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The epigenetic turn

Some notes about the epistemological change of perspective in biosciences

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Abstract This article compares two different bodies of theories concerning the role of the genome in life processes. The first group of theories can be indicated as referring to the gene-centric paradigm. Dominated by an informational myth and a mechanistic Cartesian body/mind and form/substance dualism, this considers the genome as an ensemble of discrete units of information governing human body and behavior, and remains hegemonic in life sciences and in the public imagination. The second body of theories employs the principle of the extraordinary plasticity of the (body-)organism and emphasizes the value of the (body-)organism-environment mutual interchange, known as 'the epigenetic approach'. This approach is outlined, showing a gradual, paradigmatic shift from the genecentric towards an epigenetic approach can be observed in the 'scientific landscape' over the last 20 years. The article concludes by formulating the argument that this 'epigenetic turn' in life sciences has some important implication for renewing epistemological basis of social sciences.

Keywords Organism · Environment · Plasticity · Development · Technique

Introduction

Over the last three decennia, an intensive debate in science and wider society on the development and impact of genetics and genomics has been taking place in various parts of the world. This debate had important scientific, philosophical, economic and symbolic implications. The general assumption of this article is that in spite of the wide range of actors and institutions (scientists, politicians, churches, bio-ethicists, etc.) animating this discussion with different and often opposing voices, the debate in itself takes place within an hegemonic scientific and cultural paradigm which is built upon specific conceptual interpretations of life demanding the development of a critical reflection.

The main aim of this article¹ is, on one hand, to reflect on the basic epistemological pillars of this hegemonic paradigm and, on the other, to discuss the emergence of a new scientific and epistemological turn which leaves the former in serious crisis.

The hegemonic paradigm—assumed by the opposed sides—in the debate is built upon the assumption that life is

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fundamentally *detached* from the environment in which it develops. The assumption of detachment is anchored in a long Western philosophical tradition of thinking in terms of dualistic entities (Galimberti 1983, 1999). Modern genomics represents an example of that paradigm because here life is composed of two parts, the germplasm (actually defined as DNA) and somatoplasm, with the germplasm containing all the necessary information to shape (activate) the organism (somatoplasm) which, conversely, reacts (passively) to the inscriptions of the germplasm. A dichotomy of genotype and phenotype is assumed in which the hereditary information moves only from genes to body cells and never in the opposite direction. Germplasm and somatoplasm are bound to each other through this unidirectional, causal relationship (the so-called Weismann barrier). In this vision, great weight is given to the genetic *design* of life, the genetic program that is incorporated into our cells as the result of the natural selection of random genetic mutations. It is evident that this concept of life reduces biological organisms into passive entities governed by internal mechanisms and detached from the world around.

This epistemological frame of reference of an assumed detachment of life is, however, increasingly challenged. Through epigenetics, renewed interest has developed in the relevance of relationships between organisms and the external environment, in which laboratory research has shown that environmental stimuli can be genetically assimilated and transmitted to subsequent generations even when the stimulus which generated them is no longer active (Waddington 1953, 1959).

This article refers to various bio-scientific studies that challenge the currently dominant gene-centric paradigm. The first section starts by presenting some of the core scientific assumptions on which the actual hegemony of a unidirectional and informational basis of life is built. It shows that this hegemonic reading of DNA derives from a long historical and epistemological tradition. The second section presents bioscientific arguments on which an alternative paradigm is constructed, considering the genome as an *embedded* and *plastic* entity. This section discusses various new routes that are being followed in reading the role of the genome in life processes, routes recognizing the creative role of the organism-within-an-environment, and which thus have the effect of exploding the traditional nature/nurture dichotomy.

By way of an introductory reflection for further developments, we conclude with a final section which argues that such a new (or renewed) concept of life has important implications that can also inform the social sciences in a renewal of their epistemological basis and lead them to a different approach to technology development.

The gene-centric approach: the hegemonic paradigm

Watson and Crick's 1953 'discovery' of the structure of DNA led to the formulation of the protein synthesis –the equation of one gene, one protein. This was interpreted as the uncontroversial confirmation of the Modern Synthesis, or neo-Darwinism, presenting a picture of the human genome as an ordered and sequential ensemble of basic mechanisms, the genes, seen as informational bricks governing uni-directionally the 'functioning' of our body just as programming languages govern the functioning of computers. David Le Breton has dubbed this interpretation 'genetic fundamentalism', or the informational myth (Le Breton 2004). In this first section we want to emphasize that reading and interpreting biological processes are strongly influenced by specific (tacit) rules of scientific communities elaborated within the hegemonic social-historical context (Kuhn 1962). In particular, we will emphasize that such a process in science (biology) development has contributed to disconnect the DNA from the developmental processes of organism, and to perceive DNA instead as merely an informational mode, independent of its environment.

