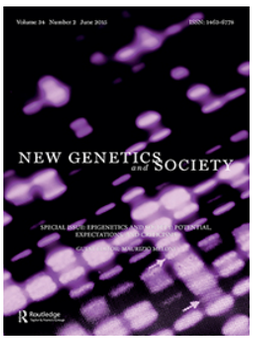

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Epigenetic determinism in science and society

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The epigenetic "revolution" in science cuts across many disciplines, and it is now one of the fastest-growing research areas in biology. Increasingly, claims are made that epigenetics research represents a move away from the genetic determinism that has been prominent both in biological research and in understandings of the impact of biology on society. We discuss to what extent an epigenetic framework actually supports these claims. We show that, in contrast to the received view, epigenetics research is often couched in language as deterministic as genetics research in both science and the popular press. We engage the rapidly emerging conversation about the impact of epigenetics on public discourse and scientific practice, and we contend that the notion of epigenetic determinism – or the belief that epigenetic mechanisms determine the expression of human traits and behaviors – matters for understandings of the influence of biology and society on population health.

Keywords: epigenetics; epigenetics revolution; genetic determinism; epigenetic determinism

Introduction

In an October, 2010, special issue, *Science* magazine took on the difficult task of defining "epigenetics", highlighting "nongenetic cellular memory, which records developmental and environmental cues", as the foundation of this burgeoning field of research (Riddihough and Zahn 2010, 611). The issue's introductory article was accompanied online by a video in which scientists were asked to define epigenetics; answers revealed "many different views of epigenetics" among researchers. Broadly, epigenetics refers to the study of how environmental exposures (including those internal to the organism) alter gene activity without changing the genetic makeup of an individual, but there is no consensus about how to explain epigenetics or epigenetics research. Besides the upsurge of diverse scientific interest in epigenetics, the

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science of epigenetics has become highly publicized, and there is increasing popular and concerted attention to epigenetic explanations for human traits and behaviors. For example, *Time* magazine, also in 2010, published a cover piece about the emerging field of epigenetics, titled "Why Your DNA Isn't Your Destiny", explaining "how your environment and your choices can influence your genetic code – and that of your kids" (Cloud 2010).

The headline about destiny reflects what some scholars have deemed the anti-reductionist promise of the project of epigenetics – that this area of investigation might steer us away from the tendency to view genetic makeup as deterministic of "destiny", or of behavioral or health outcomes. "Determinism" generally reflects a restriction of contingency; specifically, "genetic determinism" refers to the belief that a DNA sequence (a "gene") determines a trait. Epigenetics, in its definitional promise to pay attention to nongenetic factors, has been positioned in scientific and in popular discussions as a potentially anti-deterministic approach to studying human phenotypes. The prefix "epi" is literally meant to qualify genetics, switching the research focus from genetics to the mechanisms by which genes are regulated. As a framework for understanding the relationship between nature and nurture, epigenetics has emerged as a major force in conversations in science, social science, and in the popular press. While language about epigenetics may tout this new anti-determinist direction, it may simultaneously promote a novel form of determinism, one that highlights the "influential" role of environment and behavior in determining individual characteristics and even the expressed genetic code of future generations. Recent technical and popular texts on epigenetics betray the deterministic qualities of epigenetics research and discourse, laying bare the ways in which "epigenetic processes seem to rule every aspect of our lives" (Badyaev 2013b, 224). How deterministic is the paradigm of epigenetics?

In this paper, we examine how epigenetics is cast in scientific investigations and in the popular press. We build upon the rich literature on genetics and determinism in order to provide a conceptual argument for how to understand the extent to which epigenetics research and discourse engages or engenders deterministic views. We also draw on and contribute to the rapidly emerging conversation about the impact of epigenetics on public discourse and scientific practice. We will show that, in contrast to the received view of epigenetics as anti-deterministic or anti-essentialist, epigenetics research is often couched in language as deterministic as genetics research in both the popular press and in scientific publications. We argue that the epigenetic approach is firmly embedded in traditional notions of genetic control and thus remains highly deterministic. In so doing, we contend that contemporary epigenetics discourse may be understood under the framework of *epigenetic determinism*, which we conceive as the belief that epigenetic mechanisms determine the expression of human traits and behaviors.

