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Maternal Bodies in the Postgenomic Order

GENDER AND THE EXPLANATORY LANDSCAPE OF EPIGENETICS

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The neurologist and geneticist Michael Meaney argues that a stressed pregnant woman may produce offspring prone to anxiety, depression, schizophrenia, and suicide.¹ The psychiatrist Ray Blanchard warns that a mother with a large number of sons could damage subsequent sons in the womb owing to the accumulation of immune antibodies to male fetuses—causing later-born sons to become homosexual.² The recent popular science book *Origins: How the Nine Months before Birth Shape the Rest of Our Lives* (2010) reviews new research suggesting that a mother's stress level and dietary habits during gestation can “program” the fetus for a future of obesity, heart disease, and diabetes.³

Epigenetics, the study of how experiences, environments, and exposures alter gene expression, is a vibrant new area of postgenomic life sciences research. This chapter examines how maternal bodies are situated and valenced within this scientific field. Using texts and images from the scientific literature, as well as its public intellectual and popular reception, I document how epigenetics research situates the maternal body as a central site of epigenetic programming and transmission and as a significant locus of medical and public health intervention in the postgenomic age.

The science of maternal-fetal epigenetic programming converges with several major trends in twentieth- and twenty-first-century science, gender, and culture: from conceiving of motherhood as instinctual, selfless,

and intrinsically moral, to a cultural conception of mothering as an agential project of the self in which the mother's interests are often perceived to be in tension with the child's;⁴ from a psychosocial model of child development, to a model in which the critical factors in development are genetic and neurological;⁵ and from birth as the moment of personhood and medical concern, to conception, and even preconception, as the focal point of political interest and biomedical intervention in reproduction.⁶

Epigenetic studies of "maternal effects" raise vital social, ethical, and philosophical questions.⁷ Is there a potential for this research to heighten public health surveillance of and restrictions on pregnant women and mothers through a molecular policing of their behavior?⁸ How might this new research participate in the often-troubled history of notions of the supreme role of the mother in normal and pathological development?⁹ What are the empirical and methodological implications of a research focus on maternal effects to the exclusion of the larger social environment (and of paternal effects)?¹⁰

This chapter touches on all of these important questions, albeit through a side window. In the context of this volume, the central objective of this chapter is to explore what epigenetic studies of maternal effects reveal about the explanatory landscape of postgenomic science. Specifically, does epigenetics represent a challenge to, or just another version of, genetic determinism?¹¹ In this chapter I pose the figure of the maternal body in epigenetics as an index case to examine central conceptual questions about the definition, scope, and stakes of the "postgenomic" life sciences.

The figure of the maternal body as an "epigenetic vector," I argue, compels a different reading of the postgenomic commitment to complexity, to anti-determinism, and to a biosocial conception of human heredity and health than has generally been assumed. While scientists, social scientists, and philosophers theorize epigenetics as a long-awaited turn toward holistic explanations of life and a vindication of their trenchant critiques of the conceptual limits of genetic determinism and reductionism, in practice the leading-edge research agendas, experimental designs, and therapeutic interventions in human epigenetics complicate and may even foreclose this vision. Research on maternal epigenetic programming points to an emerging postgenomic explanatory order in which traditional forms of genetic determinism and reductionism are subtly reformulated. Rather than conceptualizing genes as agents in a linear causal chain, epigenetics and related postgenomics disciplines see genes as difference makers within embodied contexts. This reformulation, made especially clarion by the

case of maternal bodies in epigenetic research, highlights the need for new analytic approaches to suit the forms of explanation increasingly prevalent in the postgenomic life sciences.

Epigenetics

Epigenetics is the study of molecular mechanisms that bring about a heritable or persistent change in gene function without changing gene sequence.¹² One such mechanism is DNA methylation, the process by which a methyl group (CH₃) is appended to the physical structure of the DNA molecule.¹³ The presence of methylation at a particular gene locus typically prevents gene expression via physical obstruction of DNA transcriptase and other DNA-binding proteins.

Nonhuman animal studies allowing for experimental manipulation provide the strongest evidence for epigenetic mechanisms of gene expression modification. In mice with a gene variant linked to yellow fur color and obesity, a methyl-rich maternal diet during gestation epigenetically alters gene expression to yield brown offspring of typical body size.¹⁴ In a species of vole, maternal melatonin reflecting the season epigenetically influences the fetus's coat thickness, preparing it for its future environment.¹⁵ In rats, early maternal licking of pups epigenetically programs glucocorticoid receptor gene expression in the brain, resulting in a low-anxiety adult phenotype.¹⁶ In all of these classic studies, the epigenetic modification is introduced via the behavior or physiology of the mother—a point to which I return below.

Epigenetic alterations of gene function may be fleeting or long-lasting. Typically, they are reversible. They can be passed through cell division from one cell to another. They can also be inherited from one generation to another through the gamete, cytoplasm, or reconstruction of the environmental cues activating the trait in each new generation. This is a form of indirect, rather than direct, inheritance.¹⁷

The extent and importance of early-life epigenetic programming in human health are not yet known.¹⁸ A burgeoning scientific literature claims associations between prenatal hormonal, immunological, and nutritional exposures and adult phenotypes such as attention deficit/hyperactivity disorder, autism, schizophrenia, homosexuality, asthma, cardiovascular disease, diabetes, and obesity.¹⁹ Environmental exposures of special interest in these studies include toxins, stress, nutrition, neighborhood, and socioeconomic status (see chap. 10 of this volume). While some of this research directly studies molecular-level mechanisms of gene regulation,

most involves epidemiological research on exposures that are hypothesized to interact with the human genome via epigenetic mechanisms but have not yet been experimentally shown to do so in humans.

