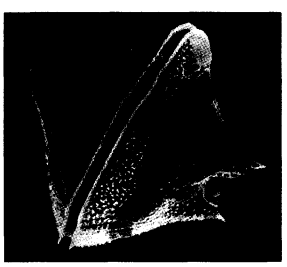
Exception to Eukaryotic Rules

"IN THE NUCLEI OF ALL EUKARYOTIC CELLS, genomic DNA is highly folded, constrained, and compacted by histone and nonhistone proteins...," write Thomas Jenuwein and C. David Allis in their review "Translating the histone code" (special issue on Epigenetics, 10 Aug., p. 1074). Although true for most all eukaryotes, this statement is not true for a large and important group of organisms, the dinoflagellates.

This diverse group of eukaryotic algae play a major role in marine food webs, and the toxic members of this group pose a health threat in the form of red tides. Basic cell structure, biochemistry, and molecular phylogeny place the dinoflagellates firmly within the eukaryotic lineage, but in contrast to all other eukaryotes, they are devoid of histones. Dinoflagellates do not contain nucleosomes, but their nuclear DNA is nonetheless organized into morphologically distinct chromosomes. Although lacking histones, dinoflagellate chromatin does contain one to four basic proteins, but these proteins represent only about 10% of the mass of DNA, compared with histones that are present in a 1:1 ratio relative to the DNA.



The dinoflagellate *Protoperidinium leonis*

We feel that an acknowledgement of a broader diversity within the eukaryotes could be incorporated into papers without affecting the scientific impact of authors' research and, at the same time, bring attention to a relatively unstudied but interesting group of eukaryotes.

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Etymology of Epigenetics

THAT IS A CHARMING EXCHANGE OF LETTERS between the 1910 traveler Mr. Bacon and two modern geneticists in "Genes, genetics, and epigenetics: a correspondence" by C.-t. Wu and J. R. Morris (Viewpoint, special issue on Epigenetics, 10 Aug., p. 1103). The authors might be correct about Waddington as the originator of the term epigenetics, but only in the modern sense of the origin of the phenotype from the genotype. The root term epigenesis goes back more than two millennia to Aristotle, as Waddington acknowledged, and was proposed in opposition to preformation, the concept favored by the Greek philosophers Democritus and Leucippus. In epigenesis, there were no preformed equivalents in the fertilized egg for later developing structures. Preformation maintained its hold in the popular mind for millennia, even capturing the attention of the great 17th-century anatomist Malpighi.

The advent of the microscope and the discovery of the germ layers in the chick embryo by Pander, and their generalization by von Baer, settled the issue in favor of epigenesis in the 18th century. Of course, genetics was unknown as such until the 20th century; until then, "epigenetics" implied the workings of epigenesis, as studied by Roux and his school of experimental embryologists in the 19th century. Waddington's adaptation of the term epigenetics to modern genetic concepts was an advance in one sense, but has apparently allowed many to forget the root and original intent of the term.

While we search for reactions that persist through mitosis, we forget that hierarchical structures maintain tissue stability. We might well contemplate as the starting point for a deeper understanding of epigenetics the insight of Sewall Wright, a founder of population genetics: "Persistence may be based on interactions among constituents which make the cell in each of its states of differentiation a self-regulatory system as a whole, in a sense, a single gene at a higher level of integrations than the chromosomal genes" (*1*). Such hierarchical thinking would help structure the many molecular interactions certain to accumulate under the current rubric of epigenetics and give them deeper biological significance.

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References and Notes
1. S. Wright, *Am. Nat.* LXXIX, 289 (1945).

Response

I AGREE WITH RUBIN THAT, FOR MANY, THE history of the term epigenetics has been lost and, with it, useful viewpoints. A colleague has further alerted me to an early discussion of "Development as an epigenetic process" by C. H. Waddington in his book *An Introduction to Modern Genetics* (*1*). This discussion is a forerunner to Waddington's 1942 paper (*2*) introducing "epigenetics" and has clarified for me how the author might have progressed from the original theory of epigenesis to "epigenetics."