DNA as a code: the informational metaphor

Kay (2000) has described the socio-historical process through which the DNA-based protein synthesis was transformed into a very powerful informational metaphor: the *code* (or the book of life). As we know, metaphors are very powerful tools in determining '*knowledge dynamics*' (Maasen and Weingart 2000). So, like other successful representations used and assumed within scientific (and wider, public) discourse ('the big bang', 'black holes', etc.), this informational metaphor—coined in molecular biology in the fifties—played a very relevant role. It has heavily influenced the subsequent development of science, even though many scientists at the time of its development protested against this biasing analogy. Kay showed that this information code metaphor had been strongly shaped in those years by the rise of communication techno-sciences, which facilitated the embedding of 'information thinking' in many scientific disciplines. This included the life sciences, in the case of which, it determined a paradigm shift from proteins to DNA. Today, as she says, it is difficult to think about protein synthesis without referring directly and immediately to information code and writing technologies, whereas up to the 1940s biology was characterized by the predominant relevance of a totally different metaphor: *specificity* (Kay 2000).

The social affirmation of the informational representation of life as a code caused a sort of 'fetishizing' of DNA, transforming *every* living form into an 'organized sum of

information' (Le Breton 2004: 1). In fact, one of the main benefits of the information conceptual category has been its neutral and universal characterization. Information has been used by scientists without any reference to a specific 'who', 'where', 'when', etc. It is a sort of wonderful, universal Esperanto that can be used at any given moment to translate any living form into a series of instructions. This transformation, according to Le Breton, has gradually removed living material from the scientific horizon, because 'information effectively puts all levels of existence on the same plane and empties things of their substance, their value and their meaning in order to make them comparable' (*ibid*). Our assumption here is that the success of the code metaphor within scientific thought lies in its capacity to meet a classical Western epistemological dualistic juxtaposition: form versus substance.

The body as a machine: the philosophical background of the form/substance dualism

We can trace the founding form/substance dualism back to Plato and Aristotle's ancient speculations, but we find in Descartes its full modern expression. As Sini (1993: V–XX) remarks, there are works marking the passage to a new era and Descartes' *Discourse on the method* is probably one of the highest and certainly one of the most emblematic example of these. Although Descartes developed ideas that we cannot consider original for the time—Copernicus, Bruno, Kepler and Galileo were probably, in fact, the outstanding protagonists of the modern, or 'Western', epistemological revolution—Descartes' work is widely considered the foundation of modern thought because it was an organic systematization of a radically new cultural climate. It was a manifesto leading to a new *mechanistic philosophy*.

The new 'Cartesianism' gave expression to the rise of a new *scientia activa*, oriented to man's *intervention in nature* and its modification, coupling knowledge to action, wisdom to power. This new science contrasted the old Scolastica *scientia contemplativa*, which was merely oriented to contemplate the grandeur of Nature created by God. The 'machine' became the paradigmatic figure of this new philosophy applied to nature (the external world), as well as to human body architecture (the internal world) through medicine. With the fallibility of perception leaving only the mental state of consciousness or awareness (the *cogito*) as unquestionably valid, which Descartes crucially blurred into thought, and thence to reason, so mathematics and geometry became considered the main sciences to understand the machine. Rigor, logical and formal abstraction, precision were the qualities of this knowledge, enabling man to 'steal' the law governing the perfect mechanisms of the natural machine. Thus did Koyré (1948)

characterize the new philosophy as the transition from the vague to the precise ('*du monde de l'à-peu-près à l'univers de la précision*'). And thus 'the clock' became the metaphor best able to represent the precise (rational) structure of the machine. Descartes depicted the Universe and Nature as well as the Human Body like they were perfect machines, indeed as clocks.² And indeed, Descartes depicted the Universe and Nature as well as the Human Body as if perfect, precise machines.

At the same time, Descartes introduced within the epistemological paradigm of modernity a new element: the mind/body dualism.³ And, separating the body (*res extensa*) from the mind (*res cogitans*), he recognized the superiority of the latter, because only the latter was capable of thinking (*res extensa* being but a 'mirror reflection'—Galimberti 1983). It was the *ego cogito* that lived the world, not the human 'I' as a whole. For Descartes, in fact, 'mind would not cease to be what it is, even if the body was not' (Galimberti 1983). So, Cartesian thought introduced the possibility of a disjunction between body and mind, and reduced the human being to the essentialism of pure spirit (or, disembodied consciousness) and this, in a nutshell, is the cultural background which made possible the hegemonic imaginary in modern society of the anatomic body.⁴

The *disjunction of body and mind* enabled modern science to focus on the body (and the material world), perceived as disconnected from the mind, thus facilitating the development of modern science (as an 'objective' methodology). In fact, the traditional separation of matter from spirit became a separation of the body from the person (Le Breton 1990). From that moment on, the person was associated with the verb 'to be' (I am, a form of solipsistic consciousness). The body, on the contrary, was associated

² And 'the clock' then also became the metaphor best able to represent the rational structure of the machine, suggests Mumford (1934), this true prototype of the ideal machine a kind of mechanistic paradigm, with its 'logic of interdependence', accuracy and efficiency.

³ It is appropriate to remember again that Descartes did not actually introduce this dualism, as it was already implicit within the ancient Platonic-Christian tradition. Rather, he explicitly separated the body from the soul (or mind) in a secular and scientific framework, providing the power of a rational systematization to this decoupling.

