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No Way Out of the Binary: A Critical History of the Scientific Production of Sex

This article examines the concept of sex as a biological "fact" in Western science from the eighteenth century to the present and, in particular, how the binary definition of sex has been maintained despite empirical flaws and contradictory evidence. It would be unfair, however, to put all the weight at the feet of science. Western civilization has divided people into male and female for a long time.[1] Feminism itself has its particular romance with the binary and the universal category of "woman." On the one hand, second-wave feminism's foundational distinction between sex (as biological) and gender (as cultural) sought to weaken biological essentialist arguments that ascribed women's inferior status to innate biological differences. Although there is no doubt that this distinction was fruitful for feminism's purposes, some scholars since the 1990s have criticized it, arguing that neglecting the body and taking for granted its sexed character left its biological nature unquestioned (Butler 1993; Grosz 1994). This also divorced politics from the body. In recent years, new-materialist feminists have argued for a turn to the body that understands it as a coproduction of biology and culture—a semiotic-material phenomenon (Barad 2007; Haraway 2008). On the other hand, the fights over inclusion of working-class women, women of color, and lesbian women—among others—within feminism showed the impossibility of reducing the multiple experiences of being a woman to one identity.

Transgender and intersex activists and scholars have also been critical of the sex/gender binary. Transgender studies developed in the early 1990s with the efforts of a group of emerging and marginally situated scholars and activists to be taken seriously on their own terms and not to be pathologized (Stryker 2006).[2] Together with poststructuralist antifoundationalist critics of gender

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[1] The same is true of many other cultures, although not all of them.

[2] See also Meyerowitz (2002) and the selection of articles in the *Transgender Studies Reader* (Stryker and Whittle 2006).

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such as Judith Butler (1993), transgender scholars have criticized the idea that sex is the foundation of gender—that gender is the social, linguistic, or subjective representation of an objectively material reality: sex. As Susan Stryker puts it, "sex, it turns out, is not the foundation of gender . . . 'sex' is a mash-up, a story we mix about *how* the body means, which parts matter most, and how they register in our consciousness or field of vision" (2006, 9).

Intersex people have been the clearest bearers of nonmatches within the sex binary. Across different historical periods medical practitioners have tried to classify them, diagnose them, and assign a sex (Dreger 1998; Mak 2006; Reis 2009).[3] The consequences of these intrusions became more devastating with the development of modern medicine in the twentieth century (Chase 1998; Preves 2003; Karkazis 2008). Early work on intersex management (Kessler 1990) pointed out the importance of intersexuality in disrupting not only the sex binary but also the sex/gender distinction because it made explicit how the cultural rules of gender are literally inscribed in the body through medical procedures. As intersex scholar Katrina Karkazis expresses it, although intersexuality may seem like "an exotic or rare issue," in fact "it brings into sharp focus mainstream cultural rules about the proper relationships among bodies, gender and sexuality that apply to all persons" (2008, 9).

Early feminist science studies scholars such as Ruth Bleier (1984), Anne Fausto-Sterling (1985), Lynda Birke (1986), and Ruth Hubbard (1990) have already pointed out science's obsession with the sex binary. They explore how the basic Western practice of separating humans into male and female engenders dualistic modes of thought such as rational/irrational, objective/subjective, and science/nature. Through the analysis of scientific language (Keller 1985), they show that this dualistic thinking has been translated into science through the use of hierarchies, relations of domination and subordination, power and control. They also theorize scientists' impulse to locate the binary in the body as an attempt to make relations of domination "appear natural" (Bleier 1984, 200).

Although traditional histories of biology present the research on biological sex in Western biological and medical sciences as a smooth progression in identifying different variables to determine sex, feminist critiques of science have revealed that this history has been discontinuous and contextually dependent. The compartmentalization of sex into several variables is in part a consequence of the history of scientific disciplines and technological developments and reveals how sex classification is contingent on changing scientific paradigms. A second generation of feminist science studies scholars in the 1990s and 2000s have produced detailed empirical accounts of the historical periods of the sciences of sex, analyzing how different scientific disci-

[3] I elaborate on this point below.

plines have focused on various body parts as markers of biological sex, including anatomy (Schiebinger 1993), hormones (Oudshoorn 1994), gonads (Dreger 1998), chromosomes and genes (Delgado-Echeverría 2007; Richardson 2013), and the brain (Jordan-Young 2010). However, I argue that there does not yet exist a comprehensive account that includes all of the sex variables and that explains the concrete mechanisms by which binary sex has operated in spite of many counterexamples. This article is an attempt to answer that question.

The first part of this article consists of a critical review of biological research on sex in Western science through the lens of feminist critiques. The purpose is to show that scientists have proposed different variables to define sex and to trace how an uncritical commitment to the two-sex model has operated in the different areas of the biological sciences. Alongside this review I present the concepts of atomization and mechanization as tools to analyze the commonalities in sex research. In the last two sections I present my proposal of the mechanisms by which the binary has been able to persist despite contradictions. First, I explore the idea that the sex binary was not questioned because it was never a hypothesis; it was a taken-for-granted starting point through the whole scientific history of sex. Finally, I return to Bernice Hausmann's concept of semiotic transposition to rethink binary sex (1999). I will argue that "biological sex" is a circular network that reproduces itself precisely because it has no clear referent.

Anatomical sex: Measuring the body

External morphology was, obviously, the first place to look. At birth, the difference is located almost exclusively in the genitalia. Later in life, other bodily features come to complement (or complicate) this first classification. Almost all cultures across all times have classified people into male and female. However, there is a qualitative difference in the way anatomy has been interpreted in the Western world since the eighteenth century. Thomas Laqueur's pathbreaking work on the history of sex (1990) explains that, at the turn of the eighteenth century in Europe, the two-sex model became the foundation of a new social order.[4] Western society started classifying humans into two ontologically distinct types (the two-sex model) rather than hierarchically ordered versions of the same type (the one-sex model). As modern science began to supplant religion as the epistemological authority, enormous effort was put into the scientific search for sexual differences. Rather than relying on descriptive and topological accounts of bodily features, scientists re-

[4] This change, Laqueur affirms, was a consequence of political, cultural, and epistemological factors.

cruited anatomy as a site of application for the new scientific method. They measured the body exhaustively and produced "objective" numbers and statistics in order to prove that the two sexes were incommensurable. The fields of anthropometry and comparative anatomy flourished in this era, as Victorian ideologies and European colonialism legitimized differences between the sexes and the races (Bleier 1984; Schiebinger 1993). However, the concept of sex was linked to racial differentiation in these early scientific years in a very complicated way. As Sally Markowitz argues, eighteenth-century conceptions of sex dimorphism were related to the "advanced races" (2001, 391). Markowitz quotes sexologist Richard von Krafft-Ebing, who in 1886 expressed this idea very clearly: "the higher the anthropological development of the race, the stronger these contrasts between man and woman" (Krafft-Ebing [1886] 1965, 28). The eugenic roots of sex dimorphism and its part in the racism of modern Western science hasn't been, in my opinion, sufficiently explored.[5]

As science progressed, the assumption that anatomical features can be clearly classified as male or female traveled unchallenged into contemporary biology, which divides anatomical sex into primary and secondary sexual characteristics. Primary sexual characteristics are defined as the body parts involved in reproduction: the genitalia (presence or absence of penis, scrotum, clitoris, and labia majora and minora) and internal reproductive organs (vaginal canal, uterus, fallopian tubes, vas deferens tubes, and gonads). Secondary sexual characteristics develop during the prepuberty and puberty stages and are considered part of the sexual dimorphism of our species, despite not being directly involved in reproduction. They include height, bone structure (mainly shoulders, hips, and facial shape), foot and hand size, muscle mass, body fat, body and facial hair, breast size, voice pitch, and larynx enlargement. While these features are traditionally divided into "masculine" and "feminine" sexual characteristics, anthropometric research using quantitative data shows that these features conform to a bell-curve distribution rather than a discrete binary. Often, however, only the mean difference between sexes is given, which obscures the intragroup variability and considerable overlap between male and female populations (Hubbard 1990, 121).