Epigenetics, genetics, and determinism

As pointed out above, "epigenetics" is a fundamentally ambiguous area; it means different things to researchers focused on developmental plasticity, evolution of development, maternal effects, and molecular biology, to name but a few topics. Examples of epigenetic research include investigations that map molecules associated with DNA (e.g. DNA methylation), studies of the mechanisms by which they affect gene expression, how environments experienced early in life have long-term consequences by causing permanent changes to such molecules, and how this can result in inheritance in the absence of variation in DNA sequence. Much like at the end of the twentieth century when the gene became shorthand for a stretch of DNA that codes for a protein (Nelkin and Lindee 1995, 4), "epigenetics" is now a quick reference to nongenetic influences on development and heredity. Recent definitions of the term in genetics and developmental biology are often broad or vague such that they can be interpreted to encompass the entire developmental process by which genes have phenotypic consequences.[1] Some scholars have argued that epigenetics – with all its definitional ambiguity – has flourished precisely because of its vagueness and flexibility in addressing multiple phenomena (Meloni and Testa 2014). Despite the proliferation of invoked and usable definitions, the majority of researchers usually appear to intend a more narrow meaning of epigenetics, which are the molecular mechanisms that are closely associated with the DNA molecule itself and that can cause gene expression states to be inherited to daughter cells (in mitosis or meiosis) without changes in DNA sequence (e.g. Armstrong 2014). The most well-known mechanism is DNA methylation, in which a methyl group is attached to a cytosine nucleotide in the DNA sequence. Methylation of cytosines has a range of different functions, including modification of gene expression. This molecular definition is also what typically appears to be intended in popular coverage of epigenetics research.[2] We adopt this perspective here as the most prevalent and will not in this paper further discuss explicit definitions of epigenetics itself.

To begin to address the extent to which, if at all, epigenetics is deterministic, we must first take one step back and discuss genetic determinism. Genes, or DNA sequences, play causal roles in development of organisms. So do other factors, including nutrition, temperature, social interactions, and so on. But genes are generally considered to have a privileged role in development. Genetic determinism usually takes the form of one of two types. First is the notion that the DNA of an organism is highly predictive of what the organism will look like (i.e. its phenotype). Genes are considered special because their variants (alleles) reliably map onto different developmental outcomes, more so than environments that are viewed as external, peripheral, and non-specific in action. Second is the notion that DNA "controls" development – that genes provide the instructions according to which biological processes build organisms. For example, Ernst Mayr famously stated "all of the directions, controls and constraints of the developmental

machinery are laid down in the blueprint of the DNA genotype as instructions or potentialities" (1984, 1262). Whereas the first notion need not imply that genes are special in terms of how they affect development, the second implies that genes occupy a special conceptual space not engaged by other causal factors in development, perhaps as the sole carriers of semantic information (discussed in, e.g. Griffiths and Stotz 2013; Keller 2000; Oyama 1985). This latter, substantially stronger, notion of genetic determination or genetic control is widespread in both science and society. For example, the idea that genes provide instructional cues underlies notions of DNA as a blueprint, or program, for development. Science studies scholars have documented the ways in which genetics discourse increasingly uses metaphors of information – what Kay (2000) calls the "transition to the information discourse" in genetics.

Many scholars and theorists have long been critical of genetic determinism. While prominent scientists have argued that the story is not all in the genes (e.g. Bateson 2006; Lewontin, Rose, and Kamin 1984; Nijhout 1990; Waddington 1957), the critique of genetic determinism has a vibrant place in the social sciences, as scholars have sought to counter the idea that complex social behaviors or health outcomes can be explained simply by understanding an individual's (or a group's) genetic makeup. As sociologists, historians, scientists, and philosophers of medicine and science have argued, external, social, and environmental (essentially, contextual) factors cannot be ignored in discussions of human health or behavior. Yet genetic information is privileged in public discourse, especially in discussions of clinical medicine and in medical thinking about disease and behavior (Conrad 1999). Genetic discoveries are frequently associated with an epistemic leap as claims are made that a gene associated with a phenotype is the root "cause" of a socially significant behavior (Rosoff 2010). Deterministic statements that present biological groupings based on race, ethnicity, or gender hold traction in science and society (Wailoo, Nelson, and Lee 2012), and social scientists have clearly documented how people tend to perceive genes as the basis of health and social outcomes (e.g. Shostak *et al*. 2009). Furthermore, although sometimes acknowledging the role of environmental factors in producing health disparities, genetic scientists often still promote narrow biological determinist approaches to studying health outcomes (e.g. Bliss 2012).

