"SEX GENES": A Critical Socio-Material Approach to the Politics and Molecular Genetics of Sex Determination

INTRODUCTION

How should the social sciences engage with the materiality of nature? The literatures of both the social studies of science and gender studies have wrestled with this question in their studies of the production of scientific knowledge. In examining the production or consumption of scientific knowledge, these literatures have demonstrated how each is a social and cultural set of activities. Within this shared terrain, however, many differences emerge both within and between these two literatures about how to theorize about the social in the scientific and the scientific in the social, and how to create a language that does not separate science from society.

One topic explored has been the biological explanations for differences between males and females. Biologists and social scientists have proposed explanations for behavioral differences, and debates abound. This article does not discuss theories or data about behavioral differences. Instead, I explore research on the material production of males and females in molecular genetic research on sex determination.

I address the question of how the social sciences should engage with the materiality of nature—in this case, the molecular genetics of sex determination. I employ a "critical socio-material" approach to social scientific engagements with the biological sciences and its relationship to the roles of actors from other sectors of society in the making of biological knowledge. The formulation of socio-material encompasses the poststructuralist view that meanings are not inherent in events, phenomena, and things. That is, it assumes that humans attribute meanings to things through complex interactions based within specific locations in society, culture, and history. For example, the meanings attributed to "nature"—how nature is

"read"—differ depending on its reader's location in time and place (see, e.g., Harding 1986; Strathern 1992; Williams 1985). This approach also builds on feminist and socio-cultural studies of science that have argued against the neat divide between "nature" (as "nature in the raw") and "culture" (as "social discourses and meanings"). To emphasize this co-production of nature and culture, Haraway ([1985] 1991, 208) uses the term "material-semiotic practices" to refer to the production process and "nature-culture" to refer to its product.

Despite this post-structural understanding of the mediation of nature-culture, a material world does at times assert itself in ways that make us take notice (Fausto-Sterling 2000; Haraway [1985] 1991). Some anthropologists have used the term biophysicality (Escobar 1999; Goodman and Leatherman 1998) to describe such occurences, while sociologists of science Latour (2000) and Callon (1986) refer to the material world as "nonhuman actants" and treat them on par with "human actants."

Given that interventions by the material or biophysical world are acknowledged, the question arises: How does one recognize and deal with the actions of biophysicalities (or nonhuman actants) if they are always mediated? To address this question, I use a critical socio-material approach to show how the materiality of sex is produced. I re-examine experimental research investigating the *Sry* and *Dax-1* genes, the so-called "sex determining genes," in mice and humans.

A critical socio-material approach allows the examination and reanalysis of the social and historical production of material knowledge. It assumes that what is taken to be material must be investigated and should not be accepted at face value. It also requires multiple readings of the same data from different socio-cultural perspectives or frames of reference. This approach takes from the theoretical efforts of feminist theorist Haraway ([1985] 1991), anthropologist Escobar (1999), and philosopher Harding (1998, 2001) and the practical efforts of social movements

around the globe to incorporate perspectives not usually included in the production of science. These varied perspectives produce new knowledge and add dimensions to what Western science calls nature.

Thus, my reanalysis of *Sry* and *Dax-1* experiments is made in the context of multiple perspectives on sex. I examine human actions in sex determination by analyzing the research methods and interpretations of geneticists as well as the efforts of sex-gender theorists and transgender activists to theorize and remake sex. By analyzing the *same* material production using multiple perspectives, I provide an alternative reading of the materiality of sex. That is, this re-examination of research on molecular genetic developmental processes provides a focus on the complex sets and pathways of events that produce a variety of material sex. These multiple pathways and multiple experimental outcomes could explain variations in human physiological phenotypes that sometimes do not fit neatly into the binary sex categories, male and female. Just as previous studies of human behavior, physiology, endocrinology, and chromosomes have met with difficulties in finally elucidating the source of male-female sex differences, so too have recent attempts to ascertain sex differences at the level of genes met with complexities and ambiguities. My reanalysis of genetic research further substantiates previous knowledge of sex as diverse and variable.

I also find that human and molecular geneticists used their own socio-historically located normative definitions of sex in their experimental designs and analytic frames. By selecting particular bodies for their sex determination experiments, these geneticists set the stage for reproducing their own taken-for-granted categories of sex. New molecular genetic technologies produced new data which could have led researchers to new insights about sex development. However, new signals read through old frames can be discounted: Researchers decided to ignore data that contradicted their initial assumptions.

This study refers to such ignored data as an "awkward surplus." Here, a critical socio-material re-examination of the awkward surplus suggests a different research conclusion from that reported by the scientists. This approach attends to unanticipated research results that experimenters recognize as problematic or awkward and thus ignored in their final conclusions. This approach provides a way to re-examine unexpected experimental data using different frames of reference and data from other sources. For example, social scientists, using knowledge of social movements (feminism, gay/lesbian movements, queer theory, intersexuals, and transsexuals) and social and cultural theory, literally can *see* differently when examining the work of geneticists and other scientists in the production of the science of sex. Further, the concept of awkward surplus provides science studies with a way of talking about materiality that does not deny human mediation but also acknowledges material agency. More generally, re-examinations of experimental material provide opportunities for natural scientists, social scientists, and other parties to approach research differently and collaboratively to produce new explanations.

THEORETICAL AND HISTORICAL FRAMES OF THE SEX-GENDER DISTINCTION

The sex-gender distinction has been the foundation of gender theory since the 1970s.[1] In their attempts to decouple biology from behavioral differences between the sexes, feminists in the 1970s and 1980s embraced the term "gender" to argue that behavioral differences between girls and boys, women and men, were "gendered."[2] That is, they were constructed within specific cultural and historical contexts (Scott [1986] 1988) and through specific technologies (e.g., de Lauretis 1987; Lorber 1994). Gendered differences, it was noted, are not uniform but

[1] This is not intended to be a complete discussion of the history of gender theory, feminism, or gender and science.
[2] The term "gender," as separated from "sex," originated in Money and Ehrhardt's (1972) studies of hermaphrodites.

situationally produced and interactionally accomplished (e.g., Kessler and McKenna [1978] 1985; West and Zimmerman [1987] 2002).[3] The term gender was also used as a to speak about sexuality in ways that did not assume or enforce heterosexuality (Rubin 1975). In this time period, then, gender became "socially constructed," while sex remained in the realm of "nature" and was left to biologists.

In the 1980s and 1990s, some feminists began to challenge this culture-nature division. Some studied the effect of hierarchies of power on the production of biological models of the body (e.g., Bordo 1993; Fausto-Sterling 1985; Hubbard 1990) and battled biological determinism by arguing that biological knowledge itself was "gendered." Critics of gendered and raced knowledges argued that humans attribute meanings to nature through complex interactions based within specific locations in society, culture, and history; that "nature" is "read" differently depending, among other things, on the differential positions of its oh-so-human "readers" (e.g., Duster 2003; Glenn 1999; Haraway 1989; Laqueur 1990; Rose 1983; Russett 1989; Schiebinger 1989; Smith 1987; Strathern 1996; Trinh 1989).