Gonadal sex: Looking inside the body

The existence of individuals whose anatomical features defied male/female classification—whom the ancient Greeks called "hermaphrodites"—was an

[5] Markowitz is a wonderful exception as is, more recently, Zine Magubane (2014).

obvious challenge to a strictly binary sex model. Historian of hermaphroditism Alice Dreger argues that the late nineteenth century inaugurated the approach of looking inside the body in search of the "true sex," which Dreger calls "the age of gonads" (1998, 139).[6] This new definition of sex coincided with the rise of gynecology and the advancement of surgical techniques for the removal and transplantation of gonads (first in animals, later in humans). The gonads promised to be a clearer and more discrete criterion than anatomy, including genitalia. In 1878, German physician Theodor A. Edwin Klebs created a classification of hermaphrodites based on gonads ([1878] 1965).[7] In Klebs's model, regardless of external appearance, a person with testes was considered male, and a person with ovaries was considered female. In this classification, most of those traditionally called "hermaphrodites" were only "pseudohermaphrodites"—technically, their existence didn't challenge the binary sex system. A challenge to the model remained in those who were born with one of each gonad or with a mixed one (the only "true hermaphrodites," for Klebs). These cases were so rare—and normally only verified postmortem (Dreger 1998)—that it was easier for Klebs to consider them an aberration. Klebs's nomenclature turned out to be so successful in medical practice and literature that it was used until very recently, when it was debunked only due to intersex activism (Hughes et al. 2006).[8]

Hormonal sex: Chemical messengers of dualism

The history of hormonal sex has been a fruitful site for feminists to criticize the scientific production of binary sex.[9] In fact, as Nelly Oudshoorn's (1994)

[6] As the two-sex model allows no other option than male or female, any case of ambiguity was by necessity considered an appearance disguise.

[7] Gonads (which include ovaries and testes) produce the reproductive cells (gametes): that is, spermatozoa or ova. Usually people are born with two of the same type, but because these organs are developed from the same tissue (the gonadal ridge) during embryogenesis, some people are born with one of each and some with a mixed gonad that contains both types of gonadal tissue, called "ovotestis."

[8] Dreger's thesis, which appeared in the 1990s, maintained that the gonads became the main indicator of someone's sex and was accepted for many years. However, in 2006 German historian Geertje Mak challenged Dreger's argument, characterizing it as an epistemological simplification that doesn't match with the real encounters between physicians and hermaphrodites—as physicians didn't have the means to impose their diagnosis on people (Mak 2006). This is also corroborated by Elizabeth Reis's research on hermaphrodites in the United States (2009).

[9] See Bleier (1984), Fausto-Sterling (1985, 2000), Oudshoorn (1994), Hausman (1999), and Irni (2016). Sari Irni's work is particularly notable here in that it shows how binary sex is deployed even in biological sites where sex was not the primary concern.

history of sex hormones demonstrates, the very concept of sex hormones was a result of the two-sex model. Prior to 1890, physiologists believed that bodily responses were regulated by nervous stimuli, but at the turn of the century, a new theory claimed that physiological processes were instead regulated by chemical substances that travel through the blood (Oudshoorn 1994). The discipline for the study of these internal secretions—endocrinology—became the new game in town, fueled by funding from pharmaceutical companies looking for new drugs. Because the first chemical messengers were found in extracts from testes and ovaries, it was assumed that only two hormones existed, in alignment with the previous gonadal definition of sex (Hausman 1999). Consequently, the hormone secreted by the testes was called "male hormone" and the one secreted by the ovaries "female hormone." It was a great surprise, then, when some years later scientists found both "male" and "female" hormones in the "opposite sex."[10] To make sense of these findings, some endocrinologists proposed a softer version of the sex-specific hormone theory, based on the hormone's function rather than its location (Oudshoorn 1994). In this version, when sex hormones were present in the "opposite body," they would be functionless or, worse, dysfunctional—which these scientists defined as the feminization of male bodies, the masculinization of female bodies, and homosexuality. This hypothesis proved to be wrong, as evidence on the normal function of sex hormones in male and female bodies was gathered through the 1930s.[11] Hormonal sex theory continued to be challenged as many more hormones were discovered in the 1940s and 1950s. Neither testosterone nor estrogen is a single hormone; rather, both are part of a chemically related group—under the umbrella of androgens and estrogens—whose components can easily be transformed into one another and operate many functions in the body (Bleier 1984, Fausto-Sterling 2000).[12] In addition, other hormones secreted not by the gonads but by the adrenal glands are also related to reproductive and sexual functions. All of them are present in all individuals, in different percentages.[13]

[10] In 1934, Benhard Zondek found high levels of estrogen in the urine of stallions. The same year, Samuel de Jongh isolated testosterone from ovarian tissue (Oudshoorn 1994).

[11] For example, testosterone is involved in the growth of the uterus and vagina, and estrogens are involved in the growth of seminal vesicles.

[12] Bleier (1984, 88–89) provides an excellent explanation of the chemical relationship and functions of the different steroid hormones. Androgens comprise total testosterone, free testosterone, dihydrotestosterone, and androstenedione; estrogens include estrone, estriol, and several types of progesterone (antimullerian hormone, lutenizant hormone, cortisol, and follicle-stimulant hormone).

[13] Recent diagnostic proposals for intersex test for *nine* hormones in order to compare the results with "normal" values for age. However, as doctors themselves recognize, these are only

Feminist works such as those by Bleier, Oudshoorn, Fausto-Sterling, and others help make sense of why the hormonal theory of sex has been upheld, despite making no sense from a scientific point of view. Not only that, they show that this model became an obstacle for science's study of the many functions that steroid hormones (the preferred name today) accomplish in the body beyond reproduction.

Chromosomal sex and the "unified theory of sex": Atomicism and mechanicism

Around the time when endocrinology flourished, advances in microscopy and novel staining techniques in cytology allowed for the creation of a new field that would become the foundation of biology for the next century: genetics. Historians Isabel Delgado-Echeverría (2007) and Sarah Richardson (2013) have investigated the convoluted history of the discovery of the so-called sexual chromosomes, exposing their contested journey to becoming a scientific "fact."[14] Chromosomes, formations that take shape in a cell's nucleus during meiosis, were identified in 1888. A group of chromosomes known as "odd chromosomes," "accessory chromosomes," or "X" became of interest because of their peculiarities. While most chromosomes appear in pairs, these appear alone or, in some species, with a smaller chromosome named "Y." In the early 1900s, the US cytologists Nettie M. Stevens and Edmund B. Wilson established a connection between chromosomes and sex, but it was not clear how they were linked.[15] One main problem was the great variability among species, as not all species have these "odd chromosomes." Even among those who do, in some species some males carry one X chromosome and females two (the X0/XX system), in other species some males carry one of each and females two Xs (the XY/XX system), and still in others the females are the heterogametic sex, which means they carry XY and males XX! (the XX/XY system, also known as the ZW system to differentiate it).

As Richardson points out, the early chromosomal theory of sex depicted X and Y as isolated elements even though they present in nature as a pair or

ranges of reference, and some intersex people do not show "abnormal" hormonal values (see Ogilvy-Stuart and Brain 2004; Ahmed and Rodie 2010; Hiort 2011). This is in part because hormone action does not depend only on hormone levels present in the body but also on the correct functioning of other chemicals that act as receptors of the hormones in the cell (as is the case in androgen insensitivity syndrome).

[14] Delgado-Echeverría's work was published in Spanish. Due to the dominance of English in academic publications, her contribution has been largely unrecognized.

[15] As with many other women scientists, Stevens's contributions were minimized while Wilson got most of the credit.