However, there are instances in medical genetics research, in particular, that complicate a wholly deterministic framework. PKU (phenylketonuria) is often employed to show the variable phenotypic consequences of therapeutic interventions vis-à-vis a genetically determined trait, as diet (or "environmental conditions") alters the course of the genetic disease (Paul and Brosco 2013). In evolutionary biology, such "gene by environment interaction" has long been recognized as a potentially important source of phenotypic variation (e.g. Falconer 1960), and more recently this approach has gained recognition in medicine and mental health research and practice (Costa and Eaton 2006; Dodge and Rutter 2011). Critiques of the UK Biobank, as just one example of an effort to biomonitor

populations in order to understand genetic and environmental factors that impact health and disease risk, have centered around the idea that even if genetic and environmental factors are accounted for in population health research, a patchy vision of which and what factors constitute environmental ones may lead to more emphasis being placed on genetic factors (see Watts 2006). Meloni and Testa (2014, 434) recently argued that novel epigenomic profiles are serving as "the new place holders to anchor the environment to the genome", and considerations abound regarding the ability of studies to actually tease apart genetic factors from environmental factors, hindering the likelihood that discourse will move beyond the determinism found in discussions of genetics.

Even so, many social scientists have viewed the epigenetics framework as a promising one that moves us away from genetic determinism (Fujimura 2005; Salk and Hyde 2012). As Pickersgill *et al*. (2013, 435) write: "such refusal to grant ontological primacy to DNA is attractive to anthropologists and sociologists who have long been critical of various forms of genetic determinism". Others note the intransigence of deterministic frameworks and caution for nuance when it comes to biological understandings of epigenetics and how they relate to social categories of people (Fausto-Sterling 2012), emphasizing that it is unclear whether or not a shift toward epigenetics represents a turn away from, or a reinforcement of, genetic determinism. Some scholars have argued that in scientists' attempts to renounce genetic determinism, epigenetic determinism still rears its head (Goldman 2009; Moore 2009), with "genetics driving epigenetics" (Furey and Sethupathy 2013).

For example, Lock (2005, 2013b) has warned of "the lure of the epigenome" – a lively new embrace of biological determinism or "neoreductionism" – in presenting social determinants of health and human life. Lock (2013a, 291) argues that epigenetic findings initiate "a new round of somatic reductionism because research is confined largely to the molecular level". Indeed, some scholars have argued fervently that epigenetics is just another form of determinism. Richardson (2015, 225) provides a cogent analysis of the field of maternal–fetal epigenetics research, arguing that:

> Rather than challenging genetic determinism and biological reductionism, it is more precise to observe that present-day research programs in human epigenetics strategically appropriate and modify these discourses to include a particular conception of the social determinants of health, one that places the maternal-infant relation at the center.

That is, while certain scientists and science studies scholars have written about the potential of an epigenetic turn away from reductionism and determinism, still others have labeled epigenetics as a smokescreen. For example, in thinking through a gendered lens about maternal epigenetic effects, we might envision challenges to the genetic code as immutable force, but instead we see "an expanded but still fully reductionist and determinate model of development" (Richardson 2015, 217). Messages about epigenetics risks also translate into prescriptive messages to prospective parents (Juengst *et al*. 2014), revealing an emergent "epigenetic biopolitics"

(Mansfield 2012) that may reify racialized and gendered notions of how genes are regulated through behavioral and environmental factors. Nevertheless, other scholars argue for a nuanced vision of epigenetics and its relationship to deterministic approaches in science and society. Meloni and Testa (2014) write that epigenetics does not offer a significant repudiation of the primacy of genetic language (such as "maps, codes, blueprints") but also that epigenetics research often innovatively defies genetic determinism by co-opting and reapplying its rhetoric and approach.

We add to this conversation by providing a conceptual argument for how to understand the extent to which epigenetics research and discourse engages in deterministic views. Drawing on our analysis of scientific and media portrayals of epigenetics, we highlight three features of epigenetics research and discourse that reveal deterministic approaches: the notion of genetic control of epigenetic regulation, the concept of developmental programming, and the discussion of transgenerational epigenetic inheritance. We propose that contemporary understandings of epigenetics may be represented by the concept of "epigenetic determinism", or the belief that epigenetic mechanisms determine the expression of human traits and behaviors.

Determinism in epigenetics research

Studying the molecular mechanisms by which cells acquire and pass on gene expression states is a fundamental task in biology. It holds the key to understanding cellular differentiation during development, the maintenance of cell-type identity, how gene expression patterns can change in response to changes in internal and external states, many types of disease, such as cancer, and loss of cellular and organ functioning with age (i.e. senescence). All of these processes are epigenetic in both the broad and narrow sense, that is, they are contingent upon the intra- and inter-cellular context and involve molecular mechanisms that enable phenotypic differentiation through changes in gene expression. Nevertheless, contemporary epigenetics research frequently couches this contingency in deterministic notions of genetic control, programming, and inheritance.

