
# THE EVOLUTION SOLUTION:
## *Teaching Evolution Without Conflict*

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"I don't believe in evolution, so why do I have to learn this stuff?" "We didn't come from monkeys." "Why don't we learn about creation *and* evolution, so we can make up our own minds; isn't that more fair?"

If such questions cause you to minimize or avoid evolution in your curriculum, maybe you should consider a different approach. Evolution is clearly a well-documented process that informs all of biology and its many applications. It is a disservice to students to teach biology without an accurate and comprehensive treatment of evolution.

Surveys reveal that many in our society have an inadequate and inaccurate understanding of evolution (Alters & Alters, 2001). Much of this can be traced directly to popular misconceptions about the nature of science. This, in turn, can be linked to misrepresentation by those opposed to evolution, although inadequate or ineffective treatment by ill prepared teachers can also be a contributing factor. Teachers must do all they can to correct this; otherwise we all lose many of the potential benefits that can come from a more scientifically literate society.

Another element could be the fact that many texts tend to launch suddenly into evolution without any clear segue or solid connections to the rest of biology, and they defend the topic with numerous examples of "evidence." This "fortress mentality" virtually assures defensive reactions and practiced arguments against the "evidence" from students with anti-evolution views (Farber, 2003).

The program proposed here effectively addresses all of this. It is built around a novel sequence of topics–using a series of classroom-tested interactive lessons–effectively minimizing conflict while students come to recognize many misconceptions and to understand why evolution is considered one of the strongest of scientific theories (Nelson, 2000).

## Background

The seed for this strategy came from the original BSCS *Blue Version* text (Biological Sciences Curriculum Study, 1963). Chapter 2 ("The Variety of Living Things") included examples of some organisms difficult to classify, and presented information about the fossil record, raising questions about some traditional views of the history of life. Evolution was then introduced as a coherent attempt to explain those conflicts.

This approach flowed smoothly, raised fewer objections, and resulted in better understanding than earlier formats. With increasing enhancements, the strategy evolved into the core of the author's course. It was "College-Prep Biology" for sophomores for many years, then for juniors when the department switched to a Physics-Biology-Chemistry sequence for the past two decades. This was in a suburban west coast school with middle-to-lower socio-economic level students, becoming increasingly multiracial, with a similar mix of religions. There were always at least a few students in each class who were strong creationists, based on their remarks and

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responses to survey questions. But once the format described here was developed, objections to the strong evolutionary content declined. In any case, due to its natural, logical, problem-solving and non-threatening nature, this approach would probably work with any biology course at any secondary or undergraduate level.

## Overview of The Evolution Solution

The effectiveness of this approach is closely tied to the particular *sequence* of topics, used as a strategy for building interest and suspense. That sequence is

1. The Nature of Science ⇨ 2. An Overview of Life (including classification and hominid anatomy), raising many questions ⇨ 3. An Introduction to Evolution, to provide testable answers ⇨ 4. Using Evolution as a unifying theme throughout the course.

The second critical element is the selection of the lessons used. Most of the material for this program can be found in the Evolution and Nature of Science Institutes (ENSI) Web site–a collection of student-centered interactive lessons and strategies gathered, designed, and classroom-tested by over 800 talented biology teachers across the nation. The lessons are freely downloadable, with full instructions and handouts for use in the classroom. A convenient list of links to the specific lessons and online resources mentioned in this article can be found in the Appendix. You can add further variety by selecting from the wealth of annotated resources found in the Wuerth *ABT* article (2004).

For maximum effectiveness, it is highly recommended that you use the "5 E" framework to present the material, as promoted by the BSCS program: Engage, Explore, Explain, Elaborate, and Evaluate. An excellent resource that demonstrates this protocol–and also expands on much of the content suggested here–is *Teaching About Evolution and the Nature of Science* (National Academy of Sciences, 1998).

## The Nature of Science

The course opens with engaging experiences, usually a number of illusions, a little sleight of hand "magic," and some discrepant events that stimulate curiosity and raise questions. Quickly, focus shifts to one of the illusions to see how a scientist might try to explain it. The idea is to begin early doing things that pique curiosity and pose problems. Specific examples of illusions, both contrived and natural, can be found on the ENSI site, especially in the new "Perception is Not Always Reality" lesson.

