Forthcoming in *Biology and Philosophy*
Preprint (not copyedited or formatted)
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# Sex By Design: A New Account of the Animal Sexes

Maximiliana Jewett Rifkin
Department of Philosophy
The Graduate Center, City University of New York
365 5th Ave., New York, NY 10016, United States
mrifkin@gradcenter.cuny.edu

and

Justin Garson
Department of Philosophy
Hunter College and The Graduate Center, City University of New York
695 Park Ave., New York, NY 10005, United States
jgarson@hunter.cuny.edu

**Abstract:** What is it for an animal to be female, or male? An emerging consensus among philosophers of biology is that sex is grounded in some manner or another on anisogamy, that is, the ability to produce either large gametes (egg) or small gametes (sperm), though the exact nature of this grounding remains contentious. Here we argue for a new conception of this relation. In our view, one's sex doesn't depend on the kind of gamete one is *capable* of making, but on the kind of gamete one is *designed* to make, where design is understood in terms of an evolutionary or ontogenetic selection process. Specifically, we argue that what it is to be, say, male, is to have a part or process that has the (proximal or distal) biological function of producing sperm. We outline and defend our view, and sketch some implications for scientific and social problems related to sex.

**Key Words:** Sex, anisogamy, design, biological function, explication

**Acknowledgements:** We're grateful to Harriet Fagerberg for feedback on an earlier draft.

## Sex By Design: A New Account of the Animal Sexes

**Abstract:** What is it for an animal to be female, or male? An emerging consensus among philosophers of biology is that sex is grounded in some manner or another on anisogamy, that is, the ability to produce either large gametes (egg) or small gametes (sperm), though the exact nature of this grounding remains contentious. Here we argue for a new conception of this relation. In our view, one's sex doesn't depend on the kind of gamete one is *capable* of making, but on the kind of gamete one is *designed* to make, where design is understood in terms of an evolutionary or ontogenetic selection process. Specifically, we argue that what it is to be, say, male, is to have a part or process that has the (proximal or distal) biological function of producing sperm. We outline and defend our view, and sketch some implications for scientific and social problems related to sex.

### 1. Sex and anisogamy

Take an individual of any animal species you like, assuming that the species in question has some female and male members. What is it for an individual of that species to be, say, male? We'd like to answer this question in a way that doesn't depend on which species you choose.

One motivation for asking this question is that it arises, quite naturally, from some of the core explanatory goals of evolutionary biology. One of the outstanding questions of evolutionary biology is why sexual reproduction evolved at all from the asexual condition of our earliest ancestors. To explain this phenomenon, it would be helpful to have a perfectly general definition of the sexes: males and females. While we're restricting our discussion to animal kinds, rather than plant or fungal kinds, we suspect that our view will be relevant to thinking in those areas as well.

Here are some answers to the question of what it is to be male that *cannot* be correct. First, being male cannot be the same as having a penis. Most birds and fish do not have a penis. Intriguingly, in barkflies, the female has a protruding genital, called a "gynosome," which she inserts into the male to collect sperm. Moreover, some males can lack a penis through accidental damage. Second, being male cannot be the same as having the XY chromosome. Male alligators do not have sex chromosomes at all. Their sex is determined by the temperature at incubation. Third, it cannot be having a large amount of testosterone cycling through one's body. Male hypogonadism is a condition in which a male infant produces far less than the average amount of testosterone.

Some theorists despair of finding a general answer to this question at all. For example, Anne Fausto-Sterling (2012) argues, on the basis of such examples, that there is no such thing as sex *simpliciter*. Rather, we must decompose sex into numerous variables (gonadal sex, genital sex, hormonal sex…), which can be mixed and matched in any individual (also see Dupré 2017). In a similar vein, Sarah Richardson (2022) argues that there is no single, universal definition of, e.g., maleness, but that scientists must "operationalize" maleness in different ways in different research contexts. In some contexts, maleness will be operationalized in terms of hormones; in others, genetics; in still others, behavior.

We think such despair is premature. Instead, we align ourselves with those philosophers of biology and other theorists who think sex is grounded, in some manner or another, in the phenomenon of anisogamy (Roughgarden 2004, p. 23; Griffiths 2020; Khalidi 2021; Franklin-Hall 2021). This is a very standard view in the sexual selection literature (Zuk and Simmons 2018; Ryan 2018).

Most sexually reproducing species are anisogamous. This means that members of the species can produce two very different sorts of sex cells (gametes): egg or sperm. One of the most remarkable differences between human sperm and egg is their size difference: a human egg is about 100,000 times larger than a sperm. They also differ in shape and function.

Not all sexually reproducing species are anisogamous. There are some species, mostly unicellular, that are isogamous: they use sexual reproduction but their sex cells are fairly uniform in size. Interestingly, biologists do not partition such species into male and female, but into different "mating types." This is a mark of how deep the understanding of animal sex in terms of anisogamy runs in biology.

To the extent that one believes that biology has some special authority to shape our ontology of sex – for example, the way that biologists talk and think about sex should inform our understanding of what animal sex is – then anisogamy seems to be the correct starting point. Of course, not everyone accepts that biology has any special authority to shape our ontology of sex.

Even if we agree that anisogamy is the right starting point for thinking about the animal sexes, there are still open questions about how, precisely, an animal's sex relates to anisogamy. The most simple and obvious theory is that *all it is* to be female is to be able to produce eggs, and *all it is* to be male is to be able to produce sperm. An animal that can produce both eggs and sperm would be both male and female, or hermaphroditic. We'll call this the "simple starter theory of sex." Versions of the theory have been advanced by Roughgarden (2004), Griffiths (2020), and Khalidi (2021).

