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"Genetic Load": How the Architects of the Modern Synthesis Became Trapped in a Scientific Ideology

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Abstract

The term "genetic load" first emerged in a paper written in 1950 by the geneticist H. Muller. It is a mathematical model based on biological, social, political and ethical arguments describing the dramatic accumulation of disadvantageous mutations in human populations that will occur in modern societies if eugenic measures are not taken. The model describes how the combined actions of medical and social progress will supposedly impede natural selection and make genes of inferior quality likely to spread across populations – a process which *in fine* loads their progress. Genetic load is based on optimal fitness and emerges from a "typological view" of evolution. This model of evolution had previously, however, been invalidated by Robert Wright and Theodosius Dobzhansky who, as early as 1946, showed that polymorphism was the rule in natural populations. The blooming and persistence of the concept of genetic load, after its theoretical basis had already expired, are a historical puzzle. This persistence reveals the intricacy of science and policy-making in eugenic matters. The Canguilhemian concept of 'scientific ideology' (1988) is used along with the concept of 'immutable mobile' (Latour 1986) and compared with the concept of 'co-production' (Jasanoff 1998), to provide complementary perspectives on this complex phenomenon.

Keywords:

Genetic load; Eugenics; History of genetics; Scientific ideology; Co-production

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Introduction

In population genetics, the genetic load model describes a reduction in the selective value of a population, compared to a population in which all individuals have the same, most favored genotype.

In 1937, J. B. S. Haldane had already proposed that deleterious mutations, regardless of their severity, could drastically decrease the selective value of a population. This conclusion draws upon the theory of hidden variability in natural populations, which states that recessive mutations eventually show up causing genetic drift. The idea, if not new, found its

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mature formulation in 1950. In *Our load of mutations*, Henry J. Muller coins the expression 'genetic load' to express his concern for the human species which was taking a tragic turn – biologically speaking – under the combined actions of medicine and politics of solidarity. Because modern systems of assistance and care prevent the elimination of less favored genotypes, they allow disadvantageous mutations to spread in populations. In turn, this accumulation of deleterious genes impedes the work of natural selection even further. With the accumulation of deleterious mutations, Muller states, a mechanism of degeneration has been triggered that ultimately threatens the survival of the human species. Eugenics is proposed as the unique solution to the problem of genetic load.

From a historical perspective, however, the emergence of the theme of genetic load and its success as a scientific topic are highly problematic. Genetic load is a mathematical model that measures a deficit in adaptation and is based on optimal fitness: it emerges from the "typological view" of evolution, according to which "variation is simply noise with no inherent meaning" (Parichy 2005, 476). This model of evolution was, however, experimentally invalidated by Robert Wright and Theodosius Dobzhansky, who showed that polymorphism was the rule in natural populations four years before the term genetic load was coined (Wright & Dobzhansky 1946). How, then, to explain the persistence of genetic load as a concept when its theoretical basis had already expired?

The present paper is an attempt to solve this historical puzzle. Our analysis is theoretically grounded within a corpus of studies that has documented how extra-scientific concerns get conveyed into scientific production, thereby blurring the boundaries between societal concerns and scientific topics. The concept of 'scientific ideology', developed by Canguilhem (1988), provides a framework for understanding how the concept of genetic load could be produced within two distinct contexts: population genetics and Evolutionary Humanism. The transportation of the concept between these two corpora of writings is apprehended through the concept of the "immutable mobile", developed by Latour (1986). While focusing on scientific writings gives no clue as to the persistence of the concept, analysis of genetic load conceived as a theme of science fiction in humanist essays explains how the metaphor of the load and its scientific modelling served both as a vivid background and a truth effect justifying eugenic-oriented policies.

Using genetic load as a case study, we conclude by showing the fecundity and limits of the Canguilhemian approach, in comparison with the more recent approach of 'co-production' supported by Science and Technology Studies (STS).

Genetic load: a scientific ideology

An epistemic puzzle

'Genetic load' is a mathematical model for determining the rate of evolution in populations. It was developed in the field of quantitative genetics. This branch of population genetics concentrates on the ways that individual variation in genotype and environment contributes to variance in phenotype.[2] Through quantitative genetics, the challenge is to reconcile the discontinuous nature of Mendelian inheritance with the continuous variation pictured in evolution. Due to the complexity of the population-level processes examined and to the long time scales over which analyzed evolutionary processes occur, mathematical models are developed that do not directly explain how evolution proceeds, but provide information on the possibility of various scenarios (Plutynski 2004).

[2] R. Fisher introduced the term "variance" and proposed a formal analysis of variance in a 1918 article "The Correlation Between Relatives on the Supposition of Mendelian Inheritance". His first application of the analysis of variance was published in 1921. Analysis of variance became widely known after being included in Fisher's 1925 book, *Statistical Methods for Research Workers*.

Model building is not, however, without consequence. Although population genetics may benefit from the simplifying value of the biostatisticians’ assumptions (Crow 2001), mathematical models also act as idealized constructions that embark scientists into “fictional states of affairs” (Godfrey-Smith 2009; Rao & Nanjundiah 2011). Idealization is a cognitive operation that allows for treating things *as if* they possessed features they do not have but would be concrete if real. Mathematical models of early quantitative genetics relied on different kinds of assumptions - some of them more powerful than others (Servedio et al. 2014). To consider populations *as if* they were infinite[3] is, for example, a *logistical* kind of assumption: it allows for identifying the effects of certain determinants by placing them in a simplified context. Nobody believes that populations are infinite. However, when biostasticians count genes *as if* they were differently colored beans in a bag, all independent one from another and without interacting effects, the assumption is not logistical but *critical*. In this case, the relevance of the model depends on a certain conception of evolution, which states that different genetic compositions at a single locus are associated with specific traits in the organism. Evolution is therefore portrayed as a statistical game where single alleles have constant and absolute selective values and where mutation is the exchange of one kind of bean for another.[4] In this model, each allele is assigned an absolute fitness value; adaptation is understood as a process of selection of the fittest allele and evolution is seen as a process leading to uniform populations composed only of the most favored genotypes – all identical, all homozygous. These mathematical models rely on the assumption that evolution results in a state of absolute conformity among the fittest individuals within a population.

