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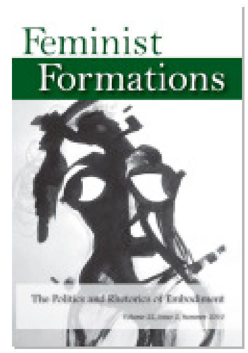

Feminism and Science: Mechanism Without Reductionism[1]

CARLA FEHR

During the scientific revolution reductionism and mechanism were introduced together. These concepts remained intertwined through much of the ensuing history of philosophy and science, resulting in the privileging of approaches to research that focus on the smallest bits of nature. This combination of concepts has been the object of intense feminist criticism, as it encourages biological determinism, narrows researchers' choices of problems and methods, and allows researchers to ignore the contextual features of the phenomena they investigate. I argue that the historical link between mechanism and reductionism is not a necessary one, that this link should be severed, and in many cases has already been severed. Separating reductionism from mechanism allows us to hold onto the mechanistic view that science should explain how things work, without mandating methods and approaches that reduce the objects of scientific investigation to their smallest parts. Mechanism without reductionism decenters reductive methods, and so creates intellectual space for a plurality of methods that may engage the world at a variety of levels of organization. This ensuing pluralism opens the door for a wide variety of approaches to research, including feminist and gender-sensitive science.

Keywords: mechanism / reductionism / biological determinism / causation / feminism / sexual behavior

Modern science is a historical enterprise born in the 16th and 17th centuries. We all know its "fathers": Francis Bacon, Rene Descartes, John Locke, Galileo Galilei, Sir Isaac Newton, Robert Boyle; this intellectual honor roll goes on and on. They developed a way of producing knowledge that was astonishing in its ability to explain the natural world. Carolyn Merchant, in her book *The Death of Nature* (1980), points out that modern science developed along with, and was dependent on, a change in the metaphors used to make sense of nature. Merchant argues that modern science took Mother Nature and turned her into a machine and that this mechanistic worldview allowed for new ways to see order in the complexities of nature, fostering an attitude of control and domination toward both women and the natural world.

Historian Londa Schiebinger (1989) argues that as this new method and metaphor developed from the infant creations of the "founding fathers" into powerful social institutions, women intellectuals were systematically excluded from modern science. The naissance of modern science involved the domination of a female world and the exclusion of women. Can there be such a thing as feminist science(s)? Developing responses to this question has become a cottage industry during the last 20 years. I am adding an analysis of the relationship between mechanism and reductionism to this literature. I argue that we need to tease the concept of mechanism away from harmful and exclusionary reductionist philosophies, and embrace, rather than merely tolerate, a plurality of scientific methodologies. Dethroning reductionism and embracing a plurality of methods that engage the world at a variety of organizational levels can create space for feminist methodologies, and for a science that is more inclusive of women and those with previously marginalized perspectives. The methodological pluralism that I endorse involves a plurality of methods and approaches to science that recognize causal patterns at, and among, different levels of organization.

Reductionism, Mechanism, and Their Strengths

Reductionism is the view that things in the universe are arranged hierarchically, and that causation only occurs at the lower levels of this hierarchy. Reductionism entails a relationship between parts and wholes such that wholes are explained in terms of their parts; hence, a reductionist scientific method focuses on describing and attempting to understand a phenomenon in terms of its parts. Reductionist views range from strong to weak depending on the level of organization to which phenomena are ultimately to be reduced. Strong reductionism assumes that there is a single most fundamental level at which entities are real, where causation happens, on which explanations rest, and where methodologies should focus. For instance, in the biological sciences, strong reductionism holds that phenomena should be reduced to their physiochemical constituents. Weak reductionism assumes that causation, explanation, and methodology should focus on the parts of wholes but does not insist that these parts be the simplest or smallest entities possible.

Helen Longino (1990) and Robert Brandon (1996) have pointed out that there are different senses of reductionism that are often conflated.[2] Brandon makes a distinction between ontological, explanatory, and methodological reductionism, and Longino makes a distinction between ontological (or metaphysical) and methodological reductionism. Ontologically (which refers to the structure of the world), reductionism means that big things are composed of smaller things and little things are composed of tiny things and so on, and that causal relations only happen among the smallest functional parts of a whole (1990). Brandon characterizes this view of causation as "bottom up" or "inside out," meaning that "parts of a whole and their interaction cause the behavior of the whole, but never vice versa. It never happens that properties of wholes cause the behavior of their parts" (1996, 189).

Methodological reductionism, in its weak and strong sense, prescribes that we should search for the physiochemical basis of biological phenomena or that researchers should characterize phenomena and search for understanding of those phenomena with respect to their parts (Brandon 1996; Longino 1990). Explanatory and ontological reductionism have been tightly linked in the causal mechanical view of explanation. According to this view of explanation, we understand phenomena by showing how they are causally produced.

