The history of epigenetics from a sociological perspective

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Introduction

Epigenetics is a research area within »biomedical and biological research« (Landecker and Panofsky 2013, 336) often defined as »the study of mitotically and/or meiotically heritable changes in gene function that cannot be explained by changes in DNA sequence« (several authors quote this definition from Riggs, Martienssen, and Russo 1996; for instance, Haig 2004). Both the use of the term »epigenetic« and the development of the research area have seen remarkable and accelerated growth since the 1990s. This phenomenon is often analyzed from perspectives coming from the history and philosophy of science, e.g., under the influence of Thomas Kuhn's theory; this latter point explains the occurrence of expressions such as »epigenetics revolution« (Meloni 2015, 141), »epigenetic turn« (Nicolosi and Ruivenkamp 2011), or »epigenetic shift« (Willer 2010, 13). Here, the main purpose is to adopt a sociological perspective in response to the question »What could a sociological account of this development look like?« Nevertheless, it is useful to keep in mind that these expressions evoke a substantial transformation.

Before shedding some sociological light on the subject, I will present the object of analysis, the rise of epigenetics, in more detail in the next section. The history of epigenetics is complex; it can be related to the old debate between »preformation« and »epigenesis« and traced back to Aristotle (Hall 2011, 9). However, to limit my analysis, I chose the coining of the term »epigenetics« as its starting point, an event that is thought to have occurred in 1942, when Waddington proposed the term for a »branch of biology which studies the causal interactions between genes and their products, which bring the phenotype into being« (cited by several authors,

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for instance, Goldberg, Allis, and Bernstein 2007, 635; although the actual original source of the quotation seems uncertain, given the lack of consensus about it). The noticeable difference between this older definition and the one previously cited deserves clarification, to which some elements in the following section will contribute.

In the next two sections, some of Mölders's (2011) ideas are applied which facilitate thinking about a sociological sense of »learning« within science as a function system. Mölders's ideas on which I base my analysis are themselves based on two main theoretical frameworks related to a sociological sense of »systemic learning« at two different levels: (1) a sociological learning-theoretical perspective strongly inspired by conceptualizations coming from Piaget, useful for accounting for learning at the level of a *disciplinary communication community*,[1] as an »equilibration« process where some of its theoretical and/or methodological structures suffer an »accommodation«; and (2) an evolution-theoretical perspective, pertinent for accounting for the way in which learned structures can reach the general level of science as a function system (in a Luhmannian sense). The two sections alluded to correspond to each of these perspectives in an attempt to answer the questions: (1) Does the emergence and development of epigenetics correspond to a learning process at the level of a disciplinary communication community in the sense of a Piagetian equilibration process? and (2) Does the spreading of epigenetic knowledge constitute a case of (re)stabilization of learned structures reaching a higher level, the level of the function system of science, i.e., going beyond the »dominant internal differentiation« (Mölders 2011, 175) of this function system? Each of these sections is in turn subdivided in two subsections: the first one presents some theoretical elements proposed by Mölders in more detail, and the second one constitutes an attempt to apply them to the case of epigenetics.

The final section shows how, by following a historical thread running through my sociological framework, I found Waddington, Piaget, and a

1 My attempt to translate »*disziplinäre Kommunikationsgemeinschaften*« (Mölders 2011, 169).

sociological learning-related evolutionary line of thought to be related in a totally different way.

Epigenetics: From the neologism being coined twice to the multiplicity of its meanings

As already mentioned, the term »epigenetics« was first coined in 1942. »First coined« could seem redundant, yet this neologism actually had »at least two semi-independent origins during the 20th century« (Haig 2004, 67).

As said above, the first proposal of this term is attributed to Waddington, who has been considered a developmental biologist (Meloni and Testa 2014, 433) as well as a geneticist (Hall 2011, 10). According to Van Speybroeck (2002a, 61), Waddington meant that »epigenesis + genetics = epigenetics.« Waddington linked embryology to epigenesis and genetics to preformation: two sides of an old debate. As Hall (2011) puts it, the concepts of »epigenesis« and »preformation« have their origins in two old hypotheses about animal embryogenesis, the first corresponding to »the successive differentiation of features during development leading to increasing complexity and the formation of the adult form« and the second to »the gradual unfolding through growth of features preformed in the egg or sperm« (Hall 2011, 9). One can infer that Waddington expected epigenetics to overcome the presupposed contradiction between these two hypotheses as well as the separation between embryology and genetics.