Consequently, early quantitative genetics fits into the scheme of typological thinking, which can be defined as a preoccupation with equilibrium rather than change (Lewontin 1974) and homogeneity over variability (Dreuil 1996). The mathematical model of the genetic load makes no exception to the typological rule, relying on the predominance of uniformity. Because, for sufficiently large populations, the rate at which a favorable gene spreads is determined essentially by the strength of selection, natural selection (if not impeded) should gradually eliminate any less favored genotype until the fittest becomes the rule. In this model where, all things being equal, variability tends to be ruled out, genetic load is nothing but a product of a disturbance in the forces. Without the imbalance that naturally favors the selection of the fittest, the genetic load model predicts the explosion of hidden variability, the spreading of genes of inferior quality and the dissolution of the human species. According to Muller’s model, once the mutation load of the human species has exerted too much pressure, the unit of the species will lose its consistency, its contours will shade, and the only connection of our descendants with mankind will be the historical one (Muller 1950, 146). There will be no more Humans. Under an unbearable pressure from mutations, not only would the species lose its chance for enhancement but also its consistency as a unit, and would therefore disappear. This potential implosion of the species reveals another typological view according to which species are morphological kinds threatened by variability (Amundson 1998). This idea contrasts with population thinking; according to which species are aggregates of individuals with a profile that shows a distribution of characteristics (Mayr 1970; Chung 2003). As such, genetic load is the typical product of the typological reasoning of early quantitative genetics. Nothing particularly innovative. Nothing worth mentioning. Except that this type of thinking had already expired when the genetic load model was formulated.

Since 1946 and the rise of adaptive polymorphism, typological reasoning had already been invalidated. The experiments lead by Wright and Dobzhansky on wild drosophilae had

[3] The Hardy-Weinberg equilibrium (1908), for example, predicts unchanging genotype frequencies in a randomly mating, infinitely large population in the absence of selection, migration, or new mutation.
[4] Mayr coined the expression “beanbag genetics” to designate the “gross oversimplification” inherited from classical population genetics that consisted in treating genes as independent entities and therefore negating interactions between them (Dronamraju 2010).

shown that polymorphism was the rule in natural populations (Dobzhansky 1946; 1949; 1950). As the two scientists swapped the standard *melanogaster* (usually used in Morgan's drosophilist group) for the wild *pseudoobscura* that had not yet been stripped of its natural genetic diversity, they were able to study experimentally the process of variation and evolution in nature. By doing so, they proved that natural populations did not reflect the state of uniformity predicted by early quantitative genetics and that variation was crucial for adaptation and fitness. The comforting standards of uniformity were abandoned and variation welcomed as an essential feature of the emerging paradigm.[5] Without the support of underlying data or observations, typological models of evolution were considered devoid of biological meaning. As early as 1946, the assumptions critical to typological mathematical models (such as genetic load) had already been proved biologically unrealistic.

Once typological thinking had been discredited, the idea of a genetic load should have been disqualified. But the opposite happened. Genetic load persisted long after its theoretical foundation had already expired. Hence the puzzle.[6] Our hypothesis is that genetic load persisted as a relevant scientific theme while it served as a scientific support for political, social and moral arguments related to eugenics.

The Eugenics behind the History of Genetics

Scientists played a leading role in the history of eugenics. The term eugenics was created in the late 19th century by Francis Galton, a cousin of Charles Darwin, who set himself the task of investigating the origins of natural ability so as to improve humanity. He established an anthropometric laboratory in London, where biologists and mathematicians who shared the same premises developed methods to understand population phenomena. From the rather obscure science formed around Galton, eugenics grew rapidly into a worldwide political movement.[7]

Genetics and eugenics are so closely interwoven that the evolution of the eugenics movement can be traced in correlation with theoretical debates between the Mendelians and the biometricians (Kevles 1995). Paradigm shifts in eugenics are shown to result from major scientific advances in genetic research and population analysis.[8] One of these shifts

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[5] "Dobzhansky, following Chetverikov, viewed species as collections of different local populations. Sturtevant, in contrast, had a rigidly typological view of species. As Ernst Mayr later observed, "he almost acted as if he considered every species genetically homozygous" (E. Mayr to Provine 1979). In other words, Sturtevant treated wild flies as if they were standard, domesticated melanogaster. Dobzhansky was always aware of the difference." (Kohler 1993)

[6] A puzzle that may be assembled differently, as shown by the historian Diane Paul when she asks whether eugenics rested on an elementary mistake (Paul, 1987). Eugenists in the first part of the 20th century indeed argued explicitly that mental defects were linked to a recessive Mendelian factor, leading some commentators to suggest that eugenists had been in error if they believed that by sterilizing only those individuals thought to be defective, the factor for defectiveness would thereby be eliminated from the population. Paul notes that the eugenics movement expanded after the time when the mistaken beliefs had been thoroughly exposed. After reviewing the literature of that time, she came to the conclusion that the majority of eugenicists favoured eugenic sterilization, even though they knew eugenic methods would not eliminate the "defective factor" from the population as a whole.

[7] For accounts of various national eugenics movements, see (Kevles 1995); (Proctor 1988); (Adams 1990); (Stepan 1991); (Paul 1995).

[8] a) The "mainline" eugenics group, based on the early biometric theories of Pearson and the unit-character Mendelian theories, dominant between 1880 and 1930; b) the "reform" eugenics group, based on experimental chromosome research with animals and mathematical analysis of population genetics carried out by the British biologists J.B.S. Haldane, Julian Huxley, and Lancelot Hogben and

corresponds to the "reform" eugenics group and refers to a very specific moment in the history of biology, the modern synthesis. This synthesis reflects the consensus, produced between 1936 and 1947, about how evolution proceeds. At its heart was the question of whether Mendelian genetics could be reconciled with gradual evolution by means of natural selection. Evidence for such a rapprochement was primarily gathered from biologists, trained in genetics, and mathematicians who proposed models designed to test the compatibility of Mendelian genetics and selection theory.

The new breed of scientists emerging from this movement developed specific eugenic views. Although they shared their predecessors' concern for the degradation of the germ plasm and remained convinced that human improvement would proceed better with the deployment of genetic knowledge, their concerns were anchored in liberal social values (Ludmerer 1972; Kevles 1995) or even Marxist views (Paul 1987; Esposito 2011) that contrasted with the early conservative eugenic leadership. They notably insisted on the importance of developing a twofold eugenic framework that would take into account genetic as well as social factors.[9] The theme of genetic load stems from views that promote social progress through the manipulation of human heredity. Although the model was presented in population genetics, the core argument of genetic load relies on an analysis of the "social obstacles" (Muller 1950, 173) that supposedly cause natural selection to malfunction. On the one hand, technological advances and social systems are blamed for relieving the pressure of natural selection. On the other hand, existing social patterns are assumed to discourage the reproduction of higher classes and encourage the reproduction of lower classes, thus producing harmful selective effects. Although genetic load describes genetic mechanisms, it is originally based on the assumption that our social constructs are inadequate with respect to our evolutionary makeup.[10] In *Our load of mutations*, the burden described by Muller is *ours* inasmuch as *we* have set up a social environment that both prevents natural selection from operating and nurtures unnatural selection.[11]

Scientific Ideology: Exploring the Ideological Contexts and Contents of Science

Is genetic load a response to a scientific inquiry or does it express a social worry? Is it even possible to distinguish one from the other? The philosopher Georges Canguilhem (1988) uses the term 'scientific ideologies' to address statements whose status appears ambivalent or ambiguous. In outline, a scientific ideology is an explanatory system that stands in a particular relationship with science and whose main characteristics can be crystallized around three features:

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the American biologist Herbert S. Jennings, between 1930 and 1960; and c) the "new" eugenics group based on the latest research in human biochemical genetics and genetic engineering, dominant since the end of the 1960s.