"dyadic kind" (2013, 197). I argue that this was due to a particular framework that held sway during the first half of twentieth-century science, which I refer to as "atomicism." According to scientific convention at the time, the world was understood as an entity composed of infinitesimal parts, or atoms. So too was life. The atomistic framework can be best recognized in physics, in cell theory (the cell as the unit of life and the body as the sum of its cells), as well as in chromosomal and genetic theory. In her pioneering analysis of gender bias in genetics, Hubbard refers to this reductionist tendency in Western science: "[Science] proceeds by breaking nature into smaller and smaller bits and then usually ignores, loses, or misreads their connections" (1990, 4). The atomicist view of biological elements was combined with a mechanicist view in terms of causality. The search for the ultimate cause of sex can be interpreted within the broader framework of twentieth-century science, the main goal of which was to find the general laws that govern the universe from the atomic microlevel of matter to the cosmological macrolevel.[16] Richardson (2013) convincingly argues that the success of the concept of sex chromosomes was due to its association with two key theories in the 1920s: T. H. Morgan's chromosomal theory of heredity and Frank Lillie's theory of sex hormones. Morgan's theory of inheritance—following the rediscovery of Gregor Mendel's laws—was based on so-called X-linked traits (characters that are carried by the X chromosome). However, as Richardson argues (2013, 57), it was not necessary for Morgan's theory of inheritance to affirm that sex chromosomes were the *determinants* of sex—they could be understood, for example, as histological *markers* of sex, as Nettie Stevens had proposed. Morgan's almost exclusive use of *Drosophila melanogaster* for his experiments—a relatively simple organism suitable for Mendelian exploration—was an important factor in the labeling of X and Y as the determinants of sex.

The cytogenetic controversy over the suitability of Morgan's chromosomal sex came to a definite closure when chromosomal theory was joined with the main theory of the time: hormonal theory. Lillie's 1916 distinction between sex *determination* and sex *differentiation* assigned chromosomes the role of initiators of sex development, while hormones would complete the rest of the job during the individual's phenotypical development.[17] This distinction solved the problem of chromosomal theory's inability to explain sexual dimorphism's fluidity and species variability in sex determination

[16] The paradigmatic example of the call for a unified theory of nature was Erwin Schrödinger's book *What Is Life?* (1944) analyzed in Keller (2000).

[17] Before Lillie, that gap was filled by the then-prevalent metabolic theory of sex (Ha 2011).

(Richardson 2013, 66). As bastions of an atomistic and binary concept of sex determination, the sex chromosomes left the complexities of human sexed bodies (sex differentiation, in Lillie's model) to the hormones. Suggesting a parallelism between sex chromosomes and sex hormones made it easy to accept them both (Richardson 2013, 70). The combination of these two sex variables into a single theory—which I refer to as the "unified theory of sex"—and the consequent alignment of two powerful scientific communities resulted in a strong foundation for biological sex research in the next century.

A last crucial event for the chromosomal sex theory was the identification in 1949 of a condensed body in the nuclei of female cells—the Barr body.[18] This discovery allowed for large-scale human population studies during the 1950s and 1960s, which brought to light several cases of chromosomal variation. In addition to Down syndrome (trisomy in pair 21), anomalous cases in the number of sex chromosomes resulted from this new research: Turner syndrome (lack of an X: 45X0); excesses of sex chromosomes, such as Klinefelter syndrome (47XXY), the so-called super-female syndrome (47XXX), and "supermale" syndrome (47XYY); and mosaicisms (where different cells of the same organism have different combinations of chromosomes).[19] Richardson (2013, 83) shows a table with as many as twenty-seven karyotypes discovered! As in the case of the sex hormones, despite all of the cases where the XX/XY model failed, the dichotomous model of sex was not abandoned. On the contrary, scientists reinforced it by considering these alternatives *aneuplodies*, literally "numerical errors." Regardless of these contradictions (and others), the new sex variable inherited the binarism of previous definitions.

Genetic sex: Digging deep into the unified theory of sex

Although they are related, chromosomal sex and genetic sex are disparate. The first refers to whole chromosomes, the second to particular genes. Genes are generally defined as parts of the chromosomes that carry hereditary traits. From the beginning, feminists' critiques of science contended the concept of the gene and the reductionists' assumptions involved in it (Keller 1982; Hubbard 1990). In relation to what I have termed atomicism, Hubbard points to the "strong ideological need to assume the existence of

[18] Discovered by Murray Barr, the Barr body is formed by chromatin—a combination of proteins and DNA that helps package the cell's genetic material into the nucleus when the cell divides—and signals the presence of two X chromosomes. On the provisional nature and later overturn of Barr's hypothesis, see Ha (2015).

[19] Both Turner syndrome and Klinefelter syndrome had been defined before, but they were given a new categorization as sex chromosome anomalies.

material substances, often particles, located within individuals, that transmit traits from one generation to the next" (1990, 71). She interprets this belief in the superior explanatory power of the smallest elements—and its corollary, the mechanicist view of single causality (the "one trait-one gene model")—as reductionism (1990, 73). Along the same lines, Evelyn Fox Keller refers to it as the "Master Molecule" concept of the action of the genes (1982, 600; see also Nanney 1957, 136).

Once the "sex chromosomes" were accepted, it was taken for granted that the genes involved in sex determination and differentiation were located on these chromosomes. During the first half of the twentieth century, the X chromosome was thought to be the sex-determining/female-determining chromosome and the Y to be mostly inert.[20] In 1959, however, Charles Ford's research on the chromosomes of individuals with Turner syndrome suggested that it was the Y chromosome that had the (male) sex-determining factor (Ford et al. 1959; see also Richardson 2013, 129). In his model, no matter the number of X chromosomes, the presence of a single Y caused male gonads to develop. This matched French physiologist Alfred Jost's previous theory of female sexual development as the default path in the absence of testes (Jost, Gonse-Danysz, and Jacquot 1953).[21] The idea of the feminine as default is not new for feminists of science. Dating back to Aristotle, it has translated into science through the use of metaphors and assumptions such as the passivity of the egg and the activity of the sperm (Martin 1991) or sociobiological interpretation of Charles Darwins's sexual selection (see, e.g., Hubbard 1990; Spanier 1995). In Jost's theory, gonadal sex (via testes formation) works as the bridge between sex determination and sex differentiation. Therefore, when genetic research became mainstream in the mid-1980s, the field had a clear goal: to find a sex-determining gene on the Y chromosome. This "testocentric hypothesis," as Vernon Rosario (2009, 273) has called it, was early criticized by biologists Eva Eicher and Linda Washburn because it neglected research on the genetics of ovarian development (1986).[22] Despite these critiques, how-

[20] This was due to a contingent factor as well, namely the extended use of the fruit fly (*Drosophila melanogaster*, in which sex is determined by the X ratio) as a model in genetic research (Richardson 2013). Hubbard has pointed out the bias among geneticists that results from the almost exclusive use of *Droshophila*—or of virus and bacteria, for that matter—as a model suitable for translation to humans (1990, 85).

[21] Jost's experiments with testes transplantation into rabbit embryos showed that male sexual development could occur in XX individuals.

[22] Eicher and Washburn proposed an alternative model in which genes interact to form both the male and female gonads. See also Fausto-Sterling (1989) and Hubbard (1990).

ever, the discovery of the sex region on the Y chromosome (SRY) led the genetics of sex research for the next ten years.

This "hunt for the male gene" (Vilain 2000, 5) produced its first result in 1990 with the identification of SRY, a gene that appeared to be the initiator of male gonad formation and therefore of male sex development. This gene became Jost's testes-determining factor, while female development was seen as the result of a genetic *deficit*: the absence of SRY. As the trigger of testes formation, SRY was appointed the initiator—the master gene—of sexual development. In the same way that the sex chromosomes appeared to be a good archetype for Morgan's theory of heredity in terms of atomicism and mechanicism in the 1920s, SRY was the perfect archetype of the 1980s master-gene model.[23]

However, findings contradicting the SRY master-gene model appeared soon after. Researching the genotypes of more than one hundred intersex people, geneticists Eric Vilain and Ken McElreavey found many cases where SRY did not explain the person's phenotype (Vilain et al. 1991). Their study showed that some XX individuals lacking SRY had testes and some XY individuals with SRY did not develop testes. They hypothesized that this was due to the duplication of a gene located on the X chromosome (named DAX-1) that overrode SRY's normal function. In addition to that, other studies found genes involved in sexual development that were not located on the sexual chromosomes: WT-1 on chromosome 11, SOX-9 on chromosome 17, SF-1 on chromosome 9, WNT4 on chromosome 1, and others (Rosario 2009). Due to these findings and geneticist Jennifer Graves's (2000) critiques of the Y-centric model, the SRY master-gene model fell out of fashion in the early 2000s, giving way to a new model in which a "regulatory cascade" of many genes interacted with one another (McElreavy et al. 1993; see also Vilain 2000).[24] Instead of one master gene triggering sex development (as in classical genetic determinism), this model emphasized gene-dose mechanisms with multiple paths: pro-testes genes but also pro-ovary genes and antitestes ones.

