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A Revolution in Evolution

Jim Bull and Holly Wichman

Evolutionary biology has emerged from its 19th-century state; the image of naturalists collecting butterflies and museum curators dusting fossils has faded. Evolution is now widely perceived and appreciated as the organizing principle at all levels of life. This principle so pervades research that the evolutionary underpinning of many experimental approaches is unstated. For example, studies in the developmental genetics of fruit flies led to the discovery of genes that control development in all segmented organisms. Protein alignments are used to identify conserved amino acid residues that are potentially important to function. Even the hierarchical use of model organisms, from bacteria to humans, in biomedical testing and research is implicitly based on a recognition that the same building blocks underlie all life and that levels of increasing similarity are nested.

The study of evolution ... has now become socially and economically relevant

Today, the study of evolution is motivated by the human drive to understand the world and our place in it. But the field has now become socially and economically relevant. Heavy use of pesticides and antibiotics has fostered the evolution of resistant pathogens and pests. Phylogenies (the underpinnings of evolutionary theory) are used to track infectious diseases, and they have just been admitted into Louisiana criminal courts to infer sources of HIV transmission. Drug development makes use of "directed" evolution, using in vitro selection, mutation, and recombination—some of nature's evolutionary mechanisms—to find molecules for specific tasks. Bioremediation exploits the evolution of novel functions in microbes to clean up toxic waste. Do we face future challenges from evolution in genetically engineered organisms or from bioterrorists producing new capabilities in pathogenic microbes?

The revolution in evolutionary biology has been advanced on several fronts through changes in technology, expansion of theory, and novel methodological approaches. Technological advances in molecular genetics have provided insights into the deepest mechanistic secrets of evolution. Aided by advances in computer technology and phylogenetic theory, molecular genetics has also provided a universal tool for uncovering evolutionary histories. On another front, the classical Darwinian model of natural selection has given way to a more complex view; selection on the "selfish" gene affects organization at all levels, giving rise to parent-offspring, male-female, and intragenomic conflicts of interest. A new wave of advances is promised by experimental evolutionary biology, as theories are tested from direct observations of evolution in the laboratory, and results are assessed at the phenotypic, genetic, molecular, and structural levels.

Notwithstanding this recent metamorphosis, many mysteries in the field remain to challenge us. Complex evolutionary phenomena are difficult to explain from well-understood elemental mechanisms, just as the weather proves difficult to predict despite advances in basic physics. One fundamental challenge is to understand the extent to which the mechanisms that account for microevolution can explain the elaboration of forms in macroevolution. On a more immediate level, can we learn the rules of adaptation at the molecular level? It is conceivable that the short-term course of adaptation in response to specific selective agents can be predicted in some species, and it is the short-term course that is most relevant to human health and infectious disease.

Evolutionary biology continues to face the social and legal opposition it has experienced since before the Scopes trial. It is viewed by some as a threat to cultural values and has been misused by others to condone bad behavior. Nonetheless, the science continues to advance profoundly, solving public health and environmental problems far beyond anything imaginable even a generation ago. However, at a time when evolution is the unifying fabric of biology, it is barely mentioned in some high school textbooks and classrooms. Will the next generation of scientists be prepared to exploit these advances?

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