[9] "One major difference between the two groups (the mainline and the reform groups) rests towards the effect of environment on character traits, with the reformers more willing to admit that environment can influence development and that sociological factors must be considered in any eugenic program. Thus Charles Davenport would argue that prostitution was caused by a gene defect, whereas a reformer might stress sociological factors. Both however would agree that a prostitute should not have children." (Melher 1987, 618).

[10] "Both *environmentally* and *genetically* the present state of mankind is unstable, at war with itself". (Huxley 1948, 56) (our italics).

[11] "Eugenically speaking, our system is characterized by the social promotion of infertility and the excess fertility of social failure". (Huxley 1948, 54).

- Scientific legitimacy: “Our load of mutations”, Muller’s inaugural paper, was published in the *American Journal of Human Genetics* - a worldwide renowned scientific review in 1950. Muller himself was a famous scientist who was notably awarded a Nobel Prize in physiology/medicine in 1946. Genetic load became a successful theme of research in population genetics from 1958 (at the time the equation was developed) until the end of the 1960’s when its ideological content started to be refuted.

- Theoretical ambition: The concept of genetic load was constructed during the synthesis of evolutionary studies,[12] a period characterized by the ambition to explain systematically all evolutionary phenomena through the integration of Mendelism and Darwinism within a coherent framework (Cain 2009). The architects of the synthesis, however, built a project that cannot be confined to its biological dimension since evolutionary knowledge was applied to the comprehension of the entire cosmos (Esposito 2011) and extended towards a reflection upon the origins of morals and politics (Delisle 2009). Flanked by so-called Evolutionary Humanism, Neo-Darwinism is driven by an immoderate ambition – not only to explain exhaustively how Evolution works but also to take control of it (Esposito 2011).

- Scientific crisis: Controversies surrounding the genetic load led to the birth of the Neutral Theory and contributed to the end of the synthesis (Dreuil 1996; Rao & Nanjundiah 2011). When, in 1966, Richard C. Lewontin and Jack Hubby discovered the magnitude of polymorphism in natural populations at the molecular level, they questioned the sheer phenomenon of genetic load. If populations could carry alleles of lower fitness at very many loci, the cost of doing so would be impossibly high, unbearable, according to genetic load. Motoo Kimura (1968) proposed a solution which allowed both theories to coexist: if the vast majority of evolution changes at the DNA sequence molecular level were caused by genetic drift of selectively neutral mutants, most mutations would be neutral. The Neutral Theory, while rescuing the genetic load concept, denies natural selection at the molecular level. The theoretical cost is high. The debate opposing Neutralists and Selectionists marks the fragmentation of a unitary theory of evolution and the break-up of the synthesis.

Genetic load meets the criteria of a scientific ideology, as defined by Canguilhem. However, the analysis doesn’t stop here: it can start from here. Now that genetic load has been identified as a potential scientific ideology, its content requires to be examined. What exactly does genetic load tells us, at this historical moment, about the normative beliefs of elite scientists, who belong to the dominant class of society? Only by exploring the ideological content of genetic load, can we explain how geneticists were able to defend, for two decades, a model that did not fit with their latest experiments but could fit with their representation of society. The concept of ‘scientific ideology’ inspired by Marx, indeed highlights the interplay of interests in a given situation and arises in response to a major social challenge.

> An ideology is an epistemological concept with a polemic function, applied to systems of representation which express themselves in the languages of politics, moral, religion, and metaphysics. These languages claim to express things as they are, whereas in reality they are means of protecting and defending a situation, that is, a particular

[12] See, for example, (Caplan 1978); (Mayr 1980); (Gould 1983); (Provine 1988); (Burian 1989); (Cain 1993, 2003, 2009); (Smocovitis1996); (Delisle 2009).

structure of the relations between (men among themselves and)[13] men and the things. (Canguilhem 1988, 29).

The Canguilhemian approach thus pushes us to look for extra-scientific elements that would have been integrated into a scientific reasoning so as to provide 'truth effects' to be used by scientific experts in their positioning towards social struggles. *De facto*, in the aftermath of World War II, there were no shortage of challenges for an emerging class of 'experts' preoccupied by both population phenomena and social policy-making – who had to deal with the changing demographic patterns of Western societies, the disruption of social status quo in many realms (labor, family, imperialism, etc.) and the threat of eugenics due to the consciousness-raising of Nazi crimes. Exploring the context in which the concept of genetic load was formulated shows how social, moral and political concerns may have been absorbed into scientific practice. As a scientific ideology, this research topic was not only subjected to scientific arguments but also nurtured by other sources. Although Muller's paper was published in a scientific journal, an attentive reading of its core argument leaves no doubt as to the extra-scientific concerns that intervened in the construction of genetic load.

Genetic Load: A Set of Societal Concerns Packaged up as a Scientific Inscription

The Shaping of Genetic Load as an Ethical Argument

Muller's ambition in "Our load of mutations" is to refute the prevailing hypothesis according to which "mutation as a direct cause of disease is extremely rare and of little practical significance". Anterior measures of hidden variability resulted from experiments on drosophilae but Muller's point is that these results cannot be extrapolated to modern humans. As progress in technology, living standards and medicine has relaxed natural selection, the human species has escaped its natural condition. Muller therefore dissociates the evolutionary model of "primitive man" from that of the "modern man", under the assumption that the determinants used to predict the evolution of the human species cannot be given the same weight when humans are no longer immersed in nature.

Although distinct, primitive man and modern man remain biologically bound. More precisely, *we*, modern man, are twice the product of our predecessors. *We* are the lineage descendants of our ancestors and *we* inherited our genetic fitness from their harsh conditions of living. Their struggles, Muller argues, made *our* fortune. As the argument moves from a descriptive to an evaluative stance, the genetic load becomes the subject of an ethical discussion. Because each generation is responsible for the living conditions that influence the quality of the germplasm they pass on to the next, generations are not only *genetically* bound but also *morally* bound. *Our* debt to primitive man obliges *us* towards future man. Muller uses the argument of indirect reciprocity[14] to assert that acting on behalf of future generations may be required as a generalized form of reciprocity for benefits received from previous generations. Is it moral to opt for *our* comfort at the cost of the fitness of future generations? Is it moral, asks Muller, to be "the debtors" (Muller 1950, 165) of *our* descendants when we are

[13] The part in brackets is translated from the French sentence, omitted in the English version we refer to.

