$ can be used to represent the "systems" to which **CFH** intends to apply. In a nutshell, they are systems in which the law of formation and evolution of hybrids hold. In a more extended way, they are systems formed by certain individuals (I) that possess (*APP*) certain characteristics ($(C_i)_{i\leq k}$), that interbreed and have offspring (*MAT*), and that, in doing so, their characteristics are distributed in a certain way in said offspring (*DIST*), generating hybrid forms or characteristics ($(H_i)_{i\leq k}$), that are in a relation of dominance or recessivity (*DOM*, *REC*) and that are distributed in a certain way (*SER*), where there is a match between what is stated by *DIST* and by *SER*, that is, between the distribution of constant differing characteristics and the distribution of hybrid forms or characteristics, given the relationships of dominance (*DOM*) and recessivity (*REC*). These structures are partial substructures of those containing the totality of **CFH**'s concepts.

On the other hand, the whole conceptual framework of **CFH** is used by Mendel with the intention of explaining the law of development/evolution (formation and evolution) of hybrids (variable as well as constant ones). By using the symbols introduced above, the following can be said. **CFH** explains the law of development/evolution of hybrids, firstly, by postulating the existence of types of reproductive cells ($(R_i)_{i \leq k}$), which distribute in a certain way from parents to offspring, and relate in a bijective way to types of constant differing characteristics ($(C_i)_{i \leq k}$) by the function *MAP*. And secondly, by postulating the existence of types of (cell) elements ($(E_i)_{i \leq k}$), which distribute in a certain way from parents to offspring, and relate in a bijective way to types of reproductive cells ($(R_i)_{i \leq k}$) through the function *MAP**. Finally, it hypothesizes what would be its "law" – i.e., how all concepts are articulated to "say something about 'the world'". This law would claim that there is a match/fit between what is stated by *SER* and by *DISTE* – that is, between the distribution of constant differing characteristics and the distribution of (cell) elements –, given the composition *COMP* of the bijective mapping functions *MAP* and *MAP**.

That is the way in which **CFH** contribute to understand in a "deeper", cellular way, i.e., to ground and explain, "the law of development/evolution of hybrids [law of combination of differing characteristics]" (of **DEH**).

The concepts *I*, $(C_i)_{i \leq k}$, $(H_i)_{i \leq l}$, *APP*, *DOM*, *REC*, *MAT*, *DIST* and *SER* that occur in **DEH**, but also in **CFH**, allow us to represent what **CFH** intends to explain, while the concepts $(R_i)_{i \leq k}$, $(E_i)_{i \leq k}$, *DISTR*, *DISTE*, *MAP* and *MAP** and *COMP* play an explanatory role.

As we pointed out previously, this distinction is usually expressed in structuralist metatheory through the distinction between **T**-theoretical and **T**-non-theoretical terms/concepts. In this case, though, the situation seems to be relatively different. Some of the new concepts occurring in **CFH** come from the cell theory of sexual reproduction presupposed by Mendel. They are the set of types of reproductive cells ($(R_i)_{i \leq k}$), their distribution after fertilization (*DISTR*), and the relation in which they are with the (distribution of) types of constant differing characteristics ($(C_i)_{i \leq k}$) through the function *MAP*. While others are specially proposed by Mendel within the framework of this theory – namely, the set of types of (cell) elements ($(E_i)_{i \leq k}$), their distribution after fertilization (*DISTE*), the relation in which they are with the (distribution of) types of reproductive cells ($(R_i)_{i \leq k}$) through the function *MAP**, and the relation between (distribution of) types of constant differing characteristics ($(C_i)_{i \leq k}$) and (distribution of) types of (cell) elements ($(E_i)_{i \leq k}$) through the composition function *COMP*.

Thus, we would say that, while both the concepts occurring in **DEH** and the concepts of the first group occurring in the cell theory of sexual reproduction are **T**-non-theoretical for the theory of the cellular foundation of the development/evolution of hybrids, or **CFH**-non-theoretical, those of the second, proposed especially by Mendel, are **T**-theoretical for that theory, or **CFH**-theoretical.

All these concepts – both **CFH**-theoretical and **CFH**-non-theoretical – are articulated to "say something about the 'world'", that is, to formulate the "laws" of this theory. Mendel has no doubt about the link between what is stated about the characteristics in "the law of development/evolution [of formation and evolution] found for *Pisum*" and what happens at the cellular level with the reproductive cells, as stated in the section "The reproductive cells of hybrids": "*pea hybrids form germ and pollen cells* *that, according to their nature, correspond in equal numbers to all the constant forms that arise from the combination of characteristics united through fertilization*” (Mendel 1865: 29[46]; Mendel’s emphasis).

As he reinforces at the end of the section:

> The law of combination of the differing characteristics, by which the development/evolution of hybrids results, finds its foundation and explanation accordingly in the conclusive principle that hybrids produce germ and pollen cells corresponding in equal number to all constant forms that arise from the combination of the characteristics united through fertilization. (Mendel 1865: 32[49])

However, this is not so in relation to the link he proposes establishing between the elements present in the reproductive cells and the formation of both variable and constant hybrids:

> This attempted ascription of the essential distinction of either a *permanent or a temporary association* of the differing cell elements in the development of the hybrids can, of course, be of value only as a hypothesis for which a wide scope of interpretation is possible given the dearth of reliable data. (Mendel 1865: 42[60]; Mendel’s emphasis)

But if we were to accept it, the theory of the cellular foundation of the development/evolution of hybrids as a whole would affirm, on the one hand, that there exist types of reproductive cells ($(R_i)_{i \leq k}$), a bijective mapping (*MAP*) between the distribution of constant differing characteristics in the offspring (given by *SER* and fulfilling the match between such function and the distribution of characteristics in the offspring established by *DIST*, given the functions of dominance *DOM* and recessivity *REC*) and the distribution of reproductive cells (given by *DISTR*) and that, on the other hand, accepting that there exist types of (cell) elements ($(E_i)_{i \leq k}$), a bijective mapping (*MAP**) between the distribution of reproductive cells (given by *DISTR*) and the distribution of (cell) elements (given by *DISTE*), there would be a match between *SER* and *DISTE*, that is, between the distribution of constant differing characteristics and the distribution of (cell) elements, given the composition *COMP* of the mapping functions *MAP* and *MAP**.