Ironically, this type of interactionist model had been long defended by feminists. Hubbard and Keller had pointed out years before that in complex pro-

[23] The 1980s genetic school of developmental biology assumed a hierarchy of genes in which some are the "master switches" and the rest follow in a cascade, continuing with the linear model of the unified theory of sex.

[24] Graves's (2000) research on comparative genomics between species suggests that SRY is a poorly conserved gene and highly variable in its sequence and function, even in closely related species. See Richardson (2013, chap. 7) on the influence of gender criticism on the abandonment of the SRY master-gene model and the articulation of a nonbinary biology of sex in the early 2000s.

cesses such as organism development it is wrong to single out any one substance or event as the cause: many components and conditions must work together in nonadditive and interdependent ways (Hubbard 1990, 80).[25] By the mid-1980s, biologists Eicher and Washburn had already proposed a model where pro-ovary genes interacted with pro-testis ones to form both gonads (Eicher and Washburn 1986; Fausto-Sterling 1989; Hubbard 1990). Without proper tribute to these women biologists, Vilain (2000) proposed a multifactorial, nondeterministic, and interactional model of sex determination that was—in principle—more open to nonbinary approaches to sex.[26] This inspired other feminist scholars' alternatives to the binary sex model, such as Rosario's "quantum sex" (2009).

Brain/neural sex: Linking hormones to the brain

Another part of the body where scientists have looked for sexual differences since the beginning is the brain. Franz J. Gall, founder of phrenology, and Paul Broca, founder of craniometry, were strong defenders of the claim that behavioral differences between men and women—including intelligence—were due to physical differences in brain anatomy. Although these claims were later disproven, the search for differences in the brain didn't stop. With the rise of neurology in the twentieth century and the availability of new brain-imaging technologies, the focus shifted to the search for differences in particular brain regions and functions.[27] Feminists have always been dubious of these attempts. For example, in the early 1980s Bleier criticized the so-called brain lateralization studies where men show more lateralization—use of the right side to process spatial information and the left for emotions and verbal information—than women (1984, 92), and Fausto-Sterling exposed scientists' failed efforts to prove that a small part of the brain known as the corpus callosum is different in men and women (1985, 2000).

[25] Keller's research on biologist Barbara MacClintock illustrates other ways of approaching the investigation of natural phenomena where knowing the causes of events doesn't have to be identified with "control"; rather, "control resides in the complex interactions of the entire system" (Keller 1982, 601).

[26] Vilain recognizes the plurality of sexual phenotypes in humans and refers to it in terms of phenotypic variability. Richardson suggests that this new model was influenced by the intersex movement and an increased sensitivity to the social consequences of scientific research on sex and gender (2013, 144). However, Vilain has been criticized by many intersex people for his defense of the term "disorders of sex development" (DSD).

[27] Neurology developed through the discovery of links between functions and particular brain areas. Broca himself located the speech area of the brain.

However, the neuroscientific field that has generated more feminist criticism has been the so-called brain organization theory, due to its focus on the study of gender differences and its widespread acceptance among neurologists and mainstream journalists. Brain organization theory links "brain sex" with "hormonal sex" in claiming that different hormonal prenatal exposure—due to the mother's and the fetus's own gonads—activates different parts of the brain in men and women. Bleier, herself a neurophysiologist and an expert in the study of the animal hypothalamus, early criticized the assumptions on which brain organization theory rests. As she explains, what the studies show is something very concrete: that the presence of androgens from the testes in fetal and newborn male rodents suppresses the ability of hypothalamic neurons to respond cyclically—an important feature of ovarian function. To generalize from this that androgens have an organizing effect on the fetal brain that determines sex-differentiated adult behaviors such as mating activity and aggressivity is an unwarranted extrapolation (1984, 85). In addition, the experiments done in rodents could not be proven in primates.[28] Taking all this into account, Bleier claimed that there was no basis for a general model for the hormonal and neural basis of *human* sex differences, especially in such complex features such as aggressivity, dominance, intelligence, sexuality, and gender identity. The wide range of brain organization theory in humans includes yet another variable—"psychological sex" or gender identity—as psychology as a scientific field became an important part of this research. The concept of gender identity is a controversial topic in transgender and intersex studies (Hausman 1995; Stryker 2006; Rubin 2012), but brain organization theory relies unapologetically on it.[29]

In the past decade, a subfield within feminist science studies known as "neurofeminism" has flourished. One of its best representatives is Rebecca Jordan-Young (2010), whose comprehensive meta-analyses of more than three hundred studies from the 1960s to 2010 reinforces Bleier's points. Jordan-Young's main conclusion is that psychosocial characteristics cannot be linked to brain structure without taking into account social and cultural factors. Brain organization theory extrapolates findings from a small number of studies while ignoring studies with contradictory findings. As it turns out,

[28] Even in rats, hormonal manipulation of mating behavior showed contradictory results (Fausto-Sterling 2000).

[29] Brain organization theory uses people with a particular intersex trait (congenital adrenal hyperplasia) as experimental subjects by confronting them with normative definitions of gender identiy. However, these researchers do not acknowledge that the very concept of gender identity was developed by John Money in his studies of intersexuality, so their results involve a kind of ironic circularity. David Rubin (2012) criticizes the erasure of intersexuality from the genealogies of the concept of gender identity within feminism itself.

as with other sex variables, there are many more similarities than differences between "male" and "female" brains. The "differences" are in fact only small statistical differences in the averages.

Genomic sex: Yet another twist

As I note above, genetic sex refers to the genes involved in sex determination. Once this is determined, gonads and hormones continue with the process of sex differentiation. Genomic sex involves a qualitative gap, as it shifts the focus from individuals to species and populations. The term "genomics era" refers to the Human Genome Project's sequencing of human DNA; "post-genomics era" refers to the period thereafter (Richardson 2013). The genome refers to the entire genetic content of an individual within a species, which includes the sequencing of all genes (positions and frequencies of DNA fragments) but also the regulatory patterns of activation and expression—epigenetics (Richardson 2013, 192). Prior to the Human Genome Project Hubbard had already questioned the scientific significance of such a laborious and expensive enterprise beyond its "heroic appeal" (Hubbard 1990, 86).[30] Another important point made by Hubbard was that the Human Genome Project did not intend to give us information about genetic diversity but "to produce the complete DNA sequence of the twenty-three chromosomes for a human 'prototype' "—a composite obtained from the cells and tissues of different people (1990, 86). This prototype, of course, assumed the sex binary.

One of the first attempts to quantify the genetic differences between the sexes after the sequencing of the Y and X chromosomes (in 2003 and 2005, respectively) was Laura Carrell and Huntington Willard's "X-escapee" hypothesis (2005). Since female embryos have two X chromosomes, one of them is deactivated in early development to equalize the dosage of genes with the ones on the single X-chromosome of males. However, some of these genes "escape" deactivation and continue to be expressed (see Richardson 2013, 179). Carrell and Willard claim that the genomic differences between men and women are so large that "there is not one human genome, but two: male and female" (Richardson 2013, 177).[31] Carrell and Willard propose a new locus of sex differences: the human genome as a whole, which is pre-

[30] Genomics is often described as "big science" due to the resources it mobilizes: biobanks, bioinformatics, microarray chips, etc.