The simple starter theory, however, can't be correct, for reasons that are widely acknowledged. First, on this theory, people who are infertile for life would be neither male nor female. Second, postmenopausal females would not actually be female. Third, juvenile males would not actually be male. The problem with these consequences is not just that they're "counterintuitive." We have no interest in basing our argument upon the "dull thud of conflicting intuitions," as Bigelow and Pargetter (1987) so memorably put it. Rather, we think this conclusion contravenes ordinary biological usage – the very usage that the theory is trying to capture. We think an account of sex that does not have these consequences is, all things equal, preferable to one that does.

Moreover, we do not accept a graduated conception of sex that treats *fertile* males and females as something like the "paradigm case" of maleness or femaleness, and postmenopausal females, or juvenile males, as marginal or borderline cases. We don't believe that fertility somehow enhances the degree to which one possesses the property of being male or female, or that a postmenopausal female is female only in a derived or secondary manner. After all, in each of these cases, there remain biological elements of anisogamy.

The problem for us, then, is to figure out how to respect the role of anisogamy in defining sex, while expanding the inclusion criteria for being female or male. Put differently: how should we ground maleness or femaleness in anisogamy while avoiding the pitfalls of the simple starter theory? We think the missing ingredient here is *design*.

We find it surprising that the (admittedly colloquial) concept of design has rarely surfaced in philosophical discussions of sex, partly because of how ubiquitous the concept of design is in thinking about the living world. Often, to say that a body part or process is "designed" to do such-and-such is to say that it is an adaptation for such-and-such. To say that the female barkfly's gynosome is "designed" for collecting sperm is to say that it is an evolved adaptation for collecting sperm. And Darwin's great achievement in biology is often described in terms of showing how there can be "design" without a "designer."

Even without further elaboration, the design criterion seems to avoid the pitfalls of the simple starter theory. First, it implies that postmenopausal females are, in fact, female, because they are designed to produce eggs. It implies that juvenile males are males, because they are designed to produce sperm. Of course, this immediately raises the question of what it is for an individual to be designed to produce eggs or sperm, and whether design can be treated as anything but a colorful metaphor. Following thinkers such as Kitcher (1993), Allen and Bekoff (1995), and Neander (2017), we explicate design in terms of selection history (see Section 3). In our view, what it is to be, say, male, is to have a bodily part or process that has the (proximal or distal) function of producing sperm.

A handful of theorists have suggested, in a rather vague or passing way, that one might define sex in terms of function, design, or other teleological considerations. Bogardus (2020, 875) in a footnote (fn. 5), notes that the standard biological definition of sex in terms of anisogamy could import "teleological notions of proper function" to help us make sense of the possibility of an infertile female or male animal. Garson (2022, 175) writes, "What makes an individual female or male depends on what sort of sex cells ("gametes") they are designed to produce: egg or sperm." Yet these earlier works fail to develop such a view rigorously, defend it from obvious objections, or work out its potential implications for important scientific and social problems.

Before setting out our view, we hasten to add a few qualifications:

First, we do not make the manifestly false claim that all individuals that belong to a sexually reproducing species are either exclusively male or exclusively female. There are hermaphroditic animals, both simultaneous (having both sexes at once) and sequential (changing sex over the course of one's lifetime). The claim that sex can be understood in terms of anisogamy does not commit one to the view that animal sexes are "binary" in this way. As we will discuss in section 5, we do not believe that sex is binary in *Homo sapiens*.

Second, our main intention is to offer a theoretical definition of sex (e.g., water is H2O) that explicates the simpler notion biologists have of anisogamy, rather than a descriptive or ameliorative analysis. We want to know the actual referent of "sex," when used in a biological context, in our world. We don't believe that our definition is suitable as a general descriptive analysis of "sex," given that many people in the world do not know what anisogamy is, and given that we are slightly revising the biologists' ordinary concept. Nevertheless, we do think obtaining a clear theoretical definition of sex is a good starting point for those who wish to pursue ameliorative projects, especially given their commitment to descriptive accuracy (Novaes 2020).

Third, questions about what sex a person is must be divorced, sharply, from questions about what benefits, rights, and privileges they should have in society. We think biological theories are shaped by evidentiary considerations. But because of how science is embedded in social contexts, we have to think carefully about social uptake. We think that reflection on biology is consistent with progressive social politics. This has real implications for marginalized groups. Attempts to recruit biology to disenfranchise trans* people, who have gender identities different from their assigned sex, are not supported by biology.

Fourth and finally, the question of what male and female are is quite different from the question of defining the terms "woman" and "man." We don't take a stand on the latter question here, though we're sympathetic to the contextualist view advanced by Jennifer Saul (2012), and to intersectional approaches advanced by transfeminists (Bettcher, 2015). We do however believe it is imperative to respect every person's first-person authority over their identity (Bettcher 2009), and that people should use gender terms on the basis of consent (Barnes, 2020).

## 2. Some alternative accounts of sex

Here, we briefly describe three alternative biological accounts of sex, and show where our view parts ways with them.

### *Franklin-Hall*

Franklin-Hall's (2021) account of sex is rather complex. She thinks that the sex of an animal is only indirectly linked to gamete size. What makes an individual male, say, is not that it produces small gametes. It has to do with the fact that its reproductive traits (say, its testes) are the outcome of a certain developmental process.