Waddington established an Epigenetics Research Unit (Holliday 2006, 76), but the growing popularity of the term »epigenetics« in life sciences since the 1990s does not seem traceable to Waddington's proposal. Rather the second »semi-independent« origin of the term seems more closely related to this increase. Nanney was responsible for it in 1958, with his paper »Epigenetic Control Systems« (Haig 2004, 68; Haig 2012, 14; Meloni and Testa 2014, 433), where he restricted the use of the adjective »epigenetic« to refer to »cellular control systems« (Nanney 1958, 712; my italics) which were not genetic. According to Nanney,

> [o]n the one hand, the maintenance of a »library of specificities,« both expressed and unexpressed, is accomplished by a template replicating mechanism. On the other hand, *auxiliary mechanisms with different principles of operation are involved in determining which specificities are to be expressed in any particular cell.* […] To simplify the discussion of these two types of systems, they will be referred to as »genetic systems« and »*epigenetic* systems.« (Nanney 1958, 712; my italics)

In other words, as paraphrased by Haig (2012, 14), epigenetic systems would relate to »which volume in the library of genetic specificities was to be expressed in a particular cell.«

Apparently, Nanney's distinction started a tradition in the use of the terms »epigenetic« and »epigenetics,« with their meaning restricted to cellular mechanisms controlling which genes are expressed, a tradition closer than the Waddingtonian one to the current field of epigenetics (Haig 2004). Nevertheless, another tradition has survived until the present, more closely linked to the original Waddingtonian distinction and implying a broader meaning of »epigenetic.« New definitions along these two lines have appeared, and still others merge the two trends, creating a multiplicity of definitions and making epigenetics an ambiguous research area (Haig 2004, 69; Hallgrímsson and Hall 2011, 2; Morange 2013; Meloni and Testa 2014). As a result, there is no unique or clear answer to the question »What is epigenetics today?«

Despite this ambiguity—or thanks to it—the research area of epigenetics, especially molecular epigenetics, is said to be »a scientific success story« (Meloni and Testa 2014, 432) since »[w]e have recently witnessed an explosion of research efforts, meetings and symposia, international initiatives, internet resources, commercial enterprises […] dedicated to epigenetics« (Goldberg, Allis, and Bernstein 2007, 635) and

> [s]imilar efforts aimed at computing the rise of epigenetics in terms of new networks, institutes, conferences, curricula and journals confirm the vertical growth of the field across the full range of academic indicators.

> Within a few years ambitious large-scale projects, such as the International Human Epigenome Consortium […] have been launched worldwide. (Meloni and Testa 2014, 432)

Waggoner and Uller (2015, 177) even claimed that »[t]he epigenetic ›revolution‹ in science cuts across many disciplines, and it is now one of the fastest-growing research areas in biology.« One is thus tempted to affirm that the case of epigenetics illustrates a kind of learning in the function system of science. What, then, could a sociological account of this learning look like?

Learning at the level of disciplinary communication communities: The case of epigenetics

An equilibration-theoretical framework

As mentioned, Mölders (2011) proposed a sociological framework which can be employed to reflect on how learning in a »supraindividual« sense—to take Miller's term up again (Miller 2002; 2006, 195)—occurs in the function system of science.

As Mölders noted, sociological learning theories are based on Piaget's cognitive-theoretical concepts, despite the fact that the latter concerned individual learning (Mölders 2011, 23). Mölders's sociological proposal is an equilibration-theoretical one inscribed in a line of thought related to the Piagetian conceptualization of »equilibration.« It is thus useful to understand some important aspects of Piagetian theory which have been influential in the development of sociological learning theorizations. Some important Piagetian concepts are »schema,« »assimilation,« and »accommodation.«

As he explained in *Biology and Knowledge*, Piaget took the term »assimilation« from biology and applied it to cognition by using it »in the wide sense of integration into previous structures« (Piaget 1982, 4). Such previous structures are directly related to the concept of schemata; Piaget decides, for instance, to »[…] apply the term »action schemata« to whatever, in an action, can thus be transposed, generalized, or differentiated from one situation to another: in other words, whatever there is in common between various repetitions or superpositions of the same action« (Piaget 1971, 7). As to accommodation, he applied the term »to any modification produced on assimilation schemata by the influence of environment to which they are attached« (Piaget 1971, 8).

As Mölders shows, assimilation implies the integration of new information in a previous schema (without modifying the latter), whereas accommodation implies an inadequacy of the previous schema to assimilate a certain new information, requiring a structural modification of the schema (Mölders 2011, 25). Piaget distinguished three phases which constitute an equilibration process: the »alpha,« »beta,« and »gamma« phases. Relevant aspects of these phases, both for the understanding of an individual cognitive process and as a source of inspiration for the analysis of a supraindividual learning process, include: during the alpha phase, a disturbance is just ignored or repressed; during the beta phase, the original schema is kept, but additional schemata are developed as a response to an assimilation disturbance; during the gamma phase, the original problematic schema is accommodated, i.e., transformed into a new assimilation schema so that the disturbance ceases to be one (Mölders 2011, 26–27).

