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# 1 Introduction: What Is Developmental Systems Theory?

Susan Oyama, Paul E. Griffiths, and Russell D. Gray

The nature/nurture debate is not dead. Open a book, read a newspaper, turn on the TV, read *Science* or *Nature* and you will find yourself bombarded with claims and counterclaims. Are there “genius” genes? If not those, then surely “gay” ones? Is aggression the consequence of social and economic conditions, or is it a product of evolution? Are cognitive differences between men and women due to genetics or upbringing? Can we shape our destiny, or are we robots programmed by our selfish genes? These are not esoteric questions, of concern only to a few academic specialists. Their answers can have social and political consequences. People are quick to draw conclusions about the possibility, or even the *rightness*, of trying to subvert nature’s plans. If intelligence is innate, then some would say that compensatory programs are a waste of effort and money. If sexual orientation is a biological given rather than a free choice, then, so it is argued, the language of morality in that context is both inappropriate and useless.

Underlying these vexed questions are a number of oppositions: nature or nurture, genes or environment, biology or culture. Developmental systems theory (hereafter DST) is an attempt to do biology without these dichotomies. This is a more difficult task and requires a greater theoretical reworking of biological concepts than has so far been realized. The standard response to nature/nurture oppositions is the homily that nowadays everyone is an interactionist: All phenotypes are the joint product of genes and environment. According to one version of this conventional “interactionist”<sup>1</sup> position, the real debate should not be about whether a particular trait is due to nature or nurture, but rather how much each “influences” the trait. The nature/nurture debate is thus allegedly resolved in a quantitative fashion. The question is no longer whether intelligence is innate or acquired, but instead whether intelligence is 50 percent or 70 percent genetic. DST rejects

the attempt to partition causal responsibility for the formation of organisms into additive components. Such maneuvers do not resolve the nature/nurture debate; they continue it. This is typical of the way in which the traditional view of development morphs into new forms when challenged and returns to plague current academic and social debates. If it is no longer acceptable to ask whether something is instinctive, then we ask whether it has a large genetic component. If that, too, becomes unacceptable, then we ask if there is a genetic predisposition toward it. What we need is the “stake-in-the-heart move” (Oyama 1985: 27)—a way of thinking about development that does not rely on a distinction between privileged, essential causes and merely supporting or interfering causes.

Other concepts in the heartland of contemporary biology, such as inheritance and evolution, need substantial reformulation as well. The reliability of many aspects of development has encouraged biologists, psychologists, and social scientists to postulate some central directing agency or “master molecule.” Inheritance and evolution are defined as the passing on and alteration of such master molecules. Other inputs to development tend to be lumped together as “environment” and treated as a standard background that is not itself in need of explanation. In contrast, DST views both development and evolution as processes of *construction* and *reconstruction* in which heterogeneous resources are contingently but more or less reliably reassembled for each life cycle. It is these cycles of contingency that we need to unpack, and it is these cycles that are the subject of this book.

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## So What Exactly Is DST?

What we have come to term *developmental systems theory* is not a theory in the sense of a specific model that produces predictions to be tested

against rival models. Instead, it is a general theoretical perspective on development, heredity and evolution, a framework both for conducting scientific research and for understanding the broader significance of research findings.<sup>2</sup> Many other biological theories play this dual role, perhaps most noticeably in recent years the idea of the “selfish gene” (see chapter 20).

Developmental systems theory is not attributable to one person or group. It draws on insights from researchers in a wide range of areas who have been dissatisfied with crude dichotomous accounts of development and have attempted to formulate an alternative.<sup>3</sup> Table 1.1 draws on a number of past attempts to specify a list of tenets of DST (Gray 1992, 1997; Schaffner 1998; Griffiths and Knight 1998; Oyama 2000b, Introduction). Programs of scientific research are not easily reduced to a set of precisely stated axioms (Kuhn 1970), so these tenets are more like what Schaffner (1998) has called “themes” of developmental systems research. In the rest of this section we expand and comment on these six themes.