Epigenetics and Postgenomics

Epigenetics is a postgenomic science. After the completion of the Human Genome Project, epigenetics emerged as a focus for institutional investment and a hot new research area.²⁰ The early 2000s saw the launch of national and international human epigenome consortia. In 2010, the National Institutes of Health allocated \$190 million to the U.S. Human Epigenome Project, promoting it as a “big science” project to succeed the genome sequencing projects.²¹

Epigenetics is shaping public understanding of the promises and prospects of postgenomic science. From pop science books such as *The Epigenetics Revolution: How Modern Biology Is Rewriting Our Understanding of Genetics, Disease and Inheritance* (2012), *Epigenetics: The Ultimate Mystery of Inheritance* (2011), and *The Genie in Your Genes* (2007) to the NOVA television series “The Ghost in Your Genes” (2008) and the *Time* magazine cover article “Why DNA Isn’t Your Destiny,” epigenetics has met celebratory popular reception.²² This reception is characterized variously by mysticism and poetic wonder, humor, and hype. Popular writing on epigenetics often projects very nascent scientific findings into practical health advice for everyday life.

Scientists position epigenetics as a bridge between basic genomics research and clinical and public health applications. Pronouncements by scientists about the social, policy, and public health import of epigenetics convey a confidence in the solidity of new epigenetics findings and a conviction that they might be soon applied beyond the laboratory. Ambitious visions of epigenetics as a transformative framework for genomics and public health are nowhere more powerfully developed than in the pronouncements of those working on brain and behavior, such as the McGill University epigeneticists Michael Meaney and Moshe Szyf. As Meaney has written, epigenetics is “likely to have profound consequences when you start to talk about how the structure of society influences cognitive development. We’re beginning to draw cause-and-effect arrows between social and economic macrovariables down to the level of the child’s brain. That connection is potentially quite powerful.”²³ Meaney envisions a science of epigenetics that will show, at the molecular level, the fine-grained biological effects of early stress, deprivation, and trauma and provide support for

1 social policies to reduce these harms. Reflecting this conviction, a con-
 2 ference policy statement from the 2012 San Francisco symposium “The
 3 Contribution of Epigenetics in Pediatric Environmental Health” concluded
 4 that epigenetics research must be conveyed to the public with the “focused
 5 goal” of making public policy changes “faster for the sake of children’s
 6 health.”²⁴ Szyf extends the implications of epigenetics to the unification
 7 of the natural and social sciences and the resolution of the nature-nurture
 8 problem. As Szyf writes, “Epigenetics will have a dramatic impact on how
 9 we understand history, sociology, and political science. If environment has
 10 a role to play in changing your genome, then we’ve bridged the gap be-
 11 tween social processes and biological processes. That will change the way
 12 we look at everything.”²⁵

13 Scholars in history, philosophy, and social studies of science echo many
 14 of these hopes and ambitions. Social scientists analyzing emerging ge-
 15 nomic research position epigenetics as a quintessential postgenomic sci-
 16 ence. They also suggest that it offers a welcome alternative to the genetic
 17 determinism of past eras. Joan Fujimura, in her influential 2005 analy-
 18 sis of emerging trends in systems biology, characterized postgenomics
 19 as heralding a holist and antireductionist turn in the biosciences. As she
 20 wrote, fields such as epigenetics are part of a rising tide of “new ‘postgen-
 21 omic’ knowledges that aim to be more ecological and ‘wholistic’ than the
 22 reductionist genetics of the last forty years.”²⁶ Adele Clarke et al. situate
 23 epigenetics similarly in their entry in the 2010 *Handbook of Genetics and*
 24 *Society*. As they write,

25 Rather than genetics revealing a deep, inner, causal truth (a conventional
 26 historical assumption), contemporary genetics is instead beginning to
 27 conceptualize a ‘flattened world’ of complex, relayed, dynamic systems
 28 of networks of gene-gene interactions, gene-environment interactions,
 29 and highly individualized gene expression and regulation that together
 30 produce future bodily states. . . . Such . . . conceptualizations also poten-
 31 tially counter some claims about how ‘deterministic’ genetic and genomic
 32 information would detrimentally transform identities. . . . Overall, then,
 33 more deterministic outlooks on the impact of genetics are giving way to
 34 analyses that emphasize the networked complexities characteristic of the
 35 causal models currently used by genetic researchers.²⁷

36
 37 Philosophers of biology, long interested in alternatives to determinist
 38 and reductionist explanations in the molecular life sciences, also figure
 39 epigenetics as heralding potentially transformative conceptual develop-
 40 ments in biology. Philosopher Karola Stotz writes, “A new epigenetic un-

derstanding of development encompassing the organism in its developmental niche takes seriously the idea that all traits, even those conceived as ‘innate’, have to develop out of a single-cell state through the interaction between genetic and other resources of development. Such a view should . . . provide us with a real postgenomic synthesis of development, evolution, and heredity.”²⁸ Biologist-philosopher Eva Jablonka is another among the prominent intellectuals cheering the postgenomic “‘move in consensus’ in evolutionary biology” toward a “revival of an approach that gives explanatory primacy to development,” a move she paints in her book *Transformations of Lamarckism* (2011) as exemplified by the field of epigenetics.²⁹ In *The Mirage of a Space between Nature and Nurture* (2010), Evelyn Fox Keller similarly suggests that new postgenomic research fields such as epigenetics, systems biology, and studies of phenotypic plasticity portend a postgenomic life sciences trending toward an appreciation of complexity, offering an alternative to the old determinist, reductionist, “particulate” explanatory paradigms of genetics. As Keller concludes, in contrast to “the particulate gene that we inherited from the early days of genetics . . . the new science of genetics coming out of today’s research laboratories may point us to a route out.”³⁰

These accounts render epigenetics as an exemplar of a particularly hopeful conception of postgenomics. Responding to what anthropologist Margaret Lock has called “the lure of the epigenome,” science studies scholars pose postgenomics as formed around a disillusionment with the genomic view of the world and its accompanying reductionism (see also chap. 2 of this volume).³¹ Holism and anti-determinism are, according to these scholars, a central and unifying frame of the biological sciences after the sequencing of the genome. The new scientific interest in epigenetics is interpreted as demonstrating that biologists are finally realizing—as science studies scholars have long emphasized—that it is not all about the gene. Postgenomics, in this view, marks a move away from an informatic view of genes as a “bag of marbles” toward a material or biochemical conception of genes within the context of the whole genome in relation with its environment. A feature of this worldview is a new respect for the complexity, interdependency, and indeterminacy of gene action. In the science studies literature, epigenetics, along with systems biology and fields such as metagenomics (see chap. 4 of this volume), appears as a prominent and especially salutary example of this new non-gene-centric vision of genomics.

