

## DEVELOPMENT

# The Flexible Organism

David W. Pfennig and Cris Ledón-Rettig

In the last chapter of *How and Why Species Multiply* (1), Peter and Rosemary Grant concluded that “[n]othing in evolutionary biology makes sense except in the light of ecology.” In *Ecological Developmental Biology*, Scott Gilbert and David Epel argue that nothing in developmental biology makes sense except in the light of ecology either.

Traditionally, ecology—the study of the relations of organisms to one another and to their physical surroundings—has not featured prominently in developmental biology. Yet, as Gilbert and Epel (developmental biologists at Swarthmore College and Stanford University, respectively) observe, biologists have known for at least a century that ecology is an essential partner in development: In 1909, Danish biologist Wilhelm Johannsen asserted that an organism’s appearance, physiology, and behavior (that is, its phenotype) derive from an interaction between its genes and its environment. Moreover, biologists long ago discovered that numerous external environmental factors—such as temperature, diet, physical stress, and the presence of predators or competitors—can alter an organism’s development, often by generating a phenotype that is well suited for its current environment. For example, some plants produce large, thin leaves (which enhance photosynthetic photon harvest) in low light, and narrow, thicker leaves (which conserve water) in high light; certain insects develop wings only if they live in crowded conditions (and hence are likely to run out of adequate food in their current location). Such environmentally contingent development is so commonplace that it can be regarded as a universal property of living things.

The emerging field of ecological developmental biology (sometimes dubbed “ecodevo”) explores how organisms develop and function in “real-world” environments (2). Analyzing development among diverse organisms under different environments is a departure from how development has previously been studied. Traditionally, research

has focused on a few species (“model organisms”) in the laboratory (3). Because development was typically studied in uniform environments,

past research fostered the erroneous view that environmentally contingent development is rare or unimportant. However, knowledge of ecology’s role in development is essential for a complete understanding of how organisms develop and evolve. Indeed, according to Gilbert and Epel, “in

addition to helping decide the survival of the fittest, the environment is also important in formulating the arrival of the fittest.”

Unraveling ecology’s role in development is not merely an academic exercise; it is also vital for matters of public health. Researchers have long known that certain environmental agents (including some commonly used household and agricultural products) can induce phenotypic variation by altering gene expression rather than gene nucleotide sequences. These “epigenetic” changes can cause diseases such as cancers and diabetes. In addition, because these environmental modifications can be passed stably from one generation to the next, conditions experienced by past generations can profoundly influence the health of subsequent generations. Yet, the descendants experiencing such health problems may live in a perfectly benign environment and have no (apparent)

## Ecological Developmental Biology

Integrating Epigenetics, Medicine, and Evolution

by Scott F. Gilbert and David Epel

Sinauer Associates, Sunderland, MA, 2009. 496 pp. \$49.95. ISBN 9780878932993.

The reviewers are at the Department of Biology, University of North Carolina, Chapel Hill, NC 27599, USA. E-mail: dpfennig@unc.edu (D.W.P.); ledonret@email.unc.edu (C.L.-R.)



**Seasonal morphs.** Spring *Nemoria arizonaria* caterpillars resemble oak catkins (left); summer ones, newly formed twigs (right).

standing how organisms are built, function, and evolve or how anthropogenic environmental change affects the health of ourselves and other organisms.

#### References

1. P. R. Grant, B. R. Grant, *How and Why Species Multiply: The Radiation of Darwin's Finches* (Princeton Univ. Press, Princeton, NJ, 2008); reviewed in (8).
2. S. E. Sultan, *Trends Ecol. Evol.* **22**, 575 (2007).
3. B. Maher, *Nature* **458**, 695 (2009).
4. T. Hayes et al., *Environ. Health Perspect.* **111**, 568 (2003).
5. C. D. Schlichting, M. Pigliucci, *Phenotypic Evolution: A Reaction Norm Perspective* (Sinauer, Sunderland, MA, 1998); reviewed in (9).
6. M. J. West-Eberhard, *Developmental Plasticity and Evolution* (Oxford Univ. Press, Oxford, 2003); reviewed in (10).
7. E. Jablonka, M. J. Lamb, *Evolution in Four Dimensions* (MIT Press, Cambridge, MA, 2005).
8. H. Kokko, *Science* **319**, 1187 (2008).
9. H. A. Orr, *Science* **285**, 343 (1999).
10. J. S. Levinton, *Science* **301**, 767 (2003).

10.1126/science.1175598

## PHYSICS

# Entanglement with a Twist

Jonathan P. Dowling

When I picked up *The Age of Entanglement*, the first thing to catch my eye was a quote on the back dustjacket, “for a moment I almost thought I understood quantum mechanics.” I thought, “Oh boy, this could be trouble.” Recollections danced in my noggin of uncomfortable conversations on crowded airplanes that begin with “Oh, you are a quantum physicist?—Then you must have seen *What the Bleep Do We Know!*” But proceeding through the book, my fear was never realized. I instead found a witty, charming, and accurate account of the history of that bugaboo of physics—quantum entanglement.

