NSTA Tool Kit for Teaching Evolution

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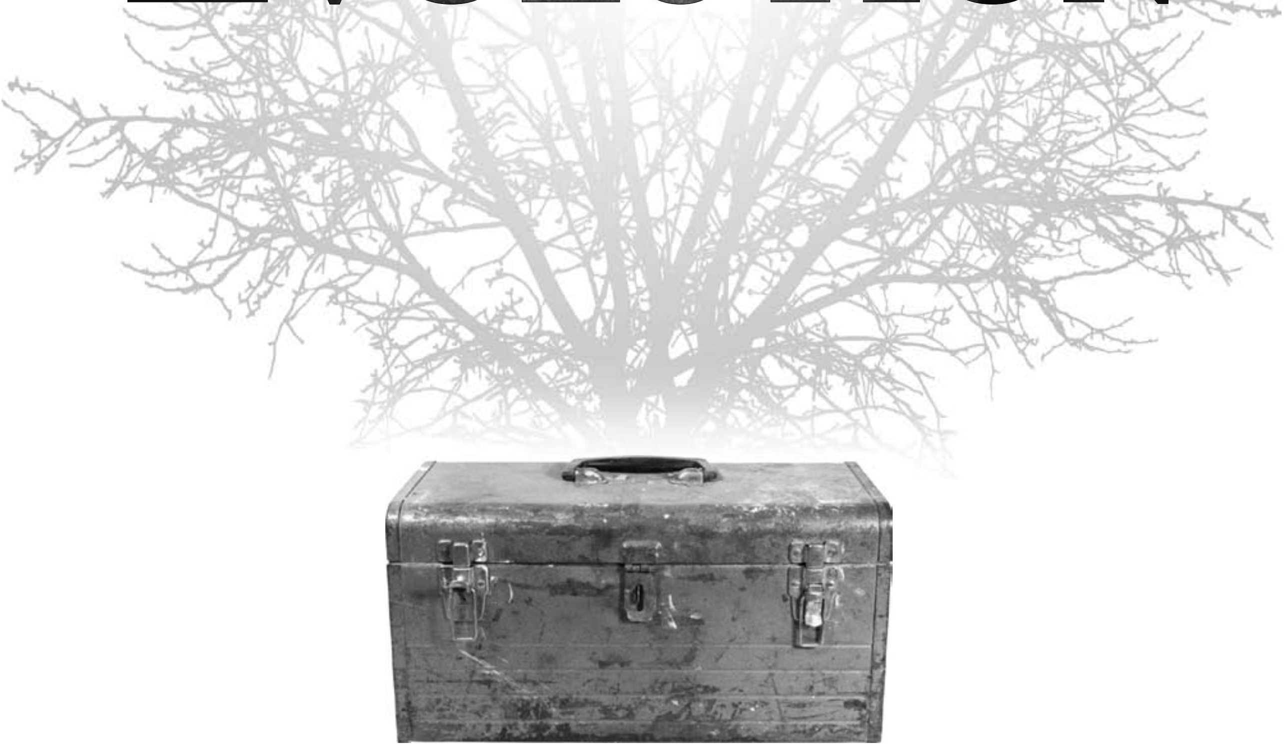

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How paramount the future is to the present
when one is surrounded by children.
—Charles Darwin, in a letter to W.D. Fox, March 5, 1852

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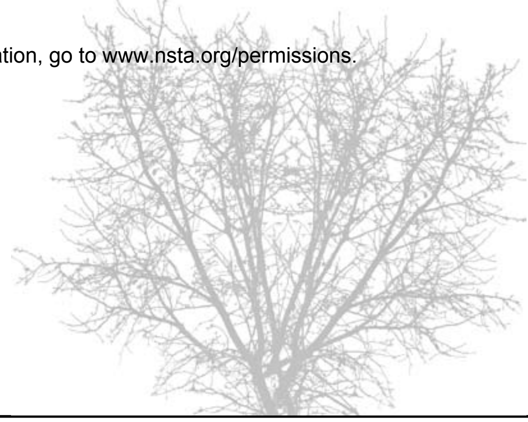

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Acknowledgments

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Introduction

You are midway through your district curriculum, and you need to pull together the subjects you have been teaching so far—nature of science, cells, biochemistry, and genetics. Have you considered teaching evolution as a way of tying these topics together? That's right, *evolution.* Or are you one of the many biology or life science teachers who say, *"I don't teach evolution because …*

1. "I don't want to be in the middle of this controversial topic. I don't know how to best answer parents, students, or others who ask why I don't teach alternative theories."
2. "I want students to develop their own opinions, yet it's difficult to frame evolution instruction in a way that leaves students' minds open but doesn't equivocate."
3. "I don't have the class time to spend dealing with parent and student biases against evolution instruction."
4. "I need more content support to feel confident about my instruction, or even to supply simple answers to basic questions about evolution and the nature of science."
5. "I need hands-on, visual teaching aids."
6. "I don't spend time on a potentially controversial topic that's not assessed on my state-mandated test."
7. "I'm unsure what my district's policy is on teaching evolution and I'm concerned that I won't receive total support from the administration."
8. "I don't really know what to say about 'intelligent design' if the topic comes up."
9. "I disagree with the policy that allows students who are offended to skip class and the negative message this sends to the rest of my class."
10. "I have to either steer clear of human evolution or 'teach both sides.'" (Omenn 2006)

If you shy away from teaching evolution, you are not alone. The 10 statements just listed are adapted from an American Association for the Advancement of Science (AAAS) survey of teachers who identified and ranked these challenges.