Let us recall that Mendel, in his theory of the development/evolution of hybrids (**DEH**), clearly and explicitly establishes “the law of combination of the differing characteristics”, and that it would govern the development/evolution [formation and evolution] of variable hybrids, while he only suggests what the law of development/evolution [formation and evolution] valid for constant hybrids would consist of and only hints at the existence of the “universally valid law on the formation and evolution of hybrids”. Something similar happens with Mendel’s theory of the cellular foundation of the development/evolution of hybrids (**CFH**).

But not only Mendel does not establish what would be the *fundamental law* of this theory, although one could do so on the basis of its *special laws* referring to what could happen with the (cell) elements present in the hybrids, both variable and constant, he only proposes them recognizing their *hypothetical* character.

However, if, on the one hand, we would accept Mendel's hypothetical statements – symbolized by **CFVH** and **CFCH** –, and, on the other hand, we would establish what would be the *fundamental law* of **CFH** – symbolized by $\mathbf{CFH}_0$ –, we could represent the most important lines of specialization of the theory-net of **CFH** in the following way:

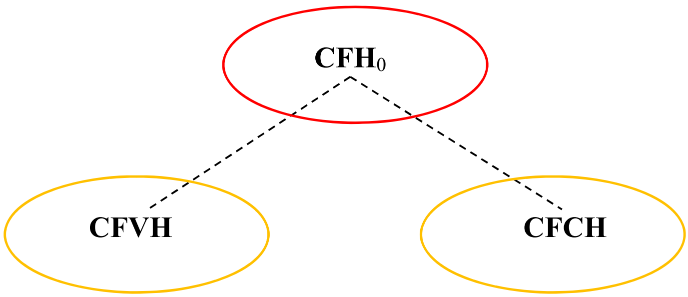

Fig. 3. The theory-net of CFH.

6. INTERTHEORETICAL RELATIONSHIPS BETWEEN DEH AND CFH

We would like to highlight two relationships between Mendel's theory of the development/evolution of hybrids (**DEH**) and Mendel's theory of the cellular foundation of the development/evolution of hybrids (**CFH**), one more restricted and one more general.

On the one hand, both theories are ontologically related. If one concentrates on the domains of the theories in the way they were represented here, there is an identity between three of their basic domains: the set of individuals *I*, the set of types of constant differing characteristics $(C_i)_{i \leq k}$, and the set of types of hybrid forms or characteristics $(H_i)_{i \leq k}$.

But in addition, there is a connection between other domains of both theories, by means of the bijective functions *MAP*, which maps (distribution of) reproductive cells of a certain type (domain from **CFH**) to (distribution of) constant differing characteristics (domain from **DEH**), and *MAP**, which maps (distribution of) reproductive cells of a certain type to (distribution of) elements of a certain type (both with domains from **CFH**), and the operation of composition *COMP* of functions MAP and *MAP**, relating a domain of **DEH**, namely, types of constant differing characteristics, to a domain of **CFH**, namely, types of (cell) elements.

On the other hand, and more general, Mendel's theory of the cellular foundation of the development/evolution of hybrids (**CFH**) is a weak theoretization of Mendel's theory of the development/evolution of hybrids (**DEH**).

> We shall say that **T*** is a theoretization of **T** in the weak sense if *some* of the **T***-non-theoretical concepts are concepts from **T**; we get a theoretization in the strong sense when *all* of them come from **T**. (Balzer, Moulines & Sneed 1987: 251)

Since the whole conceptual framework of **DEH** can be represented through structures as $\langle I, (C_i)_{i \leq k}, (H_i)_{i \leq k}, APP, DOM, REC, MAT, DIST, SER \rangle$, and the whole conceptual framework of **CFH** can be represented through structures as $\langle I, (C_i)_{i£k}, (H_i)_{i \leq k}, (R_i)_{i \leq k}, (E_i)_{i \leq k}, APP, DOM, REC, MAT, DIST, SER, DISTR, DISTE, MAP, MAP^*, COMP \rangle$, many of the **CFH**-non-theoretical concepts (namely: $I, (C_i)_{i \leq k}, (H_i)_{i \leq k}, APP, DOM, REC, MAT, DIST, SER$) come from **DEH**, while the remaining **CFH**-non-theoretical concepts (namely: $(R_i)_{i \leq k}$, *DISTR*, *MAP*) come from the cell theory of sexual reproduction presupposed by Mendel in **CFH**.

