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CURRICULUM AND EDUCATION ARTICLE

Evolutionary Medicine and the Medical School Curriculum: Meeting Students Along Their Paths to Medical School

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Abstract Over the past several years, numerous reports that have been independently prepared by prestigious organizations in the U.S. have agreed that new approaches to improve teaching and learning of biology at both the pre-college and undergraduate levels are important and timely. Their recommendations, which are based on emerging research about human learning and cognition, are in agreement that evolution is an organizing principle and foundation of modern biology and should be presented as such. This paper provides an overview of the conclusions and recommendations from those reports and proposes that helping students learn evolution through the lens of human examples that are part of the emerging field of evolutionary medicine could help biology educators improve the teaching of evolution, and biology more generally, by asking students to address biological problems that are inherently interesting and motivating.

Keywords Life sciences education · K-12 biology education · Undergraduate biology education · Premedical education · Student learning · Evolutionary medicine

> A revolution is underway in biology. The major focus of the biological sciences—understanding life—remains the same, but the science has experienced a major transformation. Many of the most exciting discoveries in the biological sciences during the second half of the 20th century occurred at the intersections of established disciplines. Emerging interdisciplinary fields such as genomics, proteomics, metagenomics, synthetic biology, biochemistry, bioinformatics, computational biology, and systems biology are leading to new discoveries, and some are changing the ways we think about and engage in biological research and explore established biological fields (such as evolutionary biology). These new integrated fields, spread across the diversity of life sciences, are opening up a vast array of practical applications, ranging from new medical approaches, to alternative sources of energy, to new theoretical bases in the behavioral and social sciences.
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> American Association for the Advancement of Science, 2011, p. 3

Nothing in biology makes sense except in the light of evolution.

Dobzhansky, 1973

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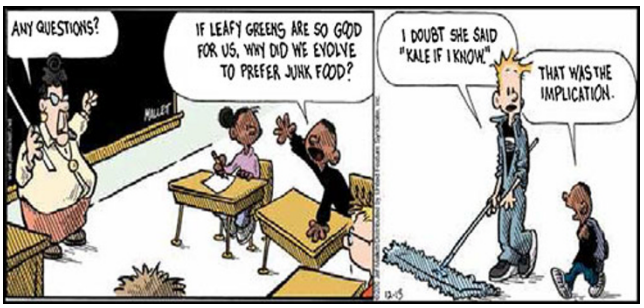

In 2009, the National Academy of Sciences (NAS) organized and hosted an Arthur M. Sackler Colloquium in Washington, DC that focused on evolution, health, and medicine.[1] As part of that colloquium, Randolph Nesse presented a paper and ultimately coauthored a paper, "Making Evolutionary Biology a Basic Science for Medicine" (Nesse et al. 2010), that appeared as part of the set of papers from the colloquium in the Proceedings of the National Academy of Sciences. In that paper, Nesse et al. argued that:

> Knowledge about evolution provides physicians with an integrative framework that links otherwise disparate bits of knowledge. It replaces the prevalent view of bodies as machines with a biological view of bodies shaped by evolutionary processes. Like other basic sciences, evolutionary biology needs to be taught both before and during medical school. Most introductory biology courses are insufficient to establish competency in evolutionary biology. Premedical students need evolution courses, possibly ones that emphasize medically relevant aspects. In medical school, evolutionary biology should be taught as one of the basic medical sciences. This will require a course that reviews basic principles and specific medical applications, followed by an integrated presentation of evolutionary aspects that apply to each disease and organ system. Evolutionary biology is not just another topic vying for inclusion in the curriculum; it is an essential foundation for a biological understanding of health and disease. (p. 1800).

I serve as the staff officer who oversees the efforts of the NAS to promote effective teaching and confront challenges to the teaching of evolution. Accordingly, the president of the Institute of Medicine asked me to organize an exploratory meeting around the theme of the opportunities and challenges of introducing concepts of evolution into the curriculum of the nation's medical schools, based in part on Nesse et al.'s paper and the urging of several members of the Institute of Medicine who have been engaged in this issue.

[1] All papers from this convocation are available at http://www.pnas.org/content/107/suppl.1.

Participants in the October 2010 meeting included a dean and a faculty member from two medical schools, faculty who are currently teaching undergraduate courses on evolutionary medicine at several research-intensive universities, an evolution researcher, and representatives from the Howard Hughes Medical Institute, National Institutes of Health, the Association of American Medical Colleges, National Evolutionary Synthesis Center, College Board, the Biological Sciences Curriculum Study, and disciplinary societies in the life sciences. Several participants are members of the Institute of Medicine and the National Academy of Sciences. They agreed that preparing future physicians to have an evolutionary perspective on both wellness and disease could be an important part of their training. Such preparation could enable more comprehensive consideration of biology in diagnosis and treatment and in understanding the etiology of diseases. However, concern was also raised by those who represented medical schools that the medical curriculum is already overcrowded and that other aspects of health essential to effective practice of medicine are also given minimal coverage in today's curriculum. Why, they asked, should evolution receive greater attention than those other issues?