Keeping this Piagetian conceptualization in mind, it is easier to grasp Mölders's proposal of a sociological understanding of learning. In cases where supraindividual learning takes place within the function system of science, Mölders shows that this system as a whole is not an entity capable of learning in a strict sense, but disciplinary communication communities do have this capacity. Following Mölders, it would be proper to say that a disciplinary communication community has learned something when its structural schemata have suffered an accommodation in response to an »irritation« triggered by a problem in such a way that the problem is solved (Mölders 2011, 169). Regarding the Luhmannian notion of irritation, one can say, with Borch (2011a, 31), that »[*i*]*rritation* should be understood here not as annoyance, but rather as an itching that calls for action.« This kind of learning could be thus conceptualized as an equilibration process.

One can thus ask if this equilibration-theoretical framework could shed light on how epigenetic knowledge and epigenetics as a research area arise. Is it possible to identify disciplinary communication communities which have »learned« thanks to epigenetics? Can the history of epigenetics be considered a story of problems that were solved thanks to the accommodation of structural schemata?

The case of epigenetics as structural learning

Looking at the case of epigenetics through the lenses of the presented frameworks, one can identify an original problematic schema which could be said to have gone through an equilibration process. Meloni and Testa (2014, 434) find that both the broad meaning of epigenetics going back to Waddington and the rather molecular one going back to Nanney »deflate the role of genes as causally privileged determinants of phenotypes.« Indeed, the multiple and »partially overlapping« (as several authors qualify them) forms of epigenetics occurring within the function system of science seem to threaten a schema which was dominant in life sciences or biosciences during the twentieth century, which denied that the evolution of biologically hereditable material—i.e., the genetic material, for some time conceived mainly as DNA—was open to informational inputs coming directly from the environment. In other words, the variation of the biologically hereditable material was supposed to be random and »then« selected, with a resultant increasing correspondence between phenotype and environment, but without a straightforward injection of information from the environment into the genetic material. Thus, epigenetics constitutes a weakening of »gene-centrism« in biology (Meloni 2015, 141; Meloni and Testa 2014; De Tiège et al. 2013; Van Speybroeck 2002a, 80; 2002b, 743).

In this respect, Van de Vijver et al. (2002) show that epigenetics can be conceived as incorporating »a developmental and an evolutionary approach as legitimately as a genetic approach« (Van de Vijver, Van Speybroeck, and de Waele 2002, 3) and find that »[e]pigenetics in this broad sense challenges the metaphysics and epistemology of a gene-centric viewpoint« (Van de Vijver, Van Spebroeck, and de Waele 2002, 4).

De Tiège et al. (2013), employing a more restricted—molecular—meaning of »epigenetic,« present the findings of epigenetics (understood as the field dealing with the relationship between the genome and the epigenome)[2] as having contributed to a general defeat of gene-centrism »in its DNA-centric form« (De Tiège et al. 2013, 58):

> Due to the discovery during the past few decades of complex post-genomic, *epigenetic* and extra-genetic processes and mechanisms in which genes and the genome are causally integrated and contextualised, the *gene-centric paradigm of life* has lost its popularity among a number of bio-philosophers and bio-theorists. (De Tiège et al. 2013, 66–67; my italics)

De Tiège et al. find that although a »modest« form of gene-centrism (namely, »NA-centrism«) is still defendable in the »subcellular level of NA/protein-based biochemistry,« the epigenetic level (in the restricted sense in which they understand it) is precisely the first one (from »lower« up to »higher« levels) where even this »modest« form of gene-centrism becomes »dubious« (De Tiège et al. 2013, 67).

For his part, Robison (2014) highlights the »challenges« posed by epigenetics, this time not to gene-centrism, but to the »Modern Synthesis.« This opinion is not surprising, taking into account that gene-centrism is closely related to neo-Darwinism. De Tiège et al. (2013, 57) find that the former »was, and still is, basic to neo-Darwinian evolutionary biology.« As a matter of fact, epigenetics is often associated with a broader paradigmatic shift (Nicolosi and Ruivenkamp 2011, 309; Van de Vijver, Van Speybroeck, and de Waele 2002) in life sciences in which the contributions of researchers Jablonka and Lamb play an important role. As Haig (2006, 418) claims,

> Jablonka and Lamb […] see a continuity of error from Weismann's neo-Darwinism (with its separation of germ-line and soma) through Modern Synthesis neo-Darwinism (with its separation of genotype and phenotype) via Molecular neo-Darwinism (with its »central

2 In part quoting Dolinoy and Jirtle 2008, Meloni (2015, 126) define the epigenome as »the set of the potentially ›heritable changes in gene expressions that occur in the absence of changes to the DNA sequence itself.‹«

> dogma« of a one-way flow of information from DNA to protein) into Selfish Gene neo-Darwinism (with its separation of replicators and vehicles).

In all these cases, »theoretical barriers […] have been erected to deny information flow from the second to the first components of these dichotomies« (Haig 2006, 418).