Genetic control of epigenetic mechanism

The genome as a program or blueprint that controls development is one of the most powerful metaphors in biology, and it permeates research and popular understanding from molecular genetics to evolution. Epigenetics is no different. In molecular epigenetics, the fact that molecules involved in epigenetic regulation are transcribed from a DNA sequence enables researchers to maintain their genetic perspective and ultimately reduce everything epigenetic to genetics. To many biologists, it does not matter that the specificity of a biological process requires reference to external conditions, because the ability to respond to external conditions, such as temperature, nutrition, and so on, are also considered to be genetically

controlled (Griffiths and Stotz 2013). This means that the contingency of epigenetic processes – that is, their dependency on context – is no different from the standard account of phenotypic plasticity. For example, transgenerational epigenetic inheritance is described in terms of proximate causation, whereas only selection on genes is granted ultimate, evolutionary, causation (e.g. Dickins and Rahman 2012). Similarly, in evolutionary biology plasticity is typically defined as the ability of a single genotype to produce more than one phenotype in response to variation in the environment (e.g. high versus short stature in plants in response to light conditions; Pigliucci 2001). This definition of plasticity does not challenge the accepted view that the genome controls the phenotype as the ability to respond, and the nature of the responses to the environment, both contingent processes, can be considered properties of the genome (e.g. de Jong 2005; see also Haig 2007).

Whereas we believe that the majority of the research on epigenetics is firmly embedded in this form of genetic determinism, there are an increasing number of biologists that resist the notion of genetic control of epigenetic processes. These researchers emphasize that our understanding of biology can be enhanced by a more mechanistic, and hence contingent, description of development and evolution. Recent thinking in evolutionary biology emphasizes how the organization of development contributes to adaptive evolution by facilitating expression of functional variation in response to novel environments (e.g. Badyaev 2013a; Kirschner and Gerhart 2005; Moczek *et al*. 2011; West-Eberhard 2003). Possible examples of how developmental processes can impose functional directionality on evolution include hypoxia tolerance in high-altitude human populations, UV tolerance in water fleas, and evolution of jaw morphology in response to diet in small mammals and fish (reviewed in Schlichting and Wund 2014). Still, the majority of epigenetics research does not replace genetic determinism but, as demonstrated by the tendency to treat plasticity as a genetic phenomenon, regard epigenetics simply as the genes' way to regulate their own expression. Genetic control is alive and well in epigenetic research.

Epigenetic and developmental programming

Research on plasticity is also associated with another form of deterministic language in the theory of fetal or developmental programming (e.g. Aiken and Ozanne 2014; Cottrell and Ozanne 2008; Ellison 2010). "Programming" in this context refers to the empirical observation that conditions, such as temperature or nutrition, experienced early in life do not only have immediate, but also long-term, effects on an individual's phenotype. For example, there is increasing evidence that adult metabolic and immunological function depends on nutrient availability during prenatal or neonatal development (Burdge and Lillycrop 2010; Cottrell and Ozanne 2008). Some of these effects have been given a mechanistic explanation by the discovery that patterns of DNA methylation, and hence gene expression, can be modified in response to diet and that those modifications

remain stable throughout life (Gluckman *et al*. 2009). Research on "developmental programming" is rapidly advancing and has been suggested to have important implications for our understanding of health and disease, including aging, which has led in turn to extensive coverage in media and popular press.

The programming metaphor gives the impression that the developmental outcome is inevitable and irreversible.[3] Thus, despite the fact that developmental programming research has replaced genetic for epigenetic variation, and that the latter is a direct consequence of the environment, it reduces contingency in development to the deterministic execution of an evolved developmental program. For example, one hypothesis states that the developmental origin of some diseases is caused by a mismatch between predictive adaptive responses to some cue early in life and the actual environment encountered as an adult (e.g. because of more rapid environmental change in contemporary human populations than we have experienced in our evolutionary past, Gluckman *et al*. 2008). This developmental program is itself easily attributed to natural selection, which puts it firmly within the standard genetic account of adaptive plasticity (Pigliucci 2001).

Transgenerational epigenetic inheritance

One of the most contentious findings in biology recently is that epigenetic variation sometimes can be passed on to subsequent generations (summarized in Heard and Martienssen 2014; Jablonka and Lamb 2014; Lim and Brunet 2013). Such transgenerational effects go beyond the developmental programming described above, because they imply that not only can the environment of the mother (e.g. her diet) affect the phenotype of her offspring directly, but that such effects can be passed on more or less unchanged down two or more generations. Transgenerational epigenetic inheritance is well supported empirically in plants (e.g. Cortijo *et al*. 2014), whereas the evidence is less convincing in animals, particularly in mammals (Heard and Martienssen 2014). Nevertheless, a number of studies have shown that epigenetic variation can be transmitted through both the maternal and paternal germ lines.