I work within a causal mechanical view of scientific explanation because science is in the business of finding out how things work, and this view is implicit or explicit in most scientific practice. Mechanism, as a philosophical perspective, is the general view that arose with the Newtonian concept of the universe consisting of matter in motion. It sees nature as machine-like and explainable without referring to any supernatural entities or causes. A mechanism is simply a causal process. A mechanical explanation is a description of the causal process that produced the phenomenon in question. Mechanism is based on causation or production. If one embraces ontological reductionism, which rests on the *a priori* assumption that causation only acts at lower levels of organization than the phenomena in question, then a causal mechanical explanation must involve descriptions of processes and entities at those lower levels. Reductive mechanism is the view that real causal processes involve interactions among the smallest parts of a whole, scientific explanations are elucidations of these low-level causal processes, and scientific methodologies should search for explanations at low levels of organization. I will argue that just because reductionism and mechanism can fit together, it does not follow that they must. Brandon (1996) argues—and I concur—that a causal mechanical view of explanation can and should stand without the *a priori* assumptions about causation entailed by ontological reductionism. If we discover causal regularities at higher levels of organization then we have examples of nonreductive causal mechanisms. Brandon gives many such examples, and I discuss the example of the role of hormones in development here.

If one is a strong reductionist, the only genuine explanations of phenomena involve descriptions of causal processes among the "least functional bits" of a phenomenon. The result is a methodological monopoly in which it is assumed that the only methods that yield genuine understanding are those that characterize phenomena in terms of those least bits. According to this view, methods aimed at higher levels of organization at best have heuristic value and at worst represent a fruitless search for nonexistent causes. If one is a weak reductionist the result will not be a monopoly of methods, but rather a systematic privileging of methods that characterize phenomena in terms of their parts at some lower level of organization. Both types of reductionism marginalize methods that search for higher level causes or which characterize parts in terms of wholes. This methodological monopoly, or privileging of lower level methods, reflects a normative continuum ranging from sciences such as physics, which is stereotypically viewed as engaging the world at the lowest levels of organization, to sciences such as ecology, which is seen as engaging the world at higher levels of organization. Thus we end up with the expression that biologists suffer from "physics envy." Although women are woefully underrepresented in science generally, it is worth noting that this underrepresentation is most severe in sciences that from a reductive perspective are seen as being the "most scientific."

I do not believe that reductionist methods, which have been at the heart of modern science since its inception, are universally misguided or inappropriate and I do not want to say that all mechanistic/reductionist research need be androcentric. The use of these principles in chemistry and biology has led to major accomplishments, such as the elucidation of the structure of the atom and the biochemical nature of DNA. These methods are powerful and are one of the reasons that science is so successful. However, I take issue with the argument that the past successes of reductive science provide a reason why nonreductionist methods should not be considered within the rubric of science. When considering past successes, one must ask, "Successful at what?" especially since the past successes of science have benefited some groups and classes more than others, and that historically researchers have paid insufficient attention to important areas of, especially biological, investigation. I want to decenter, not eliminate, reductionist approaches. Allowing for and valuing a plurality of approaches has the possibility of opening the door for a new set of successes and addressing neglected topics.

Three Feminist Concerns

Given that mechanism/reductionism has been so successful, what is the justification for feminist concerns about this sort of science? There are many reasons why some feminist theorists are hostile to scientific practice and production. I want to focus on three of these worries: the biological determinism problem, the methodological/epistemological problem, and the cultural/historical problem. These problems are interrelated in complicated ways and it would be worth considering these relationships more closely in future work.

The Biological Determinism Problem

Biological determinism (in respect to gender) is the view that the properties of gender are caused by, or determined by, the properties of sex. A tight link exists between reductive mechanistic science and biological determinism. It has received extensive treatment in feminist debates concerning the relation between sex and gender (Nicholson 1994), in feminist critiques of the biology of sex differences (Birke 1986; Longino 1990; Longino and Doell 1983), and feminist critiques of animal behavior and sociobiology (Hrdy 1986; Hubbard 1979; Kaplan and Rogers 1994). This link is due to the reductive assumption that causation acts in an upward direction from lower levels of organization to higher levels of organization. This means that biological causes are considered to be the only causes, or at least the most important causes, of feminine behavior. With this sort of tight, unidirectional causal link, upper level phenomena, such as the social characteristics connected with gender, are seen as caused by lower level phenomena, such as genetic or hormonal factors. According to this sort of analysis, as long as the lower level phenomena remain constant, the upper level phenomena will be unchangeable. More particularly, a healthy woman cannot help but be nurturing, or tend to be emotional rather than rational, or have whatever gender characteristic one cares to name. This sort of reasoning is problematic not only because it implies that seeking political change in the face of biologically determined sex differences is futile, but also because this is not an accurate explanation of the mechanisms of sex and gender.