The 1980s and 1990s also saw more explicit challenges to the feminist embrace of the sex-gender, qua nature-society, split. Historian of science Keller (1987), for example, argued against the dualities of sex and gender and of nature and science. Such dualities, she argued, gave gender unlimited cultural plasticity and made science a set of relativist, interested constructions. In place of these polarities, Keller proposed that a multiplicity of differences could produce varied ways of doing science, each of which could be legitimate. Differences do not have to be reduced to those between male and female, where males and females produce diametrically opposed kinds of science. Nor must one choose universalism as the polar alternative and the only legitimate science. Instead, Keller suggested that there are many

[3] For work on the idea of gender as process, see, e.g., Butler (2004), and Ferree, Lorber, and Hess (1999).

different possible kinds of sciences. Feminist theorist and historian Haraway (1988) similarly argued for "situated knowledges" produced by those with particular stakes in those knowledges.

Other feminist writers deconstructed the production of sex. Philosopher Butler (1993) argued that it was incumbent on feminists to show how sex itself is discursively produced under historically located regulatory regimes of gender. Haraway ([1985] 1991, 208) argued more broadly that "bodies . . . are not born; they are made. . . . The various contending biological bodies emerge at the intersection of biological research, writing, and publishing; medical and other business practices; cultural productions of all kinds, including available metaphors and narratives; and technology. " Fausto-Sterling (2000) presented concrete examples of the discursive production of bodies—specifically bones, brains, hormones, and genitalia—by medical and biological professionals.[4] Noting the conflation of the terms "sex" and "gender" in popular discourse, Scott (1999) argued that "the conflation in ordinary usage of sex and gender can be considered a correction of the 'mistake' that treats sex and nature as transparent entities outside of 'culture'; instead, both gender and sex have to be understood as complexly related systems of knowledge." [5]

I take up the challenge of Keller, Butler, Haraway, Scott, and Fausto-Sterling. I show how the materiality of sex is produced in genetic sex determination research, and I propose alternative knowledge practices and outcomes. A study of the production of the materiality of sex requires more than an examination of the shaping of sex via gendered understandings of scientists; it requires more than a study of the perception of sex in the minds of humans. Both

[4] Historian of science Hall's (1976, 92–94) 1920s research on sex hormones in endocrinology demonstrated how novel biological practices and technologies changed and disturbed established representations of sex differences. For more recent work on the history of the intersection of hormone research and sex disciplining, see Oudshoorn (1994), Clarke (1998), Fausto-Sterling (2000, chaps. 6, 7, 8). For an interesting challenge to feminist critiques of sex hormone research, see C. Roberts (2003).

[5] Feminist theorists Gatens 1996 [1983] and Grosz 1994 also argued that the early division between sex and gender was useful for its purposes at that time, but that this division now serves to keep feminists attending to "social" gender and to cede their authority over "biological" sex to biology.

have been necessary but are not sufficient. It also requires the engagement of social scientists in the production of biological sex. It requires our being in on the design, and not just in quality control. I propose, then, that feminists and social scientists go beyond simply accepting or critiquing the products of science to engaging in the actual production of science. I begin by exploring molecular genetics research on sex determination genes.

DO GENES DETERMINE SEX? ANALYSIS OF RESEARCH ON THE MOLECULAR GENETICS OF SEX DETERMINATION

If social scientists are to engage scientific research, it is incumbent on us to understand the socio-technical processes that generate knowledge. Scientific knowledge is the outcome of socially situated production, where the social and technical one process. Social scientific analysis of scientific research requires attending to all aspects of scientific knowledge production, including (1) the daily laboratory practices that produce data and conclusions, (2) the production of scientific articles, (3) the media's selective reporting of some research results and not others, and (4) the interested audiences and consumers of the knowledge produced (who are ever-present throughout the production process, not simply at the last step). My investigations included all four aspects, but here I present the experiments that produced genetic knowledge about sex determination. I include the uncertainties, ambiguities, guesses, assumptions, the omissions, and the exclusions that were part of that knowledge production.[6]

Of Mice and Men: The Design of Male Sex Determination Genetic Experiments

The search for the male-determining gene began in the mid-1980s in David Page's laboratory at the Whitehead Institute, Massachusetts Institute of Technology. Page's laboratory

produced a "male gene" which was first named the *ZFY*, or zinc finger Y, and later renamed the *TDF*, the testis-determining factor (REF).[7]

Page's experiments on the "male-determining" gene are significant because they set the research protocol for all subsequent studies on male- and female-determining genes. This protocol first studies the "pathological" human and then develops transgenic animal models[8] of the "pathology," which researchers then use to describe the "normal" developmental pathway.

Researchers in Page's laboratory used DNA from XX male human patients (or males with two X chromosomes instead of the usual XY chromosomes). According to David Baltimore, then director of the Whitehead Institute, "This is a classic use of very rare human genetic *defects* to find something very important about biology." Page stated, "The key to the whole endeavor rests with certain exceptions to the rule that Y is sex-determining. . . . XX males were the most important exception." A writer for *Science* went on to say that "XX males appear entirely *normal* . . . until they try to have children and are found to be sterile." Baltimore stated that "Page reasoned that these men [with XX chromosomes] must contain a piece of Y chromosome, attached to one of their X chromosomes, that does not show up under light microscopy."[9]

The next step was to attempt to confirm the *ZFY*'s properties in mouse experiments. This did not go well. In December 1989, a team of scientists working at the MRC National Institute for Medical Research and the Imperial Cancer Research Fund in London announced that *Zfy* did not produce testes in mice. (For the same gene sequence, the agreed upon notation in research

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[6] Since the 1970s, scholars in the social studies of science have explored how scientific knowledge is marked by its situation and process of production.
[7] See Fausto-Sterling's 1991 for an early critique of Page's research.
[8] Transgenic animals or organisms are products of genetic manipulation. Their genetic material (nuclear DNA) has been altered using recombinant DNA techniques that allow the movement of DNA from one organism into another. These DNA transfers are sometimes from a different species, sometimes from the same species.
[9] All quotes in this paragraph taken from quoted in L. Roberts 1988, 21, emphases added.

articles is *Zfy* for the mouse gene, capitalized *ZFY* for the human gene, and *"ZFY"* for the gene in all species.) The hunt was on again to find the male determining gene.

The Maleness Gene Found

In July 1990 and in May 1991, Peter Koopman, Peter Goodfellow, Robin Lovell-Badge and their colleagues made a big splash with news of a new candidate, *Sry*, for the male determining gene. They published their male gene research results in the journal *Nature*. Their approach to studying the male gene was similar to Page's: Select sterile human males with XX chromosomes, find a gene common to them, then develop a transgenic mouse model to confirm (or contest) that that gene is involved in producing testis. The 1991 article, entitled "Male Development of Chromosomally Female Mice Transgenic for *Sry*," announced that their *Sry* gene in the mouse model could turn XX female mice into males. (Again, *Sry* indicates the mouse gene, *SRY* the human gene, *"SRY"* the same gene for all species.)

A close reading of Koopman et al.'s (1991) article, however, tells a more ambiguous story. In Experiment #1 of the study, a number of fertilized eggs were injected with the *Sry* DNA sequences. The eggs were then transferred to the uteri of female mice to develop, and this produced 158 "viable" embryos. Eight of these turned out to be XX mouse embryos with *Sry* incorporated into their DNA. Six of these eight were called "female" and two "male."