7. CONCLUDING REMARKS

In this article, we have first analyzed the interrogative and then the assertive aspects of Mendel (1865) by distinguishing two hybridist theories proposed by Mendel – "the theory of the development/evolution of hybrids" (**DEH**) and "the theory of the cellular foundation of the development/evolution of hybrids" (**CFH**) – with their corresponding conceptual framework and laws (both fundamental and special ones). We have analyzed these two theories as well as their intertheoretical relationships within the framework of the so-called Metatheoretical Structuralism (Balzer, Moulines & Sneed 1987) used in an informal or semi-formal way. In both theories, we have identified what they intend to explain and how they do it as well as their basic concepts (both **T**-theoretical and **T**-non-theoretical ones), and how they interconnect in their laws of different levels of generality forming their respective theory-nets. We have also indicated to what extent Mendel either developed or just suggested the components of such theory-nets. And, lastly, we have analyzed the intertheoretical relationships between "the theory of the development /evolution of hybrids" (**DEH**) and "the theory of the cellular foundation of the development/evolution of hybrids" (**CFH**), and established that **CFH** constitutes a theoretization in the weak sense of **DEH**.

With the present article, we hope not only to have contributed to the analysis of Mendel's work but to have provided a successful example of the integration of history and philosophy of science.

8. APPENDIX
The structuralist explication of the concept of a model and the different kinds of models of a theory

Models are conceived as systems or structures, i.e., mathematical structures. In the standard version of Metatheoretical Structuralism, these structures are set-theoretical or relational structures of a certain type,[25] constituted by a series of basic domains (sets of objects) and of relations (or functions) over them, i.e. as entities of the form: $\langle D_1,..., D_k, R_1,..., R_n \rangle$, where $R_j \subseteq D_{i1} \times ... \times D_{ik}$.) (the D_i's represent the so-called "base sets", i.e. the "objects" the theory refers to, its ontology, whereas the R_j's are relationships or functions (set-theoretically) constructed out of the base sets).[26]

In order to provide a more detailed analysis of empirical science, Metatheoretical Structuralism distinguishes three kinds of (classes, sets, populations, collections or families of) models. Besides what are usually called (the class, set, population, collection or family of) "*theoretical* models" or simply (the class, set, population, collection or family of) "*models*" – also called (the class of) "*actual* models" in structuralist terminology –, the so-called (class of) "*potential* models" and (class of) "*partial* potential models" are taken into account.

To characterize these structuralist notions, two distinctions are to be considered: the distinction between two kinds of 'conditions of definition' (or 'axioms', as they are also called) of a set-theoretical predicate, and the distinction between the **T**-theoretical/**T**-non-theoretical terms (or concepts) of a theory **T**. According to the first distinction, the two kinds of conditions of definition of a set-theoretical predicate are: 1. those that constitute the 'frame conditions' of the theory and that "do not say anything about the world (or are not expected to do so) but just settle the formal properties" (MOULINES 2002: 5) of the theory's concepts; and 2. those that constitute the 'substantial laws' of the theory and that "do say something about the world by means of the concepts previously determined" (MOULINES 2002: 5).

According to the second distinction, which replaces the traditional, positivistic theoretical/observational distinction, it is possible to establish, in (almost) any analysed theory, two kinds of terms or concepts, in the sense delineated in an intuitive formulation by Hempel (1966, 1969, 1970) and Lewis (1970): the terms that are specific or distinctive to the theory in question and that are introduced by the theory **T** – the so-called '**T**-theoretical terms or concepts' – and those terms that are already available and constitute its relative "empirical basis" for testing – the so-called '**T**-non-theoretical terms or concepts', which are usually theoretical for other presupposed theories **T***'*, **T***''*, etc.

According to the standard structuralist criterion of **T**-theoreticity (originated in Sneed 1971 and further elaborated in detail in the Structuralist program; see Balzer, Moulines & Sneed 1987, Ch. II), a term is **T**-theoretical (i.e. theoretical relative to a theory **T**) if every method of determination (of the extension of the concept expressed by the term) depend on **T**, i.e. if they are **T**-dependent, if they presuppose or make use some law of **T**; otherwise, a term is **T**-non-theoretical, i.e. if at least some method of determination (of the extension of the concept expressed by the term) doesn't presupposes or make use of some law of **T**, if it is **T**-independent.

Now we are in position to characterize these structuralist basic notions:

1) The class of *potential models* of the theory $\mathbf{M_p}$ is the total class of structures that satisfy the "frame conditions" (or "*improper* axioms") that just settle the formal properties of the theory's concepts, but not necessarily the 'substantial laws' of the theory as well.
2) The class of (actual) *models* of the theory **M** is the total class of structures that satisfy the "frame conditions", and, in addition, the "substantial laws" of the theory. If A_1,..., A_s are certain formulas ("*proper* axioms" or simply "axioms") that represent the laws of the theory, *models* of the theory are structures of the form $\langle D_1, \ldots, D_k, R_1, \ldots, R_n \rangle$ that satisfy the axioms $A_1, \ldots, A_s$. (And that is the reason why models may be considered the model-theoretic counterpart of theory's laws.)

The class of *partial potential models* $\mathbf{M_{pp}}$ are obtained by "cutting off" the **T**-theoretical concepts from the potential models $\mathbf{M_p}$ ($\mathbf{M_{pp}} := \mathbf{r}(\mathbf{M_p})$, where **r**, the "restriction" function, is a many-one function such that $\mathbf{M_p} \rightarrow \mathbf{M_{pp}}$). If potential models are structures of type *x* ($x = \langle D_1, \ldots, D_k, R_1, \ldots, R_n \rangle$), *partial potential models* $\mathbf{M_{pp}}$ are structures of type *y* ($y = \langle D'_1, \ldots, D'_j, R'_1, \ldots, R'_m \rangle$), where each structure of type *y* is a *partial substructure* of a structure *x*. (And let's call a specific structure of type *y*, with specific instances of the **T**-non-theoretical concepts, a "*data model*" of **T**).