[14] This argument is now well developed in the context of intergenerational justice. See for example (Fotion & Jan 1997); (Ryberg & Torbjön 2004).

indebted to our ancestors?[15] Or do *we* owe to *our* descendants a certain "quality" of germplasm to supply future generations with the best genetic resources? *Our* current political, technological and social choices, predicts Muller, not only put the natural dynamics of hard-earned selective advantage at stake but actually threaten the human species.[16] If selection can no longer counteract the pressure of mutations and if these mutations are deleterious to our species, the survival of humanity is at stake. The moral tale narrated by Muller concludes the existence of an imminent danger that, although occurring through genetic mechanisms, would ultimately be due to our moral failure.

Throughout the article, Muller insists on the scale of the problem: genetic load can only be apprehended through the big picture.[17] A misapprehension of this scale would lead to major flaws in reasoning. This is a failure also attributed by Muller to Malthus' opponents, who, by misjudging the gravity of the modern situation, failed to comprehend that it could not be handled by social measures alone[18] and that man's heredity needed to be controlled through eugenic measures. Because what is at stake with genetic load is not simply the refutation of a scientific statement as announced in the introduction to the article but the extinction of the entire human species, the task of estimating the magnitude of the risk dictates its own philosophical treatment – a task well handled by Muller. To paraphrase Pascal's wager, there is here an infinite to gain (enhanced humanity) and an infinite to lose (humanity itself), and no matter the risks of gain and loss ("even a 10% risk of extinction"), if the stake is finite ("purposive control over reproduction" (Muller 1950, 150) then the rational choice is to wager to gain the infinite.[19]

The several pages devoted by Muller to the ethical discussion and its political implications constitute the core argument of the genetic load concept. There is a visually obvious parenthesis of prose in "Our load of mutations" that refers only to humans. Once Muller has (ethically) justified the formulation of the load in its human context, he can go back to calculating rates of evolution. And, with the formulae, the drosophilae flutter back to the paper.

The article articulates two different concerns in two different formats:

- for the drosophilae, a flat description of experimental facts interspersed with calculations;

- for humans, a passage of prose dedicated to the chronicle of a death foretold.

The differential use of text and formulae betrays the exceptionality of the concern for the human species. At this point, genetic load was not a model easily transposed to different species or populations: another operation was required to erase the heterogeneous roots of the mathematical model and render it an apparently pure scientific argument.

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[15] The term "debtor" is appropriate for such generations because, by instituting for their own immediate benefit ameliorative procedures which delay the attainment of equilibrium and raise the equilibrium level of mutant gene frequency, they transfer to their descendants a price of detriment which the latter must eventually pay in full.

[16] "His only connection with mankind would then be the historical one that we ourselves had after all been their ancestors and sponsors, and the fact that His once-human material was still used for the purpose of converting it, artificially, into some semblance of man" (Muller 1950, 146).

[17] There are for instance 28 occurrences of the expressions "on the whole", "as a whole" and "the whole population" in the paper.

[18] These methods are "in the long run, as effective as trying to push back the flowing waters of a river with one's bare hands" (Muller 1950, 146).

[19] "[…] even a 10% risk of any kind of death or extinction is a very sizeable danger. Few persons would be free from misgivings if they had to undergo an operation, to take a trip, or to contract a disease, with this amount of risk" (Muller 1950, 143).

Crow's Equation: An Immutable Mobile

It was only the equation proposed by J. Crow in 1958 that truly facilitated the circulation of the model in animal and human studies alike. This equation, published in a human population genetic study, was applied to animal models the following year.

$$L = \frac{w_{\max} - \overline{w}}{w_{\max}}$$

Where $w_{\max}$ is the maximum value of the fitness and $\overline{w}$ is mean fitness

How much explanatory burden does this tiny set of figures carry in the concept's fate? Let us count the frequency of "the genetic load" in scientific articles: used only once (Dobzhansky 1957) between 1950 and 1958, there are 77 occurrences between 1959 and 1970 – most of them concerning animal studies.[20] So, why would the condensation of the concept into an equation mark such a turning point in the scientific use of genetic load? Firstly, because an operational inscription is crucial to the construction of harder facts that complete a scientific ambition. Secondly, because, without its long justification in prose, the equation is ready to use in any context (human or animal) and the topic of genetic load available for experiments. The format of the equation erased the concern for the human species that lay at the origin of the model and made the genetic load operational.

Genetic load is a mathematical model that did not fit the chronology of biology but fitted perfectly with the spirit of the reform eugenics group; a rather sophisticated ethical argument developed in the middle of a scientific paper and a calculation adjusted to the social and cultural dimensions of the human species that was extended to animal studies. Genetic load is obviously the byproduct of intersecting processes but its rendering as an equation enabled its outsourced social and ethical concerns to be condensed under an operational format. Transformed into a scientific inscription and used in experimental models, the theme of genetic load gained scientific legitimacy. B. Latour (1986) developed a theoretical interest in the kind of objects through which many worlds and practices are re-assembled to be made presentable in a different setting. These objects, Latour argues, must be both transportable and unchangeable during transportation: they are "immutable mobiles". Once these objects succeed in folding layers of scientific practices into a flat format, they are ready to circulate outside the laboratory in order to convince those who have not supported their birth.

We argue that the privileged formats of genetic load – as a metaphor[21] and as an equation[22] – make it a topic particularly disposed to travel between the bodies of biological and humanist writing. More importantly, we argue that this circulation reinforced both the scientific legitimacy and the political efficacy of the genetic load.

- The metaphor developed in *Our load of mutations* "vehicles"[23] the assumptions of the architects of the evolutionary synthesis regarding not only how evolutionary processes work but to what end human progress ought to tend. As such, the label

[20] Web of Science, consulted on 07.25.13

[21] The English *metaphor* derives from the 16th-century Old French *métaphore*, which comes from the Latin *metaphora*, "carrying over", in turn from the Greek μεταφορά (*metaphorá*), "transfer".

[22] An equation is an optic device: it is "a complete hybrid (nature seen as fiction and fiction made as nature), with all elements made so homogeneous that it is now impossible to reshuffle them like a pack of cards" (Latour 1986, 8).

[23] A metaphor is described as having two parts: the tenor and the vehicle. The tenor is the subject to which attributes are ascribed. The vehicle is the object whose attributes are borrowed.

“genetic load” is anything but neutral: it implies that variation is a burden we carry at a time when social diversity was considered harmful for our society. The use of a pejorative vocabulary (e.g. mutational load or cost of selection) is crucial as it conveys the eugenic style of thinking;

- The equation proposed shortly afterwards allows the transportation of the model across different fields, without mentioning its heterogeneous roots and its ideological content.