[31] Carrell and Willard (2005) claim that male and female genomes differed in 250 to 300 genes (1 to 2 percent of the total coding genome): that is, more than the difference between humans and chimpanzees. Richardson shows the flows of these results (2013, 180).

sented as the definitive marker of sex once again. Geneticist Arthur P. Arnold even coined the name "sexome" for this new variable (Arnold and Lusis 2012). This still-developing sex variable considers the entire genome as imbued with sex-specific processes and sex differences in gene expression. Based on this, a whole new area known as sex-based biology has been launched in the past ten years by an alliance of governmental agencies, private pharmaceutical funding, and the women's health movement, following the idea that men and women differ at a genetic and genomic level.[32]

Importantly, the theory of genomic sex expressly breaks with the unified theory of sex that has been the paradigm for a century. For these scientists, the linear model is incorrect in that it sees only gonadal differentiation as genetically controlled, while the rest of sexual differentiation is believed to be hormonally driven. In their view, genetic sex determination extends further than the differentiation of the gonads.[33] As Richardson puts it, proponents of this new genomics-based framework believe that sex-chromosomal genes act directly and independently of hormones to influence differences between male and female bodies far beyond reproductive differences (2013, 214). In this new definition of sex, every cell in a male body is different from every cell in a female body at the genomic level.

When variables do not align

The unified theory of sex presents a linear model in which all variables—from genes to external anatomy—align along one of two possible paths due to a process of causal dependency. However, despite this simple linear structure, the reality of human bodies is messier than the model suggests, as biologists and physicians have always known. Intersex people have been the clearest bearers of nonmatches between the sex variables across different historical periods (Dreger 1998; Mak 2006; Reis 2009). Because of this, scientists have repeatedly tested their various theories on them, and medical practitioners have followed whatever theory of sex was prevalent in their time to diagnose a "condition" and assign a sex. In an article not often cited in intersex studies but very relevant to this problem, science and technology studies scholars Stefan Hirschauer and Annemarie Mol (1995) examine

[32] On the problematic role of mainstream feminism in this field, see Fausto-Sterling (2005) and Richardson (2013, 208–12). Once again, we can see the investment of (certain parts of) feminism in the idea of the sex binary.

[33] Arnold created an experiment using genetically altered mice that allowed him to distinguish hormonally and chromosomally based differences between the sexes known as the "four core-genotypes" (2012, 59).

what happens when different variables of sex—and the scientific practices related to them—conflict.[34] They suggest that these conflicts are in many cases resolved through a relation of *supremacy*: one variable is considered more important than others in defining the sex of a person (Hirschauer and Mol 1995, 373). This is indeed Dreger's argument on "the age of gonads" (1998): that, in the late nineteenth century, sex was assigned to so-called hermaphrodites based on the type of gonads present in their bodies, over any other variable. As in any relation of supremacy, this model involves a power imbalance and an institution that holds and exercises that power (the power to diagnose, to rename, to intrude, and to intervene). In the case of assigning sex, doctors and scientists are normally those exercising this power. The law is another institution involved in this process, for the assessment could result in an alteration of legal status that affected the inheritance of property, marriage annulments, and so forth. However, in the late nineteenth century, doctors could not force patients to change their names and clothing to fit their assessment (Mak 2006; Reis 2009).[35]

Conflict between variables becomes more complicated to analyze in the twentieth century, as we find contradictory situations regarding which is the supreme variable depending on the setting. One institution that deals with conflicts between sex variables and that has attracted a lot of research is the International Olympic Committee (IOC; see García Dauder and Gregori 2009; Jordan-Young and Karkazis 2012; Henne 2014). The IOC has used several methods over the years to decide whether a person can compete as a woman (competing as a man is rarely in question). In the first half of the twentieth century, the procedure consisted of direct scrutiny of the athletes' genitalia. After the 1950s, with the discovery of the Barr body, chromosomal testing (to find out if an athlete was XX or XY) became the method used. In 1992 this changed to gene screening (in particular the SRY gene test). Each of these practices was controversial and contested; none of them is currently in use.[36]

The conflict regarding the main variable in cases of misalignment is particularly visible when we compare the diagnosis and management of intersex people with cutting-edge research on the genetics of sex. The most widely used protocol for treating intersex people is the one developed by John

[34] Hirschauer and Mol refer, for example, to people with XY chromosomes but female-looking genitalia and people with hormonal values within a female-defined range but who have testes and a penis (1995).

[35] In this, Mak and Reis contradict Dreger's thesis on the absolute supremacy of gonadal sex.

[36] In a curious turn back to hormonal sex, in recent years the focus of testing—and of contestation—is high testosterone levels (Jordan-Young and Karkazis 2012; Henne 2014).

Money at Johns Hopkins University during the 1950s. A psychologist and founder of the first gender identity unit in the United States, Money authored the standards for intersex treatment for decades to come (Kessler 1990; Eder 2010). The atrocious consequences of his protocol are well documented (Chase 1998; Preves 2003; Holmes 2009).[37] My focus here is on its relationship with the prevalent biological theories of sex of the time. On the one hand, Money used Klebs's classification based on the gonads (he used the terms "true hermaphrodites" and "male or female pseudohermaphrodites"). However, gonadal sex was not his main criterion for sex assignment. It would have been possible to use chromosomal tests (available since the end of the 1950s) to assign individuals who bear a Y chromosome as male—regardless of other variables. However, Money's criteria for categorizing an intersex baby as male or female was a much more prosaic one in terms of scientific sophistication: genital anatomy and, more specifically, phallus size. Ambiguous genitalia were considered abnormal and were surgically altered. Fausto-Sterling's famous "phallometrics" diagram explains this criterion very clearly: anything shorter than 2 centimeters is considered a clitoris, anything more than 3.5 centimeters is considered a penis, and anything in between is considered "unacceptable" (Fausto-Sterling 2000, 59).[38] It is quite surprising that this feature (just one within the set that form "anatomical sex") was the main criterion used in the most important sex-assignment protocol of the century. This can only be explained through Money's own grandiose personality and his investment in a particular theory of gender (Hausman 1995; Eder 2010; Rubin 2012). Material circumstances were also key in this case: Money's position in one of the most important hospitals in the world gave him the access to the latest surgical and hormonal developments necessary to manipulate the bodies of thousands of intersex people.

Largely due to intersex activism since the 1990s, Money's protocol has been abandoned. In its place, a new set of guidelines known as the "Consensus Statement on Management of Intersex Disorders" was developed in 2006 (Hughes et al. 2006; Hughes 2008). This "consensus" is problematic for two reasons. First, it was not a real consensus, as not all the actors

[37] Sharon Preves (2003) was the first researcher to interview intersex adults about their treatment experiences. She concluded that the medical intervention often created rather than mitigated the stigma it was supposed to prevent. Morgan Holmes's personal account and activism has been key to critical intersex studies (2009). And later, Ellen Feder's work on parents of intersex children has concluded that medicine has failed parents too (2014).

[38] However, although it is not well known, intersex individuals are not the only ones who stray from binary genital criteria. As S. Faisal Ahmed and Martina Rodie write, "genital anomalies may occur as commonly as 1 in 300 births and *may not always be associated with a functional abnormality*" (2010, 198; emphasis added).

involved were represented.[39] Second, the statement proposes the use of "Disorders of Sex Development (DSD)" as the umbrella term for conditions previously named "intersex."[40] This change of nomenclature created a division in the intersex community and is still hotly debated. My position regarding the name aligns with the latest work of Hida Viloria and the Organization Intersex International (Viloria 2014, 2017), who strongly opposes calling intersex people "disordered." I agree with Karkazis when she writes "my sense is that this term, though in some ways less culturally loaded than intersex, still leaves intersexuality fully medicalized and construes gender difference as a disorder requiring treatment" (2008, 18).[41] Unfortunately, in my opinion, the wide acceptance of the term "DSD" by the medical community has strongly influenced a new generation of intersex people and their parents, as the recent work of Georgiann Davis (2015) demonstrates.