However, a close look at claims in one major area of current epigenetics research, maternal-fetal epigenetic programming, suggests a more complex picture of the relationship between epigenetics and genetic determinism. In

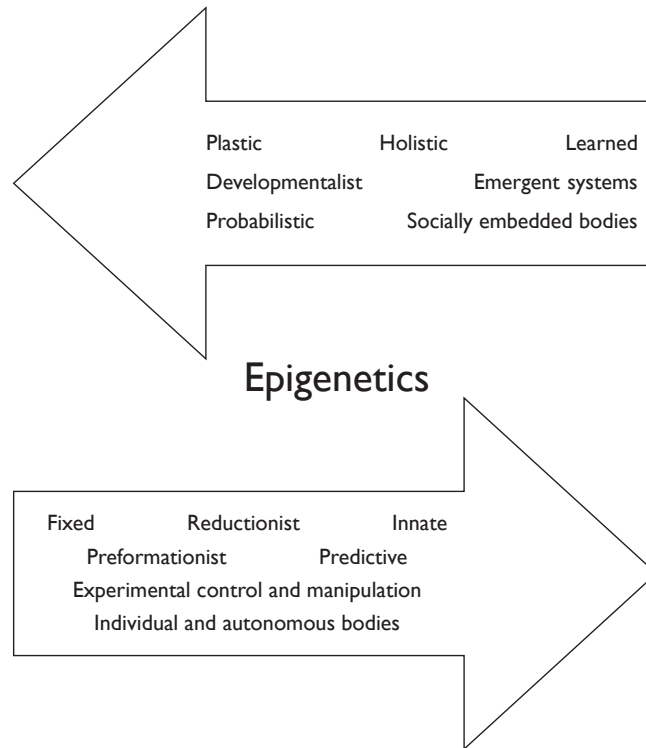


Figure 11.1. Epigenetic explanations combine elements of determinist or anti-determinist frameworks in ways that transcend received conceptual dichotomies and call for new analytic approaches. Author's illustration.

focusing on epigenetics as the alternative to genetic determinism, scholars are operating within a received, twentieth-century dichotomous framework for schematizing forms of biological explanation, one in which a plastic/emergent/socially embedded science of life is positioned opposite a fixed/preformationist/individual and autonomous one (see figure 11.1). This framework, I argue, misreads precisely what is new about the ontological and explanatory terrain of postgenomic sciences such as epigenetics. It also overlooks the significant continuities between the old and the new.

Indeed, determinism and reductionism may not be the most meaningful axis of comparison between “old” and “new” biology. Determinism has to do with the strength and directionality of the causal mechanism; reductionism, with the level of explanation. On examination, while maternal epigenetic effects are not strictly genetic, they are congenital and “fixed” in

precisely the same sense as genetically determined traits. They are determinate and predictable in their effects and, potentially, are also heritable. While epigenetic research on maternal effects challenges a notion of the body as the outcome of an indelible genetic code, in its place it offers an expanded but still reductionist and determinate model of development—a “somatic determinism.”³²

Maternal-Fetal Epigenetic Programming

Maternal-fetal epigenetic programming is a thriving area of current human epigenetics research that investigates how exposures during the prenatal and perinatal periods can induce long-lasting epigenetic changes that lead to adult disease and are potentially passed on to future generations. This research field, which is the focus of my discussion here, has come to be known as the “developmental origins of health and disease,” or DOHaD. Interest in the effects of undernutrition during gestation on adult disease drove the formation of the field. In the 1980s and 1990s, David Barker, a professor of clinical epidemiology at the University of Southampton, published a series of retrospective birth cohort studies relating prenatal undernutrition and low birth weight to later metabolic and heart disease.³³ Since then, research into the fetal origins of disease has expanded into a large area of study of the “fetal environment.” Today, aspects of the fetal environment such as maternal stress and maternal obesity are of especially keen interest.

DOHaD researchers believe that prenatal maternal effects influence development by introducing epigenetic modifications. They hypothesize that the prenatal period is a critical one for “epigenetic programming,” in which set points for gene expression are imprinted on the fetus, modifying developmental pathways in areas such as metabolism and the brain. The maternal body, in turn, is conceptualized as an adaptive environment for the fetus in which crucial early developmental cues are transmitted to the growing infant. Because this programming can imprint on a growing female fetus’s own gametes as well, the effects of the maternal environment may be intergenerational, passed through the maternal line to grandoffspring.

DOHaD is only one of the major current research areas employing epigenetics frameworks and explanations. The field of epigenetics is in principle quite large in scope. It includes many areas of basic and applied life science research, ranging from core processes of growth and development to the characterization of cancer tumors. These studies may have little connection to maternal-fetal epigenetic programming. Moreover, epigenetics

is not the sole focus of all DOHaD researchers. Not all “developmental origins” or “fetal origins” research presumes a strictly epigenetic mechanism for the phenomena under investigation. However, DOHaD, as well as closely allied basic and nonhuman model organism research on maternal epigenetic effects, holds a special status within postgenomic epigenetic science. Theories, data, and experimental paradigms arising from studies of maternal effects have at this time become canonical to the science of epigenetics writ large. There are at least three reasons for this.