However, by the time the meeting ended, some of the skeptics had been swayed by the importance of integrating "evolutionary thinking" into the medical school curriculum. One important reason for that change was the ensuing discussion about emerging opportunities to introduce evolutionary concepts to students at multiple stages of their preparation prior to professional medical training, from high school through the undergraduate years. They also became less skeptical after learning that, over the past three years, a series of reports from the National Academy of Sciences and Institute of Medicine (2008), College Board (2011), the American Association for the Advancement of Science (2011), the Association of American Medical Colleges and the Howard Hughes Medical Institute (2009), and most recently the National Research Council (2011a) have all emphasized the central importance of evolution to modern biology. Taken together, these reports and the collection of articles that appear in this special issue of *Evolution: Education and Outreach* offer a series of pathways for students who will pursue an array of careers in the medical sciences (and those who won't) to study evolution as both an organizing theme to biology education at various levels and as an opportunity to better understand the processes, nature, and limits of science.

This essay focuses on these new opportunities. It emphasizes how teaching and learning evolutionary concepts through the lens of evolutionary medicine can serve as a vehicle for engaging a broader spectrum of students in the sciences that precede medical education. It also argues that a greater emphasis on evolutionary medicine in biology courses from high school through professional training is consistent with findings from the scholarly literature on human learning and cognition, which has begun to elucidate effective practices to

improve teaching and learning. That research has demonstrated that people learn subject matter more effectively and retain that information longer when (1) the relevance of what is being taught is made clear at the outset and reinforced throughout the learning experience, and (2) when learners are actively helped to make connections with what they are learning and other subject areas (e.g., summarized in National Research Council 2000).

Teaching evolutionary concepts by emphasizing evolutionary medicine addresses both of these principles. Students are inherently interested in their bodies, the processes and the diseases that affect their health and well-being. Thus, using the lens of evolutionary medicine can help students more easily understand the importance and relevance of evolution more generally. And the confluence of thinking about the importance of evolution as a subject from grade school to grad school affords faculty in pre-college, postsecondary, and professional institutions opportunities to help students build expertise in this subject area as well as connect it to all other areas of the life sciences.

Individually and collectively, knowledge of the content and recommendations in these documents can reinforce the efforts of individual faculty who would like to infuse evolutionary concepts into existing life sciences courses (both introductory and advanced) or develop new ones, especially for students who will not pursue majors in the life sciences or other science, technology, engineering, and mathematics (STEM) disciplines. They also can serve as the basis for much needed discussions among faculty colleagues about the role of evolution in general, and evolutionary medicine in particular, in the broader spectrum of pathways through biology majors and related programs and the collective responsibility of faculty to make such opportunities available (e.g., National Research Council 2003b; American Association for the Advancement of Science 2011).

The Confluence of Recommendations for Improving Education in the Life Sciences

Any conversation about increasing pre-med requirements to include evolution has implications for undergraduate biology education (e.g., National Research Council 2003a). However, recent national reports have already raised questions about the current model of biology education (summarized in Labov et al. 2010). Efforts to improve undergraduate education in STEM disciplines are not new. Since at least the launch of Sputnik in 1957, numerous reports have called for fundamental changes to be made in high school and undergraduate science courses to make them more accessible to a broader spectrum of students and of greater interest to all students. Until recently, there has been little evidence for fundamental and meaningful changes to life sciences education in response to those publications.

However, in 2009–2011, a series of publications, conferences, and events suggested that more people and organizations in the life sciences are recognizing that biology education for both life sciences majors and those who will pursue other career paths is problematic because teaching methods are outdated, often ineffective, and fail to show students the excitement of modern, cutting-edge science (Jurkowski et al. 2007; National Research Council 2000, 2003b, 2011b). Many of our students are leaving STEM for these reasons. Indeed, some 60% of students who enter college indicating that they plan to pursue a major in one of the sciences switch to some field of study after their first year. When those who leave are asked why, a very large proportion of them indicate that their instruction is lackluster, the topics in their courses are of little interest, and instruction and assessments reinforced the idea that science is a corpus of facts to be memorized and displayed on examinations. And the evidence suggests that the academic credentials of those students who opt out of science are not statistically different up to that point from students who continue to pursue additional study in the sciences (e.g., Seymour and Hewitt 1997; Bettinger 2010). The cost to STEM in wasted human resources is far too large at a time when science and technology are increasingly pervasive in all aspects of our society and economy.