Transgenerational epigenetic inheritance challenges the unique role of the DNA sequence in heredity (Jablonka and Lamb 2014). However, epigenetic variants ("epialleles") that are stably transmitted down generations may take on a similar deterministic role as genes. Indeed, biologists tend to treat epigenetic variants that are transmitted through the germ cells as more fundamental to inheritance than those that are acquired and transmitted somatically (e.g. Youngson and Whitelaw 2008). The rationale for this is that only stably transmitted variants are analogous to genes and hence could be considered true "replicators" (e.g. Haig 2007). As a result, it is only if genes are equated with DNA that epigenetics challenge the paradigm that genes explain heredity; stably transmitted "epialleles" would be indistinguishable from DNA variation in analysis of phenotypic variation. As an effect, stable epigenetic inheritance can be treated within the same conceptual and formal framework as genetic inheritance (Shea *et al*. 2011).

Transgenerational epigenetic inheritance thus faces an interesting dilemma. On the one hand, if the flexibility of inheritance that epigenetic mechanisms enable is an adaptation to pass on information down generations, researchers tend to treat it as a form of plasticity that can be considered a genetic adaptation. On the other hand, if epigenetic marks are stably transmitted, they become as formative and deterministic as genes, part of what is inherited, and hence in some ways more "innate" than characters that obviously rely on developmental resources acquired later in development (Bateson and Mameli 2007).

We have highlighted three ways in which scientific research on epigenetics exhibits a novel form of determinism in which epigenetic expression determines human traits. Through maintaining analytic focus on the ways in which the genome controls epigenetic mechanisms, on the phenomenon of developmental programming, and on transgenerational inheritance, we argue that epigenetic science presents a framework that privileges epigenetics as the fundamental product on which individual outcomes are based. Throughout these three features of epigenetics research, epigenetic determinism retains genetic determinism, as research is firmly anchored to classical notions of genetic control or the genetic program. Now we turn to a discussion of how epigenetics is presented in the popular realm, highlighting similar themes that lead to an emergent view of epigenetics as deterministic.

Epigenetic determinism in the popular imagination

Mass media are a main source for dissemination of science findings to the public (e.g. Conrad and Markens 2001; Nelkin and Lindee 1995; Seale 2003). In the past, the media have been shown to report with enthusiasm about genetic discoveries, often couching these findings in a deterministic frame (Conrad 1997). One major critique of genetic determinism stems from its public impact; that is, the popular coverage and pitch of genetics research may influence the way that people think about themselves and others as well as the causes of health outcomes and behaviors. We are interested in what types of discursive narratives are used in disseminating broad knowledge about epigenetics and whether popular discussions of epigenetics research stray or adhere to deterministic rhetoric. To approach this inquiry and to proxy the framing of public discourse regarding epigenetic ideas, we focus here on the BBC production *Ghost in Your Genes* in addition to an examination of US National Public Radio (NPR) and UK British Broadcasting Corporation (BBC) transcripts and programs.[4]

Readings of the popular literature suggest that there is very little attempt at breaking the deterministic stance in discussions of heredity and outcomes; even when phrased as a move away from genetic determinism, it is typically very unclear what it actually means or if it implies anything beyond the well-known fact that the environment affects development. In particular, epigenetics becomes deterministic and is seen as especially controlling once there are transgenerational

effects. The tenor of popular coverage is gauged most clearly in the BBC production *Ghost in Your Genes*.

The BBC Horizon documentary *Ghost in Your Genes* examines the "ghost world" of epigenetics and delves into how the experiences of previous generations may affect the biology of future generations. This documentary makes it clear that early discoveries in epigenetics were happening in the midst of, and as a result of, the Human Genome Project, an endeavor that sought to find genetic causes and cures for all human disease. The focus in the documentary is on the ways in which genes are turned on and off – the ways in which the epigenome dictates how the book of life (the genome) gets read. Genes in the documentary are discussed as needing instructions; epigenetics serve as a sort of "light switch" to activate certain genetic expressions. Moreover, much of the documentary highlights that these switches are incredibly stable, transmitting across generations. Like *Ghost in Your Genes*, most popular coverage of epigenetics research focuses on DNA methylation as the definition of epigenetic processes. As exemplified by *Ghost in Your Genes*, three emergent features of the popular press discussion of epigenetics map onto treatments of epigenetics in science. These aspects reveal the legacy of genetic control, the programming ("light switch") function of epigenetics, and the transgenerational impact of epigenetics.