### Joint Determination by Multiple Causes

It is a truism that all traits are influenced by both genetic and nongenetic factors. According to DST, however, this “interactionist consensus” is little better than the nature/nurture dispute it

is supposed to have dissolved. There are many kinds of influences on development, and there are many ways to group these interactants together. DST does not claim that all these sources of causal influence play the same role, nor that all are equally important (whatever that might mean). Rather, different groupings of developmental factors are valuable when addressing different questions. The distinction between genes and every other causal factor in development (“environment”) is just one more grouping, possibly helpful for some purposes, much less so for many others. Many developmentally constructive interactions do not fit traditional categories, and for this reason have largely been overlooked or marginalized. Oppositions between genes (or biology) and learning, or between genes (or biology) and culture, are endemic to many fields but are miserably inadequate for capturing the multitude of causal factors needed for any reasonable treatment of ontogeny or phylogeny. DST emphasizes crucial but often overlooked similarities among resources that are usually contrasted. Phenocopying, for instance, occurs when genetic mutations, as well as changes in the outside world, can bring about similar alterations in the organism (Markert and Ursprung 1971; Waddington 1975; see also Oyama 1981 on the significance of this causal parity or symmetry in phenocopying from the perspective of DST). There are bithorax mutants in *Drosophila*, but the

**Table 1.1**

Major themes in developmental systems theory

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1. Joint determination by multiple causes—every trait is produced by the interaction of many developmental resources. The gene/environment dichotomy is only one of many ways to divide up these interactants.
  2. Context sensitivity and contingency—the significance of any one cause is contingent upon the state of the rest of the system.
  3. Extended inheritance—an organism inherits a wide range of resources that interact to construct that organism’s life cycle.
  4. Development as construction—neither traits nor representations of traits are transmitted to offspring. Instead, traits are made—reconstructed—in development.
  5. Distributed control—no one type of interactant controls development.
  6. Evolution as construction—evolution is not a matter of organisms or populations being molded by their environments, but of organism-environment systems changing over time.
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bithorax phenotype can also be induced by ether. Genes and ether shocks turn out to be developmentally equivalent in this respect. Phenomena that are usually contrasted to one another can be equivalent in evolution, too. Developmental influences may follow a lineage equally closely through evolution, even though one is genetic and the other “environmental”—genes and dietary cues, for example (see chapters 16 and 23). These often overlooked similarities form part of the evidence for DST’s claim of causal parity between genes and other factors of development. The “parity thesis” (Griffiths and Knight 1998) does not imply that there is no difference between the *particulars* of the causal roles of genes and factors such as endosymbionts or imprinting events. It does assert that such differences do not justify building theories of development and evolution around a distinction between what genes do and what every other causal factor does.

### Context Sensitivity and Contingency

The demands of interactionism in its conventional form can often be satisfied by merely admitting that every organism must have some genes and some environment. With that out of the way, the real business of settling what is due to nature and what is due to nurture can continue. Typically, this work proceeds by inferring more or less directly the extent of the correlation between genes and phenotype in one or more populations. These methods can be as direct as molecular screening or as indirect as a study of monozygotic twins raised apart. The underlying logic is very similar across this whole range of methods: The stronger the correlation, the more the genes are said to be responsible for the trait. However, as Richard Lewontin has argued, heritability estimates are not measures of global causal importance, nor do they indicate how much a trait can be modified by environmental changes (Lewontin 1974). Heritability estimates measure the proportion of variation in a specific population that is attributable to genetic differences. Be-

havior geneticists these days are quick to admit that high heritability scores do not show that it is hard to alter the trait by nongenetic means. Whenever a number of causal factors interact to produce an outcome, we should expect that the effect of changing one factor will depend on what is happening to the others. However, current theoretical frameworks encourage much more research on “genes for” traits than on statistical interactions among developmental factors in natural populations (see Schlichting and Pigliucci 1998 for a refreshing change).

The persistent tendency to minimize context sensitivity and developmental contingency when studying genetic factors in development is connected to the prevalence of information metaphors in contemporary biology (Keller 1985; Oyama 1985). As long as the DNA is thought of as containing information about developmental outcomes, it will seem sensible to inquire whether outcomes occur because they are represented in the chromosomes. Once an outcome is seen as an expression of the genetic information that controls development, it acquires a special status. It represents what the organism is “meant to be,” and deviations from it are misrepresentations of the true nature of the organism—its inner essence, which was conferred on it at the moment of conception (at least in those organisms that have such moments). In such an intellectual framework, context sensitivity is often treated as interference with the basic pattern of biological causation. For DST, contingency is basic, whether the results are expected or surprising.