Robison finds that epigenetics threatens the main assumptions of the Modern Synthesis:

> (1) that populations evolve by changes in gene frequency through random genetic drift, gene flow, and especially natural selection; (2) that genetic variation arises by random (i.e., not adaptively directed) mutation and recombination; (3) and that most individual phenotypic effects are very slight, so that most phenotypic changes are very gradual. (Robison 2014, 2)

It thus seems feasible to conceive of epigenetic knowledge as a response to irritations, which points to the problematic inadequacy of the gene-centric neo-Darwinian theoretical framework. As Willer (2010, 19) puts it, »biologically speaking, epigenetics examines what happens outside the genes; whereas, historically speaking, epigenetics is what happens after genetics.« Morange (2002, 50) even explains the multiplicity and variability of definitions of epigenetics by claiming that »epigenetics cannot be defined per se, but only as an evolving opposition to the piecemeal, reductionist approach of genetics.«

Indeed, the brief history of epigenetics can be told as a story of rebellion going back to Waddington himself—in *The Strategy of the Genes* he wrote:

> The *reigning modern view* is that, in nature, the direction of mutational change is *entirely at random*, and that adaptation results *solely from the natural selection* of mutations which happen to give rise to individuals with suitable characteristics. I want to argue that this theory is an *extremist* one […]. (Waddington [1957] 2014, 151; my italics)

The second, »semi-independent« origin of epigenetics can also be understood as a reaction to a dominant theoretical framework. According to Haig (2006, 420), »Nanney was a critic of the triumphalist molecular genetics of his day.«

As a matter of fact, the disappointment produced by the unexpected results of the Human Genome Project is sometimes related to the growth experienced by epigenetics in the twenty-first century (Meloni 2015, 126); this disappointment could be viewed as one of the irritations pointing to the inadequacy of the gene-centrism dominating in the twentieth century.

Could one say that these irritations triggered a Piagetian equilibration process? One can indeed find views in the literature about epigenetics reminiscent of Piagetian alpha, beta, and gamma phases, but they are far from consensual, so that it is impossible to trace a unique story of one disciplinary communication community going through an alpha-like phase, then a beta-like phase, and then a gamma-like phase. Rather, depending on who is speaking, it appears that a particular disciplinary communication community working on epigenetics—or a part of it—is going through an alpha-like phase, or that the arising of epigenetic knowledge constitutes a beta-like phase, or that it constitutes an accommodation phenomenon in a gamma-like phase. Only in this last case would it seem proper, under Mölders's framework, to speak of supraindividual learning at the level of a disciplinary communication community.

For instance, in her science studies paper, Tolwinski classified researchers in epigenetics in three categories »based on the claims they make about the impact and future of their field: champions, those who take the middle ground, and skeptics« (Tolwinski 2013, 366); one might relate these categories to the three Piagetian phases. If one is to believe Tolwinski's champions, epigenetics amounts to a »paradigmatic shift« in which the genetic framework has been superseded, resulting in a new »revolutionary« one, »incommensurable« with the old one—and all this Kuhnian vocabulary comes from the »champions« themselves (Tolwinski 2013, 372–73). This is reminiscent of an accommodation. If one is to believe Tolwinski's middle-ground researchers, however, epigenetics constitutes an additional assimilation schema, complementary to the genetic one, without this latter one being modified; it would be a beta-like phase. Listening to Tolwinski's skeptics, one gets the impression that epigenetics does not respond to any fundamental problem of the original schema; rather, that the knowledge produced by epigenetics can be assimilated without major difficulties by the main schema constituted by the genetic framework. Indeed, some attitudes held by these »skeptics« make one think of an alpha-like phase; for instance, transgenerational epigenetic inheritance in humans (implying that environmental factors could affect non-germ line cells in adult bodies in such a way that their traces could affect future descendants) was »widely dismissed« by Tolwinski's skeptics, despite the fact that some studies suggest its plausibility. Besides, they »refute champions' claims in contingent terms, emphasizing ›errors‹ in their scientific methods and interpretive work.« In response, Tolwinski's champions find that »insiders« (i.e., researchers aligned with the mainstream perspective) are »*blinded* by a dogmatic scientific culture« (Tolwinski 2013, 376; my italics). This could be related to an alpha phase in which a problem is ignored or repressed.