⁴ In fact, Descartes donated cultural legitimacy to an already existing medical practice and a new anatomical knowledge that had been emerging in Italy (Padua, Venice, Florence) since the fifteenth century, and had reached a turning point a century before, in 1543, with the astonishing *De corporis humani fabrica* by Vesalio (the Flemish Andreas van Wesel). In Padua, at that time the most important Gymnasium of the world, Vesalio confuted the Galen's anatomy, discovering a '*new body*'. In this sense, Vesalio was the main author of a revolution less known but no less important than that of Copernicus (with *De revolutionibus orbium coelestium*, 1543). We may say that 'the macrocosmic revolution of the 'universe factory' coincided with the microcosmic revolution of the 'human body factory'' (Cosmacini 2003: 234, translation by the author [Nicolosi]).

with the verb 'to have' (classically, bundles of properties). So, ontologically, 'I am', but 'I have a body'. Society had never been so far from the holistic dimension of the communitarian characterization of the pre-modern era. The body had become a residual entity, emptied of and detached from its spiritual environment. It became a corpse to dissect, a machine to operate (on), the human body as holistic entity in the pre-modern era now reduced and objectified by scientific investigation and experiment (Le Breton, *ibidem*: 61).

Thus, had Descartes given philosophical legitimacy to a new structure aspiring to geometric precision, as if a clock. He did not create a new sensitivity, but revealed it to the whole world. From now on, this machine (body, as well as nature) appeared as formally organized, to be studied with formal tools like mathematics (eponymously heralded just a half century after the Discourse by Newton's *Principia*).

The hegemony of the informational model of life

Oyama (1998) suggests that the ancient mind/body dualism is reproduced within the genocentric paradigm in biology. This paradigm opposes genotype to phenotype, ascribing to genotype a deterministic influence on phenotype. Here, again, the form (genotype) has the True and Structural condition, while the substance (phenotype), the physical, embodied organism, is only its material and contingent expression. In this view, it is only the form that is really important, for which we employ abstract tools (algorithms, information science, etc.) in order to capture the essential information and which cannot be tricked by the changing appearances of the substance. The onto-genetic development (the substance) is controlled by the genetic program (the form). In this sense a sort of preformistic paradigm appears, according to which a fertilised egg contains the organism design and that all information is needed to specify its development (Lewontin 2002: 6). Metaphors such as 'the genes as programs' and 'DNA as information', very common amongst biologists, represent a contemporary version of this pre-modern belief in the so-called *homunculus*. That is, the paradigm which orders the conceptualization of the genome as a 'barrel' containing discrete information units, linearly linked to a unique determination chain from genotype to phenotype, belongs to a hypothetical construction of reality which is increasingly at tension with actual observation in the laboratory.

Lewontin (2002) argues that the particular attention paid to similarities and invariance between organisms and species has led developmental biology to emphasize the deterministic power of DNA. According to this latter, organism development is, in the end, the mere 'unrolling' of a pre-determined genetic program—to the point of assuming that if we knew the complete DNA sequence of a

certain body we would be able to develop that body. He also argues that the usage in science of concepts like 'self-replicating DNA' and phrases like 'DNA fabricates proteins' are likely to present a misleading instructionist paradigm. Very little or no weight is given to the internal or (worse) external environment; evolution is envisaged as a process producing (novel) genetic programs (a sort of *design*, or informational software) that control ontogenetic development. A linear influence is assumed, and rather than mutual interchange an unbridgeable divide of ontogeny from phylogeny is assumed.

All these considerations can help us to understand why Le Breton claims that we witness today a hegemonic 'genetic fundamentalism' paradigm according to which every living being is an organized sum of genetic information. An interesting example of genetic fundamentalism can be found in Gros (1990: 20) referring to the Human Genome Project. According to Gros, we can reduce vital mechanisms and therefore also human behavior to a 'huge algorithm' whose program is determined by chromosomes. From this perspective, biology itself should be considered as an information science and the human body as a kind of complex 'Meccano' whose components are just genetic information. Le Breton is right to warn about the risk of just such a reductionist approach leading to a scientific tendency to deny differences between organisms and species, as well as between the living and not living.

One serious risk we run in following this framework is that of depriving living beings of their *specificity*.

Bertrand Jordan,⁵ someone who certainly cannot be accused of harboring an anti-science attitude, has complained that undisputed advances in biology led some scientists, the media and public opinion to overestimate the power of genetics (Jordan 2002). He talks explicitly of a culture of 'genetics mastery', where imposers and fakers can thrive. Scientists contribute to this mastery, he says, sometimes from imprudence and sometimes for other, sometimes immoral, interests. Inherently sensationalist, the media also contributes to laud genetics through oversimplification, which distorts reality. Nevertheless, new routes leading to other visions and perspectives have been opened.

The epigenetic turn

The gene-centric reading of life has increasingly been challenged by biology scientists as well as by philosophers of science over recent years. Gradually, a new way of looking at the role of the genome in life processes, based on alternative assumptions, has appeared. These new assumptions have been tracing a two-step conceptual flow

⁵ Research director at CNRS and world famous geneticist.

challenging the genetic dogma: from the idea of the isolated genome to the idea of its relationships with the living organism (first step); from the living organism to the interrelations of this latter with the environment (second step). What is crucial here is that this flow is not unidirectional, but a circular one.