First, researchers believe that the prenatal and early developmental stages of life are critical for epigenetic programming. The kinds of stable, long-term epigenetic changes of interest to researchers studying humans are most observable and susceptible to induction and manipulation during the perinatal period. Second, maternal-fetal epigenetic programming intersects with urgent public health priorities in the areas of infant mortality, early childhood development, and prevention of complex and resource-intensive public health problems such as obesity, diabetes, and cardiovascular disease. This presents a rich translational context for attracting investment and interest in epigenetics research. Third, maternal epigenetic effects are central to the most far-reaching and intellectually riveting claims about the philosophical paradigm shift represented by epigenetics. It is in the area of maternal epigenetic effects that the prospect of nongenetic intergenerational inheritance becomes a tractable question. It is unsurprising, therefore, that the leading textbook examples of epigenetic effects, such as Meaney’s experiments, focus on the role of the maternal body in inducing epigenetic change as the paradigm for postgenomic human epigenetic research.

Research on maternal effects is a new field that over the past decade has grown from a small research stream into a large scientific domain with an international profile. The field now boasts its own journals, specialty workshops, and a scientific society, the International Society for Developmental Origins of Health and Disease, which holds a biennial world congress. DOHaD research has been rapidly incorporated into textbooks and medical curricula and has been particularly influential in public health circles. The field is methodologically and disciplinarily diverse, bridging nutrition science, evolutionary biology, and reproductive physiology, and is host to a variety of perspectives and internal debates. Nonetheless, there exists a core of objectives, empirical claims, language, and conceptual frameworks that distinguish this research field and that may be accessed by surveying its primary literature. Here I profile the theories of two well-known DOHaD researchers.

University College London pediatrician and child nutrition expert Jonathan Wells is an influential theorist of early developmental programming in the prenatal maternal environment. Wells believes that metabolic disorders and obesity are somatic manifestations of the intergenerational transmission of health inequalities. Wells mobilizes DOHaD theory to model how features of the mother's social and environmental context during her own development—including social class—may be transmitted to the growing fetus, conditioning it for a life of inequality even before birth. According to Wells, the maternal body serves as a “transducing medium” for health inequalities from one generation to another.³⁴ “Maternal capital,” as he terms it, is corporealized in the maternal-fetal relation. A diagram of Wells's maternal capital model, reprinted in figure 11.2, schematically illustrates Wells's conception of how public health policies, including education and health care, may be transmitted through the “somatic capital” of the mother to offspring.³⁵

While the maternal body can transmit positive resources to the fetus, Wells focuses on “exploring different pathways by which maternal biology may generate ill-health in the offspring.”³⁶ As Wells explains, “offspring are exposed in early life to the ‘magnitude of maternal capital.’ In any given environment and population, mothers may vary substantially in their capital.”³⁷ Provocatively, Wells has dubbed “low-capital maternal environments,” characterized by social and nutritional stressors and other forms of health disadvantage, “metabolic ghettos.”³⁸ As he writes, “While the ghetto in its traditional sense reflects a form of social isolation, I want to extend this concept to a physical bodily dimension and use it to express the impact of economic marginalization on the physiology of reproduction. If pregnancy is a niche occupied by the fetus, then economic marginalization over generations can transform that niche into a physiological ghetto where the phenotypic consequences are long-term and liable to reproduction in future generations.”³⁹ The maternal body in the light of Wells's vivid metaphors of maternal “capital,” “ghettos,” and “transduction” is a vector that converts maternal social conditions into epigenetic marks on the infant's genome. As an intergenerational vessel of socially inscribed resources that condition life outcomes, the maternal body represents the past, capable of trapping the growing fetus in somatic conditions of deprivation that reproduce social class in postnatal life.

Northwestern University anthropologist Chris Kuzawa is a prominent, highly cited theorist of maternal-fetal epigenetic programming. Trained in evolutionary biology, Kuzawa is interested in the adaptive life history conditions of human metabolism. He researches the prenatal and early-life

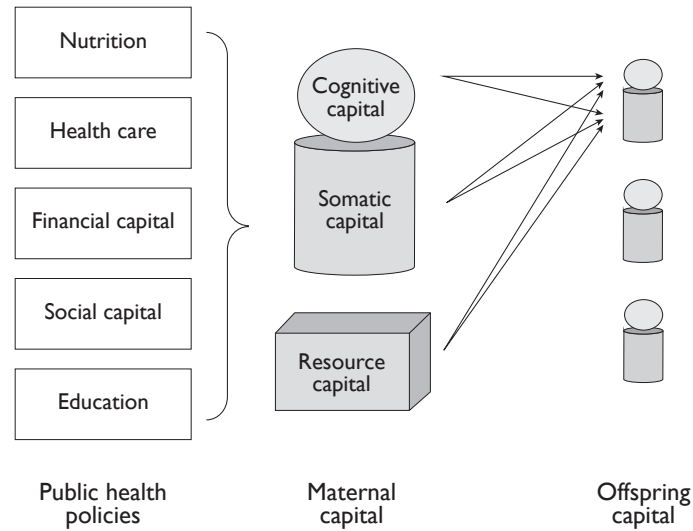


Figure 11.2. The intergeneration inheritance of “maternal capital.”
Credit: Wells, “Maternal Capital and the Metabolic Ghetto.” Permission to reprint courtesy of John Wiley and Sons. ©2009 Wiley-Liss, Inc.

origins of human metabolic diseases such as diabetes and other obesity-related health conditions. Kuzawa hypothesizes that maternal cues to the fetus, transmitted by hormones and nutrients, can alter adult phenotypic outcomes. Mechanisms such as epigenetics permit plasticity in how an organism realizes its genetic endowment in response to developmental environment.⁴⁰