When I was a graduate student in physics, I made the decision to spurn a respectable career in high-energy physics theory (if nowadays one can consider superstring theory to be respectable) and embraced a future in the foundations of quantum mechanics. As Louisa Gilder repeatedly points out, in the mid-1980s such a career move was considered the kiss of death. At that time a respected professor pointedly told

The reviewer is at the Department of Physics and Astronomy, Louisiana State University, Baton Rouge, LA 70803–4001, USA. E-mail: jdowling@lsu.edu

me, “This foundations of quantum mechanics is crackpot stuff—you will never get at job.” My, how times have changed.

There are many books out there on the history or foundations of quantum mechanics. Some are more technical, others more historical, but none take the unique approach that Gilder has—to focus on the quantum weirdness of entanglement itself as

her book’s unifying theme and to present it in an inviting and accessible way. *The Age of Entanglement* offers neither a technical nor a biographical account. Rather, as Gilder states up front, it provides a collection of reconstructed conversations among some of the 20th century’s greatest physicists. These conversations all revolve around the notion of quantum entanglement: the spooky, action-at-a-distance effect predicted by quantum theory but only slowly recognized as the theory’s defining feature and even more slowly shown to be experimentally verifiable.

Your opinion of the book will largely hinge on how you react to these reconstructed conversations. Concerning one such imagined conversation between Albert Einstein and Niels Bohr on a streetcar in Copenhagen, Gilder notes, “We know that the conversation ... happened, because Bohr mentioned it in an interview .... The content of the conversation is easy to gather from a look at what the three men were working on ... around the same time.” Rather than provide dry quotations from original sources, Gilder decided to weave information from these sources into a series of imagined conversations. The

author offers extensive documentation for these conversations in the notes, so they are not flights of fancy. Her technique leads to text such as, “‘If, however’—and here [Einstein] looked straight at Heisenberg, who was leaning forward in his chair, his pale hair shining in the dim room—

‘as is obviously the case in modern atomic physics ....’” I suppose neither Einstein, Werner Heisenberg, nor anyone else recorded that Heisenberg’s pale hair was shining in the dim room, but it makes for a good story. For this protocol to work for me, I had to first execute Coleridge’s “willing suspension of disbelief” and then engage Tolkien’s “secondary belief.” That done, I was



John S. Bell. Foundational theorizer.

enthralled and found the book delightful.

Gilder skillfully relates the early discomfort physicists felt concerning some of the arcane predictions of quantum mechanics; how Einstein, Erwin Schrödinger, and others repeatedly distilled and titrated their misgiving until they were able in the 1930s to present the essence of their fears in the form of the Einstein-

Rosen-Podolsky paradox; Schrödinger’s cat; and the now famous notion of quantum entanglement—spooky action-at-a-distance that quantum theory must contain. Much in these older “discussions” was familiar to me from other sources. What I found most gratifying were the studiously documented dialogs of later developments: Bell’s inequalities and the consequent experiments, which proved that nature is stranger than we can think. The details of the story of David Bohm and his trials, after constructing a nonlocal hidden variable theory, were new to me. The account of John Clauser and his cohorts in the race to demonstrate (by testing Bell’s theory) once and for all that this quantum weirdness did or did not exist was side-splitting. An old friend and collaborator, Clauser does in fact curse like a sailor, as Gilder often has him do. (He is a sailor, and I wonder whether the cursing or the sailing came first.) I was spellbound by the details of the struggles of Clauser and colleagues with the massive, punch-tape spewing, “coffin” contraption clanking away, day after day, in the bowels of Berkeley. It is tragic that this apparatus now lies in mothballs in the attic of LeConte Hall instead of on display at the Smithsonian.

Gilder wraps up *The Age of Entanglement* with conversations among younger quantum technologists such as Artur Ekert, Nicolas Gisin, Daniel Greenberger, Michael Horne, Terrence Rudolph, and Anton Zeilinger. As I read these pages, I wondered if I should feel slighted—there is no mention of me. Then I happened upon this description of a colleague and friend: “Meanwhile in the Sangre de Cristo Mountains of New Mexico, Paul Kwiat, an endearingly birdlike man in glasses and suspenders with boundless energy and encyclopedic knowledge, led his team in attempting various eavesdropping strategies on their Alice and Bob.” Thank goodness for small favors, I thought, smiling to myself.

10.1126/science.1176008

**The Age of Entanglement**  
When Quantum Physics  
Was Reborn

by Louisa Gilder

Alfred A. Knopf, New York,  
2008. 462 pp. \$27.50, C\$32.  
ISBN 9781400044177.