DNA as a plastic entity focusing on organism—environment mutual interchange

Over the last three decades and stimulated by the pioneering work of Conrad Waddington,⁶ many scholars started to feel dissatisfied by the hegemonic gene-centric approach and started to take a different direction. The traditional epistemological divide between inside and outside was radically reconsidered and perceived as too mechanistic a vision. Through this divide, Lewontin (2004) argues, the organism is read as the passive meeting point of independent external and internal forces. Whereas, according to him, the relationship between living organism and environment is a process of mutual dependence and feedback, a process of co-construction, in which the organism plays an *active role*. In this perspective, the environment is a space importantly defined by the activities of the organism (Lewontin 2004: 46). This implies:

1. Organisms may search for or select micro-habitats or habitats with specific physical conditions;
2. Organisms are active players in building the world they inhabit;
3. Organisms can survive by altering their environment, consuming the resources they need for this;
4. Organisms are highly sensitive to cyclical changes in their environments.

Therefore, organic life is a *process* based on the transformation of the environment, a transformation that is continuous and retroactive. The transformative change causes reactions in a round of continuous change, a perpetual, *interdependent process of co-construction* involving organism and environment (which, of course, includes other organisms). For this reason, Lewontin suggests that organic processes cannot be understood within universal explanations: they have *historical contingency*.

Within this biological 'new wave' also appears *another way of understanding the process of selection*. Many

⁶ According to Waddington, laboratory empirical research showed that some somatic non-inherited changes provoked on phenotypes by environmental stimuli can be genetically assimilated and transmitted to following generations even when the stimulus which generated them is no longer active. Fundamental here is the fact that the genetic mutations are not random, but environment-oriented or phenotype-centered: that is, genes serve the organism within a specific environment.

scholars share the idea that we live today in a post-genomic era, a period in which the central dogma of 'one gene, one protein' (the one-to-one model) is unquestionably in crisis. Adherents of this view emphasize that we need to talk about '*smart changes*' produced by cells and that we have much empirical evidence and a (revived) theoretical basis for depicting the genome as a *plastic entity* and an *integrated complex system*. They recognize a newly important and creative role to the organism-within-an-environment ultimately collapsing the traditional nature-nurture dichotomy.

Phenotypic plasticity, epigenetics and the emphasis on the development process

Within the one-to-one model and gene-centric approach there has been an underestimation of various phenomena, such as:

1. Pleiotropy: one gene affects several traits simultaneously;
2. Epistasis: genes affect other genes, giving shape to complex genetic architectures affecting a trait;
3. Redundancy: different triplets specify the same aminoacid.

Rather than underestimating and even neglecting these phenomena in the reading of the genome, many scientists during the last 20 years have emphasized the importance of *phenotypic plasticity*, the '*property of a given genotype to produce different phenotypes in response to different environments*' (Pigliucci 2001: 1). Rather than a linear geno-phenotype relation, this suggests a dialectical relationship between genes and environment. But what is really revolutionary here is the combined effect of two concepts: *phenotypic plasticity* and *epigenetics*. As Massimo Pigliucci (2001) emphasizes, the epigenetic interpretation of phenotypic plasticity makes *development process* the crucial node in the genes-environment dialectical relationship.

A consequence of this new way of understanding the relationship between organism and environment is that geno-phenotype interactions are also differently conceived. For example, West-Eberhard (2003: 16) claims to 'adopt a phenotypic definition of selection'. West-Eberhard explicitly links species differences and new phenotype creation to the reorganization of 'ancestral phenotypes' (developmental recombination) and the consequent 'genetic accommodation' of change. In fact, she says, selection does not act directly on genotypes: it affects phenotypes first (West-Eberhard 2005a). So, novel traits can originate through environmental induction as well as mutation (for example, as a side-effect), and then undergo genetic accommodation and selection. In fact, as she wrote:

If the resultant phenotypic variation has a fitness effect, that is, it correlates with the survival or reproductive success of the affected individuals, then selection (differential reproduction of individuals or other reproducing entities with different phenotypes) occurs. If the phenotypic variation has a genetic component, selection leads to 'genetic accommodation', that is, adaptive evolution that involves gene-frequency change. Genetic accommodation of regulation adjusts the frequency, timing, and circumstances of the novel response (e.g., by adjusting the threshold for its expression), and genetic accommodation of form refines the characteristics and efficiency of the newly expressed trait. (West-Eberhard 2005b: 6544)

Since phenotypic novelties arise in this approach from adaptive developmental plasticity, they cannot be considered as 'random'. More precisely, according to West-Eberhard's research evidence, phenotypic accommodation is a specific adaptive adjustment, within which we cannot find genetic change. This adjustment follows new input during development and may start adaptive (Darwinian) evolution in a new direction. What is really important here to emphasize is that the argument that, contrary to common belief, *environmentally initiated novelties may have greater evolutionary potential than mutationally induced ones*. In this perspective, genes are seen 'more as followers than leaders in evolutionary change' (West-Eberhard 2005b: 614).

Another important contribution to the epigenetic approach to the genome has been made by Eva Jablonka and Marion J. Lamb through their book '*Evolution in four dimensions*', in which the gene-centered version of Darwinian theory makes way for an analysis of inheritance as determined by four dimensions (four systems): genetic, epigenetic (cellular transmission without DNA mutation), behavioral and symbolic (language and communication). Named the Epigenetic Inheritance System (EIS),⁷ this would certainly seem to represent a radical alternative to neo-Darwinism rather than just an extension of the Modern Synthesis.