These mechanisms are *adaptive* when the mother provides the fetus “access to a cue that is predictive of its future nutritional environment,” but they may also be *maladaptive*.⁴¹ According to Kuzawa, the mother avoids giving maladaptive miscues through a process that Kuzawa labels “intergenerational phenotypic inertia.” Epigenetic mechanisms allow the maternal body to transmit a reservoir of signals to the fetus from past maternal ancestors, an inertial adaptation that prevents too great and too rapid phenotypic plasticity. As Kuzawa hypothesizes, “The flow of nutrients reaching the fetus provides an integrated signal of nutrition as experienced by recent matrilineal ancestors, which effectively limits the responsiveness to short-term ecologic fluctuations during any given pregnancy.”⁴² Continues Kuzawa, “Intergenerational influences on fetal nutrition and growth may act as a form of what may be called intergenerational phenotypic inertia, in the sense that the growth response of the fetus to abrupt ecologic change

is tempered by the collective nutritional experiences of recent matrilineal ancestors. Because *the fetal nutritional signal reflects the mother's chronic nutrition tracing back to her own uterine environment, and thereby to prior generations of the matriline*, this may allow the fetus to 'see' an average nutritional environment as sampled over decades and even generations."⁴³ Kuzawa likens this to a "crystal ball" that allows "the fetus to predict the future by seeing the past, as integrated by the soma of the matriline."⁴⁴ Problems arise when this fetal environment for developmental modification and "fine tuning" is either "impaired" or mismatched with current environmental conditions.⁴⁵ Maternal epigenetic cues during the prenatal period, he writes, "might be likened to an 'ontogenetic bottleneck' through which any adult metabolic traits must first pass."⁴⁶

Maternal Bodies as Epigenetic Vectors

In DOHaD research, the maternal body emerges as what I call an "epigenetic vector," an intensified space for the introduction of epigenetic perturbations in development. I use the term "vector" here to invoke a series of associations that point to forms of causality that are conduit-like rather than strictly cause-effect, directional rather than distinctly determinative, and relational rather than cleanly linear. In epidemiology, vectors carry disease-causing agents from one organism to another. In aviation, vectoring is a synonym for guiding or directing. In mathematics, vectors determine the position of one point in space in relation to another. Here I identify four critical elements of this vector-like model of explanation and intervention in maternal epigenetic programming research.

First, DOHaD research principally advances a model of epigenetic modifications as a source of error, adverse effects, or disease risk. We might term this a *deficit* model of the relationship of epigenetics to disease. While scientists acknowledge that epigenetics may also provide a route to human enhancement or therapy, at this time the central object of concern is how to prevent the adverse effects of impaired or maladaptive maternal environments that cause epigenetic lesions in human lineages.

Second, maternal bodies are the central targets of epigenetics-based health intervention. Writes Wells, "Public health policies must be developed to aid the beneficial accumulation of somatic capital and metabolic capacity across generations. . . . I believe this may be achieved by targeting multiple interventions through the transducing medium of maternal capital."⁴⁷ As Kuzawa writes, "From an applied perspective, if a trait like fetal growth is designed to minimize the effects of short-term fluctuations

by integrating information across generations, public health interventions may be most effective if focused not on the individual but on the matriline.”⁴⁸ Note that in this vision, the scope of what counts as a “maternal body” is quite large and includes all premenopausal women. As Wells writes, “Whereas [others] have suggested that the reproducing female should be the primary target of interventions to improve health in the next generation, I argue that it is the total period of development of mothers, including experience in their own early life, that is critical to health in the next generation.”⁴⁹

Males provide parental care in many species, and male gametes are also subject to environmental exposures that may affect future generations. Although paternal effects are increasingly recognized by scientists and there exist several studies substantiating the existence of intergenerational effects in mammalian paternal lines, currently the focus in DOHaD research is overwhelmingly on the maternal.⁵⁰ Typical is the highly cited 2010 review article by Tie-Yuan Zhang and Michael J. Meaney, “Epigenetics and the Environmental Regulation of the Genome and Its Function,” which, as a simple metric, uses the terms “maternal” and “mother” 137 times, the terms “parental” and “parent” 11 times, and the terms “paternal” and “father” 3 times.⁵¹

Scientists defend this imbalance, arguing that “maternal phenotype clearly has substantially greater capacity to shape offspring phenotype through the processes of pregnancy and lactation.”⁵² But while the exposure of the fetus to the mother is certainly more intimate than to the father in most placental species, this does not fully explain the neglect of research on paternal effects in this field. In her study *Exposing Men: The Science and Politics of Male Reproduction* (2006), the political scientist Cynthia Daniels persuasively documents how, despite evidence that paternal behaviors and life experience such as alcohol use, smoking, and pesticide exposure can impact the health of offspring from conception, scientific research and public health interventions on fetal harm consistently focus on the mother and minimize paternal effects.⁵³ This pattern endures in DOHaD research. As Daniels demonstrates, this asymmetry originates in long-standing Western cultural and ideological convictions. This includes, on the one hand, a belief in the vulnerability of female bodies and the primary liability of the mother for infant care and development and, on the other hand, a resistance to notions of male reproductive vulnerability and to paternal responsibility for the development of embryos and infants.

Third, while the target of intervention is the maternal body, the desired outcome of epigenetics-driven health interventions is improved fetal

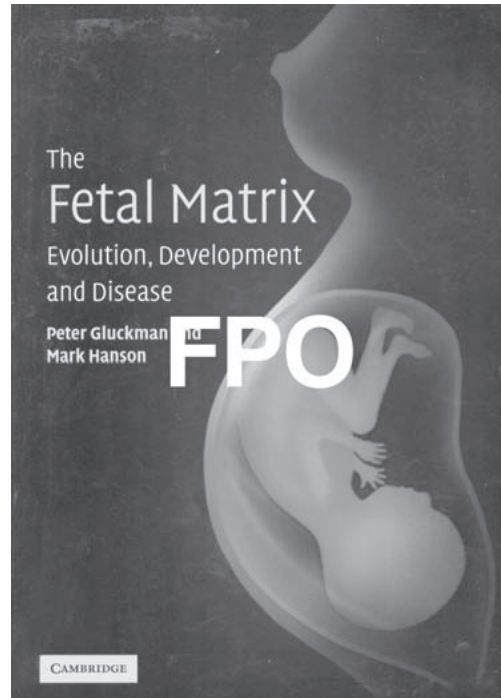


Figure 11.3. *The Fetal Matrix* (2005), by Peter Gluckman and Mark Hanson. Credit: Gluckman and Hanson, *Fetal Matrix*.