In Experiment #2 of Koopman et al. (1991), fertilized eggs were injected with *Sry* DNA sequences and the resulting embryos were transferred to the uteri of female mice to develop. Ninety-three animals grew to term. Of these 93, three were transgenic XX mice that had incorporated the *Sry* gene into at least one of their X chromosomes. Of the three *Sry* transgenic XX mice, two were females that produced viable eggs and reproduced. The third was called an

XX "male." It produced no sperm and was infertile.[10] The term "male" was applied because the animal had testes, although the testes were only 22% the size of "normal" mouse male testes. Human geneticist Giovanna Camerino, when commenting on this experiment, said "[S]ize doesn't matter. What is important is that [the mouse] acted as a male when put in a cage with female mice."[11] That is, the transgenic mouse tried to mate with the females. This single transgenic "male intermouse" was the pride of the Koopman et al.'s experiment, and its photograph was displayed on the front covers of *Nature*, *Science*, the *New Scientist*, and on the front pages of the *New York Times* and the *Boston Globe*.

Thus, in the two Koopman et al. experiments, out of 251 mice injected with the proposed testis-determining gene sequence *Sry*, the researchers obtained just one XX "male." This "male" produced no sperm and had very small testes. In addition, they judged two of their 14-day-old embryos to be "male." In Experiment #1, there were three times as many XX females carrying *Sry* (six) as XX "males" carrying *Sry* (two). In Experiment #2, there were twice as many XX females carrying *Sry* (two) as XX "males" carrying *Sry* (one). In sum, the *Sry* gene appeared to produce many more females than males, but still the gene became the poster "boy" of male-determining genetics.

Interestingly, the Koopman et al. (1991) article frequently referred to this fabricated *Sry* XX mouse as "normal." That is, the mouse exhibited "normal" size and weight, "normal" copulatory behavior (that is, "he" copulated with females four times in six days), "normal"

[10] Koopman et al.'s explanation for the mouse's sterility is that "The presence of two X chromosomes in a male mouse always results in sterility. . . . It was therefore not surprising that the sex-reversed transgenic mouse m33.13 was also sterile" (Koopman et al. 1991, 119).
[11] Interview with Giovanna Camerino, Professor of Human Genetics, University of Pavia, Italy, October 10, 2000.

populations of leydig cells, a "normal" reproductive tract (even though it did not produce sperm), and "normal" production of Anti-Mullerian hormones and testosterone.[12]

More interesting, though, are the *Sry* females produced in the Koopman et al. experiment. Like the "male" mouse, the genome of these mice had also incorporated the *Sry* gene and yet they displayed "female" physical characteristics. However, Koopman et al. treated these cases as *anomalies* that did not complicate the findig that *Sry* produces males.

> A further two XX transgenics, m32.10 and m33.2, showed an external female phenotype, yet both carried many copies of *Sry*. These mice have produced offspring and so have functional reproductive tracts and ovaries. They also provide further evidence, along with the transgenic XX female fetuses, that f741 [*Sry*] does not always cause sex reversal. Although there could be subtle rearrangements of the *Sry* gene making it non-functional, the possibility of this occurring in all these cases is remote. There are two more probable explanations. First, these females could be mosaic for the transgene, with only a small proportion of the cells making up the somatic portion of the genital ridge carrying functional *Sry* gene copies. Analysis of XX <-> XY chimaeras suggests that females or hermaphrodites develop if less than about 30% of cells are XY. Secondly, the expression of the transgene could be affected by the position at which it integrates. Except for a few cases where locus-controlling regions are present, expression of transgenes almost always depends on their chromosomal location. These two alternatives can be examined by breeding from the adult XX transgenic females. Mouse m33.2 has not yet produced transgenic offspring. However, m32.10 has transmitted the transgene to female offspring, suggesting that it is not mosaic (Koopman et al. 1991:120).

To translate, Koopman et al. (1991) offer two explanations for the occurrence of *Sry* female mice. The first argues that the mice might be "mosaics"—mice that have incorporated *Sry* into some cells (perhaps less than 30%) but not into others. However, not only is one mouse (m32.10) a fertile and probably non-mosaic *Sry* female, she also initiated a new and genetically unique strain of mice that produce *Sry* females (Koopman et al. 1991, 120). This means that she

[12] Leydig cells produce the hormone testosterone when stimulated by another hormone. The Anti-Mullerian

incorporated *Sry* into her germ cells passed on the *Sry* gene to her offspring. If *Sry* is the male determining gene, how then can a reproductive female mouse carrying *Sry* in her cells still be a female? Here the Koopman et al. pose a second explanation—that this particular *Sry* mouse is female rather than male because *Sry* is integrated in a position along the X chromosome that somehow prevents it from being expressed. This conjecture requires further research, since Koopman et al. could provide no evidence to support it.

It is not unusual for scientific experiments to raise more questions than they answer. Indeed, it is the norm. Why, then, did the Koopman et al. article begin and conclude with the bold statement that *Sry* is *sufficient* to produce maleness?

> It is now shown that *Sry* on a 14-kilobase genomic DNA fragment is *sufficient* to induce testis differentiation and subsequent male development when introduced into chromosomally female mouse embryos. (Koopman et al. 1991, 117; emphasis added)

Analyzing studies of genetic sex determination allows us to highlight the interpretations made by scientists in the process of experimentation. The Koopman et al. (1991) experiments produced one XX-*Sry* sterile mouse with 22% sized testes (classified male) and three female-classified XX-*Sry* mice , one of which reproduced other females carrying the *Sry* gene. Although *Sry* researchers noted that these different outcomes of the same gene did not fit with their original hypotheses, they still interpreted their results as confirming their initial hypothesis that *Sry* was the male determining gene.

Examining the details of Koopman et al. (1991) also provides an opportunity to make other interpretations. One could, for example, raise an alternative plausible explanation for its complicated results: that is, that the presence of *Sry* females is evidence that genetic sex determination is more complex than the researchers claimed, and that it involves interaction

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hormone is a protein that inhibits the development of the ducts in a male embryo. If not inhibited, these ducts develop into the upper vagina, cervix, uterus and oviducts. The ducts disappear as the male develops.

between many genes as well as other possible factors (e.g., RNA, mitochondrial DNA, particular proteins in the area, or other epigenetic elements and events).[13]If these females have the *Sry* gene, could there be other genes or other factors that might be guiding the embryo toward femaleness? What is maleness; what is femaleness? Do genes determine sex? Or are things more complicated?

Of Mice and Women: Female Sex Determination Genetic Studies

Early views were that the embryo is "female" until something triggers a change which leads to the development of male testes (Jost 1953). As many feminist writers have pointed out, the development of females appears to be discussed by biological and medical texts in terms of passivity—in the absence of an active trigger required to induce male development, an embryo develops ovaries, a female secondary sexual characteristic (e.g., Fausto-Sterling 1993a, Martin DATE).[14]Early *Sry*/*SRY* experiments were based on this same assumption: Embryos develop into female organisms if they lack the *Sry* gene to trigger the onset of male secondary sexual characteristics. Testes and ovaries distinguish males from females in this experimental world of human and molecular genetics. However, experiments in the 1990s countered this truism by presenting evidence for a separate gene involved in female sex determination.