These specific concerns about reductionism and biological determinism, although focused on sex and gender as an object of scientific investigation, are also crucial to women as scientists. The results of deterministic reductive analyses of sex and gender support cultural understandings of femininity that call into question women's ability to enter and remain in the traditionally masculine world of research. Sandra Harding writes, ". . . were these biological determinist arguments true, a 'woman scientist' *should* be a contradiction in terms" (Harding 1986, 93 [original italics]). Consider the gender characteristics that are argued via reductionism to have a biological basis and hence be static, and ask which tend to be associated with women and which tend to be associated with men: mathematical and spatial ability, rationality, competitiveness, compassion, listening and nurturing skills, emotional awareness, and cooperation. The first four characteristics correspond not only to traditional Western understandings of masculinity but also to traditional conceptions of science as objective, impersonal, and competitive.

This conflict between stereotypical feminine and scientific virtues can be ameliorated in at least two ways. On the one hand, one can attempt to break the association between masculine values and science, showing that this association already is mythical or unnecessary. For example, Evelyn Fox Keller (1983) reports that the intimate, emotional connection between Barbara McClintock and the individual plants, cells, and chromosomes of the corn she studied allowed her to conduct her Nobel Prize-winning work on transposition. On the other hand, one may also argue against the reductionist perspective that leads to biological determinism and hence to the construction of an essentialized woman's (and man's) nature. Readdressing the masculine gendering of conceptions of science is an important task, but here I want to tackle the problem of reductionism and determinism, which leads to the calcification of cultural stereotypes of women's intellectual nature. If nonoppressive scientific investigations of sex and gender are to be conducted, scientists must address the problem of reductionism.

One tactic, which both defends science and ameliorates the effects of the stereotypical conclusions concerning the nature of women, is to argue that the science that "shows" that women, for example, lack spatial ability is simply bad science. Studies showing that women are less apt than men at tasks traditionally associated with the practice of science, such as spatial or mathematical tasks, have largely been discredited due to statistical problems and unjustified assumptions (see Longino 1990, 123–6 for an overview). It must be clear to what the "bad science response" refers. If it refers to poorly conducted statistical analyses, then presumably the research can be redone more clearly and produce better data. If, on the other hand, it refers to assumptions about the nature of causation, for example ignoring or discounting the existence of higher level social causes, then the "bad science response" is more radical because it reveals a foundational reductive ideology. Even though there is justification for setting aside these particular results, the problem of reductive determinism still exists. As long as one holds the assumption that causation only works from the bottom up or inside out, then higher level phenomena associated with gender will be viewed as determined by lower level phenomena associated with sex.

The Methodological/Epistemological Problem

Reductionist mechanism leads to several methodological and epistemological feminist concerns. It puts blinders on researchers that limit their choice of problems and objects to study. Many possible sources of bias can limit the problems that researchers focus on. One source springs from the assumptions of reductionistic mechanism. If one believes that scientific explanation involves revealing causal interactions that take place at low levels of organization, then one may not think to, or may consciously choose not to, investigate complex phenomena or problems that do not appear reducible to tiny enough bits. This set of assumptions leads to hostility toward holistic approaches to medicine and environmental problems, and the exclusion of things recalcitrant to reductionism from the domain of scientific investigation. For example, Sue Rosser points out with regard to dysmenorrhea that "[o]nly after prostaglandins were 'discovered' was there widespread acceptance among the male medical establishment that this experience reported by women had a biological component." (2002, 231) The discovery of a possible low-level hormonal basis for dysmenorrhea accorded it the status of being biological, even though women had long been reporting bodily experiences of the phenomenon.

Reductive mechanistic science not only limits the choice of problems and the recognition of objects of investigation, it also limits methods of inquiry. Strong reductive mechanism enforces a methodological monopoly on the study of acceptable scientific problems, such that if one is investigating a phenomenon or problem that could be approached from either above or below, one must approach it from below because that is where the true causes of the phenomenon are to be found.

Finally, mechanistic reductionism leads researchers to decontextualize their objects of investigation. By seeking to understand a phenomenon in terms of its smallest parts, relationships between the phenomenon and a greater whole are lost. Possible higher level causal influences that may affect the phenomenon disappear and become inaccessible to investigation, giving false support to the reductionist view that causation only happens at low levels of organization. For example, Jacquelyn Zita (1988) argues that clinical discourse creates a reductionist view of the female "medicalized body" according to which causal patterns are located within the body. With regard to research on premenstrual syndrome (PMS), she notes that researchers tend to assume that only internal variables and not contextual variables can sufficiently explain the patterns of observations related to PMS.

The Cultural/Historical Problem

The third problem concerns the historical association of reductionism and mechanism and the current effects of this association. Merchant (1980) argues that during the 17th century machines became models for not only the way that the world was structured, but also for the best, or perhaps the only, way emerging scientists gained knowledge of that world. According to Merchant, these new metaphors make possible an ideology of control and domination of nature and of women; human beings create machines to do the tasks that they require. This machine metaphor developed into a mechanical philosophy that came to dominate European science.