Combining Darwinism, Lamarckism and Punctuated Equilibrium Theory, the Epigenetic Inheritance System is seen as driving genetic selection, producing mutational biases and moving towards systemic mutation. For Jablonka and Lamb, developmental and evolutionary adaptation are not always the expressions of opposite paths. While it is true that development implies *instruction* and evolution

implies *selection*, certain inherited variations are clearly controlled by physiology and development.⁸

Jablonka and Lamb suggest that, except for few cases, all specialized cells (liver, skin, kidney, etc.) are differentiated on the basis of epigenetic differences. Although they have the same genetic information, they work differently. It is *the specific developmental history determining which genes will be active* and how their products will interact (Jablonka and Lamb 2007: 140). What is really important in the argument, here, is that several specialized cells are able to transmit their phenotype to their daughter cells without changing DNA sequences. Jablonka and Lamb describe four different types of EISs: the self-sustaining loops,⁹ structural inheritance,¹⁰ chromatin-marking system¹¹ and RNA interference (or the 'silencing' of the genes).¹² Jablonka and Lamb believe, following the lead of many microbiologists, that the already known EISs are only the 'tip of a very large iceberg' (Jablonka and Lamb, *ibidem*: 172). Probably, this claim is overemphatic, but to support this idea they present some very interesting cases of methylation able to cause inherited phenotype variations both in vegetal (*Linaria vulgaris*) cases and mammals (Whitelaw's mutant mouse strain).

However, what is theoretically really important in Epigenetic Inheritance Systems (EISs) is that they are, at the same time, both onto-genetically and phylo-genetically relevant. They play a key role within development (ontogenesis) and within evolution. For this reason, it is possible to use the neologism *evo-devo* to indicate processes they imply and to start thinking about a new way of reading and living life.

⁸ For example this is the case of the so-called *alternative splicing*. Here we have a process by which a single DNA sequence is able to produce different mRNA and, by consequence, multiple proteins. In the alternative splicing, the environment and the developmental conditions determine which polypeptide will be set. At the same time, several cells are able, with the help of specific enzymes, 'to cut and paste' RNA and DNA itself.

⁹ A temporary stimulus induces a gene to be active, and its product induces the gene's activity. It is a model in which A produces B and B produces A within a feedback system. Daughter cells inheriting the gene's product reproduce the active state.

¹⁰ Here the existing structures of some cells can mold similar ones in daughter cells. It is the membrane *organization* to be modified and transmitted. Some pathogen agents are, in fact, self-modeling, famously the prions in Bovine Spongiform Encephalopathy (BSE) and Creutzfeldt-Jakob disease (CJD) in human beings.

¹¹ Such as the DNA methylation enabling gene activity or inactivity states which are then transmitted in cell lineages.

¹² Called RNAi, this is an EIS able to bringing about stable and inheriting gene silencing: some abnormal RNA molecules are recognized and chopped by a special enzyme (dicer) and the resulting fragments (siRNA) are able to eliminate the mRNA abnormal copies through methylation or a protein mark (Jablonka and Lamb 2007: 166).

⁷ That is the transmission of information from a cell or multicellular organism to its descendants without that information being encoded in the nucleotide sequence of the gene.

Re-reading the genome as a place of potentialities, illustrating the creativity of living systems

In our view, the philosopher of biology Oyama (1998), interpreted excellently this new mood. Her work presents a radical re-interpretation of the ontogenetic development concept as well as biological evolution in general, adopting a view considering *development as the intersection of many interconnected levels*. Oyama proposes to exit from traditional oppositions implied by the nature-nurture binomial, defining each system as a ‘natural-cultural’ as well as ‘environmental-genetic developmental system’. In fact, following the experimental evidence collected even by the end of the 1990s, she re-conceptualizes the genome, presenting it not as a barrel—full of discrete units of information linearly interconnected (genes)—but as an integrated system, a non-linear multilevel network related to cells and organisms. From this perspective, the genome is a ‘*place*’ of potentialities influencing the developmental process with different modalities, context-dependent. The genome is the place where, against the common wisdom, living systems show their incredible creativity.

Oyama supports her thesis referring to the Developmental System Theory (DST). In such a system, there is no room for the dualistic interpretation of body/mind or nature/culture relationships. These are not pairs of ‘interacting’ entities because this interaction logically assumes a (prior) differentiation between these *as* distinct entities. Here, on the contrary, development is seen as an ‘*interactive emergence*’, where the system is self-organized, and in which the ‘self’ is not a *primum mobile* but an *entity-with-its-world*.