Specifically, for an animal to be male, the developmental process that causes it to have male reproductive organs (sometimes called the Wolffian pathway) must be a direct lineal descendent of the (very ancient) developmental process that took place in our earliest sperm-producing ancestors (p. 188). The core benefit of the view is that it restores a certain amount of explanatory power to animal sexes. When I designate an animal as "female," I am pointing to a developmental process that gives rise to a number of coordinated and sex-typical characteristics.

One aspect of Franklin-Hall's view that we largely endorse is that sexes are historical. To say that a property is historical just means that, to possess that property, an individual must have the right history. The property does not entirely supervene on current-day causal powers. Being a sibling, or being an adaptation, are historical properties. Being male, or being female, is also a historical property.

In our view, design is an intrinsically historical notion. What it is for an organism to be designed to produce eggs, rather than sperm, is to possess a part or process the biological function of which is to produce eggs, or sperm. Whether or not a bodily part or process has the biological function of producing eggs, or sperm, is determined by its selection history, a point we will elaborate in Section 3.

One difference between Franklin-Hall's view and ours is that we do not tie one's sex quite as directly to ancient evolutionary history as she does. In our reading, the notion of design is more flexible. Design can refer not only to the products of evolutionary natural selection, but also to the things that human beings make and produce, or more generally, the ways that we transform the living or non-living world. For example, someone who plays Tetris every day is literally, through a process of trial-and-error, redesigning parts of their brain to be good at Tetris. As we will explain in Section 5, our view leaves open the theoretical possibility that a human being might literally change their sex, by virtue of the intentional design modifications they make to their bodies.

Another difference between Franklin-Hall's view and ours worth highlighting is that we do not think the animal sexes lack any intrinsic, synchronic properties. Following Khalidi (2013, 271-2), we think appealing to historical *and* intrinsic properties better explains the causal origin of biological kinds and the developmental trajectory of their members. In our view, part of what makes an organism male is that it presently has parts or processes with the function of producing ova or sperm. These parts and processes are intrinsic, synchronic properties of males and females that (ordinarily) realize these functions. But the presence of these intrinsic properties in males and females and the specific function they realize is ultimately to be explained by a causal historical process of some kind (Otto 2009). Hence, we think including synchronic, intrinsic properties in our ontology of sex in addition to historical properties is important for explaining both the phylogenetic origin and ontogenetic development of the animal sexes as we understand them. That said, we don't think males and females are best identified by the specific intrinsic, microstructural properties that realize their reproductive function or by the specific phenotypical properties those functions yield. Rather, like other functional kinds, we think the animal sexes are best identified by having the function to produce eggs or sperm.

### *Griffiths*

Griffiths (2020), as we noted, initially defines sex in terms of the ability to produce certain kinds of gametes: "Males produce small gametes, and females produce large gametes." He then points out that, on this definition, not all individuals within a sexually-reproducing species will have a sex. For example, he suggests that sterile worker bees are not really female, since their genomes are designed to terminate ovary development before they can reproduce. As he puts it, "there is a human imperative to give everything a sex…but biology doesn't share it." Biology admits some gaps or lacunae, and we just need to get comfortable with that fact.

We think his account takes a more questionable turn when he applies the same lesson to "juvenile organisms and postmenopausal females." That suggests that he does not think, say, a male infant is really male or a postmenopausal female really female. Are these just more examples of the sorts of gaps and lacunae that the biological world admits? This conclusion, we think, violates the ordinary biological usage of “sex” – the very usage it seeks to explicate.

He briefly suggests an amendment to his original theory to avoid these problematic implications. Instead of one’s sex being determined exclusively by the *ability* to make certain gametes, he suggests that it can also be determined by the fact that one will grow into an individual who is able to make certain kinds of gametes: “After fertilisation, therefore, we can say that an individual mammal or bird has a sex in the sense that it has started to grow the ability to produce either male or female gametes.” We imagine that he could, by a similar maneuver, avoid the implausible consequence that postmenopausal females are not really female: a postmenopausal female has a sex in that it once possessed the ability to produce gametes. Yet his view would still have the dubious consequence that an individual who is infertile for their entire life does not have a sex.

Our view does not face any of these implausible consequences. On our view, a prepubescent male animal is male not because it will grow up to produce sperm, but because its body is designed to produce sperm. We also believe that postmenopausal females are female by virtue of the fact that their bodies are designed to produce eggs. We will return to this central point in Section 3 below, where we introduce a specific naturalistic account of what it is for one’s body to be designed to produce eggs or sperm. By “naturalistic,” we just mean one that only deploys concepts and constructs that have a respected role within the contemporary natural sciences.

### *Fausto-Sterling* & *Richardson*

A third approach is Fausto-Sterling’s (2012) pluralistic approach. As noted above, Fausto-Sterling despairs of finding any core biological trait that all and only male animals share, and another that all and only female animals share. Instead, to acknowledge the diversity and variety of manifestations of sex, she recommends decomposing sex into different variables, such as hormonal sex, genital sex, and gonadal sex, which can be combined in different ways in different individuals.

Our view is that, despite the plurality of indicators that scientists use to infer what sex an organism is, there is a non-trivial, overarching phenomenon that biologists in different research domains are tracking together. We think the various aspects of sex Fausto-Sterling identifies – genital sex, hormonal sex, and gonadal sex – are best seen as empirical (and defeasible) indicators of that overarching phenomenon. We agree entirely with her, however, that the sex of an individual is not always determined by their genes, but by epigenetic factors as well. (For example, the sex of alligators is determined by incubation temperature, rather than sex chromosomes.) So, nothing in our conception of sex implies the simplistic genetic reductionism that she rightly rejects.