In August 1994, Giovanna Camerino, working in human genetics at the University of Pavia in Italy, Edward McCabe, in pediatrics at the University of California at Los Angeles, and their colleagues reported finding a gene region on the X chromosome that "is powerful enough to

[13] This complexity applies to even a limited definition of epigenetics. See the special issue of *Science* on epigenetics (2001, vol. 293, 1163–1105), especially the exchange about the devolution of the term (Wu and Morris 2001, 1103–1105).

[14] However, Kraus (2000, 152) finds that Drosophila sex determination research "does *not* provide a good example of androcentrism—but, rather, provides a counter-example." She uses this case to argue for a reconsideration of feminist critiques of science

override the influence of the *SRY* gene" (Bardoni et al. 1994).[15]In an article entitled "A Dosage Sensitive Locus at Chromosome Xp21 Is Involved in Male to Female Sex Reversal," published in the science journal *Nature Genetics,* the Bardoni, Camerino, McCabe, and colleagues proposed a female-determining sex gene that operated at about the same time in the development of the embryo as the *SRY* gene. The embryo, they argued, is destined to become a male unless a gene in the *DSS* (Dosage Sensitive Sex reversal) region counters the effect of *SRY*. "A group of four [human] patients found to have a working *SRY* gene nonetheless exhibited varying degrees of feminization, an event that should not happen if the maleness gene were the dominant determinant of gender. Three of the four displayed feminine external genitals, while the fourth had ambiguous genitals. All had been raised as girls" Bardoni, et al. 1994). In these cases, a section of the X chromosome was doubled, giving them a double-dose of the *DSS* gene. Two copies of a gene in the *DSS* region of the X chromosome can help push the fetal gonads, which have the potential to become either ovaries or testes, to become ovaries. Thus, an extra dose of the gene in males would undermine the efforts of the *SRY* factor to build testes. In a follow-up study (Swain et al. 1996), Camerino, and colleagues proposed that a gene in the *DSS* region called "*DAX-1*" was responsible for undermining the "*SRY*" gene's action.

Of Mice, Humans, Leakiness, and Complexity

Later studies conducted in Larry Jameson's laboratory at Northwestern University (e.g., Yu et al. 1998) argued that *Dax-1* is not a female determining gene. They reported that "disabling" the *Dax-1* gene in female mouse embryos did not prevent these embryos from developing into mice with ovaries. Moreover, they reported that male mouse embryos with

[15] See also Dabovic et al. (1995), Zanaria et al. (1995), Graves, Camerino, and McLaren (1995), and Swain et al. (1996).

disabled *Dax*-1 genes became sterile. Their conclusion was that "*DAX-1*" is not an ovary determining gene, but rather has a critical role in spermatogenesis, the generation of sperm.

Camerino accepted the Jameson lab's claims for their mouse model, but not for humans. She believed that species differ in their genetics of sex determination. *Sry*/*SRY*, she argued, acts very differently in mouse and man in the timing of the expression of the gene. Camerino further contended that interactions between human *SRY* and *DAX-1* also differ from those between mouse *Sry* and *Dax-1*. Subsequent studies have shown that sex determination genetics also differ between organisms in different phyla, thus reinforcing Camerino's position on mouse-human differences (Goodfellow and Camerino 1999).

Camerino's late 1990s studies have pointed to the vital role of *DAX-1* in sex determination in humans. In 1999, after Camerino's research on *DAX-1* raised questions about *SRY*'s power to transform embryos, Koopman (1999) hypothesized that the embryo did not develop into a male because the *Sry* mouse gene may be just one trigger in a series of steps that transform the XX embryo into a male mouse. Other possible explanations were that "*SRY*" may act to repress genes that activate the female pathway of development, or to repress the repressor of the male pathway" (Koopman 1999, 840–41), or that "*DAX-1*" represses "*SRY*'s" action (Goodfellow and Camerino 1999).

Goodfellow and Camerino (1999) proposed a hierarchic cascading view of sex determination, where *SRY* and *DAX*-1 in humans act as triggers at the top of the hierarchy of a series of genes and activities necessary to the development of sex (here defined as ovaries and testes). Thereafter, many other events occur in the process of the organism's sex development—for example, other genetic switches turn on or off during the embryo's development. These different genes and their expression generate subsequent genetic actions, and a cascade of genetic switches and expressions produce the organism's final sex characteristics.

But there are more complications in sex determination and more questions than answers. Some argue for proliferation in genes of promoter regions, of structural genes, of different forms of proteins from the "same" gene, and so on, that complicate the picture of sex determination (Goodfellow and Camerino 1999). There is a long list of genes that are suspected of being involved in sex determination, and this list gets longer every year. In addition to *SRY* and *DAX-1*, these include: (1) *Wilm's tumor* 1 or *WT-1*, whose expressed protein has several different splicing alternatives and produces up to 24 different forms of the protein;[16] (2) *SF-1*, which is a nucleo-hormone receptor that is expressed in the hypothalamus, pituitary, gonads, and adrenals; (3) *Sox-9*, which is similar to *Sry*. Then there are the interactions among the genes. As Camerino says,[17] "*Everybody has found interaction of everything with everything*. With different results, etc. [Sex determination] is complex, and the genetic term is leaky. Leaky. This is a prokaryotic genetics term.[18] It means that things are not that stable. They are not something strongly determined."

Camerino believed that "*Dax-1*" is a female sex determination gene high up in the hierarchy of sex determination (higher than *Sox-9*, *SF-1*, etc.) along with *Sry* for male sex determination (Camerino and Goodfellow 1999). Although this has not yet been demonstrated, she believes that future experiments could prove it to be true. In the meantime, Camerino calls "*DAX-1*" an "anti-testis" gene because it has been shown that a double dose of it can turn off "*SRY*." The interactions among all of these genes and proteins contribute to the instability, or "leakiness," in sex determination.[19]

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[16] See also Parker, Schimmer, and Schedl (1999).
[17] Interview with Camerino, October 10, 2000.
[18] Prokaryotes are organisms like bacteria whose DNA is not enclosed in a nucleus. Eukaryotes are usually multi-cellular organisms whose DNA is encased in a nucleus.
[19] Interview with Camerino, October 10, 2000.

What is sex? How is it determined? Does "*SRY*" cause males to develop? Does "*DAX-1*" cause females to develop? Does a cascade of molecular elements and interactions determine sex? At this writing it is thought that "*SRY*" and "*DAX-1*" are key genes that act initially to trigger male or female development in an embryo. However, it is believed that other genes also are needed to continue development toward male or female. These genes interact with each other, and the interactions can lead to other events. One possibility is that they could lead to hermaphroditic combinations of characteristics. Another possibility is that different cells in the same embryo have different genes, which then leads the embryo to develop into a hermaphroditic body. These embryos are called mosaics. At this point, genetic studies point to more complex interactions and unanswered questions than to any clear answers. These complex interactions are part of the "leakiness" of genetics.[20]

DO HUMANS DETERMINE SEX?