The social destiny of the concept of genetic load does not, therefore, stop with its formulation as an equation but becomes all the more fascinating as the topic starts to circulate between scientific articles and humanist essays. The following section is an attempt track genetic load as a central theme in the corpus of Evolutionary Humanism. Whether they express their thoughts in conclusive chapters of biological works or devote entire books to the societal and political implications of evolutionary studies, the architects of the synthesis demonstrate varying commitment to the humanist cause. We are particularly interested in Julian Sorell Huxley and Theodosius Dobzhansky, who left a sufficient quantity of published material to allow a fairly complete reconstitution of their humanistic theses that include the promotion of the genetic load and who occupy a very different position with regard to science.

- Huxley’s bibliography rehearses the double identity of an author who wrote *Essays of a Biologist* in 1923 and *Essays of a Humanist* in 1964. But Huxley is not only a brilliant scientist and an enthusiastic humanist. He also is a politician. His political career led him to become the first Director-General of the UNESCO in 1946. During his investiture speech, Huxley defended scientific Humanism as the unique source of inspiration for effective politics. Huxley explained how the fact of evolutionary progress provided an objective foundation for "ideology" – a term he used to denote an integrated system of morality, ritual, emotion, and belief. Interestingly enough, most historians of science working on Huxley reversed this connection between evolution and politics and admitted that Huxley's idea of evolution was rather structured by his political commitments and his humanist aspirations.

What makes Huxley’s Humanism so unique is the connection between two spheres: science and politics; which considering his own path is not so surprising. Huxley emphasized that knowledge meant power of control and he was obsessed with designing a ‘technocratic utopianism’ (Esposito 2011) whereby the whole would prevail over the individuals. This mode of reasoning belongs to a history of well-intentioned plans for improving the human condition, where idealized images of social order were created and then millions of lives ruthlessly redesigned to match their vision, so as to finally go tragically awry (Scott 1998). Common to all these planning disasters is the "high-modernist ideology" that places confidence in the ability of science to improve every aspect of human life. A theme highly familiar to Huxley, whose scientific legitimacy and political status conferred him the power to promote a form of social order tending to excellence, where eugenics could considered a desirable mean.

- Dozhansky is a prolific author. His name is associated to more than 600 writings. He published experimental works as well as theoretical papers, some anthropological essays and philosophical books – all related to the notion of evolution. An important claim in the definition of evolution by Dobzhansky lies in the refutation of biological reductionism: “Human evolution is the outcome of interactions between biological and cultural factors” (Dobzhansky 1956, 56). But Dobzhansky worries about culture interfering with the course of evolution. Dobzhansky still refers explicitly to the genetic load as an inescapable prophecy in a humanist opus written in 1962. His defense of the genetic load is all the more striking given that the next year, he does not credit the concept of any scientific validity in his biological writings (Dobzhansky 1963). In 1968, in his book written with Boesiger, he devotes one entire chapter to the refutation of genetic load. The arguments rely mainly on knowledge of polymorphism he already had gained in 1955. The difference in attitude results from a difference in concern, since in his humanist writings; the theme of the genetic load occupies a crucial position between dramatic developments about the tragic turn of human populations and a faithful defense of eugenics.

Since both authors have developed a rich humanist perspective, where science is intertwined with moral and politics, although they both lead a different career and speak about science from a different perspective, we propose to examine Huxley and Dobzhansky's humanist essays in order to shed light on the thematic patterns that knit together scientific and moral, political or social representations concerning genetic load.

Genetic Load: A Successful Theme of Science Fiction

Whether expressed as a mathematical model or a narrative, genetic load includes fictional thought. Based on a series of "what ifs", the genetic load extends the path of known evolutionary processes to predict the possible future of populations. As such, humanist essays that elaborate on genetic load benefit from both its scientific legitimacy and its dramatic impact. Genetic load thus deserves to be treated as an element of science fiction, i.e. a "realistic speculation about possible future events, based solidly on adequate knowledge of the real world, past and present, and on a thorough understanding of the nature and significance of the scientific method" (Heinlein et al. 1959). These narratives are precious in the Canguilhemian analysis, based on the notion of ideology, as they explicitly inscribe scientific practices in the current representations of the society in which they were developed.

'Back to the Future'

The architects of the synthesis are used to time travelling. Modern synthesis bridges the gap between the work of experimental geneticists, naturalists, and paleontologists. Under the umbrella of the synthesis, the fossil record has become a major support for evolution and interest in the primitive stages of the human species has gained scientific value. But Evolutionary Humanism goes further. In humanist essays, the picture of prehistoric men is turned into the hypothetical condition that preceded our corruptive modernity. Prehistory here plays a role analogous to the state of nature in political philosophy – a thought experiment unveiling an original position of man and guiding both our understanding of the present and ultimately our planning of the future.
Humanists typically look back from the future to interpret present and past. Huxley sketches this exact movement at the end of his book, *Man in the Modern World*.

> Whether or not I have been asking you to accompany me too far into the visionary future, I will end this essay with a concrete suggestion for the present, backed by a warning from the immediate past. (Huxley 1948, 61)

Several rhetorical devices settle this dialectic of time. The first time machine is *time's arrow*. Humanists draw the direction of evolution on a "natural history", where the impulse of both the profusion of mutations and natural selection operate as a motor of history. As long as selection lowers the pressure of mutation, a sense of direction is can be traced (Huxley 1956, 105) – connecting past, present and future. This connection is essential as it allows us to understand the present in light of the past and to plan the future according to our action in the present.

The second time machine is the *scenario*. In the scenarios that proliferate in Evolutionary Humanism,[24] present and future both determine each other: the future depends on our present behavior and the vision of the future shapes our action today. As an illustration, Huxley masters the art of script writing when he describes and combines three possible futures – each one being the product of our present way of dealing with genetic load (Huxley 1948, 50-3). The most desirable future depends on our current determination to create a social environment favorable to the expression of desirable genetic qualities. Although the selection of the most favored traits is in itself a somewhat arbitrary decision based on the ideals of the era in question,[25] the pressure of selection is *in fine* favorable as it promotes standardization and increases the chance of equity among the future members of the population. We are not a million miles away from the standardized melanogaster here. And, *de facto*, Huxley sets up the experimental geneticist as a model for this operation of standardization.[26]

Based on their scenarios, humanists take up the old idea that society needs to be managed through scientific *planning*.[27] Planning presents a way to travel both through time dimensions and from science to power. Planning therefore reveals the true mission of science, which is to increase "both comprehension and control" (Huxley 1964, 103). Using planning as a third time machine, genetic load becomes the perfect narrative through which to call for responsibility towards the future and motivate political action.