There also is greater recognition that research in the life sciences is becoming increasingly more interdisciplinary and interconnected; biology education also must change to acknowledge and adapt to these new realities and opportunities (National Research Council 2009). In addition, major public and private funding organizations (e.g., National Science Foundation, National Institutes of Health, Howard Hughes Medical Institute) are emphasizing more interdisciplinary and interconnected approaches and themes for undergraduate education in the life sciences.

The importance of evolution in biology has been prominently featured in several recent reports and papers:

- "*A New Biology for the 21st Century*" by a committee under the aegis of the National Research Council's (NRC) Board on Life Sciences (National Research Council 2009). The report proposes a bold new integrated research agenda and builds on an earlier report of the National Research Council (2003a) with important implications for the future undergraduate and K-12 science education. The authoring committee stressed the importance of evolution to all of biology and hence the importance for students to recognize that understanding evolution can allow students to understand concepts such as the unity of life.
- *Scientific Foundations for Future Physicians*, published jointly in 2009 by the Howard Hughes Medical Institute and the Association of American Medical Colleges. This report calls for a change in undergraduate science

education away from a system based on courses to one based on "competencies." According to the committee, "A competency-based approach will give both learners and educators more flexibility in the premedical curriculum and allow the development of more interdisciplinary and integrative courses that maintain scientific rigor, while providing a broad education." (Executive Summary, p. 1)[2]

Evolutionary concepts are very much a component of this vision for premedical and medical education.

- Competency M3, Learning Objective 1: Describe the functional elements in the human genome, their evolutionary origins, their interactions, and the consequences of genetic and epigenetic changes on adaptation and health. (p. 12)
- Competency E8: Demonstrate an understanding of how the organizing principle of evolution by natural selection explains the diversity of life on earth. (p. 35)

- *Vision and Change in Undergraduate Biology Education*: This report was based on a series of conversations held across the U.S. over two years and a summit in Washington, DC in July 2009 that was organized by the American Association for the Advancement of Science with support from the National Science Foundation. The summit brought together more than 500 people to consider future pathways for undergraduate education in the life sciences (Woodin et al 2009; Mervis 2009a).[3] A formal report from the summit was released earlier this year (American Association for the Advancement of Science 2011). Similar to the College Board's four Big Ideas, Vision and Change stresses five "Core Concepts" in biology. Evolution is the first of these Core Concepts.

- Core Concept 1 (Evolution): The diversity of life evolved over time by processes of mutation, selection, and genetic change. (p. 12) The importance of evolution is also woven into other Core Concepts. For example:
- Core Concept 2 (Structure and Function): Fundamental structural units and molecular and cellular processes are conserved through evolution and yield the extraordinary diversity of biological systems seen today. (p.12)

- Earlier this year, the College Board released a set of frameworks for Advanced Placement (AP) Biology that reflects a multi-year restructuring of this course in science for high school students (College Board 2011). This restructuring closely follows the recommendations of a report from the National Research Council (2002) and calls for teaching fewer concepts in greater depth. Restructuring also requires developing and implementing means to measure students' level of conceptual understanding (Mervis 2009b; Woodin et al. 2009). The framework for biology, as in all of the other AP science courses that are undergoing revision in response to the NRC report, articulates several "Big Ideas" that undergird the discipline. In biology, evolution is the first of four Big Ideas: The process of evolution drives the diversity and unity of life. (p. 4)
- *A Framework for K-12 Science Education: Practices, Cross-Cutting Concepts, and Core Ideas*: This report was released in July 2011 by the NRC's Board on Science Education. This document is designed to serve as a guide to the production of new science education standards over the next 18 months, replacing the Benchmarks for Science Literacy published by the American Association for the Advancement of Science in 1993 and the NRC's National Science Education Standards that were published in 1996. As with the aforementioned documents, the authors of this new framework view evolution as one of the organizing theme of the life sciences, and they provide a set of guidelines for the production of new K-12 standards that would use the multiple concepts of evolution as a theme throughout the pre-college years. If the still-to-be-produced science standards are viewed as common core standards by the states (some 46 states have agreed to date to adopt common core standards in language arts and mathematics),[4] then the teaching of evolution could become a much more prominent component of science education in the nation's schools for very large numbers of students over the coming decade. The key challenge will be to find ways to engage these students in the study of evolution. As noted in the next section, using approaches and examples that students find relevant to them, their families, and communities may help many of them to appreciate science more deeply. Medical evolution could provide that lens.