For the purpose of my analysis here, however, I ask of the consensus statement the same question that I ask of Money's protocol: which variable(s) are privileged in the assignment of sex? The statement's authors say that chromosomes and genetics are the primary factors in the new diagnostic classification (Hughes 2008; Ahmed and Rodie 2010).[42] This turn toward molecular biology has been noticed by critical intersex studies scholars, sometimes with optimism (Rosario 2009) and sometimes with pessimism and criticism (García Dauder and Romero Bachiller 2012).[43] Despite its name, however, the "consensus" is not shared by all even within the medical community. For example, Ian Aaronson and Alistair Aaronson—two pediatric urologists who deal directly with intersex newborns—criticize the use of karyotype- and gene-based classifications because, in their view, it "is diagnostically non-specific, and is

[39] One intersex person—Cheryl Chase—and one advocate—Alice Dreger—were invited as presenters at the conference of the Lawson Wilkins Pediatric Endocrine Society and the European Society for Paediatric Endocrinology, which normally is reserved for medical professionals. But Chase and Dreger's position of accepting the change of nomenclature (from "intersex" to "DSD") was not shared by many members of Intersex Society of North America (see Davis 2015; Viloria 2017).

[40] For accounts about the controversy of the mid-2000s, see Diamond and Beh (2006), Reis (2007), Karkazis (2008), and García Dauder and Romero Bachiller (2012).

[41] Karkazis conducted her research at a high point in the controversies. Her book is one of the most complete in that it includes the perspectives of doctors, parents, and adult intersex people themselves.

[42] The criteria of DSD classification are the chromosomes: the "disorders" are classified as 46XX DSD, 46XY DSD, or Sex Chromosome DSD.

[43] As in the case of Delgado-Echeverría's book, this excellent article was published in 2012 in Spanish, and it has not been cited in any of the Anglo-American journals.

not in itself relevant to subsequent clinical developments" (Aaronson and Aaronson 2010, 443). They consider the new genetics of sex determination "conceptually attractive from the scientific perspective" (444) but unable to provide more specific diagnostic criteria. Because of this, they advise a return to a classification based on the gonads.[44] On the other side of the controversy, one of the most important figures in the genetics of sex determination, Arthur Arnold, writes that "gonadal differentiation should be displaced as the central event of sex determination and replaced with whatever other condition is the unitary origin of all sex differences," which, in his view, is the genome (2012, 55). In an article defending the new nomenclature, Alice Dreger and April Herndon (2009) consider the term "DSD" progressive in ethical and epistemic terms, as well as more scientific regarding the etiology of the disorders. But whatever "progress" Dreger and Hendon were considering is not that clear a decade later.

What remains stable: A binary with no way out

My review of the history of biological sex through the lens of feminist critiques of science has shown that each attempt to find the definitive marker of sex has been a dead end. After two centuries of research, none of the variables can be claimed to be the decisive one in defining an individual's sex. The strategy that has lasted the longest is what I have called the "unified theory of sex," a linear model that aligns all the variables in a relation of sequential dependency by distinguishing between sex determination and sex differentiation. But even this model has been put under review after the collapse of the 1990s-era master-gene model.

However, despite all the dead ends and the past and current controversies about the supreme variable, something has remained unchallenged since the birth of biology in the eighteenth century: *the assumption of the dichotomous character of sex*. The definition of sex as a binary, while many times challenged, has stubbornly remained at the core of scientific research on sex. In addition, I argue that while the multiplication of variables has made the definition of sex more complicated over the years, it has also had the paradoxical effect of reinforcing the binary instead of disrupting it. This has happened in two ways. On the one hand, some variables have supported the binary by covering the explanatory gaps of other variables. This is the case with the unified theory of sex, where hormonal sex explained the vari-

[44] Ian Aaronson issues a call to "restore the gonad to its rightful place at the center of the classification of DSD" and proposes a classification of four DSD types based on gonadal histology: ovarian DSD, testicular DSD, ovostesticular DSD, and dysgenetic DSD (2011, 389).

ability of sexed bodies that couldn't be explained only with chromosomal sex. On the other hand, new dichotomies have been created where old ones have failed—as if, when one variable doesn't work, another comes to the rescue of the binary.[45] This is very clear, for example, in the turn from genetic sex to genomic sex. In the early 2000s, the research on the genetics of sex determination arrived at a dead end. The search for male and female sex-determining genes (identified with the search for the genes responsible for testicular and ovarian development) became so complicated that it was almost impossible to maintain the sex binary, as the work of Vilain and others showed. But it was precisely at that moment that a new way of defining sex—genomic sex—appeared, bringing the binary back by other means. Claiming to be the definitive marker of sex once again, the genomic concept of sex applies whole-genome technologies to reinscribe sex differences at the genetic level—and even "discover" new ones (Richardson 2013, 213). When I read Richardson's description of researches using genomic technologies "to quantitatively characterize sex differences in gene expression in every tissue of the body, from the heart to the brain and the liver" (213), I cannot help but remember the words of Londa Schiebinger thirty years ago when she explained how nineteenth-century anatomical scientists found sex differences "in every bone, muscle, nerve and vein of the human body" (1986, 42).

Years ago, Anne Fausto-Sterling wrote that "Western culture is deeply committed to the idea that there are only two sexes" (1993, 20). The problem with this commitment is precisely its character of assumption. In an enterprise (science) that bases its epistemic legitimacy in demonstrations and proof, the problem with the sex binary is that there has never been a hypothesis or a theory to test—it is an epistemological framework that runs behind, above, and beyond particular theories and research projects. In Western biological sciences, the binary is common sense, a kind of tacit knowledge that permeates many other aspects of our culture.[46] This is because, if we broaden the scope and look at the history of sex in the way Laqueur (1990) did, we can see that all the sciences of sex are built upon what he called the "two-sex model." The assumption that sex is a binary was never questioned because it was never a hypothesis: it was the taken-for-granted starting point.

[45] Cases of new dichotomies created when old ones fail also occur within one sex variable. For example, the theory of the sex-specific *function* of sex hormones replaced the previous idea of the sex-specific *origin* of the sex hormones once the latter was disproved (Oudshoorn 1994).

[46] A clear example of how the binary is introduced from the beginning is the current biology of sex research, where most of the articles begin with "sex differences in . . . ." With that as the starting point, what else are they going to find?

"Sex" as an areferential network: Misnomers and semiotic transpositions

My goal in this article has been to investigate the concrete mechanisms by which the binary definition of sex has been maintained despite empirical flaws, contradictory data, and counterexamples. This review of the history of biological sex has illustrated how the different variables of sex have intertwined through their scientific history in ways that have maintained a shaky yet persistent stability of the binary. With the proliferation of variables coexisting (and many times contradicting each other), then, the question that comes to mind once and again is this: what is "sex," after all?

The answer has to do with semantics and the multiple meanings of the word "sex." In her analysis of the history of sex hormones, Bernice Hausman interprets the identification of steroid hormones with sex as a semiotic transposition, which she defines as the process by which a sign becomes a signifier for something else—in her case, "the reduction of the concept of sex to the chemicals that produce it" (1999, 169). As Hausman reminds us, a chemical molecule cannot qualify as male or female; those terms only apply to whole organisms.[47] Hausman bases her argument on a close reading of a 1939 text by Frank Lillie, in which he affirms that "there is no such biological entity as sex. What exists in nature is a dimorphism within species into male and female individuals. . . . Sex is not a force that produces these contrasts; it is *merely a name for our total impression of the differences*" (Lillie 1939, 3–4; emphasis added). As Lillie correctly reasons, if sex is not an entity, it cannot be a causal "force" that produces those differences. Hausman picks up on this idea and stresses how, contrary to Lillie's warnings, this is precisely what has happened during the past century. As Oudshoorn (1994) and Richardson (2013) argue regarding "sex hormones" and "sex chromosomes," respectively, these terms are misnomers—both in the general sense (male or female can only be applied to whole organisms) as well as in the sense that it has not been demonstrated to be the cause of either maleness or femaleness.[48]

My review of the multiple variables of sex shows that this process of semiotic transposition is in fact applicable to all the sex variables, due to what I have referred as the atomicist view of sex. The atomization of body parts was

[47] In particular, the terms only apply to individuals of those species with a system of sexual reproduction, which is, in fact, only a subset of the animal kingdom.