The legacy: understanding the epigenome in the reflection of genetic control

When the BBC's *Ghost in Your Genes* aired on PBS NOVA in 2007, the program began with a discussion of the Human Genome Project and its import within the scientific community. Despite its promise, the show explained, scientists soon learned that the human genome was no more complex than that of plants, prompting the research community to ponder what else could explain human complexity. *Ghost in Your Genes* reveals that this discovery led to the first evidence that something other than genes passed between generations – that some mechanism influences genes directly, turning them on or off. While the popular press has for some time described the genome using the metaphor of "the book of life" or a "blueprint", the epigenome is consistently referred to as the "instructions" for the program grounded by the genome. So, while scientists are quoted in the popular press as saying that the epigenome "controls" or "determines" how the book of life is expressed, the genome is still cast as the basic program (i.e. the instructions that enable epigenetic control are to be found in the DNA sequence). The epigenome is characterized in the *Ghost in Your Genes* documentary as the software that tells the hardware what to do. To establish hierarchy, a television program description for the PBS NOVA version of *Ghost in Your Genes* describes the epigenome as a "kind of second genome".

Social scientists have written at length about the deterministic language in genetics. This discourse bestows a kind of authority and traction that works well in the popular press, and it informs discussions of epigenetics. In one NPR story about longevity, an interviewee explains to the host:

> when we're all talking about genetics, and when I answered you, I was really referring to changes in the sequence of our DNA. But there are mechanisms that are called epigenetics. There are some things that can sit on the DNA and regulate it without the need to change any of the components of the native DNA. (Flatow 2011)

This speaker reveals the tendency to speak in terms of genetics and to highlight the genetics of an individual. Even accounting for the mechanism of epigenetics, the "native DNA" remains stable, thus perpetuating discussions about the expression of one's basic genetic makeup.

In a piece called "Frontiers: Epigenetics" on the BBC (2010), a speaker clearly states that "epigenetics isn't meant to be a challenge to genetics . . . it's additional to genetics, it's not instead of". Another BBC (2007) program explains: "epigenetics is a layer of additional information that is applied to the genome . . . ". The genome is thus presented as primary, the base layer of biology. While the epigenome is seemingly given agency, the genome remains a determinative factor, perhaps yielding at times to environmental variation but maintaining its program all the while. As another example, a scientist in *Ghost in Your Genes* explains that the next great challenge facing modern biology is to decipher the epigenetic code, much as the genetic code was mapped in the Human Genome Project.[5] The epigenome in this statement is depicted through the lens of the genome.

Epigenetics, while discussed as cutting-edge science and as revolutionary in biology, is positioned in the shadow of the Human Genome Project and within a discourse of genetic essentialism. To be sure, the end of the twentieth century saw great confidence in the power and agency of genes (Keller 1995) and a resurgence of social and scientific interest in explaining human problems through a genetic lens (Conrad 1997). In this way, genetics research, and its attendant deterministic rhetoric, is the frame through which a discussion of epigenetics (and its accompanying determinism) is perennially angled.

The light switch: activating the program and its potential

Widespread in discussions of epigenetics is the idea of programming. This is expressed through both metaphor and vivid imagery. One interviewee in *Ghost in Your Genes* describes epigenetics using the metaphor of a "light switch", highlighting the idea that genes are turned on and off with epigenetics. Similarly, a professor in a BBC piece about research on twins and disease explains that "epigenetic switching is like a dimmer switch for gene expression" (Feilden 2012). Another piece from NPR (Hamilton 2013) on how maternal choices putatively turn genes on and off, titled "How a Pregnant Woman's Choices Could Shape a Child's Health", has the accompanying image of a pregnant woman pushing buttons both on her protruding abdomen and on a switchboard, as if she holds the key to activating the basic program of the fetus' genome. The notion that environmental or behavioral factors may activate or deactivate the genome in particular ways reveals a deterministic epigenetic discourse, one that emphasizes the idea that a

single time point sets a genetic program in motion. While theoretically reversible or manipulable, programming has the connotation of definitiveness – that once something is programmed, it retains its set form. However, in contrast to the genome, the epigenome can be "reprogrammed" by the environment, which creates a delicate balance between stability and flexibility that genes do not possess.