### Extended Inheritance

A traditional way to privilege genes over other causes in development is to argue that genes are the only things organisms inherit from their ancestors. Hence the biological nature of organisms must be in the genes. DST insists on a definition of inheritance that explicitly recognizes the wide range of resources that are “passed on” and are thus available to reconstruct the organism’s

life cycle. Some of these resources are familiar—chromosomes, nutrients, ambient temperatures, childcare. Others are less familiar, despite the recent explosion of work on “epigenetic inheritance” (see chapter 9). These include chromatin marks that regulate gene expression, cytoplasmic chemical gradients and gut- and other endosymbionts. Another important topic in recent biology is the participation of the organism in the construction of its niche. Hence a further aspect of inheritance is the local physical environment, altered by past generations of the same species and other species as well as the organism’s own activities (see chapters 10 and 12). Many of these inherited resources have distinctive roles. DNA is unique in acting as templates for protein synthesis. Membranes are unique in acting as templates for the assembly of proteins into more membrane. Chemical traces from foraging play a characteristic role in diet choice in many rodents. A written text, interpreted in an enormously complex personal and cultural setting, is distinctive in yet other ways. DST explores these diverse roles, acknowledging differences but resisting any attempt to divide them into, say, one set contributing to the organism’s “nature” and another that influences its “nurture.” Oyama has argued that if these vexed terms are to be retained, then “nature” should refer simply to the outcomes of development and “nurture” to the processes that produce, maintain, and alter those outcomes (Oyama 1985).

### **Development as Construction**

Developmental systems theory is a thoroughly epigenetic account of development. Current use of term “epigenetic” is ambiguous. It is often used to mean “in addition to the genes,” as in the phrase “epigenetic inheritance” (see chapter 9). Its basic meaning, however, derives from a contrast between preformationist and epigenetic theories of development. Classical preformationism held that the egg contains a tiny organism, so that embryologists only had to explain increases

in size, not the generation of biological order (Pinto-Correia 1997). Modern preformationism is subtler: The organism is not preformed in the egg, but the information that programs its development is preformed in the genes. By contrast, an epigenetic account of development is one that never sidesteps the task of explaining how a developmental outcome is produced. The claim that development occurs because it is programmed to occur or because it has been selected by evolution is merely a promissory note redeemable against future developmental biology. Similar views about biological explanation have been described elsewhere as “constructivist interactionism” (Callebaut and Stotz, forthcoming; Oyama 2000b; see also chapter 15, this volume). Despite its clumsiness, this phrase succinctly expresses two major themes of developmental systems theory. The life cycle of an organism is developmentally constructed, not programmed or preformed. It comes into being through interactions between the organism and its surroundings as well as interactions within the organism.

The conviction that development involves multiple, interdependent causes is entirely compatible with the practical requirements of research. Practicing researchers have to draw boundaries around the system to be studied, placing certain factors in the foreground while taking others for granted. In this book the contributions of Gilbert Gottlieb, Frederik Nijhout, Deborah Gordon, Pat Bateson, and Peter Klopfer show that a strategic concern with complexity and context dependence need not interfere with the process of identifying individual causal contributions by controlling other variables. The practice of changing one variable at a time while holding others constant is important, but it is incomplete. Additional investigation is required, both to show how a causal factor is coupled in a system of causes and to reveal the ways in which these links change over time. It does not require considering everything at once, as some seem to fear, but can be done by coordinating diverse

investigations. In fact, having a richer strategic vision should allow researchers to make more intelligent and flexible “tactical” use of reductionistic research strategies (Wimsatt 1980; see also chapter 17).

### **Distributed Control**

Taking a systems perspective on developmental processes means, among other things, attending to the ways in which the developing organism functions as a resource for its own further development. The organism helps determine which other resources will contribute to that development, as well as the impact they will have. The roles played by the vast and heterogeneous assembly of interactants that contribute to a life-course are system-dependent and change over time. So DST creates an inhospitable context for moves that preempt the investigation of actual processes by identifying one type of resource as controlling or directing the process, leaving other interactants to function as background conditions, raw materials, or sources of disturbance. We believe that despite the widespread talk of genetic blueprints and programs in contemporary biology, there is no scientifically defensible sense in which a subset of developmental resources contains a program or set of instructions for development.<sup>4</sup>

The most obvious way to defend talk of genetic programs and genetic information is to argue that it is in some unproblematic sense related to information theory. “Information” in this statistical sense is the systematic dependence of a signal on a source, a dependence that is created by a set of channel conditions. In the case of development, the genes are typically taken to be the source, so the channel conditions are all the other resources needed for development to occur. But in information theory the role of source and channel condition can be reversed. A source is simply one channel condition whose current state the signal is being used to investigate. If all other resources

are held constant, the outcomes of development can give us information about the genes, but if the genes are held constant, outcomes give us information about whichever other resource we have decided to let vary. Every resource whose state affects development could thus be considered a “source of developmental information.”