[48] Both authors point out alternative names that were available in the early days of endocrinology and cytogenetics, suggesting we use those names instead of "sex hormones" and "sex chromosomes." Examples include "homosexual and heterosexual hormones" or "steroid hormones"; X and Y were also known as "accessory chromosomes" or "heterochromosomes."

accompanied by its anthropomorphization, a common trend in the early twentieth century where the idea of preformationism was widely accepted.[49] Seen as mini-individuals, body parts were understood as sexed as well—which was supposed to be a specular version of the individual's overall sex. The assumption of the binary character of sex was translated to each new variable/part of the body that was alleged as the new and definitive locus of sex.

As Hubbard noted years ago, Mendel specifically selected for his experiments traits that show differences "in kind rather than of degree" (1990, 74). But the reality is that most traits are quantitative (varying continuously), not just qualitative (present or absent), and do not follow Mendel's laws.[50] Although Richardson does not refer to Hubbard's point, it is very relevant for her argument about the sex chromosomes because defining sex with a single (qualitative) trait and identifying the two sexes with each of the two chromosomes—as if they were alleles—produced a simple, elegant theory within the mechanicist framework. The atomistic and dualistic view of X and Y aligned perfectly with the dichotomous view of sex. As bastions of an atomistic and binary concept of sex determination, the sex chromosomes left the complexities of human sexed bodies (mostly quantitative traits—which in Lillie's system are developed in the process of sex differentiation)—to the hormones. The same phenomenon of atomicism is shown in the early definition of "sex hormones" as only two chemicals. As I explain above, suggesting a parallelism between "sex chromosomes" and "sex hormones" made it easy to accept them both. Once the name was accepted, scientists used the trope of the two-sex model to associate them with gender stereotypes: the X became identified with femaleness and the Y with maleness (a process that Richardson calls "sexing the X" and the Y [2013, chaps. 5 and 6]). This induced a false symmetry that was embedded in chromosomal research for the next several decades, creating many contradictions for future scientists. Over the years, the list of anatomical and physiological elements assumed to be binary has only grown. In the same way that the sex chromosomes appeared to be a good archetype for Morgan's theory of heredity in the 1920s in terms of atomicism and mechanicism, SRY was the perfect archetype for the 1980s master-gene model. In this way, the binary has been an *epistemological* obstacle for the correct understanding of sex

[49] Preformationism is the idea that organisms develop from miniature versions of themselves (Richardson 2013, 49).

[50] Mendel's focus on qualitative traits led geneticists after him "to assume that the difference is mediated by different forms of the same gene, called *alleles*" (Hubbard 1990, 75).

variability but also a *diagnostic* obstacle for those who, in one way or another, fall outside the grid.

Going back to my initial question of how the binary has managed to perpetuate itself despite this convoluted history, my thesis is that it is precisely this back and forth between the macro- and microlevels of the organism in the process of assigning sex, together with imprecision in the meaning of sex, that has allowed the perpetuation of the binary. This back and forth has rendered semiotic transpositions invisible. Only through being semantically rigorous can we make these inconsistencies visible. What we find then is that biological sex is a tautological network where, when pushed to the limit, sex becomes a signifier for itself (Hausman 1999). Instead of a line between meaning and entity, "sex" is a circular network in which meaning travels from one place to the other with no clear origin and in which challenges to the binary are buried by the weight of centuries of a two-sex model. With no clear reference, the imprecision is precisely where the power of the network resides.

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References

Aaronson, Ian A. 2011. "Terminology for Disorders of Sex Development: Clarity or Confusion?" *Journal of Urology* 185(2):388–89.

Aaronson, Ian A., and Alistair J. Aaronson. 2010. "How Should We Classify Intersex Disorders?" *Journal of Pediatric Urology* 6(5):443–46.

Ahmed, S. Faisal, and Martina Rodie. 2010. "Investigation and Initial Management of Ambiguous Genitalia." *Best Practice and Research Clinical Endocrinology and Metabolism* 24(2):197–218.

Arnold, Arthur P. 2012. "The End of Gonad-Centric Sex Determination in Mammals." *Trends in Genetics* 28(2):55–61.

Arnold, Arthur P., and Aldons J. Lusis. 2012. "Understanding the Sexome: Measuring and Reporting Sex Differences in Gene Systems." *Endocrinology* 153(6):2551–55.

Barad, Karen. 2007. *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning*. Durham, NC: Duke University Press.

Birke, Lynda. 1986. *Women, Feminism, and Biology: The Feminist Challenge*. Brighton: Harvester Wheatsheaf.

Bleier, Ruth. 1984. *Science and Gender: A Critique of Biology and Its Theories on Women*. New York: Pergamon.

Butler, Judith. 1993. *Bodies That Matter: On the Discursive Limits of "Sex."* New York: Routledge.

Carrel, Laura, and Huntington Willard. 2005. "X-Inactivation Profile Reveals Extensive Variability in X-Linked Gene Expression in Females." *Nature*, no. 434: 400–404.

Chase, Cheryl. 1998. "Hermaphrodites with Attitude: Mapping the Emergence of Intersex Political Activism." *GLQ* 4(2):189–211.

Davis, Georgiann. 2015. *Contesting Intersex: The Dubious Diagnosis*. New York: New York University Press.

Delgado-Echeverría, Isabel. 2007. *El descubrimiento de los cromosomas sexuales: Un hito en la historia de la biología* [The discovery of sex chromosomes: A milestone in the history of biology]. Madrid: CSIC/Estudios sobre la ciencia.

Diamond, Milton, and Hazel Beh. 2006. "Variations of Sex Development Instead of Disorders of Sex Development." Letter to the editor, *Archives of Disease in Childhood*, July 26. http://www.hawaii.edu/PCSS/biblio/articles/2005to2009/2006-variations.html.

Dreger, Alice Domurat. 1998. *Hermaphrodites and the Medical Invention of Sex*. Cambridge, MA: Harvard University Press.

Dreger, Alice D., and April M. Herndon. 2009. "Progress and Politics in the Intersex Rights Movement: Feminist Theory in Action." *GLQ* 15(2):199–224.

Eder, Sandra. 2010. "The Volatility of Sex: Intersexuality, Gender and Clinical Practice in the 1950s." *Gender and History* 22(3):692–707.

Eicher, Eva M., and Linda L. Washburn. 1986. "Genetic Control of Primary Sex Determination in Mice." *Annual Review of Genetics* 20:327–60.

Fausto-Sterling, Anne. 1985. *Myths of Gender: Biological Theories about Women and Men*. New York: Basic.

———. 1989. "Life in the XY Corral." *Women's Studies International Forum* 12(3):319–31.

———. 1993. "The Five Sexes: Why Male and Female Are Not Enough." *The Sciences*, March/April, 20–25.

———. 2000. *Sexing the Body. Gender Politics and the Construction of Sexuality*. New York: Basic.

———. 2005. "The Bare Bones of Sex: Part 1—Sex and Gender." *Signs: Journal of Women in Culture and Society* 30(2):1491–27.

Feder, Ellen K. 2014. *Making Sense of Intersex: Changing Ethical Perspectives in Biomedicine*. Bloomington: Indiana University Press.

Ford, Charles E., K. W. Jones, Paul E. Polani, J. C. de Almeida, and James H. Briggs. 1959. "A Sex-Chromosome Anomaly in a Case of Gonadal Dysgenesis (Turner's Syndrome)." *Lancet* 273(7045):711–13.

García Dauder, S., and Nuria Gregori. 2009. "Designing the Margin of Feasible Bodies." *Eurozine*, September 28. http://www.eurozine.com/articles/2009-09-28-garciadauder-en.html.

García Dauder, S., and Carmen Romero Bachiller. 2012. "Los deplazamientos políticos de las categorías médicas" [The political displacements of medical categories]. In *Cuerpos y diferencias* [Bodies and differences], ed. Eulalia Pérez Sedeño and Rebeca Ibáñez Martín, 213–40. Madrid: Plaza y Valdés.

Graves, Jennifer A. M. 2000. "Human Y Chromosome, Sex Determination, and Spermatogenesis—a Feminist View." *Biology of Reproduction* 63(3):667–76.

Grosz, Elizabeth. 1994. *Volatile Bodies: Toward a Corporeal Feminism*. Bloomington: Indiana University Press.