Merchant describes several intertwined assumptions that linked science and machines and were constitutive of this new mechanistic worldview. These assumptions are still involved with what many consider to be "the scientific method" (Merchant 1980, 228–35). The first assumption concerns the particulate structure of nature. In the 17th century matter came to be seen as "corpuscular, passive and inert; change was simply the rearrangement of particles as motion was transmitted from one part to another in a causal nexus" (Merchant 1980, 102). This assumption that matter has a fundamental low-level structure and that change can be characterized at this level paves the way for reductionism. A second assumption is that the universe has a law-like natural order. The concept of order is the heart of a mechanistic view both in the 17th century and today. The replacement of an organic conception of order corresponds with the replacement of Aristotelian science, which searched for the purpose of phenomena in the context of the universe as a whole, with modern science, which abandoned questions of purpose in a quest to discover how things work. The domain of modern science included those things that exhibited law-like behavior, or in a more general and contemporary sense, those things that exhibit causal regularities. In the modern worldview the machine was the perfect metaphor because it was an artifact. The relationships among its parts are transparent and its purpose is obvious because humans designed the machine to do a particular job.

A third assumption is that knowledge and information can be abstracted from the natural world. Merchant calls this the assumption of context independence and points out that it springs from the idea that "only quantities and context-independent entities can be submitted to mathematical modeling" (Merchant 1980, 230).[3] The idea behind this assumption is that the world is organized such that we can describe it in terms of discrete entities and that scientists can come to know and manipulate these entities independently of the context in which they occur. A final assumption is that "problems can be analyzed into parts that can be manipulated by mathematics (the methodological assumption)" (228).[4] The methodological assumption, as Merchant presents it, involves an ambiguity between a reductive approach to problems and a reductive approach to entities in her analysis of Descartes and Hobbes respectively.

With this list of assumptions Merchant reveals that the heart of early mechanistic philosophy in the modern period is based on the idea that the world can be understood in terms of the motions of particles engaging only in efficient, proximal causal interactions, and that this conception of nature paid little attention to higher causes. I agree with Merchant's arguments regarding the changing metaphors of nature, her general conception of early mechanistic philosophy, and her thesis that mechanical metaphors grant permission and develop a means for a science that is based on control and domination. These arguments have contemporary counterparts. For example, Emily Martin, in her book, *The Woman in the*

Body, a Cultural Analysis of Reproduction (1992), reveals a strong metaphor in which a woman's body with its reproductive functions is seen as a machine and the gynecologist and obstetrician are mechanics who not only maintain the machine, but also retain tight control of the reproductive process, especially the process of birth itself. Merchant's historical arguments and Martin's contemporary analysis show the cultural and political effects of a reductive mechanistic view, and provide impetus for deconstructing this position.

Although the four assumptions that Merchant lists co-occurred in the development of a reductive mechanistic worldview, they do not imply one another. They are tied together by ontological reductionism. Once this cord is severed, context-stripping and methodological reductionism can be teased away from the heart of the mechanistic view. Although the assumption of the particulate structure of nature was developed in terms of reductionism, it need not imply or prescribe ontological reductionism. Modern physicists were interested in describing observable interactions among medium sized composite bodies (for example, billiard balls). The existence of causal interactions among particles is not an argument against the possibility of higher level causal interactions.

Once the assumption of ontological reductionism is set aside, natural order, in the mechanistic sense, need not be confined to interactions among the least bits of phenomena. Without ontological reductionism there is no *a priori* justification for context stripping. Only if one presumes that causal interactions happen exclusively within an object, or at lower levels of organization than the object in question, can one feel secure considering an object out of its context because one presupposes that there are no contextual causal relations that may be overlooked. Similarly, unless one holds an *a priori* commitment to ontological reductionism one cannot prescribe methods that focus exclusively on illuminating the interactions among the parts of an object. One of the goals of science (many would argue the primary one) in both modern and contemporary periods is to reveal causal patterns and regularities in nature. But those regularities may well include interactions at higher levels of organization in which the context of a phenomenon plays an integral role. This search for causal order need not be limited to methods that characterize a phenomenon in terms of its parts, since order may well be found in the interactions between the phenomenon and its context. If one abandons presuppositions of ontological reductionism, it becomes clear that the assumptions Merchant lists concerning modern science are historically—but not necessarily—connected.

While it is true that machines are made of parts, are based on order, and give us power over nature, the machine metaphor need not be reductionist. Brandon gives the example of a car engine:

> If we go inside the engine and look, say, at the behavior of an intake valve, reductionism fails us. The internal constitution of the valve is not totally irrelevant to its behavior. . . . But consideration of its internal parts does not begin to explain its up and down motion. To explain that we imbed it into the larger mechanical system, the engine (1996, 195).

Merchant's important thesis about order, domination, and control is not contradicted by a nonreductionist conception of mechanism. The discovery of causal regularities allows us to intervene in nature more efficiently. Coupled with technological advances, this gives humans incredible power over nature, which deserves immediate and continued critical attention. But focusing on nonreductive mechanism highlights the contingent relationships among the scientific assumptions that generate this power, forces us to pay attention to context, and endorses a plurality of methodologies that search for causal patterns at a variety of levels of organization. For example, research which pays attention to the ecological context of an endangered species and uses methods which engage nature at high levels of organization may help us more effectively intervene to protect that species and the environment in which it lives.