Students work to solve one of those problems (or other problems), getting a real taste of one of the processes of science, without the formal terminology. Labels and connections can be added later, in the "Explanation" phase, after they have the experiences.

To "Elaborate," the focus shifts from these contrived illusions to natural illusions. The seemingly "flat Earth" and "moving Sun" are familiar and generally recognized as natural illusions. However, many students are surprised to learn that their "perfect" vision has holes (blind spots), the "face on Mars" is just a hilly area, and species really have come and gone over vast periods of time. Science has revealed that reality is often not what it seems.

Even more important than knowing the *processes* of science is to have a deeper understanding of the *nature* of science. From numerous surveys, much of the public is clearly ill informed about those important features, which are seldom adequately presented in textbooks. They include the realm of science, its limits, rules, social context, values and assumptions (Lederman & Lederman, 2004).

Using several ENSI Nature of Science lessons, many of those topics are interactively explored, including:

- Science can only deal with natural phenomena and natural explanations. Supernatural explanations cannot be used because they are not disprovable, and science operates largely by trying to test–*or disprove*–proposed explanations, not "prove" them, as popularly assumed.
- Scientific knowledge is inherently tentative and uncertain.
- In spite of strategies to be objective, science is still biased.
- Science is not fair or democratic. Beliefs or opinions alone–popular or otherwise–don't count; critically confirmed observations do.
- Science can be done well, or done poorly.

Most of the resistance to science in general, and evolution in particular, is built upon public misperceptions about these aspects of science. As a result, many people are easily deceived by a number of pseudoscience belief systems that claim to be scientific, but ignore the rules of science. Students need to know those rules.

## Overview of Life

After two or three weeks on the nature of science, students begin working with microscopes so they can see cells and microorganisms firsthand and begin to use one of the traditional tools of biology. Emphasized is the basic similarity of all cells, especially between widely different organisms: plants, animals, and protists. This prompts the question "Why are all cells so much alike?" Key questions like these should be posted on the board.

From here, it's an easy step to explore the great diversity of life–both living and extinct, from microorganisms to the more familiar macroworld of plants and animals–so students get a broad sense of what biologists study. Be sure to show a scaled timeline diagram that shows the vertebrate classes (fishes, amphibians, reptiles, mammals, and birds) making their first appearances about a hundred million years apart, fully supported by the fossil and molecular records. The perimeter of your room can be scaled to 4.6 billion years (try 1 cm = 1 million years). Add time markers and graphics to illustrate important events.

Students need to see that the so-called "Cambrian Explosion" of increased diversity was not an instantaneous event, but took over 5 million years (5 cm on the room scale), and was built upon a pre-Cambrian diversity of soft-bodied organisms (Parker, 2003). Out of this come other questions: "Why is there so much diversity?" "Why have life forms changed so much over time?" "Why have so many new and different life forms first appeared in different periods of time, and then disappeared much later?" Add these to the classroom list.

## Classification

"With all of this diversity, how can we make sense of it? How can we see patterns?" Such questions provide a transition to introduce the formalities of classification so students begin to recognize the nested organization of life and some of the criteria used for classification. Use appropriate ENSI lessons along with your text material. Students should gain a sense of biological relationship: that degrees of similarity in structure suggest corresponding degrees of relationship, much like one sees in personal families, or members of the cat or dog families. This is possible without any overt mention of common ancestry—or evolution—at this time. However, students must see a number of "intermediate" organisms, those that do *not* seem to fit easily into any one major group. They possess traits associated with two different groups, making it difficult to know where to classify them (Table 1).

Then, using one of the "Contrivances" lessons, students must discover that organisms are never "perfectly adapted" to a particular environment, as commonly believed. Instead, species exhibit many "adaptive compromises" (imperfections or contrivances in structures and biochemical processes) such as the panda's "thumb," our "wisdom teeth," pseudogenes, and many more. "Why are there so many imperfections?"

