Evolutionary biologists have a secret. While our research is motivated by a desire to reconstruct life’s history, it can also provide novel insights into fundamental cellular mechanisms in modern organisms. Studies of evolution reveal how the cell’s component parts were “assembled” over time, how and why cells are vulnerable to disease and death, the molecular mechanisms that are responsible for fundamental cellular processes, and those mechanisms that distinguish the morphology and physiology of different lineages of organisms from each other. Studies of “evolutionary cell biology” promise to deepen our understanding of how cells function.

Exciting recent advances in our understanding of the “nature” of cells have come from a focus on genome evolution and cell-intrinsic molecular mechanisms. One of the major success stories has come from the use of evolutionary principles to study the composition and biosynthesis of cilia (also known as flagella) and basal bodies. Cilia found in diverse eukaryotes (including amoeboid flagellates, green algae, and humans) contain a highly conserved protein core and therefore likely evolved before the divergence of all modern eukaryotic lineages. However, a few eukaryotic lineages (most notably the land plants and fungi) have lost cilia, basal bodies, and the genes most closely associated with ciliary function. By capitalizing on the evolutionary pattern of ciliary gene conservation and loss, proteomic approaches coupled with comparisons of genomes from diverse eukaryotes have revealed dozens of previously uncharacterized genes with potential roles in ciliary assembly (Li et al., 2004; Merchant et al., 2007; Fritz-Laylin et al., 2010). These discoveries, in turn, have fueled research into the molecular mechanisms underlying ciliary function and biomedically relevant ciliopathies (e.g., see Marshall, 2004; Dammermann et al., 2009). Therefore, combined knowledge of which flagellar parts are universally conserved and their functions have illuminated the core assembly mechanism.

Yet, the “nature” part of cell biology is not everything. The evolutionary perspective forces one to consider how the extracellular environment influences or “nurtures” the physiology and evolution of cells. While it has long been known that cells in multicellular organisms communicate information by signaling to each other, we are only beginning to discover how interactions with other species and abiotic environmental factors can also communicate biological information. The influence of bacteria extends to the origin of eukaryotes, when the engulfment of an α-proteobacterium laid the foundation for the evolution of mitochondria (Margulis, 1970; Gray et al., 1999). Interactions with bacteria continue to exert strong effects on eukaryotes. In many modern eukaryotes, associations with specific commensal bacteria are essential for development and homeostasis (Table 1; Lefranc et al., 1990; McFall-Ngai, 2002; Hogan et al., 2004; Matsuo et al., 2005). The absence of these bacterial partners results in a phenotype, as surely as mutations to the genome do.

Likewise, connections between abiotic environmental factors and cell biology have profoundly influenced eukaryotic evolution. Elevated oxygen concentrations in the Neoproterozoic were likely a prerequisite for the evolution of multicellularity (Knoll and Carroll 1999), and the connection between multicellularity and environmental oxygen persists in modern animals. For example, angiogenesis in mammals is regulated, in part, by oxygen levels (Fraisl et al., 2009), as is the synthesis of collagen fibers that underpin the integrity of diverse animal tissues (Towe, 1970). By merging the evolutionary perspective with molecular and genetic approaches, we can better understand how nature and nurture influence cell biology.

The reunification of “nature” and “nurture” in the lab has just begun. Whereas the last 50 years of cell biology research have benefited from a stripped-down focus on molecular mechanisms gleaned from tightly controlled experiments, we have the opportunity over the next 50 years to better understand the influence of the environment—be it extracellular or from neighboring cells—on cell biology. Many of our future advances will be made possible as new technologies are applied to emerging model systems. For example, the coupling of diverse fluorescent proteins with new forms of microscopy allows cell biologists to study complex populations of cells, including bacterial biofilms, tissues, and embryos. An ever-growing pantheon of emerging model systems, made experimentally tractable by the ’omics revolution, promises to provide unique insights into cell biological mechanisms and the evolution of cell biology.

There is much to be learned by studying the influence of evolution and the environment on cell biology. Countless
genome sequences, technological advances, and powerful new analytical tools provide everything needed for emergence of a field of evolutionary cell biology. Therefore, young scientists may wish to view the evolution of cell biology as an empty niche, one with great potential to expand our understanding of modern cell biology and its origins.

REFERENCES


Table 1. Bacterial induction of eukaryotic morphogenesis

<table>
<thead>
<tr>
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<td>Mouse</td>
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<td>Sea weed</td>
<td>Thallus differentiation</td>
<td>\textit{Zobelia uliginosa}</td>
<td>Matsuo \textit{et al.}, 2005</td>
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