Feminist concerns about biological determinism, methodological problems (such as narrow choice of problems, privileging methods that engage the world at low levels of organization, and context stripping), and cultural/historical problems in which the combination of reductionism and mechanism allows for a science of domination and control, are in varying degrees ameliorated by removing reductive assumptions from a mechanistic view of science. Feminist critiques of reductionism need not be critiques of mechanistic science.

Philosophers on Mechanism

I previously defined a mechanism as a causal process; at this point this terse and vague definition needs to be fleshed out. I turn to two conceptions of mechanism: Wesley Salmon's, which is central to contemporary ideas of causal mechanical explanations, and that of Peter Machamer, Lindley Darden, and Carl Craver, which is recent and under development.

Philosopher of science Wesley Salmon (1984, 1989, 1994, 1998) championed a causal mechanical view of explanation in which an explanation of a fact is a description of the causal processes that produced the fact. Salmon points out two kinds of causal mechanical explanations. A *constitutive* explanation describes "the causal processes that constitute a phenomenon and exhibit the phenomenon's internal causal structure" (1984, 270). A constitutive causal explanation of a clock would involve exhibiting its gears and springs and revealing the causal processes that they undergo. Although this type of explanation is at least weakly reductive, as it is looking at wholes in terms of parts, it does not specify that those parts be least bits. This is an example of Brandon's inside out characterization of ontological reductionism.

Salmon's second type of causal mechanical explanation is *etiological*: one explains "a given fact by showing how it came to be as a result of antecedent events, processes and conditions" (1984, 269). In this case, an explanation fits the fact-to-be-explained into an "external pattern of causal relationships" (270). This second type of explanation does not explain a whole in terms of its parts, but rather in terms of its history. This sort of an explanation of a clock would reveal how the clock was made, or how winding it up starts a process that allows it to keep time. This kind of explanation may have reductive aspects if one assumes that these antecedent causes need be low level.[5]

Salmon's view is based on a revolutionary reconception of causation in terms of causal processes and not in terms of a chain linking discrete events. There is controversy in the philosophy of science concerning what sorts of processes count as casual in this new view. Jim Woodward (1989, 2003) argues that Salmon's view applies primarily to simple cases in physics, such as the momentum and energy involved in the collision between a baseball and a window. If this is the case, causal interactions that are not based on physics will be ruled out and we are back to ontological reductionism.[6] However, Salmon (1989, 1998) employs examples of causal mechanical explanations that range from physics, to psychology and anthropology. Furthermore, there is a significant body of literature in the philosophy of biology that documents higher level causal interactions in terms of Salmon's view. For example, Brandon (1990) gives a causal mechanical account, based on Salmon's work, of evolutionary adaptation explanations. Given the possible reductionist implications, this is an area in the philosophy of science that merits further feminist attention.

Machamer, Darden, and Craver (2000) have recently developed a more general theory of mechanism. Although Salmon's view need not be reductive, if critics are not convinced by the replies to the concerns regarding Salmon's view, Machamer et al.'s position escapes these concerns. Machamer, Darden, and Craver offer the following definition: "Mechanisms are entities and activities organized such that they are productive of regular changes from start or set-up to finish or termination conditions" (2000, 2). They still hold the general view that descriptions of mechanisms "explain how a phenomenon comes about or how some significant process works" (Machamer, Darden, and Craver 2000, 2). Both the set-up and termination conditions are idealizations that are privileged for any number of local reasons. The set-up conditions are those conditions that scientists privilege as the beginning of the mechanism. The termination conditions are the privileged end point of the mechanism and are a description of what it is that the mechanism is being used to explain. In this sort of mechanistic explanation of a clock, the entities involved are the springs and gears and the activities are what those springs and gears do. The start-up conditions include the existence of the clock and the activity of winding it up. It then regularly and expectedly undergoes a series of activities that result in the clock keeping time. Scientists in different disciplines, at different stages of an investigation and with different goals, may privilege different points as the beginning and end of the mechanism that they are attempting to describe. A mechanism may contain intermediate entities and activities that fill in the gap between the set-up and termination conditions, showing that a continuous process produces the phenomenon that scientists are trying to explain. It is a description of this productive process that makes a mechanism intelligible. Before analyzing what Machamer, Darden, and Craver mean by "intelligibility," I illustrate these two concepts of mechanism at work in an example that has received extensive treatment in feminist science criticism.