'With Great Power Comes Great Responsibility'

Scientists have a duty to enlighten politics so as to promote a social environment which connects our social realm with our genetic makeup. This is the only way to counteract the corruptive modernity and reposition humanity on its path towards endless progress. Knowledge calls for action. The architects of the synthesis cannot restrain their views to the purely scientific realm because the general knowledge they have acquired may (and therefore should) benefit humanity. Paving the way for the future experts who would soon invade political institutions and ground policy-making in scientific knowledge (Jasanoff 1998), the contributors to Evolutionary Humanism are first and foremost scientists who feel obliged towards humanity by virtue of their superior knowledge. As Muller argues:

> It is the responsibility of those who already have knowledge of the genetic facts to be prime movers in driving home an adequate realization of them among both the lay and medical public, and among all groups concerned with social matters, until appropriate changes are adopted in their daily practices and precepts. (Muller 1950, 163)

[24] "They (The Architects of the Synthesis) shared an obsession with the future of humankind; an obsession that was often translated into speculations about possible future scenarios" Esposito (2011).

[25] "Even if we imagine we are working to absolute genetic standards, we are in reality thinking of them, albeit unconsciously, in relation to some ideal environment of the future, or to the needs and realities of the present social environment, or, very frequently, to our bias and a priori views about this present environment and how our opinion it ought to be changed" (Huxley 1948, 48).

[26] "[…] to disentangle the effects of nature from those of nurture in so far as we follow the footstep of the geneticist and equalize environment" (Huxley 1948, 52).

[27] "Man needs to use his best efforts of knowledge and imagination to use a system of thought and belief which will provide both a supporting framework for his present existence, an ultimate or ideal goal for its future development as a species, and a guide and directive for practical action and planning" (Huxley 1964, 77).

The theme of responsibility is also pervasive within the argument of the genetic load. As Dobzhansky puts it: "Man is not just an overgrown Drosophila" (Dobzhansky 1962, 148). Evolution has culminated in the human species[28] to the point that humans have escaped the natural order and are now in charge of their existence. The Rubicon has been crossed: humans occupy a chosen place in nature, a place actually above nature, and this dominant position confers upon them a mission:

> Man's destiny is to be the sole agent for the future evolution of this planet. He is the highest dominant type to be produced by over two and a half billions of years of the slow biological improvement effected by the blind opportunistic workings of natural selection; if he does not destroy himself, he has at least an equal stretch of evolutionary time before him to exercise his agency. (Huxley 1964, 81-2)

> (Humans are) called upon to participate in the construction of the best thinkable universe. (Dobzhansky 1973, 115-6)

The human species is not an object that humanists are interested in but matter they propose to work on by taking charge of its heredity.

'A Brave New World'

Architects of the synthesis rely on their genetic knowledge to prove that eugenics is both necessary and omnipotent. The list of "genetic disabilities" (Huxley 1964, 256-7), whose burden should be removed from humanity, includes pathologies of diverse severity, vague categories ("some mental defect") and conditions whose genetic conditioning has not yet been proven ("some kinds of sexual deviation"). Huxley also reports the successes of human behavioral geneticists in proving that intelligence but also "persistence, willingness to work, originality, creativity, leadership, ability to get along well with others, and plain human decency" (Huxley 1964, 40) are grounded in the genetic endowment. Eugenics should therefore draw on genetics knowledge to re-shape humanity and allow human enhancement. Positive eugenics can favor genetic susceptibility for curiosity and improve future scientists. Eugenics can favor creative imagination and improve future artists. Eugenics can even favor devotion and improve future saints (Huxley 1964, 259)!

Two complementary modes of action are usually proposed: euthenics which "proposes to work with existing genetic equipment and to create environments in which the best potentialities will be brought to realization" (Dunn & Dobzhansky 1949, 83); and eugenics which "aspires to alter the genetics of human populations and mankind" (Dunn & Dobzhansky 1949, 85-6). Eugenics exists under two forms:

> Positive eugenics programs urge people who are regarded as carriers of desirable gene combinations to undertake the responsibilities of parenthood. [...] More *enthusiasm* has been shown in many places for negative eugenics, which urges elimination of undesirable genes by discouraging or making it impossible for persons who show the effects of such genes to have children. Since voluntary abstention from parenthood may be difficult, sterilization for individuals who are likely to have severe hereditary defects is recommended. (Dunn & Dobzhansky 1949, 83)

[28] "The biological evolution has transcended itself in the human revolution. A new level or dimension has been reached. The light of the human spirit has begun to shine. The Humanum is born" (Dobzhansky 1967, 58).

Scientists are not simply interested in designing eugenic plans. They are enthusiastic about it. The rhetorical use of emotion in the architects' writings is, in itself, a further indication that the concept of genetic load encompasses sorrows and visions that exceed the scientific argument. In *Our load of mutations*, Muller's prophetic insights about the extinction of the human species turned him into a Cassandra of modernity. The insertion of drama or joy into scientific accounts is all the more surprising given that the scientists are themselves wary of it. Dobzhansky is, for instance, suspicious about emotions that would harm his argumentation. He prefers the term 'genetic elimination' to 'genetic death' because of the latter's emotional impact,[29] but at the same time does not hesitate to embark on colorful descriptions of the genetic load that are themselves relatively emotionally loaded. The acceptance of emotion on the one hand when it is refused on the other can be interpreted as a shift in perspective. Genetic load threatens the human species whereas eugenics *only* threatens individuals. Or, as Huxley emphasizes, the scale according to which problems are considered impacts their moral examination. How much does the evanescent present weigh in the horizon of evolution?

> All the objections of principle to a policy of positive eugenics fall to the ground when the subject is looked at in the embracing perspective of evolution, instead of in limited perspective of population-genetics or the short-term perspective of existing socio-political organization. (Huxley 1964, 282)

Population genetics, the biological basis for genetic load, is itself disqualified to the benefit of a more poetic vision of evolution open to the infinite.[30] Genetic load is a scientific fiction that relies on the 'truth effects' of science (methodology, experiments, and formulae) but supports aesthetic, moral and political commitments. The history of the genetic load provides a basis for further discussion of the connection between scientific claims and policy-making.

Science and Policy

The Translation of Genetics into the Promotion of Eugenics

The genetic load model is an argument that connects genetics and eugenics. This connection is not easy to define as eugenics itself varies in status and may be considered by the same author as a religion,[31] a social science,[32] a methodological effort to bridge social research and

[29] (Dobzhansky 1962, 290): Muller (1950, 1954, and other writings) refers to the elimination of detrimental genetic variants as genetic death. I prefer a less dramatic term – genetic elimination. [...] "Genetic death" is obviously an emotionally loaded phrase. It invites misunderstanding. Genetic death does not always produce cadaver.