Whenever epigenetics is discussed in the popular press, it is indeed introduced and defined as the mechanism through which genes come to be activated or deactivated. In this way, epigenetics is depicted as determining the particular expression of the genome. For instance, a 2010 NPR piece on the brain explains: "Although genetic factors – which themselves reflect ancestral environmental pressures and adaptations – largely govern the growth of anatomical structures in the brain, non-genetic, environmental (*epigenetic*) factors determine their function" (Noë 2010). And in a piece called "Is Social Intelligence More Useful than IQ?" the determining factor in outcomes is not just genes but rather, and seemingly more importantly, how those genes are controlled. We include here an excerpt from the text:

> And the surprise for most people is that how you turn out behaviorally is not just determined by the genes you're born with; more critical is whether they express themselves or not. Many genes we have never express themselves. We may as well not have them. (Conan 2006)

In this view, genetics are not paramount; epigenetics determine because they program. Moreover, epigenetics as programming technology is discussed as a means through which to bolster and determine the health of future generations.

The lived memory: touting the transgenerational impacts of epigenetics

Much of the popular coverage of epigenetics also centers on the transgenerational component of epigenetics research. A BBC overview of *Ghost in Your Genes* articulates this aspect of epigenetics:

> at the heart of this new field is a simple but contentious idea – that genes have a 'memory'. That the lives of your grandparents – the air they breathed, the food they ate, even the things they saw – can directly affect you, decades later, despite your never experiencing these things yourself.

The light switches as described above are characterized in the popular press as incredibly stable, thus adding to the notion that epigenetic outcomes are inherited. Indeed, the "mysterious" world of epigenetics as discussed in *Ghost in Your Genes* refers to the lives of our ancestors. Epigenetic effects are positioned in this documentary as multigenerational effects, as evidence that environmental effects may be passed down through generations. Science and popular press articles have recently hyped this phenomenon with titles expressing the impact of one's grandmother's ovaries. For instance, the headline of one BBC news article reads "Higher birthweight 'linked to grandmother gene'" (Bowdler 2012). By defining the

"grandmother gene" through an epigenetic framework, the discussion represents deterministic thinking via a deterministic epigenetic discourse. These types of conversations do not focus solely on maternal effects. One BBC program from 2013 highlights a study (Dias and Ressler 2014) that revealed "ancestral fear" among rodents that "causes brain changes" through conditioning a shock in grandfather rats (BBC 2013a). In another 2013 story from the BBC about the generational effects of chemicals, epigenetics is defined not just as the mechanistic manner of gene expression but also as embodying the notion that parents pass on those "subtle differences" in the ways that genes manifest (BBC 2013b). That is, epigenetics is presented as being synonymous with transgenerational influence, suggesting not only an environmental – genetic interactive effect but also one that is stably transmitted, essentially determining the next generation.

It is the transgenerational impact of epigenetics that suggests perhaps the most deterministic language among our three highlighted features of epigenetic determinist discourse. If the outcome is laid out for an individual in the behavior of previous generations, what is he or she to do to overcome this determined path? Once something is inherited, it can be interpreted as essential or innate, thereby being more deterministic than an effect that occurs within generations due to environmental factors. The popular epigenetics discourse intimates that when a phenotypic outcome is passed on unchanged over time, it determines one's path. By reducing traits or behaviors to epigenetic inheritance, the transgenerational discourse of epigenetics reveals epigenetic determinism.

Conclusion

The epigenetic "revolution" in science cuts across many different disciplines, and it is now one of the fastest-growing research areas in biology. Increasingly, claims are made that epigenetics research will change our perception of ourselves. At the heart of these claims is the view that epigenetics represents a move away from the genetic determinism that has been prominent both in biological research and in understandings of the impact of biology on society. We have aimed in this article to explore the extent to which epigenetics research actually engages deterministic/non-deterministic views and how these different approaches may or may not facilitate understandings – in both science and society – of the impact of biology and society on population health. Our conclusion is that contemporary scientific research and coverage of epigenetics in the popular press fail to move away from biological determinism, embedded as they are within the traditional context of genetic and reductionist science. We have scrutinized how epigenetics is anchored in genetics in both science and society, showing that the underlying rationale is still to treat the genome as blueprint. Alternative perspectives exist in the scientific literature (e.g. Badyaev 2013a; Bateson and Gluckman 2011; Jablonka and Lamb 2014; Laland *et al*. 2014; Nijhout 1990; Noble *et al*. 2014; Oyama, Griffiths, and Gray 2001), but these remain minority views and critics often counter the arguments by pointing

to the perceived explanatory sufficiency of the traditional perspective (e.g. Dickins and Rahman 2012; Scott-Phillips *et al*. 2013; Wray *et al*. 2014). Epigenetics rests on the product of genetics. While epigenetics is about potentially rethinking genetic control, there remains an active explanatory linking of outcomes and traits back to genes and genotype.

