

MAKING EVOLUTION RELEVANT AND EXCITING TO BIOLOGY STUDENTS

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Several years ago, the Texas State Board of Education (BOE) undertook its periodic review of biology textbooks for use in Texas high schools. This is a regular event that most educators in the state have come to dread. The supposed intent of these reviews is for the BOE to determine if textbooks meet the standards set for the Texas high school curriculum, and to determine if the books contain any errors. Books that are approved for use in the public schools are purchased by the state and are available for adoption by individual school districts.

Few members of the BOE have any academic background in science, and the process of book review typically is dominated by various political agendas. However, the curriculum is recommended by individuals with backgrounds in the respective disciplines. Because modern biology courses make no sense without a thorough coverage of evolution, the state standards for the biology curriculum do include coverage of evolutionary biology. Thus, all the textbooks must have thorough coverage of evolution to meet the state curriculum standards. Some members of the BOE, however, are elected on an antievolution agenda, and they attack the coverage of evolutionary biology in the textbooks. A favorite strategy is to pick on particular examples and classic experiments in the textbooks, bring in a supposed “expert” to criticize the example, and then argue that the book is factually incorrect and should be rejected. It will come as no surprise to many readers that these “experts” are rarely academic biologists, but rather staff from antiscience organizations with an antievolution political or religious agenda.

Fortunately, Texas state law prohibits the BOE from rewriting or editing textbooks, and also fortunately, the antiscience members of the BOE have been in a minority in recent years. However, several members of the BOE are viewed as swing voters, and have in the past either voted in support of strong science textbooks, or against them, depending on the political climate and the testimony

at the BOE textbook hearings. Thus, it has become increasingly important for academic biologists throughout the state to come to the public hearings and testify about the biology textbooks. Otherwise, the only testimony the BOE hears is from people with an antiscience agenda, many of whom claim to have expertise in biology.

For the 2003 hearings, I obtained copies of all of the biology textbooks that were up for consideration. This was quite a long list, and included virtually all the textbooks that are used from ninth-grade biology up through the textbooks used in university courses for biology majors (these latter books are used in the high school advanced placement biology courses). I reviewed the evolution coverage of all these textbooks. I also asked my son Erec, then a sophomore in high school, to read the evolution sections of the books. We also both read the written criticisms to the BOE from various antievolution groups about supposed errors and weaknesses of the books. We then sat down together and compared our rankings of the books and notes on the criticisms.

All the books we reviewed were, almost without exception, factually accurate. They all covered the basics of evolution at a level that was understandable for high school students. We each testified (at two different hearings) that the books should be approved for use in Texas high schools, an action that was eventually taken by a majority vote of the BOE. Erec’s testimony (one of a few by high school students) undoubtedly carried more weight than mine did. One of the criticisms of the books had been that they did not cover alternatives to evolution by natural selection. He impressed some BOE members by citing specific page numbers from his notes about where other evolutionary mechanisms (such as drift) were discussed in the books, and by providing specific details about the books under consideration in response to other criticisms. In contrast, most professional biologists (including myself) who testified tended to focus more on the general issues (e.g.,

the importance of evolutionary biology; scientific versus nonscientific approaches to inquiry) than on the specifics of individual books. This experience made me realize that a balance between both messages is important, and that most boards of education are more likely to deal with specifics than with generalities.

Despite the overall accuracy of the textbooks, however, both Eric and I were disappointed in many other aspects of the books. The evolutionary biology coverage was not nearly as exciting as it could be, and the relevance of evolution to everyday life was not emphasized. Many of the evolutionary examples in the textbooks have been overused, even though they are not necessarily among the best or most recent examples. Overall, the books seemed stuck in the 19th century, repeating the arguments that Charles Darwin had advanced to convince a Victorian-era public about the importance of natural selection. This approach makes evolution sound like an old-fashioned area of science that was resolved over 150 years ago, rather than a vibrant and exciting research field with new findings being discovered and new applications being developed every day. In addition, although evolutionary principles are critical for understanding many aspects of biology, these connections were rarely made clear throughout the books.

Based on my review of these biology textbooks, I developed the following “top 10 wish list” of criticisms and recommendations, meant for authors and publishers of introductory biology textbooks. After talking about these issues with various publishers, I have joined as a coauthor of one of the major books used in university biology courses (*Life: the science of biology*. 8th ed. Sinauer Associates and W. H. Freeman) to try to address these issues. My hope is that these ideas will be considered and adopted by other textbook writers as well. If the textbooks are inspiring and interesting, then instructors will be much more likely to use them effectively, and students are much more likely to read and understand the material. Undoubtedly, there are many other ways that evolution coverage could be improved, and I welcome any feedback or suggestions of other features that should be added to this list.