In the experimental arena of sex determination, molecular and human geneticists are the arbiters. But do genes and geneticists determine human sex identity? Physicians, psychiatrists, parents, courts, prison officials, and at one time the International Olympics Committee have all taken positions on human sex determination, often with little contest. Recently, social scientists, feminist theorists, queer theorists, and transgender activists (gay rights, intersexual, and transsexual activists) have attempted to gain authority in debates about sex determination.

Intersexual Social Movement

The sex determining gene experiments discussed were based on initial studies of human patients who exhibited genitalia and reproductive organs that did not fit neatly into standard

[20] Interview with Camerino, October 10, 2000.

categories of “male” and “female.” Often classified as “intersexuals,” people with sexually indeterminate bodies have become both subjects and objects of research and activism in the last ten years. Medical and research professionals have often treated intersexuals as residuals—people whose bodies do not fit commonly understood sex categories and need to be managed, explained, or made to fit into one or the other category. Recently, however, intersexuals have begun to organize to contest the medical definitions of their bodies and to work toward building collective identities to differentiate themselves from standard male and female categories and to establish “intersexuality” as a new and standard category of sex identity.

In the United States, medical practices have been used to manage intersexual infants and to surgically and chemically mold them to fit dimorphic sex categories (Dreger 1995). It has been common for doctors to “fix” sexually ambiguous babies soon after birth by surgically creating either male or female genitalia to accord (when possible) with internal reproductive organs. Sociologist Kessler (1990) found that decisions about which sex to assign to an infant were made primarily on the basis of what she calls "aesthetic" concerns, such as length of penis. If doctors guessed that the infant's penis was destined to be too small, then female genitalia were constructed. However, physicians saw their work as merely restoring the person's “natural” sex to “him” or “her,” and along with parents regularly made decisions about these matters to “protect” children from psychological damage. Kessler argued that these physicians displayed a “failure of imagination” in attributing their decisions to nature. “Rather than admit to their role in perpetuating gender, physicians ‘psychologize’ the issue by talking about the parents’ anxiety and humiliation in being confronted with an anomalous infant” (Kessler 1990, PAGE).

Gender “reassignment” has not necessarily produced happy outcomes in adults, and some have organized themselves into the Intersex Society of North America (ISNA), which is based in San Francisco. In the late 1990s, ISNA member and founder Cheryl Chase and her colleagues

generated a social movement to halt surgical practices on infants, or at least to insist on more discussion before infants are "transformed" into one or the other sex. ISNA members marched on medical schools to halt sex reassignment surgeries and published newsletters and press releases to educate the public about intersexuality. They have been the subject of Nova programs aired by the Public Broadcasting Company and of articles in major newspapers. In an October 14, 1996 press release, entitled "Intersexed Decry American Genital Mutilation," the ISNA compared intersexual infant surgery to African genital mutilation (Chase 1996).

Chase and her ISNA colleagues have produced their own versions of naturalist baselines and categories to resist the medical practices that have pathologized and transformed their bodies.

> Intersex specialists are busily snipping and trimming infant genitals to fit the Procrustean bed that is our cultural definition of gender. . . . Surgical and hormonal treatment allows parents and physicians to imagine that they have eliminated the child's intersexuality. Unfortunately, the surgery is immensely destructive of sexual sensation as well as one's sense of bodily integrity. Because the cosmetic result may be good, parents and physicians complacently ignore the child's emotional pain in being forced into a socially acceptable gender. The child's body, once violated by the surgery, is again and again subjected to frequent genital examinations. Many "graduates" of medical intersex corrective programs are chronically depressed, wishing vainly for the return of body parts. Suicides are not uncommon. Some former intersexuals become trans-sexual, rejecting their imposed sex. (Chase 1996)

By violating the "natural" body in their pursuit of a "socially normal" child, Chase contended, physicians and parents actually produce pathology.

Chase is a major protagonist in *Sexing the Body*, written by feminist biologist Fausto-Sterling (2000). She uses contemporary and historical biomedical scientific research on intersexuals and sexology to argue for multiple sex categories. Earlier, Fausto-Sterling (1993b) published a provocative op-ed piece in the *New York Times* proposing that humans should have

five sex categories rather than two. She argued that there is a physical continuity between the sexes of male and female, and rather than make bodies and persons fit into just two categories, male and female, she proposed that additional categories be embraced by medicine and society.[21]

ISNA, Dreger, Fausto-Sterling, and Kessler have made a difference. Intersexuals now have more support if they choose speak out about their physiologies. Physicians do not automatically perform surgery on infants with some conditions; parents are more involved in deciding whether or not to surgically transform infants with ambiguous genitalia into males or females (see, e.g., Navarro 2004). Nevertheless, two sex categories still dominate the choices and frames for physicians, parents, and scientists.

Transsexual Activism

In their debates about biology and sex identity, many transsexuals insist on dichotomies, but not those determined by anatomy or physiology. They argue that their bodies are not natural, that they "naturally" feel that they are members of the "opposite" sex. That which is usually taken as natural, the body, becomes unnatural, while that which is usually assumed to be socio-culturally produced, gender, becomes natural. In this way, they argue differently from Chase and others who use bodies and biology to argue against dichotomies. Some transsexuals argue against the male-female dichotomy and for a wide range of gender identities, but they also argue for the naturalism of gender (e.g., Roughgarden 2004). Other feminist writers have argued that body and behavior are not separate entities, that materiality and gender identity are co-determined (e.g., Butler 1993). They argue against trying to adjust the body to fit an ideal gendered identity and for the complex and varied possibilities of the body—for a transsexual

[21] On "third" sexes, see, e.g., Nanda (1989), who wrote on the Hijras in India, and Herdt ([1994] 1996) who wrote on Two-Spirit people in the U.S. (formerly called berdaches).

position that speaks from outside the boundaries of binary sex-gender.[22] Transsexuals, then, are not homogenous in their positions regarding sex-gender dichotomies and naturalistic explanations for gender and sex identity. Despite, or perhaps because of, this heterogeneity, transsexuals contest the simplistic sex-gender, natural-social dichotomies in ways that emphasize the discursive construction of bodies and identities.

ANALYSIS OF DATA AND DISCUSSION

What is sex? Will genetics be the final authority in answering this question? Sex gene experimenters have argued that "*SRY*" is an active element in the development of testes and that "*DAX-1*" is an active element in the development of ovaries. As stated earlier, to explain the ambiguities in *Sry* experimental outcomes on mice, some researchers have argued that, in addition to *Sry*, a cascade of other genetic and non-genetic factors and interactions are necessary to determine sex. But they do not question the assumption that testes indicate males and ovaries indicate females.[23] In contrast, some intersexual and transsexual activists, feminist theorists, and social scientists have contested this medical definition of sex. Although their definitions of sex are heterogeneous, transsexuals agree among themselves that possessing testes or ovaries does not determine their sex identities. Intersexual activists, biologist Fausto-Sterling), and psychologist Kessler use the existence of phenotypic features like ambiguous genitalia and reproductive organs as evidence that sex is not a male-female dichotomy.