Hormones as Causes of Behavioral Sex Differences

There has been significant feminist analysis of studies of genes and hormones as causes of the development of behavioral sex differences. Longino (1990) and Longino and Doell (1983) have analyzed the role of male bias in this field, and have used this as a case study to show how different kinds of values influence scientific practice. Lynda Birke, in her book, *Women, Feminism and Biology* (1986), scrutinizes the problems that reductionism has raised with regard to the role of hormones in developmental biology. One example that she discusses is the study of hormonal effects on the development of sexual behavior in rats. These rodent studies are not only an interesting example of research concerning sex in the animal kingdom, but are also important because animal studies are centrally used in research on human sex differences, particularly in scientific studies of human sexual orientation. In an early model of this system, which Longino has called the "linear-hormonal model," prenatal and perinatal hormone levels are assumed to be the basis for behavioral sex differences. The assumption is that a gene on the Y chromosome triggers the development of testes, and that the hormones released by these brand new testes affect the structure of the rodent brain during a critical developmental period. The presence of testes and the hormones that they produce are assumed to cause the male brain to develop such that the male performs "stereotypical" male sexual behavior such as mounting; in the absence of testes and the hormones that they produce the female brain develops in such as way as to cause the female to perform "stereotypical" female behaviors such as lordosis (when the female arches her back and raises her rear, presumably to solicit mounting). Longino (1987, 52) points out that in this explanatory model it is assumed that there is a "unidirectional and irreversible sequence of (biochemical) events."

Birke writes of this early model:

> Even if it is not always made explicit, the framework within which this line of reasoning has progressed is that hormones in early life are the prime determinants of adult patterns of sexual behaviour. To a large extent this assumption still holds, and the existence of sex differences in behaviour in adults is frequently attributed to perinatal hormone effects. Now it may well be true that hormones exert a large effect. The problem is not there, but with the exclusive focus on hormones from the individual's own testes or lack of them which dominated research for several decades (1986, 96).

This is a powerful model because it fits within a reductive framework and is a case of reductive mechanism: genes cause anatomical differences, which cause hormonal differences, which cause brain differences, which cause behavioral differences. Notice that this causal structure proceeds from lower to higher levels of organization. Birke argues that the relationship between hormones and behavior is much more complicated than this tidy reductionist picture implies; an "interactionist model" is replacing the linear-hormonal model. She points out that research is beginning to embrace a much more complex picture of the causes of sexual behavior, a picture that involves interactions among the mother, the fetus, the physiological and social environment as well as the genes, the internal anatomy, and the brain structure of the developing fetus. In this model, before birth the pups are influenced by factors such as the sex of other members of the litter, the mother's environment, and the mother's hormonal states. Birke writes, "even before birth . . . it is difficult to separate the individual pup and its hormones from a network of complex processes" (Birke 1986, 97). After birth, factors such as the pup's own hormones, maternal care (which is differential depending on the sex of the pup), the physical environment, and the other pups influence adult sexual behavior. When the pup becomes an adult, factors in its physical and social environment as well as its hormonal states and its own behavior influence its sexual behavior.

The linear-hormonal model fits both types of mechanism, and is reductionist. In terms of Salmon's view it has both constitutive and etiological components. The causal processes are inside the individual. The constitutive parts of the individual—genes, hormones, and brain structure—produce the behavior. The etiological aspect involves the causal processes that take place during the development of the individual. The causal process begins with the genes and ends with the behavior. In terms of Machamer, Darden, and Craver's conception of mechanism, the linear-hormonal model can be described in terms of a series of entities and activities that begins with the individual's genetic makeup and terminates with the sexual behavior in question.

The interactionist model is mechanistic, but not reductionist. In the interactionist model, there is not a simple linear causal sequence from the bottom up, from genes to hormones to behavior, all occurring within an individual. Instead, the social and physical environments also provide complicated and interacting causes. Factors at higher levels of organization, such as the ratio of the sexes among the littermates, or the behavior of the mother, affect phenomena at lower levels of organization, such as the sexual behavior of the individual pup when it reaches maturity.

The interactionist model can be described as a causal mechanism in terms of Salmon's work. There are still constitutive causes of the behavior within the organism. But the set of etiological causes is greatly expanded to include such things as social interactions. Note that etiological explanations place phenomena in the causal nexus that makes up the world. The interactionist model provides a much more detailed and accurate description of the causal nexus in which we can locate sexual behavior. Very clear causal patterns connect maternal behavior and social environment with pup behavior, and these patterns are not limited to low-level genetic and hormonal interactions that occur during the development of the pup.

The interactionist model fits very well with Machamer, Darden, and Craver's definition of mechanism. Entities regularly and predictably go through activities, but we are not limited to looking downward along the hierarchical organization of developmental processes. The set-up conditions include not just the presence or absence of a Y chromosome or testes, but also the social environment of the pup and the mother, the behavior of the mother, etc. Also, this is a multilevel mechanism; the entities and activities involved are found at many levels of biological organization. The entities range from genes, to hormones, to individuals, to social and physical environments, and the activities range from biochemical to social interactions. Birke's description of the interactionist model is an example of very good, nonreductionist, and yet mechanistic science.