The notion of a substructure and of a partial substructure

A structure *y* is a *substructure* of another structure *x* (in symbols: $y \sqsubseteq x$) when the domains of *y* are subsets of the domains of *x* and, therefore, the relationships (or functions) of *y* are restrictions of the relationships (or functions) of *x*.

A structure *y* is a *partial substructure* of *x* (also symbolized by $y \sqsubseteq x$) when, besides being a substructure of *x*, there is at least one domain or relationship (or function) in *x* that has no counterpart in *y*. (A *partial* substructure *y* contains less components – domains or relationships (or functions) – than the structure *x*. Thus, structures *x* and *y* are of different logical types).

If *y* is a *substructure* (either partial or not) of *x*, it is also said, inversely, that *x* is an *extension* of *y*.

The structuralist explication of the concept of a theory

The point of departure of the structuralist explication of the concept of a theory is the recognition that the term "scientific theory" is ambiguous, or better: polysemic, in its pre-systematic use. Sometimes it means just one law (like when one speaks indistinctly of the *law* of gravitation or of the *theory* of gravitation). This sense is not explicated by the structuralist concept of a theory, but by the structuralist concept of a law. Sometimes, the use of the term "scientific theory" corresponds to what is explicated by the structuralist notion of *theory-element*. In this sense, a theory-element is the smallest portion of science that seems to possess all the characteristics usually associated to theories. However, even this smallest sense of theory *cannot be identified with a clas*s (or set or population or collection or family) *of models*, although it *can be identified mainly through them*. Despite the fact that such a class is the most basic component for the identity of a theory, it is not the only one. A *theory-element* – i.e., the simplest kind of set-theoretical structure that can be identified with, or can be used as a rational reconstruction of, or can be regarded as a formal explication of, a theory (in an informal, intuitive sense) – can be identified, as a first approximation, with an ordered pair consisting of the "(formal) *core*", symbolized by **K**, and the theory's "domain of intended applications", symbolized by **I**: $\mathbf{T} = \langle \mathbf{K}, \mathbf{I} \rangle$.

The *core* **K** constitutes the formal identity of any empirical theory with a certain degree of complexity, which is composed by the ordered classes of *potential models*, *actual models*, *partial potential models*, *constraints* and *links*, i.e., $\mathbf{K} = \langle \mathbf{M_p}, \mathbf{M}, \mathbf{M_{pp}}, \mathbf{C}, \mathbf{L} \rangle$.

In the previous section we already introduced the classes of *potential models*, (*actual*) *models*, and *partial potential models*.

While the innertheoretical relationships between the different models of a theory are represented by the so-called *constraints* **C**, the intertheoretical relationships are represented by the so-called (*intertheoretical*) *links* **L**. They characterise the theory's "essential" relationships to other theories by connecting the **T**-non-theoretical terms with the theories they come from.

Any empirical theory is related to "reality" or "outside world", i.e., to some specific phenomena or empirical systems submitted to some specific conditions, to which it is intended to be applied and for which it has been devised. These empirical systems also belong to a theory's identity because otherwise we would not know what the theory is about, for the class of models contains "all" models, intended as well as non-intended. They constitute what is called the theory's *domain of intended applications* **I**. The domain of *intended applications* of a theory, even when it is a kind of entity strongly depending on pragmatic and historical factors that, by their very nature, are not formalizable, is conceptually determined through concepts already available, i.e., through **T**-non-theoretical concepts; thus, each intended application may be conceived as an empirical (i.e., **T**-non-theoretical) system represented by means of a structure of the type of the partial potential models $\mathbf{M_{pp}}$. All we can formally say about **I** is, thus, that it is a subset of the class of partial potential models $\mathbf{M_{pp}}$.

Theories are not statements, but are *used* to make statements or claims, which then have to be tested. The (empirical) statements (or claims) made by means of scientific theories are, intuitively speaking, of the following kind: that a given domain of intended applications may actually be (exactly or approximately) *subsumed* (or *embedded*) under the theory's principles (laws, constraints, and links). Normally, in any "really existing" theory, the "exact version" of the so-called *central empirical claim* of the theory – that the whole domain of intended applications may actually be (exactly) subsumed (or embedded) under the theory's principles – will be strictly false. What usually happens is that either there is a subclass of intended applications for which the empirical claim is true, or that the central empirical claim is, strictly speaking, false but *approximately true*.[27]

Some "real-life" examples of scientific theories can actually be reconstructed as *one* theory-element, but usually single theories in the intuitive sense have to be conceived as aggregates of several (sometimes a great number of) theory-elements. These aggregates are called *theory-nets*. This reflects the fact that most scientific theories have laws of very different degrees of generality within the same conceptual setting. Usually there is a single fundamental law or guiding principle "on the top" of the hierarchy and a vast array of more special laws – which apply to specific situations – with different degrees of specialization.

Each special law determines a new theory-element. What holds together the whole array of laws in the hierarchy is, first, the common conceptual framework (represented in a model-theoretic way by the class of potential models), second, the common **T**-theoretical and **T**-non-theoretical distinction, and third, the fact that they are all specializations of the same fundamental law.

The theory-element containing the fundamental law(s)/guiding principle(s) is called the "*basic* theory-element" of the theory, i.e., of the theory-net. The other theory-elements of the theory-net are specializations or "*specialized* theory-elements".