Using feminist and social scientific perspectives in light of research on transgender social movements, I now present an analysis of two processes through which socio-cultural frames

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[22] See also Bolin ([1994] 1996), Bornstein (1994), Feinberg (1998), Stone (1991), and Stryker (1998). For a history of transsexuality, see Meyerowitz (2002).

[23] An exception is Blackless et al. (2000), who argue against binarism even at the level of chromosome composition, not just gonads and reproductive organs. Dewing et al. (2003) found differential gene expression between the developing brains of male and female mouse embryos and hypothesized that gonadal hormones may not be the only

entered into the design of the sex determination experiments I have presented above, and how these frames influenced the analysis of the resulting data.

Experimental Design: The "Normal" Defines the "Pathological" and Back

The *Sry* and *Dax-1* mouse experiments show that human and molecular geneticists used their own definitions of "normal" sex and "pathological" sex to design their scientific investigations. Despite their differences, both *Sry* and *Dax-1* researchers set up their initial experiments defining sex as a binary. They built this assumption into their experiments by choosing patients who presented themselves in the clinic with "non-standard" sex phenotypes. In the mid-1980s, Page's laboratory used DNA from XX male human patients who were impotent (Page et al. 198??). Koopman et al. (1991) began with sterile male human patients with XX chromosomes whose common gene was used to develop a transgenic mouse model. In the early 1990s, Camerino and her colleagues (Bardoni 1994, Zanaria 1995) used data from female human patients with a "working *SRY* gene" who exhibited varying degrees of "feminization."

These researchers' choices of patients for their studies set the parameters for their definitions of "normal" sex to be males or females who can heterosexually reproduce. The researchers would classify any variation from this to be pathological. However, as sociologists and historians have argued, classifications, categories, and taxonomies of scientific and medical knowledge, in particular, are produced within particular historical situations. Further, categories of normal/healthy and pathological/ill are historically co-constituted categories, defined only in relation to each other (Canguilhem 1978; Foucault 1970, 1978). There is no normal without a pathological, and vice versa. Foucault argued that such classifications and taxonomies of

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influence on male-female sex differences in brain development and behavior. This research should be carefully examined.

scientific and medical knowledge constitute a map of the power relations of the particular time period and also have the power to normatively govern the ways humans act and feel.

Biomedical categories and classifications, then, are not natural, value-free, or innocent. Sex categories, in particular, operate within socially prescribed systems of meaning. Human and molecular geneticists use their own socio-historically located normative definitions of sex to design their on sex determination. As a result, new molecular genetic experiments on sex determination do not challenge the previously determined socially defined categories. Instead, they *give material form* to socially defined ideas. By selecting particular human bodies in the design of their sex determination experiments, these geneticists have reproduced their own taken-for-granted categories of sex.[24]

The genetic experiments I have presented are producing particularistic, not universalistic, knowledge. However, because of the power held by science and medicine in our world, the two sexes—male and female—are once again rendered natural and original, this time through the *Sry* and *Dax-1* mouse experiments. However, power is a process that is never finalized. Just as feminists, queer theorists, and transgender activists are attempting to transform definitions of sex, this study challenges this power by showing how human and molecular geneticists insert normative societal assumptions into their scientific practices.

Experimental Data Analysis: In Search of the Male-Determining Gene

Sry mouse experiments incorporated yet another set of assumptions: They focused on the male determining factor rather than on the female. Hypothesizing that a gene common to XX men induced embryos to develop as males, the *Zfy* and *Sry* mouse studies were designed in an attempt to find that gene. The researchers found a version of that gene and inserted it into XX

[24] See Hacking (1992) and Fujimura and Chou (1994) on self-authenticating practices in laboratory sciences.

female mice to see of it would transform the females into males. When Koopman et al. (1991) produced a mouse with small penis, they concluded that they had found the male determining gene. They acknowledged that many more XX embryos had incorporated the *Sry* gene and developed as females rather than males, including one reproducing female that reproduced female offspring carrying the *Sry* gene. However, in their frame of reference—the focus on male sex determination—the researchers relegated the "female" *Sry* mice to the status of "anomalous" data and omitted them from their published conclusions.

The researchers' focus on finding male sex determinants is in line with the history of sex determination research. As stated earlier, it has been assumed that an embryo is "female" until something triggers a change, causing the development of male testes (Jost 1953). Thus, sex determination research has been structured to search for the determination of the male phenotype (Eicher and Washburn 1986). Eicher and Washburn (1986, 329) note that "the genetics of testis determination is easier to study [than ovary determination] because human individuals with a Y chromosome and no testicular tissue, or with no Y chromosome and testicular issue, are relatively easy to identify." [25]While some experiments have countered the idea of passive female sex development, the idea of active female sex development has not entered easily or consistently into the literature (Fausto-Sterling 2000, 346). The research of Camerino and her colleagues on *Dax-1* joins this minority tradition, although it still represents sex as a binary male-female dichotomy. The field of sex determination is dominated, however, by *Sry* research and continues in the vein of early twentieth-century ideas.

<u>Examining the "Awkward Surplus" from New Frames of Reference</u>

[25] This point further distinguishes Camerino's research on determinations of female sex.

The mouse studies of *Sry* employed new molecular transgenic technologies to investigate the details of sex development in mice. The introduction of these new technologies made new signals possible. These new signals could have led researchers to new insights about sex development. I show, however, that new signals read through old frames are not *seen*.

One fascinating aspect of empirical scientific research is its ability to surprise research with unanticipated results. Although philosopher and historian of science Thomas Kuhn (1962, 5–6) argued that the paradigmatic frame of normal scientific practice does not aim at novelty, and even suppresses it, he also acknowledged that it often yields "pre-novelties" in the form of anomalies. Kuhn also argued, however, that anomalies must be *recognized*—that is, recognized as new knowledge and not as errors or noise. Kuhn suggested that it is usually not the paradigmatic practitioners who recognize anomalies as novel, but instead it is the new generation of researchers, or even researchers from another field, who can see novelty because they are not immersed in the governing paradigm.

Anomalies can, in Kuhn's (1962) schema, lead to the production of both new knowledge and a new paradigmatic order, a new form of normal science. However, in Kuhn's discussion, the sources of the differences in perception required to recognize novelty remained within the science community, albeit in a different generation or discipline. Historian of science Nancy Stepan (1993) went beyond Kuhn to argue that paradigms are not just limited by a scientific community's set of theories and practices, but also by social and cultural metaphors. In contrast to Kuhn's intellectualist explanation that a paradigm changes with the accumulation of a critical mass of anomalies that cannot be explained by the paradigmatic frame, Stepan argued that it is often through social, political, or economic changes in society that both scientists and citizens come to see that cultural metaphors have governed how we perceive reality and that they no longer apply.

The data produced by the *Sry* and *Dax-1* mouse experiments, the questions raised about sex/gender by transgender and feminist activists, Kuhn's (1962) discussion of anomalies, and Stepan's (1993) revision of Kuhn's ideas together suggest that there may be "awkward surpluses" of data that tend to be ignored because they do not fit the frames of reference of their observers. The notion of awkward surplus also stipulates that the introduction of new frames of reference may illuminate results of experiments that have been ignored in the investigation's conclusions.[26] In this way, the concept of awkward surplus can aid in the rereading of experimental conclusions and thereby produce alternative interpretations with different social consequences.