health. DOHaD researchers hope that a collateral effect of their policies will be to enhance resources for pregnant women. However, their proposed interventions are directed toward the most efficient methods to ensure developmentally optimum outcomes for the fetus. The symbols favored by DOHaD researchers—on the insignia of its international society, or the cover of one of the field’s leading textbooks, *The Fetal Matrix* (2005; figure 11.3)—are fetuses encapsulated in headless, legless maternal abdomens.⁵⁴ The maternal body is a transducing and amplifying medium necessary to get to the fetus, an obligatory passage point, not a primary endpoint or subject of DOHaD research.

The possibility of postnatal interventions to reverse maladaptive prenatal epigenetic programming, which would bypass the maternal body, is under investigation. Kuzawa reports, for example, that “the finding that epigenetic changes are durable does not imply that, under changed conditions, the impacts could not be fully or partially reversed. For example, HPA-axis programming in response to maternal care in mice is reversed if

1 offspring are fed a diet supplemented with methyl donors as adults. Simi-
 2 larly, some of the negative metabolic effects of prenatal undernutrition in
 3 mice can be reversed by exposure to the fat-derived hormone leptin im-
 4 mediately after birth.”⁵⁵ While avoiding the maternal conduit, these en-
 5 visioned interventions to reverse epigenetic programming nonetheless
 6 reinforce the message that the field’s primary focus is on fetal, not mater-
 7 nal, outcomes. Moreover, dietary or hormonal supplementation to reverse
 8 prenatal programming later in life is considered high risk and difficult to
 9 test in humans. Researchers express a sense of resignation that the most
 10 powerful point of intervention in humans will likely be prenatal. As Wells
 11 writes, in humans “post-natal interventions may be incapable of halting
 12 the process, since the adaption has already commenced prior to birth.”⁵⁶

13 Fourth and last, while maternal bodies are conceptualized as hav-
 14 ing great power to influence future generations and are positioned at
 15 the center of the intervention model advanced by DOHaD, the DOHaD
 16 model accords individual women very little power to influence their own
 17 outcomes. On the one hand, women are instructed to do all they can to
 18 prevent harm to their fetus. At the same time, an individual woman can
 19 do little to improve outcomes for her own offspring if they are trapped
 20 in the intergenerational epigenetic “feedforward cycle” hypothesized by
 21 DOHaD research. In the DOHaD model, adverse effects originate either
 22 in a misalignment between a fetus’s inertial epigenetic programming and
 23 her eventual environment or in the failure of the maternal environment to
 24 provide the necessary epigenetic cues for normal development. In the first
 25 scenario, the mother herself is not necessarily the culpable or causal agent.
 26 As Kuzawa writes, “If a system is designed to develop with the benefit of
 27 ecologic information integrated across multiple generations, short-term
 28 treatments in any single generation may reap limited long-term benefits.
 29 For such conditions, the most effective focus for intervention may not be
 30 the individual but the matriline.”⁵⁷ Rather, the mother’s body is a ge-
 31 netically programmed, evolutionarily adaptive system that transmits signals
 32 from the past and present environments to the fetus through epigenetic
 33 mechanisms at the level of maternal-fetal physiology. This system contains
 34 its own inertia. It is beyond conscious or individual control. Change mani-
 35 fests at the level of the intergenerational lineage rather than the individual
 36 female. The significance is that DOHaD research advances a shifting and
 37 mixed message regarding maternal agency and responsibility: it exhorts
 38 mothers to make lifestyle changes in the service of their genetic lineage,
 39 while maintaining that these changes are unlikely to bring them or their
 40 offspring any benefit. At the same time, it produces a model of the mater-

nal body that suggests that maternal experiences, exposures, and behaviors may have very significant, amplified consequences for her offspring, her descendants, and society at large.

The multivalenced concept of a “vector,” perhaps even more precisely than Wells’s metaphor of “transduction,” points to the distinctive causal-mechanistic explanatory landscape of postgenomic epigenetic science. As an epigenetic vector, the maternal body is at once a background element, a medium for the fetus. Yet it is also a “critical” developmental context in which environmental exposures are amplified, cues are transmitted, and genes are programmed. In epigenetic explanations, elements of agency, control, and intervention mix ambiguously with models of nondirective, inertial developmental systems. Nonetheless, *genes remain very much at the center*. Environments—nutrition, toxins, social policy, stress—are collapsed into molecular mechanisms acting at the level of the DNA. As Kuza-wa puts it, epigenetic mechanisms are like “volume controls for genes.”⁵⁸ It is genes, ultimately, that are expressed and regulated by these epigenetic mechanisms and that create the phenotypic outcomes of concern in this scientific field.

Genetic Determinism and Reductionism in the Postgenomic Order

Epigenetic research on maternal effects advances a model of human inheritance and development in which the wider social and physical environment can be seen as heritable and as a determinate of future biomedical outcomes via discrete biochemical modifications introduced by the amplifying vector of the maternal body. This model is crisply epitomized by a *New Yorker* illustration from a 1997 article on fetal origins research, in which a vector of future developmental outcomes extends outward from the fetus in the woman’s abdomen (figure 11.4).⁵⁹ 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.