Maynard Smith (2000) has recently suggested that this does not capture what is really meant when biologists talk about genetic information. According to him, biologists use information in an intentional or semantic sense—a gene has an intended meaning as well as causal consequences, and this intentional sense of information reveals the true asymmetry between genes and other developmental resources. Sterelny and Griffiths say: “A distinctive test of intentional or semantic information is that talk of error or misrepresentation make sense. A map of Sydney carries semantic information about the layout of Sydney. Hence it makes sense to say of any putative map that it is wrong or that it has been misread” (1999: 104).

Maynard Smith draws on Ruth Millikan’s (1984) attempt to explain intentional information in evolutionary terms. This “teleosemantic” theory says that things carry intentional information about whatever evolution has selected them to represent; a gene contains intentional information about a phenotype that it has been selected to produce. But the same can be said of any developmental resource whose presence can be given an evolutionary explanation. As we argued in the section on extended inheritance, many kinds of developmental resources are inherited and evolve. The teleosemantic account does not show that only genes carry developmental information.

We believe that the heuristic value of the idea of developmental information in certain contexts is more than outweighed by its misleading connotations. Locating information in a single type of developmental resource obscures the context-dependency of causation by localizing control.

Some contributors to the present volume, however, are happier to deploy information concepts than we are, and do so in their chapters.

### Evolution as Construction

The idea of construction through the interaction of many different factors is applicable to evolution as well as development, and it highlights striking similarities between the two processes (Oyama 1992). Just as there are no preexisting representations or instructions that shape organisms from within, there are no preexisting niches or environmental problems that shape populations from without (see chapter 6). Evolutionary change is the result of interactions in which outcomes are codetermined, or co-constructed, by populations and environments with their own, often intricately interrelated, histories and characteristics; outcomes are not imposed by or prefigured in only certain interactants. Extended inheritance both increases the range of developmental outcomes that can be given evolutionary explanations and alters our view of evolutionary dynamics (see chapter 16). If evolution is change in developmental systems, then, as just noted, it is no longer possible to think of evolution as the shaping of the organism to fit an environmental niche. Rather, the various elements of the developmental systems coevolve. Organisms construct their niches both straightforwardly by physically transforming their surroundings and, equally importantly, by changing which elements of the external environment are part of the developmental system and thus able to influence the evolutionary process in that lineage.

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### Aim of This Book

A common response to the confusion and political mischief caused by the nature/nurture debate is to scold the participants for their empirical sloppiness and technical errors (Kitcher 1985, 2001). Though this is often a valuable exercise,

we believe that it does not go far enough (Oyama 1987). Like Levins and Lewontin (1985), we think that the fundamental problem lies in the way causation is viewed in biological systems. This book does not therefore focus on debates about the (mis)application of biological concepts and techniques in arguments about intelligence, aggression, and gender, but rather on the concepts themselves: on the kinds of understandings of biology, development, and evolution that make poor practice likely and render critiques of that practice less than optimally effective. The purpose of the present collection is thus to provide a forum for exploring DST's alternative conceptions of development, heredity, and evolution. The contributors did not necessarily have to identify themselves as proponents of DST, nor were they required to adhere to any party line. In fact, some were selected because they could offer informed criticism. We selected contributors whose writing promised to extend, illustrate, challenge, parallel, or contrast with issues raised in DST. Many were invited to present their own empirical work, but they were asked to confront developmental systems ideas in a substantive way as well. In addition, authors were sometimes encouraged to address key concepts such as genetic information, program, and transmission.

Many of the papers collected here aim at nothing less than a root-and-branch transformation of contemporary biological thought. We do not expect such large hopes to be fulfilled in the immediate future, but we will be gratified if we can convince some readers that there are some real objections to ideas that have previously seemed unproblematic—ideas such as the gene/environment dichotomy and the genetic program for development. We also hope that by drawing attention to alternative ways of thinking about biological systems, and to some programs of research that embody them, we will persuade others to try out some of these alternatives in their own work.

Part I deals with key influences on developmental systems thinking, starting with Daniel S.