If these three positions on epigenetics coexist among researchers within the field itself, it is no surprise that one can find them in other disciplinary communication communities as well. Griesemer (2011) sheds light on the lack of consensus about the significance of the possible role of epigenetic inheritance in evolution. He distinguishes »risk-averse« or »conservative« research from »risk-tolerant« or »transformative« research—which he relates to Kuhnian »normal science« and »new paradigms« (Griesemer 2011, 32), respectively. »Research is conservative if it involves empirical work to support the specification of current theory […]. Research is transformative if it forces change in what we already understand« (Griesemer 2011, 24). Thus, »conservative« or »risk-averse« research could be related to an unaltered schema (assimilation), while »transformative« or »risk-tolerant« research would imply accommodation. On that basis, Griesemer shows that epigenetic implications for inheritance and evolution are perceived differently by »mechanistic molecular sciences (MMS) and quantitative dynamical evolutionary sciences (QDES) because these sciences construct models and theories in very different ways« (Griesemer 2011, 16). Acknowledging a role of epigenetic phenomena in transgenerational inheritance and evolution can result in conservative, low-risk research in the former, while provoking transformative, high-risk research in the latter. That could help explain why »[m]olecular and cellular biologists have claimed for 20 years that epigenetic phenomena have significant implications for evolution, not only as adaptations but also as inheritance systems that could fuel evolution at a level above the genetic level« while »[e]volutionists sometimes support and sometimes doubt the implications claimed« (Griesemer 2011, 15). In turn, Griesemer's framework helps understanding some alpha-like and beta-like episodes in the history of genetics regarding what are now considered epigenetic phenomena:

> Jablonka and Lamb (1995), in their argument for the significance of epigenetic inheritance in evolution, reviewed many cases of variable expression from classical genetics experiments and argued that the conservative strategy swept the epigenetic phenomena under the rug rather than faced up to the need to transform genetic theory. (Griesemer 2011, 30)

After reading authors such as Graham (2016), it is possible to find ideological reasons which might also be linked to such alpha-like reactions:

> Established Russian geneticists, who know that Lysenko was a poor scientist, have been somewhat unwilling to explore transgenerational epigenetics because of their concern about the attempted rehabilitation of Lysenkoism. Given their experiences and history, they are a little frightened of epigenetics. […]
>
> Some of the best university textbooks on genetics in Russia, written by fully qualified scientists who are critical of the recent upsurge in Lysenkoism, avoid extended discussions of transgenerational epigenetic inheritance. They fear saying anything that might be used by Lysenko's supporters. (Graham 2016, 268)[3]

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3 It may be helpful to remember that an »exponent of the inheritance of acquired characteristics in the twentieth century was Trofim Lysenko, the agronomist who ruled Soviet biology for several decades. With Stalin's support, he purged the field of his critics. […] In the West, ›Lysenkoism‹ became synonymous with ›pseudo-science.‹ It was a prime example of

In any event, it seems possible to reconstruct the history of epigenetics as an equilibration process going through Piagetian phases. But in order to speak of learning within the function system of science as Mölders proposes, it would be necessary to clearly identify disciplinary communication communities going through this learning process. Yet in an ultra-specialized scientific world, which is at the same time rich in interdisciplinary, trans-disciplinary, and multidisciplinary research, it is no easy task to identify which disciplinary communication communities are learning about epigenetics during its development, because it is not easy to delimit the implicated communities in the first place. A note by Niewöhner (2011, 283) about environmental epigenetics is particularly illustrative:

> This field of research in formation is too heterogeneous to have received a single name or label as yet. Environmental epigenetics is sometimes used by those in the field to describe their own work, yet other labels such as developmental epigenetics or behavioural epigenetics are used interchangeably.

To begin with, it is not easy to identify in which community this knowledge was first learned, since it seems to have arisen precisely in a void where a discipline was lacking, as a bridge between developmental biology and genetics.

Nor is it easy to say if a particular disciplinary communication community could be identified as the »epigenetic« one because this area is considered by some to be a subfield of biomedical sciences and by others a subfield of biology; and in this latter case, it can be considered a sub-branch of different branches, for instance, a »subfield of molecular biology« (Niewöhner 2015, 221) or »of systems biology« (Hallgrímsson and Hall 2011, 1) because biosciences are constituted by »partially overlapping« subfields themselves.

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the ruinous effects of political rule over science.« (Graham 2016, 266). Ideological reasons may also »encourage« epigenetic research but, ironically, this is valid not only for Lysenkoists but also for neoliberals, given the kind of links highlighted by authors such as Lupton (2013) between some implications of the field regarding health and ideas about self-responsibility.

In any event, it is possible to identify isolated cases in which a disciplinary community seems to have learned an epigenetic structure. For instance, the following narration suggests that developmental biology learned »to talk and think in terms of complex gene networks and interactions« (Jablonka and Lamb 2002, 85):

> The distinction between epigenetics and developmental genetics was […] a difference in focus, with epigenetics stressing complex developmental networks […], while developmental genetics was more concerned with the hierarchies of actions that led from a gene to its effects on the phenotype. Today, the situation is different, since all developmental biologists tend to talk and think in terms of complex gene networks and interactions; the epigenetics perspective has to a large extent replaced that of classical developmental genetics. (Jablonka and Lamb 2002, 85)

However, in part because of the difficulty of identifying isolated disciplinary communication communities learning epigenetic structures, and in part because epigenetic expansion concerns so many disciplines, another level of analysis would now be enlightening: the level of the function system of science.