Richardson (2022) takes a slightly different approach from Fausto-Sterling, in that she moves away somewhat from the metaphysics of sex into an examination of how sex is operationalized differently in different scientific contexts. As she describes it, “sex contextualism is the view that the definition of sex and sex-related variables, and whether they are relevant in biomedical research, depends on the research context" (p. 9). For example, a group of researchers studying infertility is going to operationalize sex differently than a group of researchers studying the genetics of sexual differentiation. We agree entirely with Richardson that sex must be operationalized differently in different research contexts. But we don't believe that this indicates that "sex" itself is ambiguous – any more than the fact that we can operationalize length in various ways implies that the term "length" is ambiguous.

## 3. Sex, design, and biological function

On our view, the sex of an individual does not depend on disposition, but design. What makes an individual male is not that it has the capacity or disposition to produce sperm, but that it is designed to produce sperm. We realize that "design" is often used metaphorically. The question, then, is how to cash out this notion of design in naturalistic, non-mysterious terms.

The most obvious way to understand what it is for an individual to be designed to produce sperm is in terms of *the possession of parts or processes the biological function of which is to produce sperm*. Having testes is a way of possessing a part that has the (proximal) biological function of producing sperm. Having an active copy of the *Sry* gene is another way of possessing a part that has the (distal) biological function of producing sperm. So, having an active copy of the *Sry* gene is a sufficient condition for being male, but it is not necessary.

Putting the account as concisely as possible, we suggest the following (taking *X* to be an individual animal):

> *X* is female iff *X* has biological parts or processes that have the (proximal or distal) biological function of producing eggs.
>
> *X* is male iff *X* has biological parts or processes that have the (proximal or distal) biological function of producing sperm.

Of course, nothing in our account precludes sequential hermaphroditism (an animal changing its sex over the course of its life) or simultaneous hermaphroditism (an animal having both sexes at once). Moreover, by "producing eggs" we refer to the ovary's function of maturing eggs from the oocyte to the ovum stage, not to the initial fetal production of oocytes.

Obviously, the plausibility of our definition requires an equally plausible notion of biological function. Taking our cue once more from the idea of design, we think that function is an essentially historical property; specifically, we will understand it in terms of selection history. We think an individual is male if and only if that individual has a biological part or process that was *recently selected for producing sperm*, by evolutionary natural selection or some comparable selection process. We are open-minded about the prospect of defining "sex" in terms of function, but using some other notion of function instead, such as a goal-contribution or causal role account. We think, however, that trying to define "sex" by using an ahistorical notion of function faces special challenges.

In particular, the selected effects theory permits a strict separation between what it is for a trait to *have* a function and what it is for the trait to be *able to perform* that function. For the concept of function to expand the inclusion criterion for maleness or femaleness beyond the mere capacity to produce sperm or eggs, its definition must allow for the possibility that something can have a function yet fail to perform that function. Goal-contribution and causal-role accounts, because of the way that they tie the possession of a function to the ability to perform a function, are somewhat more problematic on this account, though we don't wish to discount such views entirely (see Kingma 2015 and Garson 2019, Chapter 8, for discussion of whether the standard goal-contribution account can make sense of dysfunction or malfunction). We also think that a historical notion of function allows us to draw principled distinctions between parts and processes that merely enable versus realize the function in question. For example, while the heart enables the production of sperm, it lacks the distal function to produce sperm because it was not selected for it in our evolutionary history. It's an open question whether other notions of function can plausibly make this distinction, and we are similarly open to that possibility.

Let's consider three examples of how our approach to sex deals with our "problematic" cases:

> *Example 1.* Suppose a male animal has undescended testicles, which causes it to be infertile for life. In this case, this individual is still male, because it has a biological part or process (testes) that has the (proximal) biological function of producing sperm.
>
> *Example 2.* What if a female animal has her ovaries removed? Then it would seem that it lacks a part or process that has the (proximal) biological function of producing eggs. In this case, however, since it still has, say, hypothalamic estrogen receptors, then it has a biological part or process that has the (distal) biological function of producing eggs.
>
> *Example 3*. What about postmenopausal female mammals? Much the same can be said here. On our account of function, the ovaries, by virtue of their selection history, possess the function of producing eggs. As we will argue in the next section, this is true even in postmenopausal females. The same can be said for the testes of juvenile males.

We close this section by summarizing four core virtues of our account of sex. The first, and most obvious, is that it respects ordinary biological usage while avoiding the problematic consequences of the simple starter theory.

A second virtue of our view is that it shows how there can be numerous empirical indicators of sex that are not identical to sex, such as an individual's chromosomes, external genitals, or sex hormones. All of these are valid empirical indicators of what sex an individual is insofar as they constitute evidence of design. On this point, we agree with Richardson (2022) that different research programs can, and should, operationalize sex in different ways, since there are many different empirical indicators of sex. Our view shows how recognizing the plurality of indicators of sex is consistent with sex being a single, overarching phenomenon.

Third, the claim that the sex of an individual depends upon which gamete they are designed to produce coheres well with biological thought about the nature of the animal sexes. As we have noted, many theorists have sought to understand the sexes in terms of anisogamy. Moreover, teleological concepts such as design, purpose, and function have always played a major role in biology. Despite attempts during the scientific revolution to expunge teleological concepts from biology, they have proven to be extremely stubborn. As a consequence, many thinkers have sought to deploy evolutionary reasoning to vindicate teleological concepts, rather than to expunge them (see Lennox 1993). Our view draws both of these themes together (design and anisogamy) into what we see as a compelling picture.