Lehrman's classic 1953 critique of the concept of innateness. As Timothy Johnston shows in his introduction to this essay, aspects of what we would now call a systems view of development can be discerned in Lehrman's work and in that of other animal behavior researchers such as Kuo (1967) and Schneirla (1966). The work of these early critics of traditional understandings of instinct and maturation remains relevant because those understandings are still with us. Eschewing pseudo-explanatory notions such as instinct and innateness allows us to ask a host of questions about the actual causal influences at each stage of development. Gilbert Gottlieb has devoted his career to elucidating these influences. In chapter 4 he looks back on this long and fruitful history of research and outlines the conceptual framework he has helped build. The ongoing research tradition stemming from Lehrman, Kuo, and Schneirla and ably represented by Gottlieb (see Michel and Moore 1995 for a recent text in this tradition) provides a standing reply to the challenge that developmental dichotomies are the only way to render complex developmental systems amenable to empirical study.

In the remainder of part I, Richard Lewontin examines the implications of his constructionist view of development and evolution for research in genetics in a new introduction to his classic paper "Gene, Organism and Environment" (1983) which is reproduced here as chapter 6. In this and other papers published around the same time, Lewontin questioned the traditional model of adaptation in which the environment acts on a passive organism and fits it to a preexisting ecological niche. Lewontin's discussion of the role of organism in constructing its own niche is elaborated elsewhere by Kevin Laland, John Odling-Smee, and Marcus Feldman (chapter 10) and by Paul Griffiths and Russell Gray (chapter 16).

Part II looks at attempts to reformulate the idea of heredity so as to do justice to the facts of development. The essays by Eva Neumann-Held and Lenny Moss focus on the concept of the gene itself. Tracking the changing definition of "gene"

and describing the relationship between the genes of classical transmission genetics and those of molecular biology has proved extremely difficult (Falk 1984, 1986; Kitcher 1982, 1984; Sarkar 1998). Neumann-Held and Moss show how a developmental perspective can move this debate forward, in part by revealing how the neglect of development has distorted theoretical conceptions of genes and gene action and marginalized other developmental factors. Despite these similarities in approach, Moss and Neumann-Held propose quite different reconceptualizations of the gene. Both are grounded in the practice of contemporary genetics, and both provide ways to integrate developmental systems thinking into genetics. The future dialectic between these two views should prove illuminating.

The remaining chapters in part II reflect two exciting innovations in recent evolutionary biology. Eva Jablonka's book with Martha Lamb, *Epigenetic Inheritance and Evolution* (Jablonka and Lamb 1995), makes it difficult to go on minimizing the theoretical and empirical significance of extragenetic mechanisms of cellular heredity. Until now, phenomena such as DNA imprinting have been assimilated by conventional neo-Darwinism by invoking developmental programs in the cell or by arguing that their impact on evolution is small when compared to genetic inheritance. Needless to say, Jablonka herself does not accept such maneuvers, but rather traces out the full implications of these phenomena for theories of development and evolution.

Kevin Laland, John Odling-Smee, and Marcus Feldman introduce their work on the significance of niche construction, giving many examples of the reciprocal influence of organisms and their surroundings that Lewontin described in the early 1980s. Laland and his coauthors show how models of gene-culture coevolution can be adapted to explore such phenomena. The theme of niche construction runs through much of this volume, and it is treated in a variety of ways (compare chapters 10, 16, and 19, for instance). There is still some uncertainty about the best

way to integrate this important concept into our picture of evolutionary change.

Even readers who are sympathetic to the concept of a developmental system and aware of the problems it helps to resolve sometimes ask what difference it makes in practice. The chapters in part III, like Gottlieb's chapter in part I, show how the ideas of DST are deployed in actual research. The papers in this section make it clear that similar ideas have been generating important work in a number of fields for many years. One aim of the present volume is to bring these research traditions into closer contact with one another and to show how they complement one another. H. Frederik Nijhout provides a developmental perspective on the genotype/phenotype relationship. He shows what happens when a simple but realistic developmental model of how genes influence phenotypic traits is added to a conventional population genetic treatment of evolution. The results of this modeling exercise challenge the conventional idea that the selection of phenotypes results in the selection of "genes for" those phenotypes. Deborah Gordon gives a DST-style treatment of an entity above the level of the individual organism (an ant colony and its nest). She shows how behavioral patterns that are both complex and flexible can be regulated without a central locus of control. Transindividual units also figure in Peter Klopfer's contribution. Klopfer examines relations between infants and parents, and evaluates several popular metaphors of development. Patrick Bateson reviews some pervasive confusions over heritability and development, and gives examples of the kind of adaptive developmental flexibility that has been a focus of his long-term interest in fusing the developmental and functional perspectives.