When the highest degree of concretization or specificity has been reached, i.e., when all functional dependencies (concepts) are completely concretized or specified, "*terminal* special laws", which determine the most specific class of (theoretical) models, are obtained. The empirical claims associated to the corresponding "*terminal* specialized theory-elements" can be seen as particular, testable and, eventually, refutable hypotheses, which enables the application of the theory to particular empirical systems.[28] In the simplest model-theoretic way of representing these particular empirical claims, they state following: "*data model*" *d* of **T** can actually be (exactly or approximately) extended to, or subsumed or embedded in, the "*theoretical model*" *m* of **T**.

The resulting structure of a theory may be represented as a net, where the nodes are given by the different theory-elements, and the links represent different relations of specialization (see Fig. 1).

A theory-net **N** is the standard structuralist conception of a theory from a static or *synchronic* point of view. In this sense, a theory is *a complex*, *strongly hierarchical* and *multi-level* entity.

But a theory can also be conceived as a kind of entity that develops over time. A theory in the *diachronic* sense is not just a theory-net, which exists in the same form through history, but a *changing* theory-net, which grows and/or shrinks over time. Such an entity is called a *theory-evolution* **E**. It is basically a sequence of theory-nets satisfying two conditions: at the level of cores, it is required for every new theory-net in the sequence that all its theory-elements are specializations of some theory-elements of the previous theory-net; at the level of intended applications, it is required that the domains of the new theory-net have at least some partial overlapping with the domains of the previous theory-net.

Moreover, Metatheoretical Structuralism has been proposed to represent not just *intra*theoretical changes that occur in science (by means of the concept of a *theory-evolution*) but also different types of *intertheoretical changes*, such as *crystallization*, *embedding*, and *replacement with (partial) incommensurability* (Moulines 2011, 2014).

Finally, that metatheory also explicates some of the standard global intertheoretical relationships, such as reduction and equivalence, and the global intertheoretical relationship introduced in Sect. 6, that of theoretization, both in the strong and weak sense.

On theoreticity in DEH

The concepts of individuals, of constant differing characteristic, of appearance and of mating seem not to be foreign to "breeders" and "hybridists" before Mendel. The "novel" concept for them is the one that represents the statistical analysis carried out in the crosses, which yields the ratio or relative frequency of constant differing characteristics of a certain type observed in the progeny: the function *DIST*, which describes the transition from parental constant differing characteristics to distributions of constant differing characteristics in the progeny.

However, despite being "novel", i.e., *not* "antecedently available" and, in that sense, "theoretical", according to Hempel's "historical" criterion (1966: 73–75), if the structuralist usual criterion of **T**-theoreticity is applied (see e.g. Balzer, Moulines & Sneed 1987: 47–73, 391–393), more "systematic" than Hempel's, according to which a term is **T**-*theoretical* if *every* method of determination (of the extension of the concept expressed by the term) depend on **T**, that is, are **T**-dependent, presupposing directly or indirectly the validity of the laws of **T**; if *some don't* presupposes it, i.e. if it can be determined independently of **T**, the term is **T**-*non-theoretical*, the function *DIST* is a **T**-non-theoretical term for theory **DEH**, that is, **DEH**-non-theoretical, since the determination of the ratio or relative frequency of constant differing characters of a certain type observed in the progeny doesn't depend on **DEH**. Rather, it suffices to count the total number n of progeny as well as the number m_i of individuals with the constant differing characteristic of that type in the progeny in order to determine the ratio or relative frequency of occurrence of that particular constant differing characteristic r_i, which is obtained by dividing m_i over n. If we collect all of these ratios or relative frequencies, we obtain the distribution or ratio or relative frequency of constant differing characteristics in the progeny.

Thus, we see that, even though the novelty of a concept is in general an indication of the plausibility *prima facie* of considering such a concept as theoretical for a theory **T** where it is introduced for the first time, Hempel's "historical" and structuralist "systematic" criteria do not need to coincide necessarily.

On the other hand, the concepts of hybrid form or hybrid characteristic, as well as of dominant or recessive constant differing characteristic, seem to be **T**-theoretical concepts for theory **DEH**, that is, **DEH**-theoretical concepts. And this is so, because in order to determine their extensions it is required to make use of the law of formation and evolution of hybrids. Let's see the case of the concept of hybrid form or characteristic. A form or characteristic will be *hybrid* if, in case the plant is self-fertilized, the constant differing characteristics are distributed in the ratio 3:1. And in order to find out whether a constant differing characteristic is *dominant* (or *recessive*), one has to first find out, at some time point, that the characteristic is hybrid, and then, depending on the result of the self-fertilization, determine which of the constant differing characteristics that constitute the hybrid characteristic or form is *dominant* and which one is *recessive*. To do that, one needs to appeal to both the law of development/evolution of hybrids and to the relation of dominance (or its converse, recessivity). This means that the concepts of *hybrid* form or characteristic $(H_i)_{i \leq k}$ as well as of the relation of *dominance DOM* (and *recessivity REC*) are **DEH**-theoretical concepts. The function *SER* is also a **DEH**-theoretical concept. The theoreticity of the concept that represents the *transition of parental dominant or recessive constant differing characteristics and hybrid characteristics to their distribution in the progeny SER* – i.e., the *series for the formation of hybrids and of the evolution for the progeny of the hybrids* – is inherited from its arguments or its values that are **DEH**-theoretical as well, such as hybrid characteristics or dominant or recessive constant differing characteristics. Moreover, the correctness of the special form of *SER* adopted in each application is tested by means of (the fundamental law of) **DEH** by checking whether there is a match or fit between the values of the functions *DIST* and *SER* through *DOM* (and *REC*).