Ha, Nathan Q. 2011. "The Riddle of Sex: Biological Theories of Sexual Difference in the Early Twentieth Century." *Journal of the History of Biology* 44(3):505–46.

———. 2015. "Diagnosing Sex Chromatin: A Binary for Every Cell." *Historical Studies in the Natural Sciences* 45(1):49–84.

Haraway, Donna J. 2008. *When Species Meet*. Minneapolis: University of Minnesota Press.

Hausman Bernice L. 1995. *Changing Sex: Transsexualism, Technology, and the Idea of Gender*. Durham, NC: Duke University Press.

———. 1999. "Ovaries to Estrogen: Sex Hormones and Chemical Femininity in the 20th Century." *Journal of Medical Humanities* 20(3):165–76.

Henne, Kathryn. 2014. "The 'Science' of Fair Play: Gender and Testing." *Signs* 39 (3):787–812.

Hiort, Olaf. 2011. "Diagnostic Pathways in Disorders of Sex Development." *Clinical Biochemistry* 44(7):509.

Hirschauer, Stefan, and Annemarie Mol. 1995. "Shifting Sexes, Moving Stories: Feminist/Constructivist Dialogues." *Science, Technology, and Human Values* 20(3):368–85.

Holmes, Morgan, ed. 2009. *Critical Intersex*. Burlington, VT: Ashgate.

Hubbard, Ruth. 1990. *The Politics of Women's Biology*. New Brunswick, NJ: Rutgers University Press.

Hughes, Ieuan A. 2008. "Disorders of Sex Development: A New Definition and Classification." *Best Practice and Research Clinical Endocrinology and Metabolism* 22(1):119–34.

Hughes, Ieuan A., Christopher P. Houk, S. Faisal Ahmed, and Peter A. Lee. 2006. "Consensus Statement on Management of Intersex Disorders." *Archives of Disease in Childhood* 91(7):554–63.

Irni, Sari. 2016. "Steroid Provocations: On the Materiality of Politics in the History of Sex Hormones." *Signs* 41(3):507–29.

Jordan-Young, Rebecca M. 2010. *Brain Storm: The Flaws in the Science of Sex Differences*. Cambridge, MA: Harvard University Press.

Jordan-Young, Rebecca, and Katrina Karkazis. 2012. "Some of Their Parts." *Anthropology News*, June 15. http://onlinelibrary.wiley.com/doi/10.1111/j.1556-3502.2012.53601.x/epdf.

Jost, Alfred, Pernette Gonse-Danysz, and Robert Jacquot. 1953. "Studies on Physiology of Fetal Hypophysis in Rabbits and Its Relation to Testicular Function." *Journal de Physiologie* [Journal of physiology] 45(1):134–36.

Karkazis, Katrina. 2008. *Fixing Sex: Intersex, Medical Authority, and Lived Experience*. Durham, NC: Duke University Press.

Keller, Evelyn Fox. 1982. "Feminism and Science." *Signs* 7(3):589–602.

———. 1985. *Reflections on Gender and Science*. New Haven, CT: Yale University Press.

———. 2000. *The Century of the Gene*. Cambridge, MA: Harvard University Press.
Kessler, Suzanne J. 1990. "The Medical Construction of Gender: Case Management of Intersexed Infants." *Signs* 16(1):3–26.
Klebs, Theodor A. Edwin. (1878) 1965. *Handbuch Der Pathologischen Anatomie* [Handbook of pathological anatomy]. Vol. 2. Berlin: Hirschwald.
Krafft-Ebing, Richard von. (1886) 1965. *Psychopathia Sexualis*. Trans. Franklin S. Klaf. New York: Stein & Day.
Laqueur, Thomas. 1990. *Making Sex: Body and Gender from the Greeks to Freud*. Cambridge, MA: Harvard University Press.
Lillie, Frank. 1939. "General Biological Introduction." *Sex and Internal Secretions: A Survey of Recent Research*. 2nd ed., ed. Edgar Allen, 3–14. Baltimore: Williams & Wilkinks.
Magubane, Zine. 2014. "Spectacles and Scholarship: Caster Semenya, Intersex Studies, and the Problem of Race in Feminist Theory." *Signs* 39(3):761–85.
Mak, Geertje. 2006. "Doubting Sex from Within: A Praxiographic Approach to a Late Nineteenth-Century Case of Hermaphroditism." *Gender and History* 18 (2):332–56.
Markowitz, Sally. 2001. "Pelvic Politics: Sexual Dimorphism and Racial Difference." *Signs* 25(2):389–414.
Martin, Emily. 1991. "The Egg and the Sperm: How Science Has Constructed a Romance Based on Stereotypical Male-Female Roles." *Signs* 16(3):485–501.
McElreavy, Ken, Eric Vilain, Nacer Abbas, Ira Herskowitz, and Marc Fellous. 1993. "A Regulatory Cascade Hypothesis for Mammalian Sex Determination: SRY Represses a Negative Regulator of Male Development." *Proceedings of the Academy of Natural Sciences* 90(8):3368–72.
Meyerowitz, Joanne. 2002. *How Sex Changed: A History of Transsexuality in the United States*. Cambridge, MA: Harvard University Press.
Nanney, David L. 1957. "The Role of the Cyctoplasm in Heredity." In *The Chemical Basis of Heredity*, ed. William D. McElroy and Bentley Glass, 134–64. Baltimore: Johns Hopkins University Press.
Ogilvy-Stuart, Amanda L., and Caroline E. Brain. 2004. "Early Assessment of Ambiguous Genitalia." *Archives of Disease in Childhood* 89(5):401–7.
Oudshoorn, Nelly. 1994. *Beyond the Natural Body: An Archaeology of Sex Hormones*. New York: Routledge.
Preves, Sharon E. 2003. *Intersex and Identity: The Contested Self*. New Brunswick, NJ: Rutgers University Press.
Reis, Elizabeth. 2007. "Divergence or Disorder? The Politics of Naming Intersex." *Perspectives in Biology and Medicine* 50(4):535–43.
———. 2009. *Bodies in Doubt: An American History of Intersex*. Baltimore: Johns Hopkins University Press.
Richardson, Sarah S. 2013. *Sex Itself: The Search for Male and Female in the Human Genome*. Chicago: University of Chicago Press.
Rosario, Vernon. 2009. "Quantum Sex: Intersex and the Molecular Deconstruction of Sex." *GLQ* 15(2):267–84.

Rubin, David. 2012. "An Unnamed Blank That Craved a Name: A Genealogy of Intersex as Gender." *Signs* 37(4):883–908.

Schiebinger, Londa. 1986. "Skeletons in the Closet: The First Illustrations of the Female Skeleton in Eighteenth-Century Anatomy." *Representations*, no. 14: 42–82.

———. 1993. *Nature's Body: Gender in the Making of Modern Science*. Boston: Beacon.

Schrödinger, Erwin. 1944. *What Is Life: The Physical Aspect of the Living Cell*. Cambridge: Cambridge University Press.

Spanier, Bonnie B. 1995. *Im/partial Science: Gender Ideology in Molecular Biology*. Bloomington: Indiana University Press.

Stryker, Susan. 2006. "(De)subjugated Knowledges: An Introduction to Transgender Studies." In Stryker and Whittle 2006, 1–17.

Stryker, Susan, and Stephen Whittle, eds. 2006. *The Transgender Studies Reader*. New York: Routledge.

Vilain, Eric. 2000. "Genetics of Sexual Development." *Annual Review of Sex Research* 11:1–25.

Vilain, Eric, Ken D. McElreavey, Michel Vidaud, François Richaud, and Marc Fellous. 1991. "The Analysis of SRY Doesn't Explain all the Pathology of Sex Determination." *Annales d'Endocrinologie* [Annals of endocrinology] 52(6):435–36.

Viloria, Hida. 2014. "Op-ed: What's in a Name; Intersex and Identity." *The Advocate*, May 14. http://www.advocate.com/commentary/2014/05/14/op-ed-whats-name-intersex-and-identity.

———. 2017. *Born Both: An Intersex Life*. New York: Hachette.