[30] "Most important of all, (Evolutionary Humanism) brings together the and largely unutilized resources of our knowledge, and orders them to provide a new vision of human destiny, illuminating in every aspect, from the broad and enduring sweep of cosmic process to the present-day politics, from the planetary web of world ecology to the individual lives entangled in it, from the dip roots of man's past to the dawning possibilities of his far future" (Huxley 1964, 78).

[31] "Once the full implications of evolutionary biology are grasped, eugenics will inevitably become part of the religion of the future, or of whatever complex of sentiments may in the future take the place of organized religion" (Huxley 1948, 28).

[32] "Eugenics is not, as some of its devotees have unconsciously assumed, a special branch of natural science: it is a branch of social science. [...] True that it aims at the improvement of the human race by means of the improvement of its genetic qualities. But any improvement of the sort can be made

social reform,[33] or an application of natural science.[34] When considered as an applied science, scientists are fully aware of the risks pertaining to the translation from science to its application. Dobzhansky, for instance, is lucid about the potential collapse of Darwinism with current ideologies (like colonialism[35]). He details some precedents of "a manifold misuse of biology for purposes of political propaganda" (Dobzhansky 1956, 57). In his analysis, Dobzhansky is particularly concerned by the value-laden notion of 'progress', which may be vulnerable to a political hold. This point is crucial because, although the notion of 'progress' violates the taboo against introducing value judgments into science, it remains a prevailing theme in synthesis writings (Greene 1990). Historians of science explain this widespread use differently. Esposito (2011) relies on an historical analysis of post-war, challenging times when he suspects that "this definition of evolutionary progress was especially important [...] because the humankind's future progress was not guaranteed". Ruse (1988) grounds progressivism in psychological reasons: since, in science, competitive research yields to cumulative progress, scientists consider themselves the product of an improving humanity and are thus predisposed to believe in progress. When we turn to the texts in which the architects of the synthesis directly address the origin of the notion of 'progress', we encounter a spiral argument, where factual evolution is believed to lead to the emergence of human conscience, thus asserting that subjective values and factual progress advance together.[36] The precious dialectic hereof produced turns out to be fruitful for both scientific and humanist writings, as it inscribes both missions towards the same horizon: the enhancement of humanity.

Faith in progress, from which the concept of the genetic load emerges, is a gateway for the intrusion of social concerns into scientific claims. Through the notion of progress, social values guide what is considered the *telos* of humanity. According to Dobzhansky, however, qualified biologists are immune to the misappropriation of progressive evolutionary views (Dobzhansky 1956, 59). Science is pure. And this view extends to the translation of science provided it is monitored by scientists. When Dunn and Dobzhansky wonder about the conditions under which scientific knowledge is ready to be applied, they argue solely on the basis of intrinsically scientific criteria (Dunn & Dobzhansky 1949, 83). If the scientific knowledge is advanced, as they believe genetics to be after its rapid progress in the 1930's and 1940's, this knowledge can be turned into actions. In this argument, maturity of science is evaluated endogenously and the process is assumed to be informed and guided by

realized in a certain kind of social environment, so that eugenics is inevitably particular aspect of the study of man in society" (Huxley 1948, 31).

[33] "The next step for eugenics, as I urged at the beginning of this essay, is a methodological one. We eugenists must familiarize ourselves with the outlook and the concepts of sociology, with the technique and practice of social reform; for they are indispensable part of the machinery we need to realize our aims" (Huxley 1948, 62).

[34] "The thread running through most of these essays is the attempt to discover and apply in certain fields as much as possible of this scientific conception to several different fields of reality" (Huxley 1923, XIV).

[35] "The tenor of the theory of natural selection suited the intellectual climate of the second half of the nineteenth century remarkably well. [...] With colonial empires abuilding and with imperial nations preparing to dispute each other's claims to world mastery, it was a comforting thought that when the strong exploit or oppress the weak they are merely obeying natural laws and striving towards 'progress'. [...] Darwin's theory was good biology which was perverted by others to support bad sociology" (Dobzhansky 1956, 59).

[36] "What we have found is that there exists a certain general direction of movement in the evolution of living things; towards the increase of certain of their properties. But when we make a further analysis, we find that movement in this direction is a movement towards realization of the things judged by the human mind to have value (increase of power, knowledge, of purpose, of emotion, of harmony [...]). What is important is that the human idea of value finds its external counterpart in an actual historical direction in phenomena, and that each becomes important because of the relationship" (Huxley 1923, 59-60).

scientists themselves. Society is considered a pure recipient and societal forces can neither shape the orientations of science, nor oppose any resistance to scientific imports.

This comprehension of the translation and application of science has changed over recent decades. The notion of "scientific ideology", in particular, challenges this vision of an immaculate science.

The Model of Scientific Ideology vs. the Model of Co-Production

Science, according to Canguilhem, embraces a cyclic temporality, where transitions from one theory to another are phases susceptible to incorporate extra-scientific concerns and thus convey ideological expressions. The identification and deciphering of 'scientific ideologies' is thus particularly helpful in informing our critical approach to the relationship between science and society, by highlighting the themes and patterns that, throughout the history of science, connected scientific practices and social concerns.

Since Canguilhem's work on 'scientific ideology', several disciplines in science studies have shown how social, political, and cultural values affect scientific research and how this, in turn, affects society, politics and culture. The concept of co-production developed in the field of Science and Technology Studies (STS) is particularly interesting from this point of view. Co-production is shorthand for "the proposition that the ways in which we know and represent the world (both nature and society) are inseparable from the ways in which we chose to live in" (Jasanoff 2004, 3). With the model of co-production, sociology of science moves from extreme technological determinism and social constructivism, to a more systemic understanding of how technology and society 'co-produce' each other.

Contrarily to the historical concept of 'scientific ideology', the sociological framework of co-production can be applied to understand reciprocal relations in the making, between science and society. Other than questions of temporality, there are at least two profound differences between the two concepts that underline contrasting views on both science and society.

- First, as a sensitizing concept, the idiom of co-production looks at four themes: "the emergence and stabilization of new techno-scientific objects and framings, the resolution of scientific and technical controversies; the processes by which the products of techno-science are made intelligible and portable across boundaries; and the adjustment of science's cultural practices in response to the contexts in which science is done" (Jasanoff 2004, 72). These are sensitive places to investigate, along the scientific process, how scientific experts and other groups co-generate new knowledge and technologies rather than specific phases in the theoretical cycle of science. When 'co-production' emphasizes the practicality of science, 'scientific ideology' relies firstly on the examination of its inner theoretical content, as expressed within scientific concepts.