In his insightful 2011 article “Epigenetics: Embedded Bodies and the Molecularisation of Biography and Milieu,” anthropologist Jorg Niewöhner suggests that epigenetics may make possible the truly biosocial, contextualized science of life that biologists and social scientists have long sought. Niewöhner terms this the “embedded body.” Elaborating current science



Figure 11.4. The maternal body as epigenetic vector.
Credit: Laurent Cilluffo illustration from S. Hall, "Small and Thin." Permission to reprint courtesy of Laurent Cilluffo.

studies consensus on the paradigm-shifting significance of epigenetics, Niewöhner presents the embedded body as a novel and exciting alternative to the classic Western biomedical model of the body as mechanistic, genetically determined, and autonomous. But close attention to Niewöhner's articulation of this "emergent phenomenon . . . made plausible by environmental epigenetics" reveals certain constitutive exclusions common to many science studies accounts of the theoretical innovations of epigenetics.⁶⁰ As Niewöhner writes, "Epigenetics produces an 'embedded body', that is, a body that is heavily impregnated by its own past and by the social and maternal environment within which it dwells. It is a body that is imprinted by evolutionary and transgenerational time, by 'early-life' and a body that is highly susceptible to changes in its social and maternal environment. This notion of the body differs significantly from the individual body with its notion of skin-bound self and autonomy. . . . It suggests an altogether different degree of entanglement between body and 'context.'"⁶¹ Niewöhner's account offers a highly discerning analysis of contemporary epigenetics yet never comments on the prominent figure of the maternal body in epigenetic theory. The embedded body, according to Niewöhner,

is ever changing, entangled, emergent, and imprinted by its environment. Indeed, it appears that the “embedded body” is an archetypal fetus. In turn, the environment is embodied by the fuzzy, receding figure of the maternal.

An appreciation of the figuring of the maternal body as a vector in epigenetics leads to a different reading than Niewöhner’s. Epigenetics does not so much “make plausible” the embedded body; rather, it fixes the molecular gaze on the embedded body, an already-formed and highly charged entity in the science of maternal-fetal relations, and elevates it to the center of biomedical theory, intervention, and surveillance.⁶² Here epigenetics does not so much “entangle . . . bodies and contexts”; rather, it brings the “environment”—transduced through the maternal body—into processes of biomedicalization, optimization, and manipulation of life initiated by the twentieth-century molecular life sciences.⁶³

Scientists and science studies scholars position epigenetics as a holist, antireductionist, anti-determinist counterdiscourse to the genetic determinism of twentieth-century genetics. Yet models of causality, mechanism, and intervention at work in maternal-fetal epigenetic programming research suggest that this dichotomous opposition between epigenetics and genetic determinism is inadequate to appreciate the conceptual shifts and social, ethical, and philosophical challenges introduced by postgenomic ventures such as epigenetics. Reflection on epigenetics-based biomedical and public health interventions recommended by scientists such as Wells and Kuzawa suggests a need for science analysts to shift the critical terms of debate away from a discussion driven by a concern over the harms of genetic determinism to one more sensitive to how certain bodies or spaces become intensive targets of intervention when conceptualized as amplifying vectors of developmental or epidemiological risk.

The ground has shifted under science analysts’ feet. The terms of debate—the relevant distinctions and differences that ordered theoretical approaches to molecular genetics—have been reordered. What is interesting and critical is not the assessment of epigenetics in terms of old oppositional fault lines of determinism versus redundancy and pleiotropy, reductionism versus holism and complexity. This old framework was built to analyze a different genomic moment. In collapsing the oppositions of the old, the postgenomic order, to the extent that it is continuous with the explanatory landscape of epigenetics, breaks received binaries and calls for new conceptual maps.

Gender analysis of knowledge production in maternal-fetal epigenetic programming research suggests that the postgenomic order, as I call it, is one that blurs, reforms, or breaks down the received oppositional binaries of the molecular genetics era depicted in figure 11.1. This is an exciting

agenda for science studies scholars in the postgenomic era. To access the new ontology, we might heed Karen Barad's calls for a "diffractive" rather than merely "reflective" reading of the "entanglements" that produce knowledge claims. Diffractive reading, in Barad's formulation, focuses on "what differences matter" and where the "agential cuts" are made within an explanatory apparatus.⁶⁴ The case of the maternal body in epigenetics hints that hybrid assemblages comprising vectors, spaces, boundaries, amplifications, temporalities, and hot spots may point to the foundations of the explanatory and analytical language of the postgenomic order.

Conclusion

The case of the maternal body in epigenetics research reveals gender as an analytical frame for examining epigenetics with fresh eyes and from a new vantage point. The foregrounding of the maternal body as an epigenetic vector in postgenomic biomedical research resonates with the history of highly politicized conceptions of maternal responsibility and may further extend biomedical manipulation and social control of the reproductive female body. Gender analysis of science, however, offers insights that extend beyond investigation of the consequences of scientific research for women. By attending to the production of embodied differences, gender analysis can help to reveal theoretical shifts instantiated in the postgenomic age not apparent through standard analytical frames. Abandoning simple views of the gene and of gene action, and providing a mechanism for gene-environment interactions, the burgeoning field of epigenetics attests to what some see as the hallmark of postgenomics—a disillusionment with a reductionist molecular genetic view of the world. Yet, as I argue in this chapter, in its focus on biochemical modifications of DNA mediated by the maternal body, epigenetic science reproduces and subtly reformulates determinist strategies and reductive methods. The figure of the *maternal body as epigenetic vector*, I wish to suggest, can be seen as one highly enriched ensign of the explanatory landscape of an emergent postgenomic order that yet lies beyond the grasp of our preformed categories.