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NOTES AND REFERENCES

1 The preference for this latter denomination shows a clear influence of Argentinian cinema: “The official story” is the title of the Argentinian film that was awarded the Oscar as best foreign film in 1985. [Note: The single Spanish term “historia” stands for both story and history, hence the play of words].

2 See Heimans (1962, 1969, 1971), Bennett (1964, 1965), Olby (1979), Brannigan (1979), Corcos & Monaghan (1985, 1990a, 1990b, 1993), Callender (1988), Lorenzano (1995).

3 For Mendel’s life, see, besides the classical Iltis’ biography (Iltis 1924), Richter (1942), Weiling (1991), Orel (1996), Klein & Klein (2013), and Fairbanks (2022).

4 The usual translation of “Entwicklung” is “development”. However, this term is ambiguous. Whereas in modern German it means “development”, back then – towards the middle of the 19th century – it was used to refer to any process of development, including both ontogeny and phylogeny, i.e., both to embryonic development and what later be called “evolution”, free of any embryological connotation. It would be a mistake to suppose that Mendel always used “Entwicklung” in the sense of individual development. If that were the case, with no distinction between individual ontogeny and evolution of a lineage, the phrase “Bildung und Entwicklung” – here translated as “formation and evolution” – would be redundant. In fact, Mendel was looking for a law that governed both development and evolution. On the other hand, the expression “Entwicklungsgeschichte” was used with the sense of our “evolutionary history” or, simply, “evolution”. The German term “Evolution” was not introduced until the second half of the 19th century by influence of the English “evolution” and well into the 20th century the theory of evolution was still denominated “Stammesgeschichte” or “Abstammungslehre”, as well as “Descendenztheorie” o “Evolutionstheorie”, neologisms that were in fact less common that the previous two.

5 For the influence of Unger on Mendel, see Olby (1967), Orel (1968, 1971), Weiling (1983), Wunderlich (1983), Gliboff (1998, 1999).

6 As Buchdahl (1973) shows, Schleiden’s understanding of induction is not aligned with that of Bacon, Mill or the neoinductivism yet to come. It is induction in Apelt’s sense and, to a lesser degree, in Whewell’s. Apelt (1854: 41–50) differentiates both conceptions of induction through his distinction between *rational induction*, based on the Kantian conception of regulative ideas and guiding maxims, and *empirical induction*, the one Bacon and Mill were concerned with.

7 We first indicate the pagination of the original publication of Mendel’s “Versuche über Pflanzenhybriden” and then use square brackets to refer to Weiling’s edition of 1970.

8 We can find this distinction suggested in Roberts (1929) and, with different terminology, depending on an allusion to the distinction between work performed on plants and that performed on animals, in Bowler (1989) among others.

9 The connection between the task sketched (finding a “generally applicable law governing the formation and evolution of hybrids”) and the problem of the origin of new species by hybridization was familiar in the context in which Mendel conducted his research. In Gärtner (1849) we find several passages underlined by Mendel (Gärtner 1849: 250) and even marked with double line on the left margin, which is what he used to do with texts he found of utmost importance (Gärtner 1849: 250, 272); see also Gärtner (1849: 153). In support of the connection between Mendel’s work and the problem of the origin of new species by hybridization, we would also like to bring forward the introduction written by another of the hybridists mentioned by Mendel, Wichura, to his book of 1865 (Wichura 1865). We might suppose Mendel to have read it before sending to print his lectures of the same year. There we can see a formulation of the goal in terms very similar to Mendel’s, also relating it clearly with the problem of the origin and multiplication of species, as well as with results obtained by others, such as and Gärtner, but also, and more interestingly, Darwin (Wichura 1865: 1–3).

10 For a positive answer to this question, see Linnaeus (1744, 1755), and more clearly, elaborately, and decisively (1760); also, in the work of his followers Haartman (1751), Daldberg (1755), and Grĺberg (1762). Gmelin (1749) suggested that the issue should be settled experimentally. For the acceptance of the challenge and a discussion and negative answer to that question, see the work of "the two authorities in this branch of knowledge, Kölreuter and Gärtner" (MENDEL 1865: 38[55–56]), Kölreuter (1761–1766) and Gärtner (1849). Gärtner is the most referred author in Mendel (1865) and his book *Versuche und Beobachtungen über die Bastarderzeugung im Pflanzenreich* ("Experiments and Observations on Hybrid Production in the Vegetable Kingdom") (1849) is the only work from the authors mentioned by him (who, besides Kölreuter and Gärtner, are Herbert, Lecoq and Wichura) cited by title, even when in an abbreviated way: "Die Bastarderzeugung im Pflanzenreiche" (MENDEL 1865: 3[21]). According to Gärtner (1849, 14–15, 152–153, 551–552, 587–588), the origin of new species by hybridizing preexisting ones was also held by Sageret (1826), Wiegmann (1828), Herbert (1837, 1847), Puvis (1837), Lecoq (1845), Reichenbach, Nees von Esenbeck, Kunze and Voigt (*Oken Isis* 1837: 479).

11 Breeders Knight and Sageret are quoted repeatedly by Gärtner (1849). Gärtner (1849: 153, n. 171) refers to the German translation of Knight's most influential paper on hybridization (KNIGHT 1800), the English original of which was published in 1799. The journal in which Knight's German translation appeared is found in the university library with the stamp of the Agricultural Society, to which Mendel belonged (OREL 1996: 19). Goss and Seton, on the other hand, are only mentioned once, whence, after describing the results of his experiments with *Pisum sativum viride* Gärtner claims that "These results coincide in essence with those announced by Goss and Seton" (GÄRTNER 1849: 85). Right next to this sentence Mendel writes the bibliographical reference given by Gärtner, which, though it is not said there, is really a German translation of Goss' and Seton's papers – with changed indications of the years of experiments – and signed simply by "G", which might suggest that the anonymous author describes his own experiments (G 1837).