- Second, 'co-production' is functionally comparable to the concepts of positive feedback or co-evolution, which describe how two or more variables of a system affect and essentially create each other. In this systematic framework, *all* scientific claims incorporate social factors and are subject to negotiation. The notion of 'scientific ideology', on the contrary, introduces a dichotomy between ideological and no ideological science. Canguilhem thus maintains a place for a substantially defined scientific rationality and even uses the inherently normative history of science to "judge" the past of science (Canguilhem 1970, 13). Going back to the case study of genetic load, one can however ask how to disentangle, historically speaking, ideological genetics from 'pure' genetics and if this proposition would even make sense.

As our vision of the relation of science and society has evolved, there may not be a place any longer for the notion of scientific ideology in the tools box of the historian of science. The emphasis on the practicality of science – significant enough to lead to developing subfields of philosophy and history of science in practices (Ankeny, Chang, Boumans, & Boon 2011; Leonelli 2012; Müller-Wille & Charmantier 2012) –, and maybe more importantly, the systematic approach that enables historians to interpret a seminal debate about experimental science in relation with its political fallout without judgment as to the intrinsic scientific value of the arguments involved (Shapin & Schaffer 1985), may prevent from an approach that seeks for ‘scientific’ concepts that betray the penetration of ideology in critical theoretical phases.

However, we argue that the heuristics attached to scientific ideology remains fruitful to discuss the framework of co-production and its potential pitfall: noetic flatness. If science and society co-produce each other equally, the justification for maintaining the boundary between them dissolves. Co-production, if used to broadly or uncritically, thus leads to a radical discourse of relativism and to the loss of scientific rationality. In contrast with this systematic framework, the Canguilhemian approach invites historians to identify and decipher scientific concepts where extra-scientific elements permeate scientific rationality, thus maintaining boundary-work within the process. Canguilhem’s appreciation of the intricacy of science and non-science remains subtle throughout his work. First, Canguilhem recognizes the decisive role of valuation within science (Canguilhem 1966). Second, his judgment on otherwise wrong theories includes the appreciation of potential beneficial effects in the course of science. That was for example the case for vitalism, considered as an epistemological obstacle to the development of better theoretical systems in explaining biological phenomena, that however kept biologists’ concepts open to the uniqueness of the phenomena they are designed to understand and that did warn them against the reductionist pretentions of successful mechanistic theories (Canguilhem 1977). Canguilhem’s critics against vitalism are as such rather nuanced. It is thus not surprising that the concept of scientific ideology inherits from the same kind of ambivalence, being “at the same time an obstacle and a condition of possibility [...] for the constitution of science” (Canguilhem 1988, 38). As such, Canguilhem’s lesson may well lead to a nuanced understanding of science rather than to a clear-cut separation of ideology and genuine science or to the loss in significance of scientific rationality.

Conclusion: Past and Present

Genetic load history is intriguing because its ideological content nurtures its scientific fate. It is also alarming because this specific ideological content touches the darkest hours of eugenics. Based on our examination of genetic load as a scientific ideology, we conclude by indicating how some ideological elements that allowed the genetic load to persist as a relevant topic of population genetics beyond the expiration of its theoretical basis can still be observed in up-to-date science.

In an evidence-based movement, where some knowers are privileged over others in policy decision-making, the legitimacy derived from experimental fact is key. This was true at the time of emergence of the genetic load model and is still true today. The ‘from cells to society’ approach, recently developed in a public health context, constitutes an attempt to anchor social interventions in molecular knowledge. The growth of the discipline of environmental epigenetics illustrates such a program. Epigenetics is commonly defined as the “the structural adaptation of chromosomal regions so as to register, signal or perpetuate altered activity states” (Bird 2007). Put more simply, epigenetics refers to those mechanisms of gene regulation that do not involve changes in DNA sequence. The discipline therefore brings debates about soft inheritance back to the fore (Meloni 2015). If material and social factors seem massively engaged in producing aspects of our own biology, then social control may allow us to take charge of our own heredity. Here we are, more than half a century after the genetic load model was formulated, on the basis of entirely different claims, with the same proposal to enhance social progress and population health via the manipulation of our most intimate chemistry.

A significant body of scholarship has already started to outline the implications of the anticipated translation of environmental epigenetics to social measures. In this matter, the political application of scientific claims is a double-edged sword. Showing how acquired traits can be inherited may, hopefully, serve to promote social reform provided social investment proves worthwhile by the passing on of good habits across generations. However, if bad habits become bad biology, and the scars of past exposures and traumas give rise to ideas of specific groups being too damaged to be rescued, epigenetics may well become the basis for reproducing and consolidating structural differences in society – class, gender, and race (Katz 2013; Mansfield 2012). Whether or not the translation of epigenetic into public health follows one set of values or another is not up to the scientists to decide but will eventually depend on the broader socio-political context in which science circulates (Dupras 2014). Although every era tends to assert that "its science somehow levitates above the social, economic, political forces of the day – and is free from such immersion" (Duster 2015, 22), scientists are always caught in the social fabric of their times and the potential translation of scientific claims into policy-making adds thick layers imbued with social meaning and power to the investigation. A specific interest in the application of science might even shape the pursuit of scientific endeavors. Because intervention might well be the *telos* that orients the generation of knowledge, there are 'political epistemologies' at stake in the most experimental settings. In the end scientific claims cannot be separated from their ideological surroundings.

Eugenicists seemed to have the weight of rigorous, quantitative, and thus scientific evidence on their side when, in actual fact, their scientific claims were controversial and were ultimately invalidated. To those with economic and social power and imbued with the new spirit of scientific planning, the tale of the eugenic load offered a rational approach to dealing with social problems. But it turned out that those social concerns had, to a great extent, led to the construction of the concept of genetic load (and not the other way around). The way in which society shapes scientific endeavor is not obvious. The pursuit of science presupposes metaphysical, political and moral commitments, such as those identified in the construction of the genetic load model. But scientific ambition for objectivity overturns these commitments and strips them away. Advocates of Evolutionary Humanism were thus reduced to claiming the scientific sanction of evolutionary biology for values that originated elsewhere and could be argued for in the language of ethics and politics.

The persistence of the concept of genetic load results from its position in limbo between a scientific argument and a political argument. Recent developments in science result from the same kind of ambiguity. To cite just one example, the rise of environmental epigenetics is not only playing an important role in shaping the contours of socio-biological boundaries, but doing so, it also advocates in favor of certain conceptions of justice (Loi 2013). Because of the weight given to scientific claims and, in particular, to experimental evidence in policy-making – or, to put it differently, "when men define situations as real, they are real in their consequences" (Thomas 1928, 571) – we must remain aware of the fact that laboratories are not places outside the world but reflect our own struggles within society. This might well be the lesson of Canguilhem today.

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