How the incoherent state of science and mathematics education undermines biological (and scientific) literacy. for colorado higher education news

150 years ago Darwin and Wallace recognized, through observation and deduction, the importance of inheritable variation in the origin and evolution of species; however, the source of that variation was a mystery to them. In the intervening years, biologists established the role of random genetic mutation as the major source of heritable variation. Thus, it is rather surprising that at present the role of random processes in evolution appears to remain a mystery to high school and college students, many of their teachers, and as a result much of the general public. Students have been found to harbor stubborn misconceptions related to organisms “wanting” to evolve, changing environments “causing” organisms to develop new, more adapted traits, and entire populations evolving over time to reach an Aristotelian “essence” or static end goal for their species. These misconceptions share a common foundation: they omit the role of random molecular processes in natural selection.

What explains this rather odd state of affairs, given that the molecular origins of variation are no longer a mystery? Certainly, the manner in which evolution is presented in the popular media is a contributing factor, as is the extent to which the topic of evolution has been de-emphasized in US school curricula as compared to that of other industrialized nations. However, we argue that the situation has deeper origins that, while troubling, also suggest solutions. In particular, we note the difficulties teacher preparation programs face when tasked with developing science and mathematics teachers’ abilities to employ teaching strategies proven to impact student learning. Even fewer teacher education courses focus specifically on the differences between how different sciences should be taught, and even these content-specific courses rarely address the knowledge base required for teaching (and learning) physics, chemistry, or biology.

The incoherent nature of many science majors is equally important. For example, it is not at all clear that the physics and chemistry courses required of biology majors - including those that may continue to become science teachers - prepare them to understand key foundational principles, such as the laws of thermodynamics, chemical bonding, the nature of stochastic processes, the behavior of molecules and their interactions, and the role of entropic factors in biological systems. While historically considered "advanced", these ideas are accessible to high school students provided that we apply interactive instructional techniques and employ researchbased teaching materials. Similarly, the math skills required for the analysis of random events and regulatory interactions, common in biological systems from the molecular to the ecological, are often not an integral part of the science curriculum. In fact, most introductory physics courses restrict their focus to macroscopic phenomena (the orbits of planets and the behavior of pulleys and pendulums) and fail to consider the microscopic processes most relevant to biological systems.

The fault is certainly not restricted to physics, chemistry, and math, but extends to biology as well. Biology curricula can leave students with a weak understanding of how mutations influence the activity of gene products, the ubiquity and importance of gene and genome duplication events in the appearance of new structures, the relative roles of genetic drift and selection in adaptation, speciation, and extinction, the myopic nature of adaptive changes, the role of fortuitous "neutral" variation in enabling future adaptive changes, the inherent "cost-benefit" nature of selection itself, and the overall historical nature of biological systems. As a result of these conceptual shortfalls, students too often believe in rather than understand the scientific basis of evolutionary processes. Our research indicates that the problem begins in undergraduate science education, and continues through teacher certification.[1]

So what do we recommend? Clearly, modern science rests on foundational physical and chemical principles that must be addressed in both the preparation of K12 teachers and in the design of the curricula they are called upon to teach. Given that most biology majors take only two courses in physics, it is critical that these courses address the relevant issues, such as the physics of Brownian motion as first described by Einstein in 1905, that will serve as the foundation for their understanding of evolution, the central unifying tenet of biology. Similarly, chemistry builds on just this physics to address how atoms interact to form molecules, how reactions transform one molecule into another, whether they are favorable and the rate at which they occur, how catalysts work and how changes in entropy influence molecular and supramolecular organization. Finally, biology needs to address how variations arise and act at the molecular level, so that Darwin and Wallace's macroscopic insights make sense. Throughout such a "coherent," stepwise science curriculum, students need to be introduced to, and learn to use the mathematical concepts and skills required to analyze data and deduce and test patterns. It is important to note that such an integrated mathematics and science curriculum will be, by its

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[1] Our awareness of these conceptual hurdles arises from research into student and teacher thinking at the college (through the NSF-funded, Biology Concept Inventory project) and high school levels (Garvin-Doxas & Klymkowsky, 2008; Klymkowsky et al, in preparation; Furtak, in press).

very nature, more restricted than conventional curricula; there is a need to focus on key observations, concepts and skills, rather than fritter way precious time on peripheral material. We recognize that this curricular trimming will lead to heated debate, but if there is one lesson to be learned from studies of student learning it is that more is rarely better, and often leads to conceptual uncertainty and confusion.

Given the fact that current science certification rules in Colorado enable a teacher to teach all sciences, rather than the science in which they specialized in college, providing teachers with a robust scientific and math foundation will require a restructuring of the relevant courses and curricula. Only in this way can we insure that students leave high school with a robust understanding of the scientific enterprise and its major conceptual foundations, an understanding increasingly important in our increasingly science-dependent future.

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