Illuminating Biology: An Evolutionary Perspective

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Illuminating Biology: An Evolutionary Perspective

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The evolution symposium series, in its fifth year, continues to be popular.

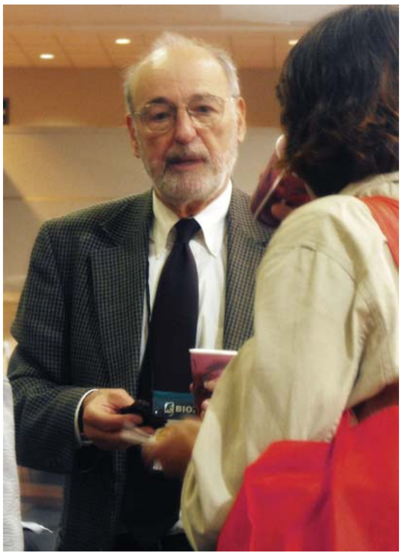
What do biochemistry, developmental biology, molecular biology, and neurobiology have in common? Evolutionary concepts related to these topics have not traditionally played a prominent role in an educator's toolbox. But that needn't be the case any longer. In October 2008, four prominent scientists presented examples from current research that can help educators incorporate evolutionary theory into each of these biological subdisciplines.

The American Institute of Biological Sciences and the National Evolutionary Synthesis Center (NESCent) provided the venue for these presentations at their fifth evolution symposium, "Illuminating Biology: An Evolutionary Perspective," held in Memphis, Tennessee, at the annual conference of the National Association of Biology Teachers.

Gene sharing and evolution

Joram Piatigorsky, of the National Eye Institute at the National Institutes of Health, and colleagues developed the concept of gene sharing, which presents some remarkable insights into proteins. "The common view is that proteins specialize in one job. In fact, proteins can specialize in more than one job," he said. Through gene sharing, a protein that evolved to perform a specialized function may also acquire other biological roles.

Take crystallin, for example. It is a crystal-clear, water-soluble protein normally found in the lens, where it is responsible for the eye's optical, refractive properties, which are required for focused vision. In some species of jellyfish, crystallins are expressed not just in the lens but in several unexpected places, such as the tip of its tentacles. Another surprise comes from a worm that lives in the gut of a grasshopper. A red shield around its eye lens, allowing light to come through, is made up of hemoglobin. Piatigorsky showed slides comparing vertebrate eyes to demonstrate how common this multifunctionality is. The eyes looked and acted the same, and the lens focused in the same way. However, the proteins refracted light in a special way in each species, indicating that the regulation of the crystallin gene had undergone some change over time. And what's more, a common enzyme involved in metabolism turns out to be a crystallin in different animals.



Joram Piatigorsky heads the Laboratory of Molecular and Developmental Biology at the National Eye Institute, National Institutes of Health, in Bethesda, Maryland.

Evolution shows tremendous pragmatism, Piatigorsky said. Gene sharing raises a paradoxical problem: How can specialization and diversification go hand in hand? Piatigorsky asked educators to consider other implications of gene sharing: If some proteins perform a variety of functions in the same and in different species, what are the boundaries of a gene? How is a gene identified, by its structure or its function? Should regulatory sequences be considered part of a gene? What is the influence of gene expression on natural selection of protein functions? Piatigorsky amply illustrated the need to rethink the complex interrelationships among genes, proteins, and evolution.

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Robert Blankenship is the Lucille P. Markey Distinguished Professor of Biology and Chemistry at Washington University in St. Louis.

Evolutionary relationships among phototrophic bacteria

Energy has become the number one global concern for a whole host of reasons, and the need for new ways to produce it is one of the primary scientific challenges of our time. Robert Blankenship, of Washington University in St. Louis, pointed out that photosynthesis is the source of much of our energy, as essential in the production of our food as it was in generating fossil fuels. "The invention and perfection of photosynthesis is without question one of the true milestones in the evolution of life on Earth," he said. The understanding and teaching of this process is more important than ever.

Blankenship's talk took participants along the complex evolutionary path that led to the modern process of photosynthesis. Ancient Earth was anoxic for its first 2 billion years. Photosynthetic organisms developed the ability to oxidize water, forming molecular oxygen and changing the redox balance of Earth, about 2.4 billion years ago. Only then was the energetic base established for more advanced life to emerge. Even though photosynthesis is so important in Earth's history, scientists do not have enough information about how it developed from simpler, and presumably more primitive, anoxygenic (non-oxygen-evolving) forms of photosynthesis. Today, oxygenic photosynthetic organisms rule the planet, and most anoxygenic organisms have settled into specific environmental niches.