Ten Ways to Improve Evolution Coverage in Biology Textbooks

1. *Demonstrate that evolutionary research is current and ongoing.* The history of science is important, but discoveries and ideas in evolutionary biology did not stop with Charles Darwin. Certainly, textbooks should make it clear that Charles Darwin had many important insights into evolutionary biology, but they should make it equally clear that we have learned a great deal about evolution since his time. This is true of all aspects of evolutionary biology, but it is especially true at the mechanistic level. Many of the current textbooks say little about evolution beyond what was pro-

posed by Darwin. Post-Darwinian findings also present an excellent opportunity to teach about the process of science, and to show that the methods of evolutionary biology are the same approaches used in other areas of science.

2. *Clarify that evolution is not a synonym for natural selection.* Textbooks should be careful not to equate “evolution” with “natural selection.” Obviously, natural selection is a critically important principle that should be emphasized, and one of the most important mechanisms that results in evolution. But we also know that it is not the only way that evolution occurs. Most textbooks mention drift, but rarely is neutral evolution explained in any detail, and other mechanisms such as hitchhiking and genetic drive are rarely mentioned or explained. Creationists like to build a straw man by equating “evolution” with “natural selection,” and then pointing out that natural selection is not the only mechanism of change. This error of falsely equating “evolution” with “natural selection” should be theirs, not the textbook’s.
3. *Use fresh examples.* Textbook authors should avoid using the same examples found in other books to illustrate evolutionary principles, particularly if they are not even very good examples. I thought if I read one more description of peppered moth evolution I would scream. Creationists attack these examples as “icons” of our field, and although their criticisms are often absurd, they are right to criticize the books for always using the same examples. If students are presented with the peppered moth example in every biology course they take (and most are), they begin to think that this must be one of a few examples of evolution by natural selection observed by humans. There are a myriad of other examples published in the scientific literature, and many of them are much more relevant to the students’ lives than is the color of moth wings. It helps for students to read different examples to illustrate principles such as natural selection each time they take a new biology course. Textbooks are far too derivative of one another already, and there is no reason each should use the same examples to illustrate important principles.
4. *Show how evolution is relevant to human lives.* Evolutionary biology is highly relevant to human health and to agricultural practices, and those connections should be made clear. A few textbooks are beginning to make these connections, but they could do much better. The study of many human diseases depends greatly on the techniques of evolutionary biology. For instance, with HIV/AIDS, our knowledge of where the disease came from, information about the viruses’ original hosts, the timing of transfer of the viruses into human populations, the identification of human genes that result in resistance to infection from HIV, the number of times that immunodeficiency viruses have entered human populations,

the current and past status of the various epidemics, information about how the disease is passed among individuals, and models of effectiveness of various drug and vaccine treatments all depend on evolutionary analyses of the viruses and of humans and other primates. Many newly emerging diseases are now identified from evolutionary studies, and treatment strategies for many diseases depend on evolutionary principles. In particular, studies of genes and gene regions that are under positive selection for change are rapidly allowing biologists to identify genes that are important for defending against pathogens, as well as providing structural information on the mechanisms of these defenses. Furthermore, evolutionary biology has many applications in agriculture (such as the development of strategies for maintaining disease resistance in crops). These and related applications are directly relevant to students' lives, and students are much more likely to take the effort to understand evolution when they can see these connections.

5. *Use examples of evolutionary biology from popular media.* Evolutionary principles and methods have many applications in forensics, and there is a great opportunity to use the current popularity of forensic-science television shows and movies to explain the relevance of evolution. In my lectures, I like to use clips from episodes of popular television programs, in which evolutionary analyses are used to detect crimes or catch criminals. For instance, in one *CSI (Crime Scene Investigation)* episode, the forensic investigators tell the suspect that they linked him to his murder victim by a phylogenetic analysis of HIV sequences. This presents an excellent opportunity to tell the class about the real forensic cases that served as a basis for these episodes, and to show the students an application of phylogenetic analysis that they all find exciting and interesting. These real-world cases are also excellent for use as examples of the relevance of evolution in biology textbooks. Finally, forensic examples help students understand phylogenetic methods that can be used to uncover the evidence of ancient relationships that are encapsulated in the genomes of all extant species.
6. *Include experimental evolution.* Experimental evolutionary studies have become commonplace over the past few decades, but students rarely read about these studies in their textbooks. Students should know that evolution is not just something that can be studied in an historical framework, but also something that can be observed directly in a laboratory or field experiment. They should also learn that evolutionary principles and techniques can and have been tested experimentally, and that techniques such as phylogenetic reconstruction have been subjected to experimental testing and have been shown to be highly accurate and effective. Ancient DNA sequences can be reconstructed both compu-

tationally and in the laboratory, and the function of ancient genes and proteins can now be studied directly. Moreover, evolutionary principles are being widely used to develop new compounds in the laboratory, and *in vitro* evolution is an excellent way to show an industrial application of evolutionary principles. Despite the many applications of *in vitro* evolution, this topic is rarely even mentioned in most introductory biology textbooks.