12 We think it would be better here to translate "Bestimmung" as "determination" rather than "definition" because what is formulated is *an operational* criterion or method for distinguishing species from varieties rather than providing necessary and sufficient conditions for the application of the concept of species. (See CARNAP 1936–1937 for a "refutation" of operationalism as a way of defining, in the strict logical sense those concepts later called "theoretical", though not as a way of providing methods, ways or criteria to determine the extension of such concepts).

13 For a discussion of the role of the "schärfste Bestimmung des Artbegriffes" in Mendel's work, see Müller-Wille & Orel (2007). On the other hand, as these authors correctly point out (MÜLLER-WILLE & OREL 2007: 177, n. 19), the term "species" is also used by Mendel in the expression "good species" ("*gute Arten*"), even though he only does it once ("For the experiments, plants were mostly used which rank as good species and are differentiated by a large number of characteristics" ["Für die Versuche dienten grösstentheils Pflanzen, welche als gute Arten gelten und in einer grösseren Anzahl von Merkmalen verschieden sind"], MENDEL 1865: 39[56]) and from it alone it is not entirely clear (as these authors hold) that he is trying to establish a systematic distinction between "species (without qualification)" and "good species", these latter being characterized as differing "in a great number of traits"; the previous passage is also consistent with considering "species" and "good species" as identical and with these additionally differing "in a great number of traits" in the case at hand. Unfortunately, we haven't been able to find the expression "good species" in any of the other texts by Mendel relevant to this topic (neither in the paper on *Hieracium*, nor in the letters to Nägeli, nor in the *Notizblatt 1* and *2*) that might help us resolve the issue. However, this does not affect the central point in his discussion. For Müller-Wille & Orel (2007), dealing with the problem of hybridization following "die schärfeste Bestimmung von Spezies" is what forces Mendel to concentrate simultaneously in the transmission of individual traits, which both separates him from the tradition of "hybridists" and explains why it is appealing to those who read it later, at the beginnings of the 20th century.

14 Such an analysis, though not the goal pursued, as will become clear later, was new to the traditions mentioned (although not to biological sciences in general), a novelty Mendel was aware of and that would also distinguish him from the aforementioned Knight, Goss and Seton and from the results they obtained on *Pisum*, which were expressed qualitatively and comparatively and not quantitatively. The use of mathematics on Mendel's part was in complete agreement with the book he studied (BAUMGARTNER & ETTINGSHAUSEN, 1839) already in Olmütz, before going to study to the University of Vienna, during an eight-week physics course based on that book, where, in a Kantian spirit, it is asserted that "in natural sciences there is no more science that the mathematics there contained" (BAUMGARTNER & ETTINGSHAUSEN 1839, 7). Andreas von Ettingshausen was also his teacher in the University of Vienna, as Christian Doppler's successor, with whom Mendel would also study, at least for a whole year. Another book by Ettingshausen that undoubtedly excerpt-

ed a strong influence on Mendel's approach was Ettingshausen (1826), devoted to combinatorial analysis (Mendel found that traits of plants could be combined, expressing their proportions by combinatorial series). This use of mathematics was also in agreement with another book read by Mendel and that will be mentioned again later, Schleiden (1849), where "the importance of the mathematical viewpoint and its predominance in the whole of natural knowledge" (SCHLEIDEN 1849: 37) is declared as well as that "complete theoretical knowledge, in which we explain the connection between facts and laws, is only possible through mathematics and inasmuch it is applicable" (SCHLEIDEN 1849: 39). Finally, it was also in agreement with the Pythagorean perspective on life characteristic of German romantic *Naturphilosophie*, even if the latter was no longer favored in the 1840's.

15 For more on the distinction **T**-theoretical/**T**-non-theoretical concepts, see the Appendix.

16 It is a misrepresentation to say that, according to the semantic conception, a theory *is* a class of models, in the sense of being *identified with* a class of models or being *identical to* a class of models. The semantic conception claims, rather, that a theory can be characterised in the first place for defining/determining the class (set, population, collection or family) of its models: to present/identify a theory means mostly presenting/identifying the characteristic models as a family, because it is an essential component of a theory, but not the only one. (For more on the notion of model, see the Appendix).

17 It is worth noting that this option neither supposes nor intends to disregard the statements (sentences or propositions) or, in general, certain resources or devices or even linguistic formulations. It does not mean that resources or devices of any kind, including linguistic ones, are superfluous for the metatheoretical characterization of the theories. Of course, we need some resource, device or language in order to determine or define a class of models. Nobody intends to deny this. Insofar as the models are determined explicitly and precisely in the metatheoretical analysis, they are determined by giving a series of axioms, principles or laws, i.e., through statements. But, although the determination of the models is made through a series of axioms, the identity of the theory does not depend on those specific resources or those specific linguistic formulations. The different resources, devices or linguistic formulations are essential in the (trivial) sense of being the necessary means for the determination of the models, but in a really important sense, they are not, since nothing in the identity of a theory depends on whether the resource, device or linguistic formulation is one or another. (For further connections between linguistic formulations and models, see the Appendix).

18 For a characterization of the notions of a substructure and of a partial substructure, see the Appendix.

19 At least in the "standard" case of *Pisum DOM* and *REC* are homogeneous dyadic relationships, i.e., irreflexive and asymmetric. However, they could be generalized as homogeneous *n*-dyadic relationships to represent the case in which more types of characteristics are involved, the so-called "compound characteristics", as in the case of the color of flowers and seeds in *Phaseolus multiflorus*, also mentioned by Mendel (1865: 33–38[51–55]).