In this earlier piece, Waddington explicitly mentioned epigenesis and preformation, putting each into the context of development. With respect to epigenesis, he said that as "the interaction of these constituents [of the fertilized egg] gives rise to new types of tissue and organ which were not present originally,...development must be considered as 'epigenetic.'" Waddington then considered the manner in which tissues and organs are induced during development. He discussed the concepts of genotype and phenotype but noted that they "are not adequate or appropriate for the consideration of the development of differences within a single organism." That is, "the difference between an eye and a nose, for instance, is clearly neither genotypic nor phenotypic." Instead, the difference "is due...to the different sets of devel-

Letters to the Editor

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opmental processes which have occurred in the two masses of tissue." Waddington suggested that the terms epigenetic constitution or epigenotype be used to refer to the "set of organizers and organizing relations to which a certain piece of tissue will be subject during development." These terms in hand, he then urged that we consider "the appearance of a particular organ [as] the product of the genotype and the epigenotype, reacting with the external environment." Thus, in this manner, Waddington drew the original concept of epigenesis closer to those of genotype, phenotype, and development.

With regard to the quotation from Wright that Rubin mentions, I would also agree. We must keep in mind the context in which a gene works and that, as we broaden our understanding of the gene, the boundary of the gene might become less obvious. By way of thanks, I append a quotation from a paper published by H. J. Muller in 1938. Its focus, the phenomenon of position effect, differs from the issue addressed by Wright, but its flavor seems reminiscent of Wright's message.

> In the production of phaenotypic effects the gene must begin by interacting with cellular substances so as to produce a highly specific product or products, which must diffuse out from the locus of activity of the gene and in turn cause (or affect) further physiochemical changes. In the course of one of these chains of reaction, that has its origin in an individual gene, there will be many opportunities for interaction with other chains of reaction present in the complicated mixture; thus, the reactions will really form a kind of multi-dimensional net, rather than a simple chain. The final phaenotypic manifestations lie at the ends of the net furthest removed from the inner gene ends, and their quality depends upon the character and strength (including speed) of all the intermediate reactions and interactions (*3*, 1938, p. 588).

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References and Notes

1. C. H. Waddington, *An Introduction to Modern Genetics* (Allen & Unwin, London, 1939), pp. 154–156.
2. ———, *Endeavour* **1**, 18 (1942).
3. H. J. Muller, *Proceedings of the 15th International Physiological Congress*, Leningrad-Moscow, 1935 (State Biological and Medical Press, 1938), pp. 587–589. Reprinted in *Studies in Genetics: The Selected Papers of H. J. Muller* (Indiana Univ. Press, Bloomington, IN, 1962), pp. 137–140.
4. I thank M. Green at the University of California, Davis, for alerting me to Waddington's 1939 discussion of epigentics.

Speciation and Centromere Evolution

A NEW MODEL FOR THE ORIGIN OF SPECIES IS proposed by S. Henikoff and co-authors in their review "The centromere paradox: Stable inheritance with rapidly evolving DNA" (special issue on Epigenetics, 10 Aug., p. 1098). Referring to the research in *Drosophila* to illustrate their idea, Henikoff *et al.* suggest that concerted evolution of centromeric satellite DNA and the centromeric histone protein centromere identifier (Cid) in isolated populations should result in a loss of compatibility between these elements in the hybrids. This should lead to chromosome nondisjunction (the failure of homologous chromosomes to segregate properly during meiosis) in the hybrids, and their sterility. Therefore, "speciation is an inevitable consequence of centromere evolution."

The authors suggest several tests for their model, but there is a simple test that should be definitive. If the model is correct, then the genes for hybrid sterility must be located predominantly at centromeres or the sites of Cids (or both). Alas, the mapping data from *Drosophila* and mouse indicate that they are not.