One may object that even though the hormonal influences on development may come from many sources—some from the fetus, some from the litter mates, some from the mother, and some caused by the behavior of the mother—the action of these hormones, no matter what their source, still occurs at the microlevel of the biochemical interaction of the hormone and its receptor site. In other words, the objection is that even in this more complex view of the role of hormones in development, the action is still occurring at the microlevel and hence it does not give us an alternative to reductionism. The problem with this objection is that it involves a misunderstanding of the object of the investigation. In this example, researchers are not trying to investigate the mechanism of how hormones interact with their receptors. The interaction between hormones and their receptors is a reasonable topic to investigate, and many researchers have worked on it and are continuing this work. But in the example at hand, researchers are trying to understand sexual behavior.

The biochemical and cellular interactions between hormones and their receptor sites are associated with a wide variety of both stereotypically male and female behaviors. Both males and females have "male" and "female" hormones and receptor sites. In order to associate a particular hormone/receptor mechanism with a particular behavior or small class of behaviors that tends to be linked with one sex or the other, one needs to know such things as the abundance and activity of the receptors, and the amount of hormone circulating in an individual or the individual's ability to produce a particular hormone. Details of the microlevel hormone/receptor mechanism are not sufficient to explain these varying abundances. To answer the "how much" question, one needs to refer to causal influences that are both internal and external to the individual in question.

In Machamer, Darden, and Craver's terms this objection is an example of researchers choosing to privilege different set-up and termination conditions of the mechanism in question. One who is pushing this objection is privileging the hormone receptor before it interacts with the hormone as the set-up conditions, and the hormone receptor while it interacts with the hormone, or some cellular consequence of this interaction as the termination conditions.The interactionist model privileges a much larger set of set-up conditions.

The intuition underlying both concepts of mechanism is that figuring out how something comes about or how it works is crucial to, or, more strongly, is constitutive of, understanding the phenomenon in question. Machamer, Darden, and Craver argue that describing the continuous process from set-up to termination conditions renders a phenomenon intelligible.

Intelligibility

Machamer, Darden, and Craver point out that a mechanistic worldview is "a conviction about how phenomena are to be understood" (2000, 21). "Understanding" is a vague, multivocal term. They maintain that scientific understanding makes phenomena intelligible. Their use of "intelligibility" needs to be carefully read. They write that "intelligibility consists in the mechanisms being portrayed in terms of a field's bottom out entities and activities" (2000, 21). This talk of "bottoming out" may lead one to think that their conception of mechanism also relies on reductionist assumptions. In some passages the authors seem to support this sort of understanding. For example,

> 1 . . . lower level entities, properties and activities are components in mechanisms that produce higher level phenomena (2000, 13).

Or,

> 2 . . . mechanisms typically bottom out in lowest level mechanisms. These are components that are accepted as relatively fundamental or taken to be unproblematic for the purposes of a given scientist, research group, or field (2000, 13).

In many cases, Statement 1 will be true, but one may also read it to imply that higher level entities do not play a role in the production of lower level phenomena. If one accepts this implication, then explanatory reductionism follows; we understand upper level phenomena only in terms of the activities of their lower level parts. This is a problematic consequence, but one that doesn't necessarily follow from the core of Machamer, Darden, and Craver's conception of mechanism. Statement 1 occurs in the context of a description of the mechanisms of neurobiology and molecular biology as being multilevel, meaning that entities and activities at multiple levels of organization are required to make a mechanism intelligible. They write later in the paper that "higher level entities and activities are . . . essential to the intelligibility of those at lower levels, just as much as those at lower levels are essential for understanding those at higher levels" (2000, 23). As a result, it seems that even though they state that lower level entities and activities explain the production of higher level phenomena, the opposite can also occur, and hence explanatory reductionism does not necessarily occur.

In statement 2 it is tempting to interpret "fundamental" to mean "lower level." But this is an extremely truncated notion of "fundamental."[7] "Fundamental" refers to basic processes, entities or theories. In some instances those basics may occur at lower levels of organization than the phenomenon in question and in some they may occur at levels above the phenomenon in question. It is important to note that Machamer, Darden, and Craver's work is confined to analyses of mechanism in the fields of neurobiology and molecular biology. In these fields bottoming out activities that occur at low levels of organization may indeed be basic or fundamental, or in other words, low-level activities may be necessary to understanding neurobiological and molecular phenomena. But in other fields such as developmental biology, evolutionary biology, or ecology, the activities basic to understanding of the phenomenon may exist at levels above the entity or process being investigated. In the case of the development of sexual behavior, the social and physical environments as well as genetic and hormonal states are fundamental to an understanding of the phenomenon in question.

Machamer, Darden, and Craver's conception of intelligibility is "historically constituted and disciplinarily relative." There is no logical story to be told about how these bottom-out activities, these kinds of production, come to inhabit a privileged explanatory position. "What is taken to be intelligible . . . changes over time as different fields within science bottom out their descriptions of mechanisms in different entities and activities that are taken as, or have come to be, unproblematic" (2000, 22).