## Hominoid Skull Comparisons

Since comparative anatomy provides one of the main criteria for classification, a stimulating elaboration of this unit is the study of a series of hominoid skulls. Use full-scale resin casts of the skulls of several extinct hominids—prehistoric humans—plus the skulls of a modern human, chimpanzee, and gorilla. The "Hominoid Cranial Comparison" and "Chronology" labs provide the structure for students to discover that different series of humans have existed over time, gradually accumulating traits that typically characterize modern humans. This novel placement of an essentially human evolution lab *before* introducing evolution is an idea promoted by anthropologist Nickels (1987), and it works! Wherever tried, teachers proclaim student enthusiasm. At the same time, this raises a number of questions, mainly about how these observations seem to conflict with the traditional sense of humans arriving on the scene rather suddenly, fully formed as they are now. If students don't ask, prompt them to do so.

## Some Biological Problems

Note that there has been no mention of evolution up to this point. The students have merely experienced standard biological topics, raising a number of puzzling issues:

- Why are there basic features common to all life, yet there is a wide diversity of life forms?
- Why are some organisms difficult to classify?
- Why did diverse major life forms first emerge in different time frames?
- Why have so many major groups gone extinct over time?
- Why do so many species exhibit imperfect adaptations, or features derived from others but used for different purposes?
- Why are there series of human-like fossils suggesting gradual changes accumulating over time, looking increasingly modern?

Review these problems, and bring in others that may have arisen. A quest for resolution flows quite naturally from these findings that may conflict with common personal views. If not initiated by students, you should ask how their observations fit with popular ideas, such as the idea that all life forms were specially created in one short period of time, each independent of the other.

## The Evolution Solution

"Any ideas about what might help us to find answers to these questions?" Someone, by now, may have suggested "evolution" as a possible solution. If not, this would be a good time to use some prompts to help students suggest the process, such as "Has anyone heard of 'evolution'?"

"Let's take a look at this thing called 'evolution.' What ***is*** it, really? There are a lot of misconceptions about evolution out there, so first, let's see what it's ***not***." After going over a list of such views, take a look at what evolution ***is***.

**Table 1. Intermediate Forms**

| ORGANISM | POSSIBLE CLASSIFICATION | MIX OF TRAITS |
|---|---|---|
| *Euglena* | plant or animal? | chloroplasts (plants) and motile (animals) |
| *Peripatus* | annelid or arthropod? | annelid-like excretory system, with arthropod-like respiratory system |
| *Archaeopteryx* | reptile or bird? | dinosaur skeleton and teeth, with bird feathers |
| (*Ornithorhynchus*) platypus | reptile or mammal? | reptile-like eggs, with fur and nursing |

Be sure to include that evolution is essentially the process in which all species come from earlier species, accumulating changes over time, and leading to all the groups of organisms seen today. Show some phylogenetic trees for visual clarity. Emphasize that—fundamental to evolution—is the fact that species can and do change. They can become extinct, or they can evolve into new species, and this has been observed many times directly, for which you can give some examples taken from the *TalkOrigins Archive* site (Boxhorn, 1995). A favorite is the Dandelion-like plant of the genus *Tragopogon,* in which two new species were produced as polyploids by natural hybridization, confirmed from their karyotypes and the fact that they could not reproduce with their parents. Excellent pictures from the original paper can be used to show these new species, their parents and their karyotypes (Ownbey, 1969).

Teams of students can read about the many series of fossils showing species-to-species changes, such as the early lemur-like primates described in the ENSI background paper "Transitional Fossils." As these changes accumulate over time, students see major groups emerging that can be quite different from earlier groups. The "Becoming Whales" lesson provides vicarious experiences in fossil discoveries that lead to a compelling sequence, and then presents other kinds of studies that confirm the biological connections of whales with certain terrestrial mammals.

## Challenges

About this time, if you haven't yet been challenged, this is where it will happen. You may be confronted with statements similar to those that opened this article. Your best response to "I don't believe in evolution" should be "Good! I don't believe in evolution, either! In fact nobody should *believe* in evolution. It's really not something you should believe in, purely on faith. You might be *convinced* of its validity from the consensus of experts in the field, the abundance of observations pointing to it, and the total lack of evidence against it, or you might not. It does raise many questions and seems to conflict with some popular views, so it's something you really need to study, question, and decide for yourself whether the evidence is compelling or not. But don't ever *believe* in it. In this class, I *do* expect you to make every effort to *understand* evolution, what it is, what it is not, and how it seems to work, according to the experts."