Re-examinations of study results such as those presented here provide opportunities for natural scientists, social scientists, and other parties to attempt to work differently and collaboratively to produce new explanations. Using the notion of awkward surplus, social scientists and social activists can fill a role similar to that of scientists from another field, whom Kuhn (1962) saw as potential innovators—people who could see anomalies as sources of novel ideas and findings because they bring different assumptions to the table. With respect to the *Sry* and *Dax-1* studies presented here, I apply my knowledge and skill for understanding social frames of meaning to explore whether, when, where, and how these frames affected the researchers' scientific perception. As Haraway (1988) argued in her "situated knowledges," other actors with stakes in a problem should be involved in studying it.

In examining *Sry* experimental data, I "salvaged" the experimental results that sex gene researchers had first acknowledged and then chosen to ignore. That is, although the researchers (Koopman et al. 1991) noted that some mice did *not* perform according to their expectations,

[26] This use of "frames of reference" takes from sociologist Goffman's ([1974] 1986) argument that humans develop and use frames of interpretation to organize and make sense of the events, activities, and phenomena to which they

they failed to conduct further experiments to try to make sense of these anomalous results. Koopman et al. chose instead to continue to construct their follow-up experiments as if *Sry* caused maleness in mice. Their subsequent studies presented additional complexities and ambiguities that the scientists could not explain. One researcher, Camerino, continually referred to some of the results as "bizarre." Although some of the Koopman et al. scientists attempted iterations to make the results fit their original assumptions, these subsequent experiments did not answer their questions, and they decided to wait for "better" experiments. "Better," I argue here, refers to experiments that will yield results that make sense to them within their frames of reference.

After identifying an awkward surplus of results in the data, my next step was to explore new interpretations. By reviewing the data without thinking about sex as a binary category, I saw that the last fifteen years of research on *"SRY"* and *"DAX-1"* have provided much evidence for *complexity* in the genetics of sex determination. Recent experiments have raised the possibility of a proliferation of genes in promoter regions of the chromosome, of structural genes, of different forms of proteins being produced by the same gene, all of which complicate the question of sex determination. There is by now a long list of genes suspected of being involved in sex determination, and this list grows longer every year. If we also consider the interactions among these genes, sex determination at the genetic level is steadily increasing in complexity. When we add the interactions of genes with various proteins, developmental pathways, cell signaling pathways, and many other parts of cellular, organismal, and environmental parts and processes that are fast becoming the territory of a new field call "systems biology" (Fujimura 2005), the complexity of sex determination escalates even more.

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attend in everyday life. Goffman's frames allow us to think of scientists as acting through their formal and tacit scientific training and also through their socio-cultural contexts and experiences

A key characteristic of complexity is *instability*. Using a term first developed in the field of prokaryotic genetics, human geneticist Camerino (Goodfellow and Camerino 1999) argues that sex determination is "leaky," meaning unstable or not strongly determined. That is, there is no single pathway through which sex is genetically determined. Indeed, there may be many pathways with multiple different genes involved in each pathway. And although Camerino believes that there is a hierarchy of pathways with "*SRY"* and "*DAX-1"* involved at the top of the hierarchy, this argument must be verified.

In contrast to the geneticists' view, I suggest that a feminist, social scientific, or transgender analysis might consider the many sex variations as resulting from multiple developmental pathways that involve genetic, protein, hormonal, environmental, and other agents, actions, and interactions. These variations need not be represented as outliers, residuals, anomalies, or pathologies in a binary system. Instead, a reanalysis of *Sry* and *Dax-1* mouse research shows that genetics can produce phenotypic variations suggesting that sex is a fluid concept, not a binary concept incorporating only the conventionally gendered sexes of "male" and "female."

In summary, the concept of awkward surplus is useful, first, to help us attend to unanticipated results that are recognized as problematic or awkward by experimenters, and are thus ignored. Second, the concept provides an opportunity to re-examine unexpected experimental results either by using different frames or perspectives or in conjunction with data from other sources. Third, the examination of awkward surpluses provides a space where scientists and social scientists can work together in the production of new knowledge.

Who Adjudicates the Awkward Surplus?

In addition to the interpretations of geneticists in the original *Sry* mouse study (Koopman et al. 1991) and of my reanalysis, there may be other interpretations. The designation of awkward surplus and possible multiple explanations of what the awkward surplus means raise other epistemological and methodological questions. How do we decide which interpretations are valid? If prescribed systems of meaning frame our very perceptions of matter, is my alternative interpretation not just as situated in particular socio-cultural assumptions as those of the biologists I study? With respect to the concept of awkward surplus in particular, how do we adjudicate whether an awkward surplus provides useful or useless information? And who should adjudicate?

Answers to these questions in the social studies of science, medicine, and technology are many and are heatedly debated. Some science studies scholars argue that that our job is not to decide what is valid knowledge but to study how each possibility fares in the struggle for scientific authority. These scholars prefer to descriptively analyze scientific practice and struggles for authority without taking normative positions on knowledge outcomes (e.g., Lynch 2001). However, other science studies have also shown that many non-scientists have already intervened in the making of science. Religious groups have asserted their agendas, sometimes supporting the programs of particular scientists (Shapin and Schaffer 1985) and sometimes intervening against the programs of particular scientists through control of research funding processes of government agencies such as the NIH and NSF (Borenstein 2004). Private industrial concerns have inserted their agendas through their in-house research or through institutional funding of research in private institutes and research universities (Krimsky 2003). Governments have also selectively influenced the development of scientific knowledge in particular directions (Eden DATE, MacKenzie DATE). Beyond these overt exercises of political power in the making of knowledge, social studies of science have demonstrated the introduction of political and

cultural agendas into scientific research through subtle and unintentional processes. Indeed, as Gould (1981), Stepan (1993), and Hall (1976) argue, throughout history it has been difficult to separate scientific efforts from commonly accepted cultural knowledge.

Given the past and present roles of power and partiality in the production of knowledge, feminist scholars of science in particular argue that science analysts should play a part in the struggle for authority by taking positions and supporting some knowledge claims over others. Haraway (1988) argues that those who have the greatest stakes in a knowledge claim should act collectively to produce that knowledge. Harding (1998) has provided epistemological arguments for the production of new kinds of knowledge by participants different from professional Euro-American scientists. Scientists themselves take heterogeneous positions. Some argue that science should police itself, while others argue that there is a place for non-scientists in scientific knowledge production.

However, the epistemological frames of Haraway (1988) and Harding (1998) still leave us with the questions of who qualifies as a stakeholder in a particular problem and of how those stakeholders who are not professional scientists can participate in the making of science. For instance, the Bush Administration's conservative religious policymakers and backers argue—and have acted upon the view—that they have a stake in scientific research. They have taken up positions on stem cell research and influenced NIH decisions about which projects to fund. In the case of sex-determining gene research, I argue that intersexuals should have some authority in the making of knowledge of sex. However, the Bush Administration could similarly argue that the religious ultra-right should also have a place at the table. Is adjudication possible, or is it simply a battle of wills and power? In the battle of power-knowledge (Foucault DATE), barriers to participation are usually high.