A final virtue of our account is that it does *not* attempt to specify the mechanistic details that make an individual male, female, or hermaphroditic. Our view is that, as philosophers, we aren't the ones who should be specifying those details – scientists are. One way to appreciate our ambition in this paper is to consider the difference, which Ross (2021) brings into sharp relief, between mechanisms and pathways. We think mechanisms are useful for thinking about individual species, because they provide species-specific details about how a shared pathway is realized. In contrast, we view pathways as useful for thinking about multiple species, because they home in on a shared process that occurs, albeit often in different ways, across all of them. Accordingly, our account need not specify the mechanistic details of how the males and females of each species actually produce sperm and eggs; it need only point out that the male and female pathways are widely shared, and that the shared pathway is explanatory.

## 4. Two objections

There are two main objections we want to respond to. The first was driven home to us by an anonymous reviewer. Is it truly the case that a body part or process, such as the ovaries or testes, retain their function throughout the entire lifetime of the individual? Isn't it more plausible to say that, at menopause, the ovaries *lose* their function of producing eggs? Or that, at puberty, the testes *gain* their function of producing sperm?

At first, we reasoned in the following way. According to the selected effects theory of function, which we accept, functions attach first and foremost to *types* of traits, not token traits. It is first and foremost the type (ovary) that has the function of producing eggs, because it is that type of trait that underwent a historical selection process. A token ovary has the function of producing eggs by virtue of its membership within the relevant type (Neander 1991; Neander and Rosenberg 2012). As a consequence, any token ovary, by virtue of its type membership, will have the biological function of producing eggs. It seemed to us that the selected effects theory implies that, as a rule, functions "adhere" to traits for the duration of an individual's life.

But this line of reasoning is problematic. The mere fact that the function of a token trait is derived from the function of the type doesn't, by itself, imply that the token must possess one and the same function over the entirety of its existence. Couldn't a trait's functions change over the course of one's lifetime? Consider the *Sox9* gene. In very early embryonic development, activation of the gene supports neural migration; around week 8 in humans, it serves, in males, to promote testes development. Nothing in the selected effects theory forbids us from saying that a trait can gain or lose functions during its lifetime.

Why, then, shouldn't we say that the human ovaries have the function of producing eggs until menopause, at which point they lose that function? But if they lose their function, then we are back to the implication that postmenopausal human females (and we should add, killer whales and short-finned pilot whales) are not "really" female. These considerations are strengthened when we observe that menopause itself may be a designed feature of the human body rather than a byproduct of senescence or a malfunction (e.g., Hawkes et al. 1998). Similar considerations could be raised for the testes of juvenile males.

One might think that, even if we accept that the ovaries of a postmenopausal female have lost the function of producing eggs, that alone wouldn't jeopardize that individual's status as female. That's because that individual still has other parts such as the XX sex chromosomes. But of course, one might run the same argument for any bodily part or process you choose. Why say that the sex chromosomes of a postmenopausal female still have the (distal) function of contributing to egg production?

The claim that after menopause, the ovaries no longer have the function of producing eggs is supported by a second consideration. This has to do with charting the precise conditions under which the ovaries can be said to be "dysfunctional" or "malfunctioning." Biomedical researchers generally only talk of disorders of ovary function when they stop producing eggs *before* menopause (e.g., primary ovarian insufficiency). *After* menopause, they're not thought of as dysfunctional. One way of explaining this asymmetry of judgment is to assume that, at menopause, the ovaries *lose* their function of producing eggs – hence no dysfunction, either. By the same reasoning, the failure of a juvenile male to produce sperm is not considered a dysfunction, but only the failure of an adult male to produce sperm. That suggests that the juvenile male's testes don't actually have the function of producing sperm, but only come to acquire that function at puberty.

The puzzle for us, then, is to see whether there's still some meaningful sense in which an individual's ovaries have the function of producing eggs (or testes, producing sperm) throughout the entire lifetime of that individual (that is, starting from the time of sex differentiation). We consider two solutions to this problem; of these, we lean toward the second.

The first is this: we might say that an organ like the testes has a set of "time-indexed functions." We could say, for example, that testes have the function of producing sperm from *t1* (puberty) to *t2* (senescence). Then we would simply revise our definition of being male to say that *X* is male if and only if *X* has biological parts or processes that have the *time-indexed* (proximal or distal) biological function of producing sperm.

There's a second, simpler solution that we prefer. It draws on Neander's (2013) notion of a "response function." Many biological parts and processes possess, throughout life, the function of performing a certain activity, but only in certain circumstances. The pineal gland has the function of releasing melatonin, but only in response to the dimming of light. The immune system has the function of releasing an army of white blood cells, but only in response to tissue damage. It's not that the pineal gland daily gains and loses its function of releasing melatonin. It always possesses a response function. Response functions are philosophically well-understood and play an important role in biology and medicine.

We think response functions can help us make sense of the precise way in which an individual's testes "have the function" of producing sperm even before puberty. From the moment of their formation in the fetus, the testes have the following response function: to produce sperm in response to an extremely complex environmental trigger, which includes the uptick of certain hormones such as follicle-stimulating hormone (FSH). The testes don't gain a new function at puberty; puberty, rather, enables them to perform a function that they already have, just as nightfall enables the pineal gland to perform a function it already has. The same hormone instructs the ovaries to develop eggs. The notion of a response function gives us a principled way of holding that the ovaries have the function of producing eggs throughout the lifetime of the individual, but that at certain phases of life, the complex inner and outer conditions that enable the performance of that function do not obtain.