In recent years, there has been a widespread effort by some evolution critics to insert the somewhat modified creationist idea of intelligent design (ID) into school science courses as a "scientific" alternative to evolution. This is often combined with appeals to "equal time" and "fairness" which, as your students should now realize, are never part of science. Regardless of the impressive academic credentials of some of the ID proponents, this approach is filled with the usual fallacies and unscientific premises long associated with "scientific creationism" and other anti-evolution movements. In fact, both ID and "creation science" are excellent examples of pseudoscience, a topic that should have been explored in your Nature of Science introductory unit. For good discussions of the unscientific nature of intelligent design, see Miller (1999), Alters and Alters (2001), or Ayala (2004), or search the *TalkOrigins* and *NCSE (National Center for Science Education)* Web sites.

## Caution

Do not fall into the trap of rebutting every challenging comment, because this becomes a purely defensive exercise—even argumentative and emotional—with every rebuttal triggering a new challenge. There are cogent and valid rebuttals to every argument made by anti-evolutionists, most of them mainly to correct the many misconceptions. For students who are genuinely concerned, asking questions and trying to resolve their inner conflicts, send them to search in the *TalkOrigins* and the *NCSE* sites. Ask them to search for arguments *against* some of their claims, focus on specific points of dispute, and then discuss the pros and cons of including ID or creation in science classes, using only objective scientific information.

If students persist in raising anti-evolution issues, offer to chat with them during lunch or after school. Remind them that religious beliefs are not appropriate topics to defend or discuss in detail in a science class (for the reasons given in your introductory unit on the Nature of Science). Always be sensitive to and respectful of your students' personal beliefs, and allow nothing less from their classmates.

Avoid revealing—unless prompted—the fact that teaching creationism (in any form) in science classes has been deemed unconstitutional by the Supreme Court (Scott, 2004, p. 114). This produces more defensiveness and bypasses the many good scientific reasons why any form of creationism is inappropriate as a valid alternative to evolution in science classes, and your students should understand those reasons.

Likewise, avoid directly stating that any of the examples or studies provide "evidence against creation," as this tends to be divisive and may lead to antagonism toward (or from) those with creationist views, and further defensiveness. Science has no quarrel with beliefs in "creation," only its misrepresentation as science. Remember that many who hold strong religious beliefs or believe in some form of creation also support evolution, and most religions support evolution (Nelson, 2000; Matsumura, 1995).

If you have provided a thorough introduction to the nature of science in your opening unit, it's not likely that you will be seriously challenged on evolution in class. If you are, you can always quickly refer back to that material, with comments like "Remember the kinds of explanations that science can*not* use? Why is that?" Then you can move ahead.

Let the lessons speak for themselves. They provide a series of positive experiences on which guided discussion or even quiet reflection should encourage a more objective view of evolution, as held by nearly all practicing biologists. They are, by training, very skeptical people, who would welcome legitimate notoriety in their field, and would be the first to reveal weaknesses in evolution, if they existed. At least *your* students—if their minds haven't been closed by defensiveness—will have a more accurate understanding of evolution, and they might even be convinced of its validity.

## Moving Ahead: Evolution Continues

From this point, you can follow the sequence and content of your regular Introductory Evolution Unit. This should include a little historical background: early assumptions, and early observations that did not fit those assumptions, especially the discovery of fossils and the patterns they revealed. You should even consider Paley's argument for design, and how it was firmly discredited (Dawkins, 1987; Miller, 1999; Ayala, 2004). The story of Charles Darwin is always fascinating, especially when told with videos and illustrations. Be sure to note that his observations led to his ideas on evolution by natural selection to explain the many inconsistencies between those observations and traditional views. Also insist that students learn to avoid verbal descriptions of natural selection that sound like Lamarck's explanations, such as "Traits develop *in order to* survive." The "Lamarck vs. Darwin" lesson effectively teaches this.

As you explore natural selection, be sure your students have a chance to directly observe and measure variation of some trait in a population; measuring peanut lengths could be one of your tastier labs! And, of course, do one of the many available natural selection simulations, such as the "Stick-Worms" lab. If possible, your students should observe selection in a living lab, using bacteria, Fast Plants™, or other organisms. In any case, be sure to include ENSI lessons that present some of the critical but seldom addressed aspects of evolution, especially its cumulative nature and its mix of random with non-random elements.

