Embryology, Epigenesis, and Evolution

Historically, philosophers of biology have tended to sidestep the problem of development by focusing primarily on evolutionary biology and, more recently, on molecular biology and genetics. Quite often, development has been misunderstood as simply, or even primarily, a matter of gene activation and regulation. Nowadays a growing number of philosophers of science are focusing their analyses on the complexities of development; in *Embryology, Epigenesis, and Evolution*, Jason Scott Robert explores the nature of development against current trends in biological theory and practice and looks at the interrelations between evolution and development (evo–devo), an area of resurgent biological interest.

Clearly written, this book should be of interest to students and professionals in the philosophy of science and the philosophy of biology.

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Taking Development Seriously

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Preface

Developmental biology, as a science, is full of mystique. My imagination was easily captured by the amazing journey of the organism from egg to adult, the robustness of development under variable conditions, and the remarkable emergence of complexity during ontogeny. The project of understanding development is one taken up by philosophers of biology only recently, despite having its roots in Aristotle, and I suspect one of the reasons is that development has always been shrouded in a tapestry woven of vitalistic strands so long anathema to philosophers working on the natural sciences.

In the main, philosophers of biology have tended to sidestep development; they have, instead, tended to analyse the apparently more tractable problems of evolutionary biology (particularly fitness) and, more recently, molecular biology and genetics (particularly the relation between classical and molecular genetics). There are, of course, exceptions to these tendencies. In fact, a growing number of philosophers of biology are now exploring the complexities of development. This book catalogues some of the most interesting aspects of this philosophical work, in the context of a sustained introduction to recent developmental science and theory.

In the following pages, I offer a philosophical account of organismal development, address the character of developmental mechanisms, and argue that we should resist the assumption that development can be explained exclusively in terms of gene action and activation. Drawing on this account, I also engage a series of biological and conceptual issues in understanding the relationship between development and evolution – another area of substantial recent philosophical interest.

It is nice – no, necessary – to use real examples in the philosophy of biology. I use them throughout this book. And yet, sometimes, fictional examples can be heuristically useful. A case in point is *Jurassic Park*. Readers (and viewers) of *Jurassic Park* may be forgiven for believing that many of the problems of the development of organisms have been solved. To be sure, things go wrong for the dinosaur makers – plenty of things go wrong. Nevertheless, they succeed in building dinosaurs, however monstrous, from DNA. Deoxyribonucleic acid, we have come to understand, is the key component of life. DNA distinguishes between life and non-life, and once we have isolated the DNA, so the story goes, we can understand all life forms, extant and extinct.

That is an overarching dream of genetics and genomics, and, although DNA, in concert with ecology and development, became a nightmare for the dinosaur makers in *Jurassic Park*, the dream persists in the minds and work of many biologists. Consider the efforts to map and sequence all the genes in a hypothetical, abstract human genome, that of Hugo. (The name 'Hugo' derives from that of one of the Human Genome Project's international overseers, the Human Genome Organization.) Hugo's genome is *hypothetical* because it is not the genome of any particular human, but rather is assembled, in a patchwork manner, from the genomes of hundreds of humans worldwide. (That said, the genome sequenced by Celera Genomics independent of the publicly funded Human Genome Project is, in fact, largely the genome of Celera's former president, Craig Venter; see Wade 2002.) Nonetheless, these genomes are *abstract* because they are said to be representative of humans in general, although that is a physical impossibility, not least because we know of no core sequence of nucleotides (not even Venter's) shared by all humans whatever.

Nevertheless, the first working drafts of a complete human genome were published in *Nature* (International Human Genome Sequencing Consortium 2001) and *Science* (Venter et al. 2001) in February 2001 by the Human Genome Project and by Celera Genomics. With the draft sequences now at hand, scientists are proceeding to finalise the draft(s) and are beginning to annotate and understand the human genome. However, there are deep conceptual problems involving the relationship between Hugo's genome and the development of a human organism. The most glaring ones involve his genome's strikingly artificial nature: genomes simply do not exist independent of the complex organisms of which they are but one part; organisms are not genomes writ large.

Consider, for instance, whatever happened to development. Concerns abound regarding the relationship of genotypes to phenotypes: how does Hugo's gerrymandered, pristine genome correspond to the vast genetic diversity discernible in humans? Is the genome the prime ingredient in a human being, or are there other such ingredients? More basically, is there even any such thing as a 'prime' ingredient in an organism? Is the genome itself sufficient to produce a human animal? If not, what else is required besides DNA to yield a complex, specifically structured, functional human? What are the steps and processes, twists and turns, leading from gametic through geriatric humanity?

As we enter the post-genomic era, the real work is just beginning, for there is a vast developmental terrain to traverse between a genome sequence and a complex, functional organism – as the dinosaur makers in *Jurassic Park* learned all too well.