Thus, the life sciences and science education communities have focused attention on where biological research is likely to progress over the next several decades and how education in the life sciences might keep pace with this rethinking of research priorities and progress (Labov et al. 2010). Using evolutionary medicine as a tool for teaching basic evolutionary biology principles has the potential to address the recommendations of these reports and to engage pre-meds as well as many other students, both future life sciences majors and those who elect to pursue other career paths, in learning about evolution. And, by learning to view

[2] A separate Executive Summary for this report is available at http://www.hhmi.org/grants/pdf/08-209_exec_summary.pdf.

[3] Additional information is available at http://www.visionandchange.org/.

[4] Additional information is available at http://www.corestandards.org/.

evolution as the connection to other parts of the life sciences, students may learn biology more deeply and effectively.

Evidence from the cognitive and learning sciences as well as discipline-based education research indicate that students learn most effectively and retain content and concepts in science longer when they see the relevance of a topic to their own lives or that of their community and when the topic is inherently interesting and engaging to them. (Summarized in National Research Council 2000, 2002, 2005, 2007; Eshel 2007; Handelsman et al. 2005). Given the interest and enthusiasm of the public for topics and issues around cutting-edge science (see also next section), framing courses in the life sciences around such issues and using them to impart content, concepts, and skills could result in far greater engagement by a broader spectrum of students who are enrolled in courses the life sciences (e.g., Jurkowski et al. 2007; Labov and Huddleston 2008). The relevance of evolutionary medicine topics to premedical students could serve as an important gateway to engaging these students in more general topics of evolution as well as demonstrating the connections among what too often seem to be disparate topics as they are currently taught in many survey biology courses. Other authors in this special issue of *Evolution: Education and Outreach* provide more specifics about the concepts, approaches, challenges, and opportunities for engaging students in science by framing science courses around the wonderfully interesting questions posed by evolutionary medicine.

Evolutionary Medicine as a Way to Introduce Cutting-Edge Science in the Classroom

The pace of research and the development of new areas of focus in biology, including evolutionary explanations for human morphology, physiology, behavior, diversity (and homogeneity), and disease are increasing at breathtaking speed (National Research Council 2009; American Association for the Advancement of Science 2011). However, cutting-edge research and discoveries in science often do not appear in science classrooms and textbooks until many years after their inception, especially in grades K-12. Too many students are never afforded opportunities to learn about the cutting-edge discoveries that make biology so exciting to professional scientists and teachers. The increased focus on the evolutionary bases for human maladies along with the characteristics that define us as a species is yielding unexpected discoveries about general principles of evolution. Evolutionary medicine is also likely to lead to a plethora of practical applications, from new medical approaches to diagnostics and treatments.

Evolutionary medicine allows students to understand more deeply the conceptual bridges between genetics and ecology, or to historical changes in climate (e.g., National Research Council 2010), demonstrating the close relationship among all humans and to all species on Earth. These messages have important relevance across the life sciences and would be valuable additions to any biology class—perhaps especially those at the introductory level. Because the study of evolutionary medicine draws from and impacts a wide range of fields, it is a valuable tool for teaching themes and concepts that can be woven throughout biology education. Indeed, teaching and learning about evolutionary medicine could help catalyze the kinds of changes in K-12 and undergraduate science education that the reports mentioned above have called for over the last decade.

Some faculty feel that they must use introductory courses to provide students with the biology content they will need to understand the basic concepts of the discipline, especially if they continue on to more advanced courses in the discipline. Too often, however, such courses fail to convey the complex beauty of the living world and the innumerable ways that biology is relevant to and can impact students' lives, a missing element that research on human learning and cognition indicates is essential for effective acquisition and retention of knowledge. An emphasis at the introductory level on evolutionary medicine and its real-world implications and applications could elucidate basic principles of a wide variety of fields. These explorations would allow students to explore the connections among them and the broader relevance of scientific advances to real-world issues.

What characteristics might undergraduate courses have that emphasize an interdisciplinary approach as envisioned in "A New Biology" and the other aforementioned reports? Several examples are provided in this special issue (Stearns; Beardsley). Additional courses are posted on the website The Evolution & Medicine Review,[5] and model courses are offered by SENCER[6] and include courses with evolutionary themes such as human genetics, environment and disease, and even an evolutionary medicine course.

The life sciences and science education communities have made significant advances in articulating how undergraduate biology education can be made accessible to more students with varying education needs and learning styles. The beginnings of real consensus about the future course for life sciences education is emerging (Labov et al. 2010). Ideas for "transforming undergraduate education for future research biologists" that are envisioned in the "Bio2010" (National Research Council 2003a) and subsequent reports are being considered more seriously and implemented more widely than many had imagined when the report was published (e.g., Pfund et al. 2009). But much work still remains.