20 If this function were of the formation of hybrids, i.e., of hybrid characteristics or forms, it would rather be the "law" (corresponding to the part) of formation of hybrids (where, in the most simple case of considering just two differing characteristics, e.g., A and a, the function would be following one: $SER: A \times a \rightarrow 1Aa$ or, alternatively, $SER(A, a) = 1Aa$). Whereas if it were of evolution (of the offspring) of hybrids, it would be the "law" (corresponding to the part) of the evolution of hybrids (where, again, in the most simple case of considering just two differing characteristics, e.g., A and a, the function would be following one: $SER: Aa \times Aa \rightarrow 1A + 2Aa + 1a$ or, alternatively, $SER(Aa, Aa) = A + 2\,Aa + a$, or $SER(Aa, Aa) = \langle \frac{1}{4}A, \frac{1}{4}Aa, \frac{1}{4}Aa, \frac{1}{4}a \rangle$).

21 For a discussion on the distinction between **T**-non-theoretical and **T**-theoretical concepts of **DEH**, or better, **DEH**-non-theoretical and **DEH**-theoretical concepts, see the Appendix.

22 For this notion, see the Appendix.

23 We first indicate the pagination of the original publication of Mendel's "Über einige aus künstlicher Befruchtung gewonnenen *Hieracium*-Bastarde" and then use square brackets to refer to Weiling's edition of 1970.

24 A composition of functions is an operation $\circ$ that takes two functions f and g, and produces a function $h = g \circ f$ such that $h(x) = g(f(x))$. In this operation, the function g is applied to the result of applying the function f to x.

25 In trying to be as precise as possible, Metatheoretical Structuralism prefers the use of (elementary) set theory – whenever possible – as the most important formal tool for metatheoretical analysis. However, this formal tool is not essential for the main tenets and procedures of the structuralist representation of science (other formal tools, such as logic, model theory, category theory, and topology, as well as informal ways of analysis, are also used). Besides, there are also uses of a slightly variant of Bourbaki notion of "structure species" in order to provide a formal basis of characterizing classes of models by means of set-theoretical predicates (BALZER, MOULINES & SNEED 1987, Ch. 1), and of a version of the von Neumann-Bernays-Gödel-type

of language including urelements for providing a purely set-theoretical formulation of the fundamental parts of the structuralist view of theories (Hinst 1996). There is even a "categorial" version of Metatheoretical Structuralism that casts the structuralist approach in the framework of category theory, rather than within the usual framework of set theory (see Balzer, Moulines & Sneed 1983, Sneed 1984, Mormann 1996). The choice of one formal tool or another or of a more informal way of analysis is a pragmatic one, depending on the context which includes the aim or aims of the analysis and the target audience. Nonetheless, in standard expositions of Metatheoretical Structuralism, as well as in the presented here, models are conceived of as *set-theoretical structures* (or models in the sense of *formal semantics*), and their *class* is identified by defining (or introducing) a *set-theoretical predicate*, just as in the *set-theoretical* approach of Patrick Suppes (1957, 1967, 1970, 2002, McKinsey, Sugar & Suppes 1953).

26 In a complete presentation, we should include, besides the collection of so-called *principal base sets* $D_1,..., D_j$ or $D_1,..., D_k$, also a second kind of base sets, namely, the so-called *auxiliary base sets* $A_1,..., A_m$. The difference between them is the difference between base sets that are empirically interpreted (the principal ones) and base sets that have a purely mathematical interpretation, like the set $\mathbb{N}$ of natural numbers, or the set $\mathbb{R}$ of real numbers (the auxiliary ones). Here, auxiliary (purely mathematical) base sets are treated as "antecedently available" and interpreted, and only the proper empirical part of the models is stated in an explicit way.
On the other hand, in philosophy of logic, mathematics, and empirical science has been intensively discussed what would be a better way of understanding the nature of sets occurring in the relational structures, and of the models themselves. In relation to sets, according to the standard interpretation of 'sets-as-one' (Russell 1903) or 'the highbrow view of sets' (Black 1971) or 'sets-as-things' (Stenius 1974) sets themselves, though not necessarily their elements which may refer to concrete entities, should be considered as abstract entities, while according to the interpretation of 'sets-as-many' (Russell 1903) or 'the lowbrow view of sets as collections (aggregates, groups, multitudes)' (Black 1971) or 'sets-of' (Stenius 1974) sets have not to be interpreted that way. For theoretical models, even though they are usually considered as abstract entities, there is no agreement about what kind of abstract entities they are, i.e., what is the best way of conceive them – either as interpretations (Tarski 1935, 1936) or as representations (Etchemendy 1988, 1990), or as fictional (Godfrey-Smith 2006, Frigg 2010) or as abstract physical entities (Psillos 2011). However, due to space limitations, we will not delve into these issues.

27 For a structuralist approach to features of approximation and a precise formal explication of the notion of the approximative empirical claim, see Balzer, Moulines & Sneed (1987), Ch. VII.

28 This is the model-theoretic, semantic, in particular structuralist version of what can be said about the testability and eventually refutability of particular hypotheses/terminal special laws. While in the classical approach of testing the particular hypotheses/terminal special laws are the entities to be tested, in the structuralist approach the "empirical claims" associated to *terminal* special laws are the entities that carry the weight of testing and to which it is able to direct "the arrow of *modus tollens*" (Lakatos 1970: 102).