Here is a second objection. Does our view have the problematic implication that all human beings are, in fact, both female and male? Human males and females both possess genes that contribute to the development of testes (like *Fgf9* on autosomal chromosome 13), and genes that contribute to ovary development (like *Wnt4* on chromosome 1). That brings us perilously close to the conclusion that nobody is, in fact, exclusively female or exclusively male.

To simplify greatly, in the ordinary case in males, the *Sry* gene located on the Y sex chromosome produces a transcription factor that upregulates the expression of *Sox9*, which works together with other genes such as *Fgf9* to induce differentiation of the equipotential gonad to testes. The upregulation of *Fgf9* expression also leads to the inhibition of the *Wnt4* gene involved in ovary development. In females, the *Wnt4* and *Rspo1* genes help to induce the differentiation of the equipotential gonad into ovaries. They also work together to inhibit the transcription of *Sox9*, as well as to inhibit an enzyme that catalyzes the production of dihydrotestosterone. For these reasons, sexual differentiation in humans is sometimes described as a "tug of war" between two gene regulatory networks, one involved in the formation of ovaries and the other in testes (Kim et al. 2006; see Gross 2006 and Fausto-Sterling 2012, 20 for discussion).

The question for us, is, how should we describe these facts vis-à-vis the notion of biological function? If we say that the *Fgf9* gene has the "function" of inducing the development of testes – and therefore the distal function of promoting sperm production – then we are stuck with the implication that nearly all humans are male. And if we say that *Wnt4* has the "function" of inducing ovary development, then for the same reason we must conclude that all humans are also female. *Homo sapiens* would truly be a hermaphroditic species.

We think that the fatal flaw in this line of reasoning is its imputation of a function to a gene itself, rather than to the expression of a gene, or even to a *change* in the expression pattern of a gene, namely, its upregulation. Applied to this case, we want to say that the *Fgf9* gene, as such (that is, the nucleotide sequence on chromosome 13), does not have the function of inducing testes development. We want to say that the upregulation of expression of *Fgf9* (an event indirectly triggered by the *Sry* gene) has the function of inducing testes development.

One might suspect that we're splitting hairs by insisting on a deep distinction between attributing a function to a gene, rather than to the expression, or even changes to the expression, of a gene, but we think it's strongly suggested by ordinary biological and biomedical judgment, for two reasons.

One consideration that speaks in favor of attributing functions to gene expression, rather than genes (qua sequences of nucleotides), is that it coheres well with our ordinary judgments about the conditions under which we speak of a "dysfunction" of sexual differentiation. If the *Fgf9* gene, as such, has the function of inducing testes development, then if a person possesses that gene, but doesn't have testes, we'd infer the presence of a dysfunction. That would imply that nearly all human females have a dysfunctional *Fgf9* gene, and, by implication, a disorder of sexual development. We could apply the same form of reasoning to males.

We anticipate an objection here. Instead of rejecting the claim that the *Fgf9* gene has the function of inducing testes, why not say that the *Fgf9* gene has the "response function" of inducing testes? That is, why not say that its function is to induce testes but only *in response to* a signal initiated by *Sry*? Isn't it inconsistent to say that the ovaries have, throughout the duration of life, the function of producing eggs in response to certain hormones such as FSH, but that *Fgf9* does *not* have, throughout the duration of life, the function of initiating testes development in response to *Sry* expression?

There's a crucial difference, though, between the way we describe the function of (say) *Fgf9* and the function of the ovary. For *Fgf9* and *Wnt4* are already expressed at relatively low levels in the equipotential gonad in mammals. Expression of the *Sry* gene doesn't "turn on" the *Fgf9* gene in the way you might flip a light switch. It changes (via upregulation) its existing pattern of expression. This fact suggests that it's specifically the *upregulation* of *Fgf9* expression that has the function of inducing testes development, not *Fgf9* (or even *Fgf9* expression) as such. As Gross (2006) summarizes the point, "sex is not determined by the flip of a genetic switch but by a dose-dependent interplay between opposing signals."

A second consideration weighs in favor of our view that a gene as such doesn't have a function, but its (changing) expression pattern. Given that sex differentiation results from the "dose-dependent interplay" of two dynamic, complex regulatory networks – and that one and the same stretch of DNA can play such diverse and even contrary roles depending on the network in which it's deployed – it strikes us as at least misleading to say things like, "gene A has function F." It seems more fitting to think of the gene as a "developmental resource" (e.g., Moss 2003) that cells use to build our bodies, the function of which depends on the complex gene regulatory network in which it's embedded.

## 5. Open questions

We close by sketching some avenues of inquiry that our account of sex opens up. We do not purport to have the solution to all of these problems. The virtue of our approach is not that it solves all of these problems in a ready-made way, but that it teaches us how to even begin solving them. In other words, it frames the conversation in a way that makes it clear what one would need to find out in order to solve these problems. We describe three such problems here.

### *Challenging the sex binary*

On our view, some human beings are neither exclusively male, nor exclusively female, but both male and female. Hence, we reject the idea that human sex is "binary," in the sense that there are only two sexes, male and female, and that they are mutually exclusive.

Consider, for example, ovotesticular condition (sometimes called "true hermaphroditism"), which affects about 1 in 20,000 people. Such individuals are born with one ovary and one testis. An individual with this condition would be, on our account, male, because they have a part or process the biological function of which is to produce sperm. Additionally, such individuals would be female, because they have a part or process that has the biological function of facilitating the production of eggs.