Novel structures spreading at the level of the function system of science: The case of epigenetics

A sociological evolutionary framework

As Mölders (2011) shows, when it comes to the enforcement, at the level of the function system of science, of what is learned at the level of disciplinary communication communities, the systemic learning-theoretical framework is no longer the most appropriate one. Instead, it is pertinent to turn to a sociological evolution-theoretical framework—a framework to which sociologists such as Klaus Eder contributed. When Mölders claims, for instance, that the learned structures of a theory or a method constitute a source of variation for the function system of science (Mölders 2011, 171), this claim is reminiscent of Eder's statement that

»[l]earning […] does not guarantee evolution but provides the mutations for evolutionary processes to take place« (Eder 1999, 195).[4]

According to the sociological evolutionary perspective proposed by Mölders, one may speak of the »(re)stabilization« of »learned structures« if, after figuring in a scientific publication, they are »selected« in the sense that they are employed in other publications. Now, to set a sort of threshold to detect if such (re)stabilization has reached the level of the function system of science, Mölders proposes the moment when the corresponding learned structures are selected by »other« disciplinary communication communities beyond the »dominant internal differentiation« of the function system of science (Mölders 2011, 175). In other words, structural learning »within« disciplinary communication communities does not guarantee that the learned structures in question have reached the general level of the function system of science. In the following, I analyze the spreading of epigenetic knowledge looking for signs of such (re)stabilization.

Novel epigenetic structures reaching the level of the function system of science

As shown above, the history of epigenetics is in large part a story of linking separate disciplinary communication communities. Attempts have been made to identify an equilibration process at the level of such communities, yet it would be easier to conceive of epigenetics as the accommodation of the broad schema of the structure of biosciences, i.e., as a response to irritations pointing to the systemic problem of the isolation of some of its subfields. Just as Waddingtonian epigenetics was a response to the separation between developmental biology and genetics, the more contemporaneous version, more closely related to Nanney's argument, seems to correspond to such an accommodation as well: as Morange (2013, 453) shows, for several decades there was a »total absence of communication between researchers working on histone modification

4 »Societies Learn and Yet the World Is Hard to Change« (Eder 1999) is actually frequently cited, and thus presumably influential.

and those studying DNA methylation.« Despite the fact that »[d]escription of these marks and speculations on their […] role were initiated at the beginning of the 1960s for histones and in the middle of the 1970s for DNA methylation« (Morange 2013, 451), »the two lines of research converged at the end of the 1990s« (Morange 2013, 453). The fact that the impressive growth of epigenetics started precisely in the 1990s, which constitutes its emergence as a new field (or subfield) of research, could be read as a response to the previous lack of connection between these two communities.

Now, is it possible to apply to the case of epigenetics elements of analysis from the sociological evolutionary framework presented? Yes: first, it transcends the dominant internal differentiation of the function system of science; and second, it is precisely about the selection—through citation—of new, published structures. The following statement by Hallgrímsson and Hall (2011, 2) is illustrative of both points: »[t]he term epigenetics has increased in use in the molecular, evolutionary, and developmental literature in recent years.«

As to the first point, the following quote from Meloni and Testa (2014, 432) shows that the phenomenon goes beyond biosciences:

> Even beyond the boundaries of biomedicine, various other disciplines have started to signal the impact of epigenetics on some of their fundamental tenets: from bioethics (Dupras et al., 2012) to human geography (Guthman and Mansfield, 2013), from political (Hedlund, 2012) to legal theory (Rothstein et al., 2009), from epidemiology (Relton and Davey Smith, 2012) to the philosophy of identity (Boniolo and Testa, 2011).

It may even be possible to identify the successful publication from which a massive »selection« of the term »epigenetic« started. Haig (2004, 69) suspects »that ›The Inheritance of Epigenetic Defects‹ (Holliday 1987) was the critical paper that lit the fuse for the explosion in use of ›epigenetic‹ in the 1990s.«

Now, the fact that more and more publications speak of »epigenetics« does not suffice to claim that some learned theoretical or methodological structures coming from epigenetics have reached the function-systemic level of science, especially when it comes to science studies. For instance, if an anthropologist or a sociologist were to run a laboratory study about epigenetics researchers, this external perspective would not imply that her/his disciplinary communication community had learned epigenetic theoretical or methodological structures. One could intuitively claim that the spread of some learned structures coming from epigenetics would imply that other disciplinary communication communities took theoretical concepts or methodological innovations coming from this novel area seriously enough to incorporate them within their own theoretical or methodological frameworks. Well, it seems that this is in fact taking place.

For example, according to Meloni, even »*political theorists* and bioethicists have already started to reflect upon the ›collective responsibility‹ to protect the vulnerable *epigenome*« (Dupras, Ravitsky, and Williams-Jones 2014; Hedlund 2012; both cited in Meloni 2014, 7; my italics). This constitutes an obvious case of a selected theoretical structure.