A very fundamental idea belonging to the DST approach that we want to emphasize is the need to shift the focus of analysis from the information transmission process to the never-ending co-construction and co-transformation processes. As pointed out by Sterelny (2001), and in line with Lewontin (above), for DST, inheritance and learning are coupled concepts delineating interactive resources transforming entities and contexts throughout lifecycles. Furthermore, because the relationship between information and ontogeny is inverted within DST (and by Oyama), the (genetic) *program* metaphor—‘explicitly identified as the genome’, as Fox Keller (2001: 303) strongly claimed—loses its misleading power.¹³

It is individual ontogeny which gives pertinence to information. Development is the primary datum. This is a new paradigm, which implies a radical shift to a focus on individual process and contingency. Contingency does not

mean unpredictability, however, as it here has an *ontological* sense: it is a special case of causal determination. In developmental systems, in fact, we register a very high degree of contingency amongst different levels of causal determination—which, paradoxically, produces predictable and repeatable but, at the same time, not necessary or ineluctable trajectories.¹⁴

Development is thus reconceived as a game between internal constraints and external potentialities. This game makes life creative and flexible. This ambivalent quality of developmental systems makes life processes both reliable and unpredictable, at the same time. This is what Oyama (1998) means when she says the developmental systems are ‘ordered’, but not ‘pre-ordered’. Oyama’s work—as well as that of Lewontin and Patrick Bateson (1988)—has anticipated a very rich and influential research stream. From the socio-anthropological perspective, probably the most relevant track deriving from this stream is the so-called ecological niche construction approach, in which an ecological inheritance is emphasized alongside genetic inheritance (Odling-Smee et al. 2003).

The ecological niche construction approach: re-discovering ecological inheritance (the epigenetic inheritance)

Where Jablonka and Lamb proposed four distinct inheritance systems in evolution, Odling-Smee et al. (2003), giving a new momentum to Lewontin’s teaching, has proposed two general inheritance systems in evolution: genetic inheritance and ecological inheritance. Starting from Waddington’s fundamental assumption, according to which organisms are not passive agents obliged only to react to external local selective pressures, Odling-Smee argues that organisms are active agents perturbing and selecting (with metabolisms, movements, behaviors, choices, etc.) their own habitat (niche). That is, plastic phenotypes are able to change the natural selection pressures of local environments simply because to stay alive they must use resources from their environments through non-random work. These changes can ‘act back on the phenotypes, and on their offspring, and very likely, on other related organisms too, with “better” or “worse” consequences for the genetic fitness of all these organisms’ (Odling-Smee 2002: 165).

According to this view, ancestral organisms transmit to their descendants not only genes but also an *ecological inheritance*, that is, the inheritance of natural selection

¹³ Revealingly, this metaphor was borrowed from (early) computer science, according to Evelyn Fox Keller, introduced by Mayr (1961) and Monod and Jacob (1961).

¹⁴ Deconstructing the nature/nurture dichotomy, Oyama presents a view in which ontogenetic cycles employ a set of heritable developmental resources. Each generation reconstructs them activating a process very similar to what Maturana and Varela (1980) called *autopoiesis*.

pressures modified by the localized environmental construction activities of organisms. This represents a mix of independent sources determining the generalized environment and which act on the organism (e.g. climate, the activities of other organisms), and behavior by the organism acting on the environment that creates specific (favorable) conditions. The evolution of organisms, in other words, depends on a combination of natural selection and niche construction.

According to Griffiths (2001), ecological inheritance is a phenomenon which goes beyond the so-called 'Baldwin effect'.¹⁵ He argues that natural scientists continue to show a great interest in the Baldwin effect because they believe that without genetic traces, the epigenetic inheritance cannot leave a significant evolutionary contribution. Griffiths argues that this belief is mistaken and that the Baldwinian heterodoxy of social heredity finds in ecological inheritance theory a very good 'epigenetic' continuity. There are at least four reasons for differentiating ecological from genetic inheritance (Odling-Smee 1988): it is transmitted by an external medium, the environment; it does not imply the transmission of discrete replicators; it involves several organisms (not only two parents) within and between generations; and it does not involve only genetic relatives, but all organisms sharing a specific ecosystem (with an ecological relationship). In the words of Luca Cavalli-Sforza, ecological inheritance may be 'vertical, horizontal or oblique' (Odling-Smee 2002: 178). He, therefore, proposes a revised socio-biological approach based on an organism-environment co-evolution model.

Human culture is, of course, located within these niche construction processes. Here, cultural modification of natural selection pressures are seen as a part of a more general 'heredity' of modified selection pressures caused by the niche modification action of constructing ancestors. Culture, from this perspective, influences genes in two ways. Firstly, it influences differential survival and reproduction, as already assumed by human behavioral ecologists or, in a richer version, the gene-culture coevolution theorists (e.g. Cavalli-Sforza and Feldman 1981). Secondly, it contributes to niche construction. From now on we thus have to include within the human ecological inheritance the culturally modified natural selection pressures, artefacts included.

Exaptation and the organism as a "bricoleur"

Within this alternative post-Darwinian framework we also find an important reassessment of the concept of

¹⁵ The 'Baldwin Effect' was theorized by the American psychologist James Mark Baldwin. It describes a character change (acquired or learnt behaviour or skill) occurring in an organism as a result of its interaction with its environment and becoming gradually assimilated into its developmental genetic repertoire.

exaptation. This concept has a long history dating back to 1872, when Charles Darwin responded to the zoologist George Mivart's objections to the presumed inability of natural selection to account for the incipient stages of particularly complex biological structures. Darwin used the neologism '*pre-adaptation*' and introduced the possibility of *redundance* in nature within the relationship between organs and functions. This redundance, for Darwin, exists in order to allow that a trait developed for a certain reason could be co-opted or converted towards a function completely independent from the previous one—a functional co-option renamed '*exaptation*' by Gould and Vrba (1982), to indicate how organisms often opportunistically re-adapt available structures for new functions.