Notes

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1. Meaney, "Maternal Care, Gene Expression."	1
2. Blanchard, "Fraternal Birth Order."	2
3. Paul, <i>Origins</i> .	3
4. See, e.g., Ladd-Taylor and Umansky, " <i>Bad</i> " Mothers; Plant, <i>Mom</i> ; Warner, <i>Perfect Madness</i> .	4
5. Parke, <i>Century of Developmental Psychology</i> .	5
6. See, e.g., Casper, <i>Making of the Unborn Patient</i> ; Rapp, <i>Testing Women, Testing the Fetus</i> .	6
7. For exemplary feminist discussions of these issues in the case of maternal-fetal epigenetic programming research, see, e.g., McNaughton, "From the Womb to the Tomb"; Warin et al., "Mothers as Smoking Guns."	7
8. Ladd-Taylor and Umansky, " <i>Bad</i> " Mothers; Kukla, <i>Mass Hysteria</i> .	8
9. Schramek, "Michael Meaney"; Sebald, <i>Momism</i> .	9
10. Cynthia R. Daniels, "Between Fathers and Fetuses."	10
11. Lock, "Eclipse of the Gene"; Griesemer, "Turning Back to Go Forward"; Haig, "Weismann Rules!"	11
12. McGowan et al., "Epigenetic Regulation of the Glucocorticoid Receptor."	12
13. For an excellent review of epigenetic mechanisms see Mehler, "Epigenetic Principles and Mechanisms."	13
14. Morgan et al., "Epigenetic Inheritance at the Agouti Locus in the Mouse."	14
15. Lee and Zucker, "Vole Infant Development."	15
16. Szyf et al., "Maternal Programming of Steroid Receptor Expression."	16
17. During meiosis (the division process that generates the sperm and egg cells) and early embryo development, chromosomes are restructured and embryonic DNA experiences a genome-wide demethylation. On this basis, it is generally believed that environmentally induced epigenetic changes are not inherited through the germ line and cannot be directly passed from parent to offspring.	17
18. The most widely discussed body of data regarding the long-term intergenerational effects of early developmental exposures comes from the so-called Dutch Hunger Winter studies. A useful review of these studies is given by Roseboom, "Undernutrition during Fetal Life." For a sense of the contestations over how to interpret these findings, see, e.g., S. Hall, "Small and Thin."	18
19. Rodriguez et al., "Maternal Adiposity prior to Pregnancy"; Badcock and Crespi, "Imbalanced Genomic Imprinting"; Bocklandt et al., "Extreme Skewing of X Chromosome Inactivation"; Wright, "Prenatal Maternal Stress and Early Caregiving Experiences"; Dyer and Rosenfeld, "Metabolic Imprinting by Prenatal, Perinatal, and Postnatal Overnutrition"; Barker, "Fetal Origins of Coronary Heart Disease."	19
20. Feinberg, "Epigenetics at the Epicenter of Modern Medicine"; Petronis, "Epigenetics as a Unifying Principle."	20
21. Pennisi, "Are Epigeneticists Ready for Big Science?"	21
22. Carey, <i>Epigenetics Revolution</i> ; Francis, <i>Epigenetics</i> ; Church, <i>Genie in Your Genes</i> ; Holt and Paterson, "Ghost in Your Genes"; Cloud, "Why Your DNA Isn't Your Destiny."	22

23. Weaver, Meaney, and Szyf, "Maternal Care Effects."
24. Children's Environmental Health Network, "Contribution of Epigenetics in Pediatric Environmental Health."
25. Weaver et al., "Maternal Care Effects."
26. Fujimura, "Postgenomic Futures."
27. Clarke et al., "Biomedicalizing Genetic Health, Diseases and Identities," 26–27.
28. Stotz, "Ingredients for a Postgenomic Synthesis of Nature and Nurture," 362.
29. Jablonka, "Lamarckian Problematics in Biology," 145.
30. Keller, *Mirage of a Space*.
31. Lock, "Lure of the Epigenome."
32. Ibid., 1896.
33. Wadhwa et al., "Developmental Origins of Health and Disease." See also Barker, "Fetal Origins of Coronary Heart Disease"; Gluckman and Hanson, *Fetal Matrix*, and *Developmental Origins of Health and Disease*.
34. Wells, "Maternal Capital and the Metabolic Ghetto," 13–14.
35. Ibid.
36. Wells, "Thrifty Phenotype," 145.
37. Wells, "Critical Appraisal of the Predictive Adaptive Response Hypothesis," 230.
38. Wells, "Maternal Capital and the Metabolic Ghetto"; Wells, "Thrifty Phenotype," 163.
39. Wells, "Maternal Capital and the Metabolic Ghetto," 11.
40. Kuzawa, "Why Evolution Needs Development," 224.
41. Kuzawa, "Fetal Origins of Developmental Plasticity," 5.
42. Ibid.
43. Ibid., 12; emphasis added.
44. Ibid., 10, 13.
45. Kuzawa, "Why Evolution Needs Development," 226; Kuzawa, Gluckman, and Hanson, "Developmental Perspectives on the Origins of Obesity," 207.
46. Kuzawa et al., "Developmental Perspectives on the Origins of Obesity," 211.
47. Wells, "Maternal Capital and the Metabolic Ghetto," 13–14.
48. Kuzawa, "Fetal Origins of Developmental Plasticity," 5.
49. Wells, "Thrifty Phenotype," 165.
50. Ibid., 154; Pembrey et al., "Sex-Specific, Male-Line Transgenerational Responses in Humans"; Shulevitz, "Why Fathers Really Matter."
51. Zhang and Meaney, "Epigenetics and the Environmental Regulation."
52. Wells, "Thrifty Phenotype," 154.
53. Daniels, *Exposing Men*. On the neglect of paternal effects, see also Armstrong, *Conceiving Risk, Bearing Responsibility*.
54. Gluckman and Hanson, *Fetal Matrix*.
55. Thayer and Kuzawa, "Biological Memories of Past Environments," 801.
56. Wells, "Thrifty Phenotype," 161.
57. Kuzawa, "Fetal Origins of Developmental Plasticity," 17.
58. Kuzawa and Sweet, "Epigenetics and the Embodiment of Race," 5.

59. S. Hall, "Small and Thin."	1
60. Niewöhner, "Epigenetics," 290.	2
61. Ibid.	3
62. See also Landecker, "Food as Exposure."	4
63. See Clarke et al., "Biomedicalizing Genetic Health, Diseases and Identities."	5
64. Barad, <i>Meeting the Universe Halfway</i> .	6
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