As to novel methodological epigenetic structures, it seems that some of them are also being selected at the level of the function system of science. In the paper »From Social Structure to Gene Regulation, and Back: A Critical Introduction to Environmental Epigenetics for Sociology,« Landecker and Panofsky (2013, 345) explain how one outcome of epigenetics is the notion of a »bio-dosimeter«: an »empirically measurable« indicator of the impact of certain environmental—including social—factors. One example would be methylation levels as a bio-dosimeter for socio-economic status. Now, the same paper reveals more examples of epigenetic structures being selected by other communities: »[*s*]*ocial epidemiologists* tracking *what they call* the *epigenetic* signature of depression and posttraumatic stress disorder (PTSD) have sought similar demonstrations of the feasibility of using blood samples for studying epigenetic profiles associated with mental disorders« (my italics). In turn, the link between epigenetics, depression, and trauma as a theoretical structure has reached the field of psychoanalysis:

> […] the convergence between clinical-psychoanalytical results from the field of early prevention and from psychotherapy and the results

> from epigenetic studies on depression and trauma is fascinating and opens up new opportunities for interdisciplinary dialogue. Results from epigenetic research can support the psychoanalytical experience in new ways. (Leuzinger-Bohleber and Fischmann 2014, 84; my translation)

It can be thus concluded that some novel epigenetic structures are reaching the level of the entire function system of science. A final example is constituted by the social sciences, where one can already find texts referring to epigenetic phenomena as objective phenomena, i.e., discursively alluded to as if their existence were already taken for granted: »[a]lthough molecular epigenetic research is highly biochemical, it is of interest to sociologists because some epigenetic changes are environmentally mediated and can persist across the life span or into further generations« (Landecker and Panofsky 2013, 334).

In the final section, I will comment on a completely different relation between epigenetics and sociology. Taking inspiration from Landecker and Panofsky's title (»From Social Structure to Gene Regulation, and Back«), I could have entitled this section »From a Waddingtonian epigenetic perspective to an Ederian epigenetic perspective, and back.«

An epigenetic thread from Waddington to Eder, via Piaget

A bibliographical search on relationships between the social sciences and epigenetics yields a publication titled »Learning and the Evolution of Social Systems: An *Epigenetic* Perspective« (my emphasis), written by Eder and published in 1987. Since the boom in the use of the terms »epigenetics« and »epigenetic« started in the 1990s, it is intriguing to find this occurrence of the adjective »epigenetic« in a sociological text dating from the 1980s. Because it includes some rather obscure sentences like the one claiming that »[t]he theory of epigenetic developments in evolution […] refers to developmental processes that decouple biological from genetic evolution« (Eder 1987, 1), the reader can get the impression that the author was not sufficiently familiar with the use and evolution of the term »epigenetic« in the biosciences. The sentence quoted here is troubling because of the odd expression »genetic evolution« and because everything which is genetic can be considered to be a part of biology; it is thus difficult to understand how »biological« and »genetic« evolution could be decoupled. In any event, this understanding of the so-called theory of epigenetic developments in evolution seems to have inspired Eder to reflect on sociological evolutionary theory: he claimed that »[d]ecoupling evolutionary processes from genetic evolution is even more important for social evolution« (Eder 1987, 1). A paragraph later, Eder provides a reference which seems to be the origin of these reflections: Ho and Saunders, 1982.

The cited text, »The Epigenetic Approach to the Evolution of Organisms—With Notes on its Relevance to Social and Cultural Evolution« turns out to be a chapter of the book *Learning, Development and Culture* (Plotkin 1982a), and it does not seem an irrelevant coincidence to find in the same book, among what the editor »judge[d] to be classic pieces of writing« (Plotkin 1982b, x), an extract of Piaget's *Biology and Knowledge* (1971) as well as a text written by Waddington.

Returning to Ho and Saunders, their text sheds light on Eder's. For instance, the rather obscure »developmental processes that decouple biological from genetic evolution« seems to be a paraphrase of Ho and Saunders' claim that »[t]he existence of the epigenetic landscape is fully consistent with the effective *decoupling of genic from organismic evolution*« (Ho and Saunders 1982, 349; my italics), a sentence which makes so much more sense since it refers to the fact that, contrary to the gene-centric view of heredity and evolution, changes in genes do not always match changes in the organisms involved. Now, the »epigenetic landscape« to which they refer is a Waddingtonian invention (Goldberg, Allis, and Bernstein 2007). Indeed, in their presentation of »the epigenetic versus the genetic approach,« they seem quite informed about these two traditions of thought in the life sciences, and they refer to Waddington several times. It is then curious to find a theoretical thread from Waddington's (biological) epigenetics to Eder's (sociological) way of conceiving an »epigenetic« approach, via Ho and Saunders.