As a biological explanatory framework *du jour*, epigenetics is a ripe arena in which to examine contemporary thinking about nature versus nurture and how biological and social factors are discussed in reference to human development and outcomes. In practice, scientists who are engaged in epigenetics research have been shown to have varying opinions about whether an epigenetics framework is deterministic (Tolwinski 2013). If the idea of epigenetic determinism is more clearly spelled out, as we have attempted to do in this paper, scientists may in turn be able to draw on this framework to be more explicit about the ways in which their work contributes to or subverts a deterministic frame. In addition, our contribution in this paper to an understanding of epigenetic determinism matters for science communication and public uptake of science, especially when analyzing the dissemination of epigenetic risk messages (Juengst *et al*. 2014). Activating the idea of epigenetic determinism may also add to growing conversations about the socially relevant outputs of epigenetics research and discourse (see Meloni and Testa 2014). Although alternative perspectives that counter epigenetic determinism could be pursued in the popular press (see, e.g. Richardson *et al*. 2014), genetic explanations appear to retain privilege in public discourse. If public understanding of epigenetic influence rests on a discursive and descriptive frame of genetic determinism, then the gene will continue to play a privileged – and deterministic – role in public discourse about the origins of health, disease, and social problems. Future analyses of the ways in which media report on epigenetics research using a deterministic frame may allow for a more in-depth discussion of the pervasiveness of epigenetic determinist discourse in society.

Just as the gene has served the role of "both a scientific concept and a powerful social symbol" (Nelkin and Lindee 1995, 2), the epigenome has emerged as a potent topic in both science and the popular imagination. By employing a discourse in which individuals' traits are reduced to epigenetic mechanisms, the interpretation in science and society of epigenetics is in its essence a deterministic one. We have suggested that three aspects of epigenetics reveal a level of determinism that is prevalent in contemporary scientific and popular discussions of epigenetics. These aspects, shared between scientific and popular discourse, include the way in which epigenetics fails to move away from the hold of genetic control, the idea that epigenetic mechanisms program individuals to develop according to a pre-determined trajectory in response to external stimuli, and the notion that epigenetics provides another inherited code that channels the developmental potential of individuals. We contend that epigenetic determinism found in contemporary discourse promotes a restricted understanding of the full breadth and opportunity available in research regarding the impact of genes and environments on the

phenotypic outcomes of individuals. While scientific and popular discussions of epigenetics frequently see it as a move away from genetic determinism, in reality this is a minority view, and many of those who hail epigenetics as a solution to biological determinism simply replace one deterministic code for another.

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Notes

1. In this way, they are more similar to the original meaning of the term as introduced by Waddington (1942). For a sample of contemporary definitions of epigenetics in molecular, developmental, and evolutionary biology, see, for example, Allis, Jenuwein, and Reinberg (2007), Armstrong (2014), Dye (2012), Gilbert and Epel (2009), Hallgrimsson and Hall (2011), Jablonka and Lamb (2014), and King and Stansfield (2002).
2. We found this to be the case in media coverage of epigenetics; popular books on epigenetics also focus mostly on DNA methylation (see, e.g. Carey 2012).
3. This has spurred leading researchers in the field of Developmental Origins of Health and Disease to actively discourage the use of the term programming (e.g. Bateson and Gluckman 2011, 72).
4. In April, 2014, using the search function on the NPR and BBC websites, as well as drawing from the FACTIVA media database, we searched for NPR and BBC stories that contained the term "epigenetics". This search produced results starting from 1998. We use these sources to provide illustrative data on popular coverage of epigenetics rather than to make generalized claims about media coverage. While by no means exhaustive, these cultural data sources are both national public broadcasters that have covered stories about epigenetics at length. And although government-funded media outlets are assumed to be more liberal in orientation than privately funded media outlets, studies find that NPR, for example, presents information in a comparatively balanced fashion and that the NPR audience holds a similar ideology to that of an average viewer of mainstream programs (Groseclose and Milyo 2005; Hamilton 2004). Results were qualitatively coded, using a modified form of grounded theory (Glaser and Strauss 1967). We paid attention to the rhetorical strategies used to discuss epigenetics mechanisms and processes, highlighting explanatory use of metaphor and imagery. Three major discursive themes emerged that map onto the deterministic features of epigenetics research presented in the first empirical section of this paper.
5. A first version of this, called ENCODE, is now available (see Bernstein *et al.* 2012).

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