They also explicitly focus on the context of the phenomenon being studied, stating that, "[t]he entities and activities in the mechanism must be understood in their important, vital, or otherwise significant context" (2000, 23). This focus on historically contingent factors within scientific disciplines and on the context of the phenomenon under investigation makes their view particularly useful for feminist science studies and feminist science.

Conclusion

Whereas a reductive mechanistic approach to science results either strongly in a methodological monopoly, or weakly in privileging low-level methods, once mechanism and reductionism are teased apart, mechanistic science is open to a plurality of methods that can be used to investigate nature at a variety of levels of organization. The interactionist model provides a highly mechanistic explanation of the development of sexual behavior that is consistent with both Salmon's and Machamer, Darden, and Craver's views of mechanism. It reveals how the development of sexual behavior works, both in terms of the constituents of the behavior within the organism and in terms of the processes both internal and external to the organism by which the behavior develops. This model is pluralistic; it does not ignore or rule out the causal influence of genes and hormones, but it also does not privilege these low-level causes over higher level causes, such as social influences. Social influences as well as genetic influences exhibit causal regularities and productive processes. Very different methodologies are required to uncover the genetic influences and social influences on behavior. The interactionist view requires methodological pluralism with respect to the elucidation of causal influence at these different levels of organization. It is an example of an approach to science that produces results that ameliorate many feminist concerns about the linear explanatory model and that, because of the explicit inclusion of higher level causes and social factors, can be used to counteract one of the most central and important feminist criticisms of the biological sciences, biological determinism.

A view of mechanism unhindered by *a priori* reductionist assumptions allows us to address the three feminist concerns raised earlier. The problem of biological determinism is caused by the assumption that biological causes are the only or primary determinants of gendered behavior, and that these causes are low-level and unidirectional. Nonreductive, mechanistic approaches such as the interactionist model ameliorate this problem. The inclusion of environmental and social factors, and the explicit emphasis on the interactions among these factors means that high-level phenomena are not solely determined by genetics or hormonal states. Change in those upper level phenomena may be induced not only by genetic change, but also by environmental or social change.

The interactionist model also offers insight concerning how nonreductive mechanism escapes the methodological/epistemological problem. Although a reductive perspective encourages researchers to focus on phenomena that exhibit low-level causal regularities, a mechanistic approach need not do so. The interactionist model is an example of a mechanistic approach to the role of high-level causes in the explanation of complex phenomena. I have argued that methodological pluralism is an implication of mechanism without reductionism. Studies of low-level phenomena may very well be easier to conduct, but at least part of the reason for this is that methods that engage the world in terms of its tiniest bits are central to sciences such as physics and molecular biology. Within disciplines such as these, reductive methods have been honed and taught over long periods of time. Focusing on mechanism without reductionism provides an avenue for revaluing sciences such as ecology and evolutionary biology, which have long provided mechanistic accounts of complex ecological and biological phenomena.

Mechanism without reductionism allows for a plurality of investigational styles and methodologies. Through whatever complicated interaction of causes, it may turn out to be the case that some women approach research differently from most men. One of the characteristics that may be more common in women's labs is a tendency to engage in a more contextualized and holistic approach to their work. This concept of mechanism takes away many claims that such work is unscientific. A plurality of methods, such as those inherent in the interactionist model, opens the door for researchers to choose an approach that best suits not only the object of study but also one that may best suit their political interests. The opening up of methodology that results from teasing mechanism away from reductionism may give feminist researchers the opportunity to look at gendered issues from a perspective designed to ameliorate past injustices, or to address previously overlooked areas of investigation. Finally, sciences that attract the most women tend to be seen as the "low status" or "softer" sciences. This approach gives us an intellectual framework to revaluing those sciences. Just because evolution is not reductionist does not mean that it is less scientific or even less mechanistic.

The point of Carolyn Merchant's work was that a mechanistic worldview paved the way for a cultural philosophy of domination and control in which both women and the environment suffered. Separating mechanism from reductionism can go some way to relieving her valid concerns. A reductionist stance affects the way that we see the world. If the methods that we use to learn about the world focus on breaking our objects of study into pieces we can easily overlook the effects that changing those pieces has on the greater whole. It also encourages us to overlook the context in which we do our research. This is just the myopia that accounts for much of the success of reductionist science, but that has also led feminists to worry. This stance toward the environment and toward health care in particular has led to the neglect of a more holistic, contextualized view; it has not helped us to address our present environmental crises or to develop an empathetic practice of medicine. A science that allows for higher level and interlevel mechanisms makes it possible to conduct research that pays attention to context and complicated causal situations.

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Notes

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2. Ernest Nagel's (1961) famous work on reductionism is not within the scope of this paper.

3. One could also focus on the role of mathematical models in this analysis.

4. Merchant (1980, 228 and 232) notes a fifth assumption that I will not discuss here.

5. There is current debate in the literature regarding this topic (see Woodward 2003).

6. There is also a serious concern regarding moves from causal explanations of events to causal explanations of regularities (Woodward 1989, 2003).

7. Thanks to Marc Ereshefsky for bringing this point to my attention.

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