But this is not the end of the story. By claiming that there is an »analogy between evolution and cognitive processes,« Ho and Saunders (1982, 353) cite Piaget (1979). Thus, not only is their text an original contribution to a book containing reprinted fragments by Waddington and Piaget: they cite these two thinkers, manifesting a theoretical thread between a biological Waddingtonian approach, via a learning-related Piagetian approach, to their text, which Eder used as a bridge to arrive at his sociological perspective.

Yet there is even more to the story, for there are three important points to be made about the text by Piaget included in the same book. (1) It is explicitly based on Waddingtonian ideas: Piaget applies, for instance, the concepts of »genetic assimilation« (Piaget 1982, 150), explicitly taken from Waddington (Piaget 1971, 4), and »epigenotype« (Piaget 1982, 148), coined—or at least used earlier—by Waddington (Haig 2004, 67). (2) It reveals a connection between Piaget the biologist influenced by Waddington on the one hand and Piaget the cognitive theorist on the other (it is not simply a coincidence that the book in which this text was first printed was *Biology and Knowledge*). And (3) it reveals the origin of such Piagetian notions as »assimilation,« »accommodation,« »equilibrium,« or »adaptation,« which were all influenced by Waddington, and which Piaget was going to employ both in his biological evolutionary reflections and in his learning theory. As already pointed out, the link between these notions and the realm of cognition and learning was to be influential for a sociological equilibrium theory of systemic learning and evolution. The following quotes are particularly illustrative regarding points (1) and (3). By criticizing Lamarckism and its »indefinite power of accommodation,« as well as what Piaget called »mutationism,« implying »assimilation without accommodation,« Piaget claimed that a »third solution at last appeared in the form of *Waddington's* synthesis; now the genetic system is seen as being *adaptive* in itself, in the precise sense that there is an *equilibrium* between *assimilation* and *accommodation*« (Piaget 1982, 148; my italics). The following quote about »differentiated and more or less refined mechanisms of *equilibration*« illustrates point (2): »[t]hese are, in fact, regulations which, even in their details, present *striking isomorphisms between the organic and the cognitive domains*« (Piaget 1982, 150; my italics).

The thread from the Waddingtonian biological epigenetic perspective to the Ederian sociological epigenetic perspective is then complete, going via Piaget's biological and learning-related epigenetic perspective. Eder actually employs the term »epigenetic« in more recent sociological texts related to learning in such a way that its divergence from the current field of epigenetics is evident (e.g., Eder 1999,[5] 2006). Eder himself was probably the diverging point between the line of reflection by thinkers such as Ho and Saunders on the one hand and Eder's own understanding of »epigenetic« on the other. Nevertheless, the idea that the sociological framework employed here to examine epigenetics could share an origin with epigenetics itself invites one to point out this almost playful circularity.

Conclusion

In this paper, I adopted a sociological perspective to reflect on the history of epigenetics. I drew upon some theoretical insights provided by Mölders (2011): (1) a sociological learning-theoretical approach about learning in the function system of science conceived as an equilibration process at the level of disciplinary communication communities, and (2) an evolution-theoretical approach about the way in which learned structures reach the level of the entire function system of science, in an attempt to answer the questions »Is it possible to identify disciplinary communication communities learning about epigenetics?,« »Does the development of epigenetics correspond to a Piagetian equilibration process?,« and »Have novel epigenetic structures reached the level corresponding to science as an entire function system?«

Despite the plausibility of identifying disciplinary communication communities which have learned epigenetic structures, and interpreting some episodes of their history as Piagetian phases, in the case of epigenetics a sociological evolutionary analysis concerning the entire systemic level of science seems more feasible and pertinent for the following reasons. First, the realm of biosciences, constituted by rapidly diversified and »partially overlapping« subfields, makes the task of delimiting disciplinary commu-

5 »This evolution is based—in contrast with natural evolution which rests on genetic evolution—on ›epigenetic‹ processes which we call cultural evolution. Epigenesis is a concept that refers to learning as a mechanism secondary to natural evolution« (Eder 1999, 195).

nication communities difficult. Second, the kind of knowledge associated with the term »epigenetics« seems to have emerged outside of any preexisting disciplinary communication community: epigenetics could even be said to be a response to a problematic void between certain disciplinary communities. Finally, epigenetics seems to concern the entire systemic level of science from the very beginning because it has always transcended the dominant internal differentiation of this system.

From an evolution-theoretical perspective inspired by the one proposed by Mölders, one can claim that several (theoretical and methodological) structures coming from epigenetics have been successfully selected beyond the boundaries of disciplines, both within biosciences and beyond, through citation in scientific publications. In this sense, it can be claimed that an epigenetic shift has reached the function system of science. Actually, some novel structures drawing upon Waddingtonian epigenetics seem to have been selected by a chain of authors reaching sociologists such as Eder, nourishing in turn the learning-related evolution-theoretical line of sociology. In this sense, one can say that it is possible to apply an »epigenetic« (sociological) approach when analyzing the way in which science has selected epigenetic structures.

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