The problem of who should and can authorize science is a question that appears to be answerable only historically (e.g., Fujimura 1998). Nevertheless, some science studies scholars are attempting to wrestle with this problem in epistemological terms (e.g., Barad 1998; Haraway 1988; Harding 1998; Longino 2001), practical terms (e.g., Rosser 2000), and policy terms (e.g., Jasanoff 2000).

A Critical Socio-Material Approach

This analysis of sex determination research demonstrates the critical socio-material approach to the study of science, a theoretical approach that incorporates ideas and lessons from feminist theory and the social studies of science. I have included an analysis of science that incorporates the socio-cultural frames of reference of researchers who have stakes in and perspectives on a particular scientific problem. I call for social scientific or feminist analyses of science to include an examination of the production of the materiality that supports scientific claims. I propose that feminist social scientists and activists should include the exploration of the materiality of sex in their analyses. The biology of sex is too important to leave to geneticists alone because they usually are not trained to attend to and analyze how socio-cultural frames influence their own experimental processes. This critique is exactly what feminist, social scientific, and humanist analyses can provide. Their different frames of reference may suggest new interpretations of evidence and even new experimental designs.

The methods for analyzing the material production of science include: (1) reading research articles in search of data that could be meaningful in a frame or context of analysis different from that of the original experimenters, and/or (2) observing scientists at work producing scientific knowledge in the laboratory or the field, and (3) identifying and examining awkward surpluses of data that do not fit within the researchers' frames of reference, and finally,

(4) this analytical approach requires an epistemological argument for the claims made in the new analysis and a discussion of the proponents' stakes in their role as knowledge-makers.

CONCLUSION

I have employed a critical socio-material approach to re-examine scientific mouse experiments on sex determining genes, especially *Sry* and *Dax-1*. I have provided a critique of the investigations and an analysis of some of the investigators' "awkward surplus" data. This approach to science incorporates theoretical efforts to move beyond reading society onto nature and reading nature onto society. It does not impose sociological categories onto the natural sciences, nor does it impose biological categories onto the social sciences. Instead, it argues for a collaboration that gains from different expertises.

The results of this re-examination demonstrate that the design and analysis of molecular genetic experiments are inhabited by socio-cultural meanings and understandings. In the case of genetic sex determination, scientists used the social categories of "normal" males and "normal" females to design their experiments and protocols, and they reproduced these categories in their experimental processes.

My re-examination of research in sex determination also shows an awkward surplus of data that researchers ignored in their conclusions from the *Sry* mouse experiments. They did not view some experimental results as "findings" because they did not fit their cultural expectations.

In contrast, from the perspective of feminism and social science as well as research on transgender movements, I suggest that these residual data provide significant information on the actions of sex genes. Instead of viewing the results as "bizarre," I suggest re-interpreting the residual data to illuminate genetic instability (leakiness) and possible multiple pathways of sex development as explanations for the variations in body phenotypes that do not fit the binary

male-female norms. *Sry* and *Dax-1* mouse experimental results that fall outside the experimenters' frames of reference may be legible within other frames. Sex may be highly variable and more fluid than geneticists (and many of the rest of us) anticipate.

I argue for the examination of the awkward surplus in scientific data as a valuable research tool. Reconsideration of data and conclusions would use frames of reference different from those of the original experimenters. For example, social scientists, using knowledge of social movements (feminism, gay/lesbian movements, queer theory, intersexuals, and transsexuals) and social and cultural theory, literally may be able to *see* data differently in the work of geneticists and other scientists in the production of the science of sex.

Further, the concept of awkward surplus and its re-examination provide science studies with a way of engaging with materiality that does not deny human mediation but also acknowledges material agency. Even within the cultural framing of understandings of nature in a particular time period, we find biological outcomes that stand clearly outside scientists' abilities to control or explain them. The concept of awkward surplus provides a theoretical and methodological framework for thinking about anomalous results when meaning has not quite become fixed.

Awkward surplus is also useful for thinking about how feminist and other social theorists and activists can participate in creating knowledge about materiality. The work of transgendered activists and some feminist theorists to promote the acceptance of variations in bodies and the "normalization" of their own bodies can be useful in the production of molecular genetic research. Scientists, too, must have an opportunity to cross the divide. They can use the work of feminist, queer theorists, and transgender activists to think creatively about their own research surplus and their accepted protocols for producing knowledge. The awkward surpluses of

scientific data indicate complexities that fall outside the structures of scientific paradigms and some social frames of meaning.

With respect to sex itself, these readings of novel data suggest that the variations in and complexities of sex development raised by feminist analysts at the levels of human behavior, bodies, hormonal systems, embryos, cells, and chromosomes are replicated at the level of genes. Sex, even at the genetic level, is a socio-material process and product.

Given this conclusion, my study of the production of the materiality of sex joins arguments in feminist studies for the collapsing of the sex-gender(qua biology-society) distinction. Instead of treating sex as biological and gender as social, I argue that sex, like gender, is a socio-material product. Sex-determining gene research and the political actions of transgendered activists introduce moments of ambiguity and transgression that disturb the dichotomies of male-female, sex-gender, and nature-culture. Highlighting the social aspects of sex contests assumptions about gender and about sex, and thereby the sex-gender split.

My investigation is an argument for broadening our social imaginaries—our definitions and understandings—of the material, the natural. A critical socio-material view of sex integrates socio-cultural and historical investigations of the production of the material (e.g., the complexities and variations of sex physiologies and genetics) with diverse social imaginaries about sex and bodies proposed by feminists, queer theorists, intersexuals, and others. In this approach, we study and juxtapose the actions and interactions of social activist groups, social theorists, biologists, bodies, and genes in order to understand the collective, contentious, contradictory, and interactive crafting of sex in humans.[23]

I do not mean to argue that the “natural” should be the foundation for substantiating, explaining, or changing existing gendered arrangements in society. Social imaginaries should be enough for promoting an acceptance of diversity. Historical examples of efforts to use natural

differences to justify social hierarchies provide yet another reason for eschewing biology as foundational for social practices. The recent rise of evolutionary psychology is the latest in such efforts to produce natural arguments for social practices and hierarchies.

Nevertheless, demonstrations of the socio-material production of sex, the Mobius strip production of sex, are useful for maintaining our awareness that "natural" categories are also "social" categories. Further, even as our current language of analysis maintains the division between the natural and the social, the point of a critical socio-material approach is to move in the direction of a language where there is no division, where we are always conscious that the natural and the social are not separated.

For example, we need to think of the categories "male" and "female" not as representing stable, fundamental differences, but as already and always social categories. They form *a* set of concepts, a set of social categories of difference to be deployed for particular purposes. Ergo, what counts as male and female must be evaluated in their context of use. The categories "male" and "female," like "men" and "women," may be useful for organizing particular kinds of social investigation or action, but they may also inhibit actions.

A critical socio-material approach that joins awkward surpluses from the laboratory with the experiences of people in the world opens up opportunities to challenge the taken-for-granted scientific categories that help to construct or maintain definitions of similarity, difference, and pathology. This is particularly important today when new biotechnologies are being used to link disease and behavioral genes with particular social categories of race and ethnicity.

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