Why is evolution so hard to understand?

Realizing that function and biological meaning can arise from random processes may help people understand and accept evolution

BY MIKE KLYMKOWSKY

It is well known that evolutionary theory is not accepted by large segments of the American public, including teachers (1). Numerous surveys routinely place us at the bottom of the developed countries in this regard. This often provokes something akin, ironically, to a biblical wailing and gnashing of teeth among segments of the science and education communities. Yet I would argue that the problem is both more serious and more hopeful than it appears.

A serious problem

Why is it more serious? Because it is clear that in many cases, the acceptance of evolution is not based on a real understanding of evolutionary mechanisms. As pointed out by Gregory (2), "natural selection is generally very poorly understood, even among many individuals with postsecondary biological education." For example, about 38 percent of people responding in a recent Gallup poll said that the statement, "Humans evolved, with God guiding," comes closest to their views on the origin and development of human beings (Figure 1). My own research indicates that many molecular biology students do not understand the molecular-level mechanisms behind genetic variation and DNA behavior (3). Similarly, students have difficulties imagining that molecular-level, stochastic events can produce directed macroscopic behaviors like diffusion or evolutionary change (4).

This failure of imagination has its roots in human behavior: We are programmed, it seems, to find or project meaning onto almost everything, from finding significance in the deaths of children due to sickness and natural disasters to interpreting the vagaries of fate as reward or punishment for past behavior. Our social nature leads us to read meaning into others' expressions, tone of voice and behavior. The idea that organic things are good and artificial things are bad is commonly are assumed to be valid, but it ignores the dangers of natural toxins, among other things, and minimizes the value of technological innovations like fertilizers, genetically modified organisms, antibiotics and vaccines (5).

A hopeful solution

So why would I make the claim that the situation is hopeful? Because, while the random drivers active in biological systems and upon which evolution depends are difficult to

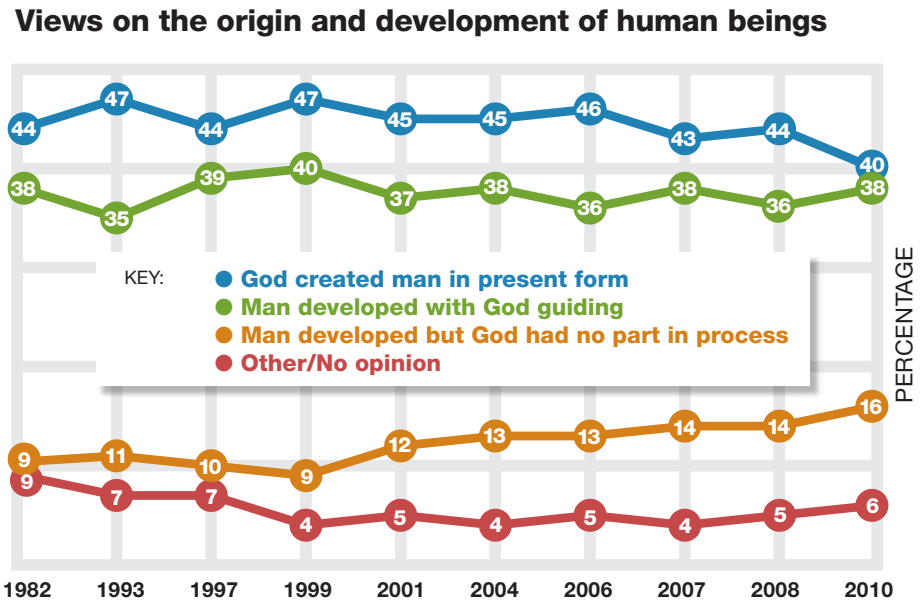

Figure 1. Results of a 2010 Gallup poll in which participants were asked which statement comes closest to their views on the origin and development of human beings.

grasp or credit, it also is the case that our current education system rarely, if ever, attempts to teach them in a serious and effective manner. So the question is, what would happen if the educational system actually addressed these issues head on? What if biology was taught in a way that stressed the fact that the molecular level processes that underlie evolutionary events are difficult to understand? Why not teach that the second law of thermodynamics drives the appearance of ordered structures even as the universe as a whole descends into chaos? Or that DNA is not particularly stable but is actively repaired and that its instability is necessary for evolution (and responsible for disease)? Or that molecular-level genomic dynamics (mutations, DNA duplication and rearrangements) occur with remarkable frequency and underlie the appearance of new traits and new species?

Would it help if students understood that molecular affinities are a function of binding energies and thermal perturbations rather than common lock and key depictions or that off-target interactions with physiological significance are not uncommon and are, in fact, responsible for a number of the side effects of drugs and, for that matter, make drugs without side effects essentially impossible? Or that off-target interactions, together with gene duplications and rearrangements, underlie the generation of new functions? Or that molecular promiscuity arises from the fundamental nature of intermolecular interactions and is used again and again to generate new functions and phenotypes (6 – 8)?

What if animations, such as the spectacular "Inner Life of the Cell" video, presented stochastic realities and eschewed scenes in which molecules appear to know where they are going? Would it help student understanding if depictions of polypeptide synthesis, for example, consistently illustrated the fact that during translation, the ribosome-mRNA complex must reject a substantial number of uncharged and charged but inappropriate aminoacyl-tRNAs before random motion brings the correct aminoacyl-tRNA to the active site? Or that transcription factors use their nonspecific, low-affinity binding to DNA to facilitate interactions with their high-affinity targets via one-dimensional diffusion? Or that regulatory noise plays a key role in how biological systems, from operons to neural networks, work? After all, the lac operon would not function if it were not leaky!

Could the fact that mutations only come in a limited number of generic types (9) and often have relatively mild effects be used to explain how drift and genetic noise can lead to evolutionary innovation in response to selective pressures (10)? In that light, would the inherent instability of DNA (11, 12) and genome dynamics, as illustrated by the prevalence of somatic mutations and copy number variation (13 – 15), make evolution in general, and the origin and evolution of cancer and other diseases in particular, more comprehensible? What if students understood that even simple systems of gene interactions can produce complex and surprising behaviors (16 – 18)?

In each case, the goal of presenting these biological scenarios would be to establish and reinforce the multiple ways that function and biological meaning can arise out of random processes. The goal is to address directly what makes the naturalistic, evolutionary explanation of life possible yet difficult to accept. Of course, the educational approach to helping students understand evolution depends on accessible and well-designed course materials and a commitment to universal learning rather than the sorting of students. Learning how evolution works will require that we provide students with the time and feedback needed to come to accept what are, on their face, implausible ideas.

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