Most people with this condition are infertile, and it goes without saying that nobody can actually perform both the male and female role in human reproduction. But recall that on our view, one's sex is not contingent on one's *ability* to produce large or small gametes, but on what one is *designed* to do. Moreover, whether one is designed to produce eggs, or sperm, depends on whether one possesses certain organs, most notably gonads, that have the biological function of producing eggs or sperm.

### *Ways of being intersex*

Intersex individuals are born with some combination of male and female sexual characteristics, whether these pertain to the genes, the hormones, the inner genitalia, or the outer genitals. Some estimates suggest that 1-2% of human beings are intersex, about the same proportion as redheads. This raises the question of what, precisely, the connection is between being intersex, and being male or female.

We prefer to think of being intersex not as an alternative to being male, or being female, but as representing a slightly different way of partitioning the space of human diversity. To be intersex is often defined as being born with some combination of male and female sexual characteristics.[1] Since we only invoke parts or processes that have the (distal or proximal) function of producing gametes, we believe the classification "intersex" does not capture what it is to be male or female at a sufficiently fine grain of resolution. Nevertheless, we acknowledge the value of the classification for capturing wider developmental variation in sex characteristics between males and females. Accordingly, we believe some intersex individuals are also exclusively male or exclusively female.

For example, consider infants with so-called "blended" genital morphologies, such as an enlarged clitoris that resembles a penis, or a small penis that resembles a clitoris. In our view, having an enlarged clitoris is one way of being intersex, but it is also consistent with being exclusively female, since genital morphology doesn't facilitate the production of gametes.

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[1] See, e.g., https://interactadvocates.org/, accessed April 2, 2021.

Of course, our goal is not to question someone's identification as being intersex, but just to point out that being intersex is, in some cases, compatible with being exclusively male or female. We emphasize that respecting how someone identifies and what they prefer to be called is an entirely separate matter from how they are classified by biologists, however legitimate we think the classification.

### *Can people change their sex?*

This is a complex question we can't fully answer here. This is because it takes us deep into unanswered questions about the nature of biological functions. Our goal is not to answer the question, but to provide the conceptual framework that we need to start thinking clearly about it.

By "design," we often think of evolved design. But evolution instilled within us an incredible amount of cognitive and behavioral flexibility, or plasticity. This flexibility is what allows us to formulate new goals, and to "redesign" our bodies and minds to better serve those goals. For example, we're more or less constantly redesigning our bodies and minds through trial-and-error learning, and other forms of practice, to better fit the contingencies of our local environments. Serena Williams has systematically redesigned parts of her brain and body for the sake of excelling at tennis. Veteran London cab drivers have effectively redesigned parts of their hippocampi to navigate the complex maze of city streets.

Such redesign, in our view, gives rise to novel biological functions. We think trial-and-error and some other forms of learning constitute function-bestowing selection processes in their own right. This idea has been floated for nearly four decades in the functions literature; see Garson (2019) for discussion. Evolutionary natural selection doesn't have, if you will, a monopoly on crafting new functions. There's nothing *a priori* implausible or incoherent about the proposition that an individual can change or modify the functions of their biological parts or processes to better accord with their own goals or aspirations.

The question of whether one can change one's sex, then, depends on whether the following can be true of an individual: at time *t1*, *X* is designed to produce sperm, and at some later time *t2*, *X* is designed to produce eggs. There are subtle questions here about whether, at time *t2*, it is no longer true to say that *X* is designed to produce sperm, or whether, at time *t2*, *X* is designed to produce both sperm and eggs. Either way, we think it's an open question whether one's sex is truly fixed at birth for human beings or whether it can be changed, that is, whether there are certain changes that one can induce that would count as coming to possess, through ontogenetic selection processes, parts or processes that have the biological function of producing sperm, or eggs.

When we speak of "sex change," it's vital for us to clarify the term's problematic history. It usually refers to the idea that trans* people transition from "male to female" or "female to male" through gender-affirming surgery to change genitalia. Such discussions tend to equate sex and gender, and hence claim that being trans* amounts to becoming either a trans man or trans woman. First, and as we have stressed, genitalia are not constitutive of sex, and hence a change of genitalia cannot constitute a change in sex. Second, since sex and gender are distinct, a change of sex would not necessarily entail a change of gender. Third, being trans* is not a strictly binary phenomenon in which people become men or women. As Currah et al. (2009, 3) point out, trans* people feel “a sense of persistent identification with, and expression of, gender-coded behaviors not typically associated with [their] sex at birth” that are not “reducible to erotic gratification, psychopathological paraphilia, or physiological disorder” and which reflect “their sense that a single individual should be free to combine elements of different gender styles and presentations, or different sex/gender combinations.” Given the historically problematic and conceptually dubious connection between sex change and gender, we think the issue of sex change should not be invoked in discussions of trans* people without accompanying arguments for its relevance. That said, it is an open question whether any kinds of existing or future gender-affirming medical technologies will be able to change someone’s sex in our sense. If any trans* person *were* to desire to change their bodies to acquire parts and processes the function of which is to produce ova or sperm, as some trans women who desire to give birth do, then they would in effect desire a change in sex and our notion of this process would become medically relevant.