Part IV deals with the overall impact that developmental systems ideas can have on biological theory. Susan Oyama's "Terms in Tension" considers the difficulties of employing terms such as *interaction*, *system*, and *construction*, which have complex histories and conflicting theoretical im-

plications. She suggests that although such histories complicate the theoretician's (and reader's) task, they can also be put to good use in elaborating an account of life processes that is adequate to the phenomena of developmental and evolutionary biology and the social sciences.

In "Darwinism and Developmental Systems," Paul Griffiths and Russell Gray systematically redefine in developmental systems terms the key concepts of evolutionary theory: inheritance, natural selection, adaptation, and lineage. They aim to show that the DST formulation of evolution can do all the explanatory work of the conventional ones and can actually extend the range of phenomena that can be given adaptive/historical explanations. Continuing the focus on evolution, William Wimsatt's chapter considers the implications of the fact that evolution must operate by producing systems capable of reliably reconstructing themselves, but also capable of evolutionary change. He argues that this has immediate implications for the sorts of systems that can evolve. Like Wimsatt, Bruce Weber and David Depew are longstanding advocates of the need for a resynthesis of evolution and development. In their chapter they explore the prospects for DST as a source of that new synthesis and also as a way to forge links between biology and the physical sciences.

Part IV concludes with Tim Ingold's examination of biology/culture oppositions in anthropology. He shows how much of our understanding of human life relies on ignoring our role in the construction of our environment, and hence in the construction of ourselves. Ingold also explores links between the gene/environment and biology/culture oppositions and, perhaps the most famous of all these dichotomies, that of mind and body.

Part V contains essays more concerned to explore and evaluate DST than to add to it or provide arguments in its support. Peter Godfrey-Smith confronts the question raised earlier: Is DST a contribution to biological science or



something more like a “philosophy of nature”? In doing so, he provides valuable insights into the variety of functions performed by scientific approaches in general. Kim Sterelny evaluates DST’s attempt to extend the concept of inheritance, taking up the challenge implicit in DST’s claim to provide a principled definition of inheritance. He argues that conventional neo-Darwinism has principled reasons for excluding some of what DST wants to include. Central DST themes of historical contingency, distributed control, and heterogeneity of developmental interactants are taken up in Peter Taylor’s chapter. Like several other authors, Taylor discusses the problem of allocating causal responsibility in complex systems, and, in addition, he addresses the crucial questions of agency and the limitations of trying to bring about change solely through the medium of ideas.

The work of Evelyn Fox Keller also resonates strongly with many DST themes. This is surely the case in her analysis of the metaphors that have sustained dichotomous thinking in modern biology (Keller 1985). In her contribution to this book, however, Keller argues that contrary to DST’s emphasis on the multiplicity of possible boundaries, some boundaries really are special. In particular, she argues that DST is in danger of neglecting the importance of the cell membrane and of the skin that comes to define the body.

In the final chapter of part V, Cor van der Weele takes up the issue of the relationship between scientific approaches and ethical systems, making explicit some of the concerns about science/society relations that are implicit in other chapters. She also discusses the “critical science” tradition to which some of the authors collected here have contributed. Her concept of an ethics of attention is relevant to the use of a systems perspective to counteract the hierarchies of importance built into prevailing ways of thinking. In raising these issues, van der Weele brings us back to the social, economic, and political problems that were alluded to in the beginning of this

introduction, problems that have motivated many of the authors collected here to pay closer attention to the ways in which we conceptualize our natures.

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## Notes

1. The term *interactionism* is widely used but has such a broad spectrum of meanings as to be almost useless. In chapter 15, Oyama examines some of these multiple senses and the problems caused by their coexistence.
2. “Approach” or “perspective” might thus be preferable, but the DST label seems to have stuck. Fausto-Sterling’s (2000) excellent treatment of research on sexuality shows this perspective at work in a field especially laden with just the sorts of social freight alluded to earlier.
3. In the areas of animal behavior and psychobiology these include Bateson (1984, 1991), Gottlieb (1997), Hinde (1968), Johnston (1982, 1987), Klopfer (1973), Kuo (1967), Lehrman (1953, 1970), and Schneirla (1966). In genetics, Lewontin (1974) and Waddington (1975); in developmental biology, Nijhout (1990); and in molecular biology, Stent (1981).
4. Argument and evidence for this view, which will strike many people as surprising, can be found in Godfrey-Smith (1999); Gray (2001); Griffiths and Gray (1994); Johnston (1987); Moss (1992); Nijhout (1990); Oyama (1985); Sarkar (1996); Sterelny and Griffiths (1999); Strohman (1997).

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