The strongest ideas in science are those with multiple independent lines of evidence (MILEs) all pointing to the same conclusion. This should be reinforced whenever your students read about examples, or, preferably, *do* investigations, that contribute to "MILEs" (Nelson, 2000). Consequently, at some point in your evolution unit (or later, especially in your focus on human biology) be sure to have your students extend their experience with hominoid skulls by exploring other material that confirms common ancestry in humans and other primates, such as chromosome and molecular comparisons.

Finally, integrate evolution with all your standard course units. To paraphrase a well-known quote, biology makes a whole lot more sense when evolution is used to tie it all together. As it turns out, both evolution and the nature of science combined make excellent themes around which to build a coherent and effective biology course, where everything makes more sense, and it's all much easier to understand.

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## Appendix. Referenced Links to Lessons and Resources.

### Nature of Science

Realm and process of science (lesson): Perception is Not Always Reality
www.indiana.edu/~ensiweb/lessons/percep.htm

Illusions (list): Illusions in Science, contrived and natural
www.indiana.edu/~ensiweb/lessons/unt.illu.html

Process and social context of science: Checks Lab (lesson)
www.indiana.edu/~ensiweb/lessons/chec.lab.html

### Classification

Contrivances (lesson): Blocks and Screws
www.indiana.edu/~ensiweb/lessons/bl%26scr.html

Pseudogenes (lesson): Pseudogene Suite (ABC): Vitamin C & Ancestry
www.indiana.edu/~ensiweb/lessons/psa.ball.html

### Human Evolution

"Skulls" (lesson): Hominoid Cranial Comparison (Skulls)
www.indiana.edu/~ensiweb/lessons/hom.cran.html

Chronology (lesson): Chronology Lab (hominid time-tree)
www.indiana.edu/~ensiweb/lessons/chronlab.html

### Evolution Introduction

What evolution IS/is NOT (paper): Introduction to Evolution
www.indiana.edu/~ensiweb/lessons/unt.ev.f.html

Transitional Fossils (paper): class-to-class: A4; species-to-species: A5
www.indiana.edu/~ensiweb/lessons/c.bkgrnd.html

Whales (lesson): Becoming Whales
www.indiana.edu/~ensiweb/lessons/whale.ev.html

### Challenges

Evolution/creation/ID info: TalkOrigins Archive
www.talkorigins.org

Evolution/creation/ID info: NCSE: National Center for Science Education
www.ncseweb.org

Understanding Evolution (Univ. of California Museum of Paleontology)
http://evolution.berkeley.edu/

### Moving Ahead

Natural Selection (lesson): Lamarck vs. Darwin
www.indiana.edu/~ensiweb/lessons/lam.darw.html

Natural Selection (critical lesson): Natural Selection: A Cumulative Process:
www.indiana.edu/~ensiweb/lessons/ns.cum.l.html

Natural Selection (critical lesson): Chaos: Living on the Edge
www.indiana.edu/~ensiweb/lessons/chaos.html

Speciation lesson: A Step in Speciation
www.indiana.edu/~ensiweb/lessons/step.sp.html

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## Appendix. Referenced Links to Lessons and Resources.

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**Integrating Evolution**

MILEs, Chromosomes: Comparison of Human & Chimpanzee Chromosomes
www.indiana.edu/~ensiweb/lessons/chromcom.html

MILEs, Chromosomes: Chromosome Connection (lesson plans)
www.becominghuman.org (click on "Learning Center")

MILEs, Primate Proteins: Molecular Sequences and Primate Evolution
www.indiana.edu/~ensiweb/lessons/mol.prim.html

MILEs, Human Evolution/Behavior: Footsteps in Time
www.indiana.edu/~ensiweb/lessons/footstep.html

Geological Dating (lesson): Date a Rock
www.indiana.edu/~ensiweb/lessons/date.les.htm

Geological Dating (lesson): Varve Dating
www.indiana.edu/~ensiweb/lessons/varves.html

Geological Dating (lesson): Time Machine
www.indiana.edu/~ensiweb/lessons/time.mac.html

Biology Topics with Evolution: Integrating Evolution
www.indiana.edu/~ensiweb/lessons/unt.seq.html