It is interesting to notice that the concept of *exaptation* put in evidence an interesting analogy between organic and technical change (Ingold 1997). It shows, in fact, that new structures in nature do not appear from nowhere. They are not designed for a specific aim '*de novo*': 'natural selection can only work on the stock of materials that are already available' (Ingold, *ibidem*: 119). In this view, changes within an ecological niche can lead the organism to co-opt one structure evolved for a specific aim to do a quite different job. In this view, organism is considered as a sort of 'plastic' *bricoleur* which faces change through the best use of what it already has.¹⁶ In this sense, flexibility is the main tool available to the organism in order to guarantee its survival, and this is enabled by imperfection, multiplicity and redundance (Pievani 2004).

Bateson (1988) goes further on this fundamental aspect. He shows that traditional Darwinian image of selection leads to a concept of evolution downplaying the role of organisms within the evolutionary process. Bateson, on the contrary, considers the Darwinian metaphor of the 'external hand', as well as the Darwinian image of 'selection' as 'encumbrances'. He describes four characteristics that valorize organisms:

- (a) Organisms make choices which can influence the course of evolution;
- (b) Organisms actively alter their physical and social environment condition;
- (c) Adaptability;
- (d) Alteration in gene expression.¹⁷

Bateson is very critical with evolutionary theory considered as 'the tendency to place so much emphasis on genes as the units of evolution and so little emphasis on how they are expressed' (*ibidem*: 192). For all these reasons, Bateson talks about '*behaviorally induced evolutionary*

¹⁶ This principle of *bricolage* is, of course, valid also at the micro-level, as claimed by Monod (1977).

¹⁷ See the 'genetic assimilation' (Waddington 1953).

change'¹⁸ and presents a picture where developmental processes are not considered merely as constraints but also as evolutionary resources. In this view, it seems that Patrick Bateson calls new metaphors able to replace the old Darwinian ones and to give emphasis to the central role played by the relationship between the *organism-as-a-whole* and the environment in life processes.

Conclusion and inputs for further debate

The philosopher of science Lenny Moss argues that paleo-anthropology and comparative genomics show that the new passwords of biology are *flexibility* and *plasticity*: no organisms are obliged to single-response patterns, albeit with varying degrees of freedom (Moss and Pavesich 2011: forthcoming). An organism's activity is multipally contingent, which is to say that the organism can and must develop highly mediated relationships with its environment. Unfortunately, however, generations of young scientists have been educated in the dogma according to which the appearance of biological novelty is always due to random and accidental genetic mutations, with no room for the creative or adaptive powers of individual organisms in specific settings. The power of this dogma is revealed by the extensive resources employed for the development of the so-called Human Genome Project (HGP). We are probably now in a position to conclude that the high expectations generated by the HGP were dramatically betrayed. The scientific dream of associating individual genes with distinctive functions has long been forsaken: humans have no more of genes than other mammals, and fewer than some, and barely any more genes even than a microscopic rudimentary invertebrate like a flatworm. Clearly 'the gradual emergence of behavioral complexity was not achieved by accumulating genes', as Bateson (1988: 201) puts it. With a range of theories and evidence re-interpreting the role of the genome in life processes, the emergence of a new theoretical framework (a new paradigm) in life sciences as presented in this article moves us from a rather deterministic, mechanical, and ultimately dualistic-based evolution towards an emphasis on active, reconstructing organisms and the organisms-environment interrelationship in development. This paradigm, presenting DNA as a rich plastic landscape and showing the biological capacity of the organism to react creatively to environmental changes (which are often ontogenetically

self-produced) demonstrates that organisms do not have a *specified* design encoded in their genome or, at least, as Tim Ingold says, there are no means for 'reading off' this specification from DNA:

There is only one reading of the genome, and that is the process of ontogeny in itself. Hence there can be no design for the organism other than its actual phenotypic form, as it emerges within particular developmental context. (Ingold 2000: 233)

We argue that this post-Darwinian interpretation of life supports a *bottom up* ecological model which is able to avoid both the limitation of genetic and cultural determinism. This is why, in this conclusion, we want to discuss, as an introductory reflection for further developments, that this epistemological change in the life sciences has some important implications which can help also social sciences to renew their epistemological basis.

Indeed, following Ingold's work we believe that the currently hegemonic interpretation of Man is based on the alliance of three complementary intellectual paradigms sharing the same informational fundamentalism and supporting each other: neo-Darwinism in biology, cognitive science in psychology and cultural theory in social sciences. Within this alliance, human beings are conceived as the juxtaposition of three complementary parts, namely body, mind and culture—with culture considered as a set of rules and representations available for transmissions across generations independently of their practical application (the so-called cultural models or schemas). In this conception, culture is supposed to be detached from experience, 'just as [the] organism genotype is unaffected by the vagaries of its life history' (Ingold, *ibidem*: 239). On the contrary, we refer to ecological psychology (Gibson 1979) and the anthropology of practice (Bourdieu 1977) to claim that knowledge, rather than being imported by the mind (as cultural *design* or *programme*), is itself generated within the contexts of experience during people's involvement with the surrounding natural/social environment. Moreover, knowledge is associated with *skills*: a knowhow that we carry in our bodies with no formal instruction but through a repetition of performed and embodied (read *enfolded*) tasks.