There are epistemological, metaphysical, and methodological impediments to Hugo's graceful coming out. Many of us have, by necessity, begun to take development into account. Genes don't work by themselves; they must be made to work in developmental context, and they must be reproduced through the generations. A standard interpretation is that the inherited genome initiates and directs development, and that we can understand the development of organisms best by beginning with the genome and investigating the minutiae of gene activation. I contend that this interpretation is misguided, that there is much more to development than the activation of genes, and that the genome may be the wrong place to start in understanding development.

Taking development into account is not the same as taking development seriously.[1] To take development seriously is not to hide behind metaphors of the magical powers of genes – they 'instruct' or 'program' the future organism. To take development seriously is rather to explore in detail the processes and mechanisms of differentiation, morphogenesis, and growth, and the actual (not ideologically or perhaps merely technologically inflated) roles of genes in these organismal activities. Despite the existence of what has come to be known as the 'interactionist consensus', according to which everyone agrees that both genes and environments 'interact' in the generation (and explanation) of organismal traits, my claim is that those swept up in genomania have nonetheless failed to take development seriously.

This is a book about the philosophy of developmental biology in relation to genetics and genomics, and so also in relation to evolutionary biology. This is not, however, a book about gene (or genome) bashing. I take the critical role of DNA in development seriously, but my primary *explanandum* is development, as set within the epistemological and methodological contexts of genomics and genetics.

Developmental biology has played a curious role in the biological mainstream of the past century or so. The halcyon days of evolutionary and experimental embryology eventually gave way to the experiments of the classical geneticists; with the synthesis of a number of biological subdisciplines in the 1940s under the aegis of population genetics, embryology had virtually no presence; when embryology was later reborn as developmental biology, it had virtually no choice but to be guided in the main by the new molecular genetics. Only lately have biologists begun to reconsider how development may not be fully explained in terms of differential gene expression, and how evolutionary biology, relatively ignorant of development, can provide only an incomplete account of the nature and processes of evolution. Drawing on a selective history of key themes in embryology and developmental biology, the burden of this book is to motivate a more integrative approach to biology and to provide a conceptual framework for understanding the central place of development in biology.

I have chosen an alliterative title, *Embryology, Epigenesis, and Evolution*, to describe the investigation in these pages. In Chapter 1, I explore what it might mean to take development seriously, in theory and in practice. I begin by detailing the central problem of development: how it is that a relatively simple, homogeneous cellular mass can become a relatively complex, heterogeneous organism. Then, framed within a discussion of some heuristics employed in developmental biology and of the impact of the respective biases of these heuristics, I critically assess the use made of certain kinds of experiments in supporting and preserving the overwhelming sense that development can be explained strictly or primarily in terms of differential gene expression. In Chapter 2, I orient the reader with three examples, one each to represent the three elements of the book's title: embryology (the experiments of Roux and Driesch); epigenesis (homeobox genes in development and evolution); and evolution (blind cave fish).

In Chapter 3, I begin to worry about particular metaphors commonly associated with the explanation of development in recent years – 'genetic programme', 'genetic information', 'triggering', and 'interaction' – and I explore their impact on biological theory and practice. Aspects of the old debate between preformationists and epigenecists comprise the subject matter of Chapters 3 and 4. Historically, preformationists held that a future individual organism is somehow contained in toto in the zygote or, more ambitiously, in either the ovum or the sperm (depending on one's sex-cell preference). The future organism merely grows into a fully formed adult without an attendant increase in complexity. Epigenecists held, to the contrary, that the complex individual, guided by some directing principle, emerges from relative homogeneity over developmental time; the future organism is formed during ontogenesis rather than pre-existing it. There are neither pure preformationists nor pure epigenecists in the world today; in fact, most views of development seek to meld aspects of preformationism with elements of epigenesis. I examine various of these modern reconciliations, representing what

I take to be the 'modern consensus' view on development, before exploring in subsequent chapters the problems with this position.

In Chapter 4, I briefly recount salient elements of the history of the conceptual and professional divorce between genetics and embryology achieved in the early part of the twentieth century. This potted history should not be taken as either authoritative or comprehensive; its function is, rather, illustrative, and it motivates an extended discussion of 'epigenetics' and an argument for the desirability of organism-centred biology. I also offer my own account of epigenetics as constitutive of genes, which serves as the basis for my discussion in Chapter 5 of the creativity of development.

In the final two chapters, I turn squarely to the third element of my title: evolution. Chapter 6 details the most promising synthesis of development, genetics, and evolution to date – evolutionary developmental biology (evo–devo). I provide a series of examples to show how development and evolution, and developmental and evolutionary explanations, can be interrelated, and I argue that taking development into account may well offer a substantive challenge to evolutionary theory as we know it. Then, in Chapter 7, I return to the question of taking development seriously. There I explore conceptual and theoretical aspects of the relationship between evo–devo and the developmental systems perspective on ontogenetic processes in evolution, indicating the benefits and limits of both approaches and elucidating the fallout of taking development seriously. Again, the aim is not to belittle the role of genes in development and evolution but rather to establish a clear and realistic sense of what genes can and cannot do for us. When we take development seriously, I contend, it becomes apparent that the explanatory burden is not discharged at the level of genes in either developmental or evolutionary contexts.

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