7. *Integrate evolution throughout the book.* The coverage of evolution should not be limited to one section of an introductory biology book. Every chapter should discuss how evolution is critical for making comparisons across organisms. The books also need to be clear that biological organisms are not fixed "optimal" designs, but rather are members of variable, evolving populations. Understanding the relationship between this variation and functional significance requires evolutionary analyses and comparisons. Every topic in biology is related to and dependent on evolutionary analyses, and so every chapter of an introductory biology book should make these connections and applications clear.
8. *Emphasize "tree-thinking."* The diversity of life should not be discussed as a progressive trip through increasing complexity. Too many students already come into a biology course with "ladder of life" thinking. To counter this problem, they need to be exposed early and often to the tree of life, and to the interpretation and use of phylogenetic trees in general. They need to learn that all extant species are equally distant in evolutionary time from the common ancestor of all life, and that many new features have evolved in all lineages. They need to be exposed to the many uses of phylogenetic analyses as a way of interpreting and using biological variation. We developed a tree of life appendix for *Life: the science of biology*, which allows students to look up instantly any of the major groups of organisms they encounter in the book, and to see how they fit into the larger evolutionary picture of life. The interactive version of this appendix on the book's website links to detailed information on each group, including links to the described species, photographs, natural history information, keys, distribution maps, and more. Textbooks may not have room for all this detail on the printed pages, but they should provide easy access to the wealth of information on biodiversity that is available on the web. Instructors can assign particular taxonomic groups to various students for further exploration, to give each student a good sense of the vast diversity of life on Earth.
9. *Emphasize the diversity of life, not memorization of scientific names.* The subject of biodiversity is complex enough without expecting beginning students to memorize lots of formal taxonomic names. Many students panic upon seeing

a Latinized name, and skip it without even trying to sound it out. Common names should be used where possible, but they should be well defined and then used consistently. Moreover, why burden students with subjective taxonomic ranks? Evolutionary biologists understand that ranks in classification are subjective and have no equivalency across groups, and yet many instructors still expect students to learn whether a particular taxon is a “phylum” or a “class.” Students can learn and understand biological hierarchy without being burdened with this “knowledge.” We need to teach the hierarchy of the tree of life, but rank names do more to hinder than to help in this process. For instance, introductory biology students should know that they are primates, mammals, amniotes, tetrapods, vertebrates, chordates, deuterostomes, animals, and eukaryotes. They should understand that these are hierarchically nested groups, and know what features we share in common with other members of these groups. They should have a similar familiarity with the other major groups of life. They do not need to know which of these groups are labeled a class, order, or phylum by a particular biologist, however.

10. *Emphasize the great magnitude of evolutionary time.* Students often have a hard time understanding just how long life has been evolving. Many students readily accept that evolution occurs across short time spans, where we can observe it directly. But many have a hard time thinking about these same processes over the four-billion-year history of life. Nonetheless, they usually can understand that if evolutionary processes are ongoing today, then the same pro-

cesses were undoubtedly occurring a hundred, a thousand, a million, or a billion years ago. What they need is a clearer picture of just how long four billion years is, and how much change can (and has) occurred over that time. I think we do a disservice to students when we speak of “microevolution” and “macroevolution,” as if they are fundamentally different processes, rather than simply different time frames. When students can see that the evolutionary rates we observe today are sufficient to account for all of life’s diversity over the four-billion-year history of life, then this false dichotomy just gets in the way of effective teaching.

In summary, textbooks need to make the coverage of evolution exciting, current, and relevant. We have great material to present, and most students are excited to learn how the living world came to be and how it continues to change. In addition, not all instructors are likely to be well educated in evolutionary biology, so strong textbooks help develop better instructors as well as better-educated students. The list that I have presented here is not meant to be exhaustive, and there are undoubtedly many additional ways that the coverage of evolutionary biology could be improved in biology textbooks. I welcome readers’ feedback on additional ideas. As the users of textbooks, we are in a position to demand that the coverage of evolutionary biology in these books capture the importance of evolution to biology as a whole. So make your voice heard to textbook authors, publishers, colleagues who teach introductory biology, curriculum committees, and boards of education: demand better coverage of evolution in textbooks.

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