Similarly to what has been suggested for the genome in the epigenetic interpretation of life, the body can be considered as an organism with no *specified* cultural design encoded in the mind. Against informational determinisms, we believe that the body, facing processes of growth and decay, enfolds in its anatomy (musculature, neurology, etc.) particular 'skills, habits, capacities and strengths, as well as debilities and weakness (Ingold 2000: 239). Then, it is really difficult to separate what is cultural and what is biological. Indeed, the epigenetic idea of the organism

¹⁸ The anthropologist Robert Foley, explicitly inspired by Bateson, used this very explanatory sentence: 'behavior, particularly the social one, which usually goes beyond the scope of paleo-biology, is essential to understand evolutionary events' (Foley 1999: 233).

scientifically supports a bio-socio-anthropological idea of Man as a real *being-in-the-world* (the *organism-person*¹⁹ in Ingold's terms): an intentional body living a reciprocal relationship with the surrounding environment.²⁰ In this direction, Noë (2010: 25) claims that the best of science and philosophy of the future will lead us to join a vision of ourselves as beings endowed both with bodies *and* world; and Craighero (2010), within neurosciences, calls an overturning of the Cartesian principle leading to the claim, '*sum ergo cogito*': our knowledge of the world is deeply linked to its translation in our experience in the first person. It is just because we are *acting beings* that we are also *thinking beings*, she says. Also the arguments of Moss (2009) move in a similar direction. According to Moss we live within '*ecologies of compensation*', where the central role is played by the complex processes leading to the acquisition of skills.²¹ Indeed, the achievement of any constructed niche (nest, tunnel, culture, etc.) constitutes a resource for 'compensatory stabilization', where *skills* assume the relevant position of a field of analysis promising to be fertile and fruitful for interdisciplinary research (Sigaut 1994). For all these reasons, Ingold, again, calls for a 'relational thinking' in biology as well as in social sciences. That is

[...] treating the organism not as a discrete, pre-specified entity but as a particular locus of growth and development within a continuous field of relationships. It is a field that unfolds in the life activities of organisms and that is enfolded (through the process of embodiment or enmindment) in their specific morphologies, powers of movement and capacities of awareness and response. (Ingold 2000: 244)

It is also interesting to notice that this vision is also supporting new streams of studies on technology development. In the field of Artificial Intelligence (AI) and Life (ALIFE), for example, the first wave of studies reproduced the dualistic and informational paradigm we critically discussed at the beginning of this article, wrongly believing

that an artificial reproduction of mind would be possible by reproducing the formal and "syntactic" interpretation of intelligence. Today, new perspectives prefer to look at the relationship amongst the brain, the body generating that brain and the physical environment which those organism interact with. Actually, Epigenetic Robotics (DevRob), as well as Behavior-Based-Robotics (BBR), manage intelligent behavior excluding the meticulous planning and implementation of a coherent conception of the world through the formal description of all the objects and the possible environmental conditions. On the contrary, the Robot learns and (re)produces skills through experience, by doing, through errors and repetitions and using information collected on the field to react to environmental challenges. For all these reasons, the new passwords of the robotic body are the same as those of the real biological organism: situatedness, embodiment, emergence (Vidal 2007). As we can easily see, the focus of the attention is displaced from the machine in itself to the particular relationship that the machine has with its environment.

But we find similar trends also in the field of agro-biotechnology. The *top-down* model, based on the imposition of 'abstract' seeds created in the labs by high-knowledge network of research financed by big corporations and up-rooted from the environment in which seeds grow led both to agronomic failures and dramatic social inequalities. Today, we are assisting with some important participatory strategies leading to a *bottom-up* ecological involvement of (*re*)skilled local farmers (together with scientists and technicians) in selecting seeds crossing traditional knowledge and technological development in their local natural environments (Ruivenkamp 2008; Ruivenkamp et al. 2008). The general assumption is, again, that we can improve seeds selection and socio-economic relations by interacting with natural/social local environments.

For all these reasons we argue that the epigenetic interpretation of life is not only a 'matter' amongst biologists, but could be a new paradigm also able to support humanities and social scientists in their analyses and interventions.

¹⁹ The locus of intentional agency, in Ingold's work, is the *person*. He says that: «every organism is an open system generated in a relational field that cuts across the interface with the environment. For the developing human organism, that field includes the nexus of relations with other humans. It is this nexus of social relations that constitutes him or her as a person. Thus the process of becoming a person is integral to the process of becoming an organism. [...]The human being, then, is not two things but one» (Ingold 1989: 220).

²⁰ It is interesting to note that this is an uncommon case in which hard sciences can help humanities to support a philosophical tradition, that of phenomenology.

²¹ These constructive phenomena until now have been incomprehensibly neglected, but today many ecologists and ethnologists are giving new relevance even to animal architectural skills, considered as a form of *ecosystem engineering* (Gould and Gould 2008).

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