## 6. Conclusion

To recap, in our view, the sex of an animal depends not on the kinds of gametes that it is capable of making, but on the kinds of gametes it’s “designed” to make. We cash out this notion of design in terms of biological function: *X* is female iff *X* has biological parts or processes that have the (proximal or distal) biological function of producing eggs. We’ve enumerated several virtues of this approach: it avoids the pitfalls of the “simple starter theory” of sex, it helps us grasp the unity of sex despite the numerous empirical (and defeasible) indicators of sex, it coheres well with biological thought by deploying the pivotal notion of proper function, and it abstracts appropriately from the mechanistic details of how sex is implemented in any given animal.

We’ve also sought to address some of the urgent social consequences of thinking biologically about sex. In our view, there are three questions that need to be pursued separately: (i) is an individual biologically female/male/both, (ii) is an individual a woman/man or some other gender, and (iii) should an individual be afforded certain benefits, rights, or privileges associated with certain genders. We think the question of whether an individual is biologically female/male/both is logically independent of the question of whether that individual is a man/woman/nonbinary person and of the question of whether an individual can or should possess any of the rights, benefits, or responsibilities generally accorded to men/women/nonbinary people. We fail to see how an answer to the first question implies an answer to the second without conflating sex and gender, and we fail to see how an answer to the first entails an answer to the third without engaging in a serious is/ought fallacy. And while we think it’s possible that being a certain gender could afford people certain associated rights, privileges, or benefits, we also think that these associated rights, privileges, or benefits can be afforded solely on the basis of first-person authority (Bettcher 2009).

Finally, even if one conflates sex and gender and accepts the perilous and dubious idea that being male or female entails access to certain rights, benefits, or privileges, we’ve argued that on our view, it is an open question whether one can change one’s sex. This would further undermine the pretenses of some to use human biology to advance pernicious traditionalist policies about sex (Sudai et al. 2022).

## References

Allen C, Bekoff M (1995) Biological function, adaptation, and natural design. Philosophy of Science 62: 609–622

Barnes E (2020). Gender and gender terms. Noûs 54: 704-730

Bettcher TM (2009) Trans identities and first person authority. In: Shrage L (ed) You've changed: Sex reassignment and personal identity. Oxford University Press, Oxford, pp. 98-120

Bettcher TM (2015) Intersexuality, transgender, and transsexuality. In: Disch L, and Hawkesworth M (eds) The Oxford handbook of feminist theory. Oxford University Press, Oxford, pp. 407-427

Bigelow J, Pargetter, R (1987) Functions. Journal of Philosophy 84: 181–196

Bogardus T (2020) Evaluating arguments for the sex/gender distinction. Philosophia 48: 873-92.

Currah P, Green J, and Stryker S (2009) The state of transgender rights in the United States of America. National Sexuality Resource Center, San Francisco, CA

Dupré, J (2017) A postgenomic perspective on sex and gender. In: Smith, DL (ed) How biology shapes philosophy. Cambridge University Press, Cambridge, pp. 227-246.

Fausto-Sterling A (2012) Sex/Gender: biology in a social world. Routledge, New York

Franklin-Hall L (2021) The animal sexes as historical explanatory kinds. In: Dasgupta S, Dotan R, and Weslake B (eds) Current controversies in philosophy of science, Routledge, New York, pp. 177-197

Garson J (2019) *What Biological Functions Are and Why They Matter*. Cambridge: Cambridge University Press.

Garson J (2022) *The Biological Mind: A Philosophical Introduction, Second Edition*. London: Routledge.

Griffiths PE (2020) Sex is real. Aeon. https://aeon.co/essays/the-existence-of-biological-sex-is-no-constraint-on-human-diversity, accessed April 2, 2021

Khalidi MA (2013) Natural categories and human kinds: classification in the natural and social sciences. Cambridge University Press, Cambridge

Khalidi MA (2021) Are sexes natural kinds? In: Dasgupta S, Dotan R, and Weslake B (eds) Current controversies in philosophy of science, Routledge, New York, pp. 163-176

Kingma E (2015) Situation-specific disease and dispositional function. British Journal for the Philosophy of Science 67: 391-404

Kitcher P (1993) Function and design. Midwest Studies in Philosophy 18: 379–397

Lennox JG (1993) Darwin *was* a teleologist. Biology and Philosophy 8: 409-21

Neander K (1991) Functions as selected effects: The conceptual analyst's defense. Philosophy of Science 58: 168–184

Neander K (2017) Functional analysis and the species design. Synthese 194: 1147-1168

Neander K, Rosenberg, A (2012) Solving the circularity problem for functions. Journal of Philosophy 109: 613-22

Novaes CD (2020) Carnapian explication and ameliorative analysis: a systematic comparison. Synthese 197: 1011-1034

Otto SP (2009) The evolutionary enigma of sex. The American Naturalist Suppl1: S1-S14

Richardson S (2022) Sex contextualism. Philosophy Theory and Practice in Biology 14:2

Ross L (2021) Causal concepts in biology: how pathways differ from mechanisms and why it matters. British Journal for the Philosophy of Science 72: 131-158

Roughgarden J (2004) Evolution's rainbow. University of California Press, Berkeley

Ryan MJ (2018) A taste for the beautiful. Princeton University Press, Princeton

Saul J (2012) Politically significant terms and philosophy of language. In: Crenshaw SL, Superson AM (eds) Out from the shadows: analytical feminist contributions to traditional philosophy. Oxford University Press, Oxford, pp. 195-216

Sudai M, et al (2022) Law, policy, biology, and sex: Critical issues for researchers. Science 376 (6595): 802-804

Zuk M, Simmons, LW (2018) Sexual selection: A very short introduction. Oxford University Press, Oxford