Blankenship's research suggests that the evolutionary path connecting the anoxygenic and oxygenic phototrophs (organisms that use light to generate energy) is complex. By constructing species trees, his team can better understand photosynthesis and other metabolic processes, such as nitrogen fixation, as they've come and gone through time. For example, energy-converting antenna systems show tremendous diversity and imply multiple evolutionary pathways, revealing the different environments to which organisms have been exposed. There is also substantial evidence that symbiosis and horizontal gene transfer played an important role in the evolution of photosynthesis.

Bringing an evolutionary perspective to developmental biology

Patricia Wittkopp, of the University of Michigan, investigates the genetic basis of phenotypic evolution. From her presentation, educators gained greater awareness of evolutionary developmental biology, or "evo-devo," a field of research that compares the developmental processes of different organisms to determine their evolutionary history. "As we understand genetics better, we get two clues at the same time: how DNA provides a blueprint for the final, adult organism, and how that organism relates to its relatives, both more and less recent," she explained.

Gene regulation is the core mechanism by which cell types become different from each other. Each gene has one or more regulatory sequences that allow it to be turned on or off like a light switch—or, to be more precise, like a dimmer switch that fine-tunes the level of expression. Differential gene expression, operating on the full array of genes in each cell from the earliest single-cell stage to the fully differentiated state, produces the variety of specialized cell types that make up a complete organism. As the cell number increases during development, the cells become progressively more specialized. A cell that winds up in the heart, for example, is groomed to become a functioning part of the heart but not part of the kidney, for instance.

Patricia Wittkopp is an assistant professor in the Department of Ecology and Evolutionary Biology at the University of Michigan in Ann Arbor.

Wittkopp's research focuses on developmental gene expression of pigmentation in insects. Fruit flies are excellent experimental subjects: their overall morphology is unchanged by Wittkopp's manipulations but their pigmentation is highly variable. A major finding of her research is that pigmentation patterns are changed through changes in the expression of pigmentation genes, not through changes in enzymatic activity or other protein functions. This type of gene regulation, called *cis* regulation, and regulatory change in general are a pattern that has emerged in the development of plants and animals alike. Wittkop encouraged educators to expand a class discussion of fitness to include the idea that "the survival of the fittest starts with the arrival of the fittest," a phrase attributed to Scott F. Gilbert, a developmental biologist at Swarthmore College. Wittkopp suggested other teaching points from evo-devo research, in particular, that protein functions and development pathways are often conserved, changes in gene expression are an important source of phenotypic change, and developmental studies can inform evolutionary investigations and vice versa.

Large and complex brains evolved repeatedly

Neurobiologist Georg Striedter, of the University of California in Irvine, aims to understand why the brains of different species have myriad similarities but still differ in many respects. He maintains

Georg Striedter is an associate professor in the neurobiology and behavior and the ecology and evolutionary biology departments at the University of California, Irvine.

that large and complex brains evolved not just in primates but also in other taxonomic groups, including octopuses, manta rays, electric fishes, parrots, crows, dolphins, and elephants.

Striedter's slides of brains of various animals reveal a central theme: evolutionary changes in brain size are related to other aspects of brain structure and function, including the brain's complexity, its neuronal connections, and the organism's behavior. Educators were surprised to learn which animals had relatively large brains. They questioned why filter-feeding manta rays have large brains but filter-feeding sharks do not, and why other sharks, such as the hammerhead, have large brains. They asked why birds, which are descended from flying reptiles, have larger brains than reptiles. Why do some birds—such as crows, which have been observed bending wire to make a tool—act smarter than others? Streidter pointed out that many animals with large brains lead complex social lives. Many have longer gestation periods and live longer. There's also a clear trend toward greater folding of the brain's surface, or cortex, which gives larger brains more surface area and more intellectual capacity than a brain of comparable volume with a smooth surface.

Symposium workshop

The day after the symposium, educators attended a half-day workshop to explore how to teach the themes of the symposium. Anna Thanukos, of the University of California Museum of Paleontology, and Jennifer Collins, teacher adviser to the university's Web site Understanding Evolution (*http://evolution.berkeley.edu*), presented the first session, "Evolution and Conservation." Participants took part in a hands-on classroom activity about monitoring commercial whale meat on the basis of phylogenetic relationships. Sam Donovan and Ethel Stanley, of the BioQUEST Curriculum Consortium, and NESCent's Brian Wiegmann and Kristin Jenkins led the second session, "Evolution and Biocontrol." Using a case study of paperbark trees in Florida, participants learned how biocontrol agents can be identified through applied systematics. Educators also heard suggestions about how to identify and address common student misconceptions about reading evolutionary trees.

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The teaching and learning resources from the 2008 evolution symposium are available on CD from NESCent. Visit the Web site *www.nescent.org/media/nabt.php* for more symposium information and other education resources.

"You woke me up for that? It better be endangered."