[5] http://evmedreview.com/?page_id=7.
[6] http://www.sencer.net/Resources/models.cfm

As described in this special issue, the general theme of evolutionary medicine and all of the areas of biology and medicine that it encompasses can offer an important path forward to attract, actively engage, and retain undergraduate students in the life sciences and related fields. Attention to aspects of evolutionary medicine and how evolution has contributed to human health and disease can also help all students who enroll in life sciences courses better understand and appreciate the processes, nature, and limits of science. This issue of *Evolution: Education and Outreach* provides an important new impetus for considering such approaches to teaching and learning in the life sciences for all students.

References

AAMC and HHMI. Scientific foundations for future physicians. Washington, DC: Howard Hughes Medical Institute; 2009.

American Association for the Advancement of Science. Benchmarks for Science Literacy. Washington, DC: American Association for the Advancement of Science; 1993.

American Association for the Advancement of Science. Vision and change in undergraduate biology education. Washington, DC: American Association for the Advancement of Science; 2011.

Bettinger E. To be or not to be: major choices of budding scientists. In: Clotfelter CT, editor. American universities in a global market. Chicago: University of Chicago Press; 2010.

College Board. AP biology curriculum framework, 2012-2013. New York: College Board; 2011.

Dobzhansky T. Nothing in biology makes sense except in the light of evolution. Am Biol Teach. 1973;35:125–9.

Eshel N. The science inside: learning. Washington, DC: American Association for the Advancement of Science; 2007.

Handelsman J, Miller S, Pfund C. Scientific teaching. San Francisco: Freeman and Sons; 2005.

Jurkowski A, Reid AH, Labov JB. From the National Academies. Metagenomics: a call for bringing a new science into the classroom (while it's still new). CBE Life Sci Educ. 2007;6:260–5.

Labov JB, Huddleston NF. From the National Academies. Integrating policy and decision making into undergraduate science education. CBE Life Sci Educ. 2008;7:347–52.

Labov JB, Reid AH, Yamamoto K. Integrated biology and undergraduate science education: a new biology education for the twenty-first century? CBE Life Sci Educ. 2010;9:10–6.

Mervis J. Universities begin to rethink university biology courses. Science. 2009a;325:527.

Mervis J. Revisions to AP courses expected to have domino effect. Science. 2009b;325:1488–98.

National Academy of Sciences and Institute of Medicine. Science, evolution, and creationism. Washington, DC: National Academies Press; 2008.

National Research Council. National science education standards. Washington, DC: National Academies Press; 1996.

National Research Council. How people learn: brain, mind, experience, and school. Washington, DC: National Academies Press; 2000.

National Research Council. Learning and understanding: improving advanced study of mathematics and science in U.S. high schools. Washington, DC: National Academies Press; 2002.

National Research Council. Bio 2010: transforming undergraduate education for future research biologists. Washington, DC: National Academies Press; 2003a.

National Research Council. Evaluating and improving undergraduate teaching in science, technology, engineering, and mathematics. Washington, DC: National Academies Press; 2003b.

National Research Council. How students learn: history, mathematics, and science in the classroom. Washington, DC: National Academies Press; 2005.

National Research Council. Taking science to school: learning and teaching science in grades K-8. Washington, DC: National Academies Press; 2007.

National Research Council. A new biology for the 21st century. Washington, DC: National Academies Press; 2009.

National Research Council. Understanding climate's influence on human evolution. Washington, DC: National Academies Press; 2010.

National Research Council. A framework for K-12 science education: practices, crosscutting concepts, and core ideas. Washington, DC: National Academies Press; 2011a.

National Research Council. Promising practices in undergraduate science, technology, engineering, and mathematics education: summary of two workshops. Washington, DC: National Academies Press; 2011b.

Nesse RM, Bergstrom CT, Ellison PT, Flier JS, Gluckman P, Govindaraju DR, et al. Making evolutionary biology a basic science for medicine (colloquium paper). P Natl Acad Sci 2010. 2010;107 suppl 1:1800–7.

Pfund C, Miller S, Brenner K, Bruns P, Chang A, Ebert-May D, et al. Summer institute to improve biology education at research universities. Science. 2009;324:470–1.

Seymour E, Hewitt NM. Talking about leaving: why undergraduates leave the sciences. Boulder: Westview Press; 1997.

Woodin T, Smith D, Allen D. Transforming undergraduate biology education for all students: an action plan for the twenty-first century. CBE Life Sci Educ. 2009;8:271–3.