Introduction

SCILINKS
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Topic:
Evolution
teaching
resources

Go to:
www.SciLinks.org

Code: ETK001

To help you overcome these challenges and teach evolution successfully, the National Science Teachers Association (NSTA) has partnered with the National Center for Science Education (NCSE) on the *NSTA Tool Kit for Teaching Evolution.* You can also use this guide to enhance your teaching of the National Science Education Standards listed in Table 1 as well as those associated with evolution in your state and district curricula.

Table 1. National Science Education Standards Pertaining to the Teaching of Evolution

Grades 5–8 Life Science

Topic: Regulation and behavior (p. 157)

- How a species moves, obtains food, reproduces, and responds to danger is based in the species' evolutionary history.
- All organisms must be able to obtain and use resources, grow, reproduce, and maintain stable internal conditions while living in a constantly changing external environment.
- An organism's behavior evolves through adaptation to its environment.

Topic: Diversity and adaptations of organisms (p. 158)

- Biological evolution accounts for the diversity of species developed through gradual processes over many generations.
- Species acquire many of their unique characteristics through biological adaptation, which involves the selection of naturally occurring variations in populations.
- Biological adaptations include changes in structures, behaviors, or physiology that enhance survival and reproductive success in a particular environment.

Topic: Structure and function in living systems (p. 156)

- Living systems at all levels of organization demonstrate the complementary nature of structure and function.

Topic: Reproduction and heredity (p. 157)

- The characteristics of an organism can be described in terms of a combination of traits. Some traits are inherited and others result from interactions with the environment.

Grades 9–12 Earth Science

Topic: The origin and evolution of the Earth system (p. 190)

- The evolution of life caused dramatic changes in the composition of the Earth's atmosphere, which did not originally contain oxygen.

Grades 9–12 Life Science

Topic: Biological evolution (p. 185)

- Evolution is the consequence of the interactions of the potential for a species to increase its numbers.
- Evolution is the consequence of the interactions of the genetic variability of offspring due to mutation and recombination of genes.
- Evolution is the consequence of the interactions of a finite supply of the resources required for life.
- Evolution is the consequence of the interactions of the ensuing selection by the environment of those offspring better able to survive and leave offspring.
- The great diversity of organisms is the result of more than 3.5 billion years of evolution that has filled every available niche with life-forms.
- Natural selection and its evolutionary consequences provide a scientific explanation for the fossil record of ancient life-forms, as well as for the striking molecular similarities observed among the diverse species of living organisms.
- Organisms are classified into a hierarchy of groups and subgroups based on similarities, which reflect their evolutionary relationships.

Topic: The behavior of organisms (p. 187)

- Behaviors often have an adaptive logic when viewed in terms of evolutionary principles.

Source: National Research Council. 1996. *National Science Education Standards*. Washington, DC: National Academy Press.

Here's more data on your peers in the classroom. In a scientific survey of practicing biology teachers, 98% taught evolution and 78% taught human evolution. The average amount of time spent on evolution—13 hours—is not adequate for students to understand the importance of this topic. Notably, teachers with more science background (more university-level science courses) taught more evolution (Berkman, Pacheco, and Plutzer 2008). The *NSTA Tool Kit for Teaching Evolution* will help you integrate evolution into your courses so that you can successfully teach it more often, regardless of your prior science experience.

What's in the *NSTA Tool Kit for Teaching Evolution*?

This go-to reference guide includes information and activities that you can use in class tomorrow. Organized into four distinct chapters, this book will

- refresh your background knowledge and help you know what to emphasize in your evolution instruction,
- support you in hands-on instruction,
- clarify the controversy to help you take advantage of the opportunities in evolution instruction, and
- identify organizations that support your professionalism in this endeavor.

As you read the *Tool Kit*, log on to *www.scilinks.org* to access the SciLinks listed throughout the book for more content, activities, and assessments. The SciLinks program was developed by the National Science Teachers Association (NSTA) to supplement classroom discussions of key science topics. This searchable database automatically filters, centralizes, and saves helpful science websites found by NSTA experts. The sites are organized by topic and presented in an accessible format for teachers and students. Use them during lectures or group activities or as homework assignments. Full access to all SciLinks tools and topics requires registration, which is free and easy. Once you are registered, provide your students with your ID # and let them explore on their own.

Q&A

Throughout this book you will also find abridgements (like the following) of a question-and-answer (Q&A) document written by past NSTA president Gerald Skoog to help dispel misconceptions about evolution. The complete text of the Q&A document is online at *www.nsta.org/publications/evolution.aspx#qanda*.

Q: ***Why have challenges to the teaching of evolution increased so dramatically in recent years?***

A: Throughout the 20th century, special-interest groups have worked to prohibit, deemphasize, or neutralize the teaching of evolution in the nation's public schools. Recently, cultural, religious, judicial, legal, and other factors have shaped the nature, intensity, and success of these efforts and challenges. The generally strong presence of biological evolution in the national and state science standards and science textbooks has catalyzed the actions of special-interest groups who currently have considerable political influence and question the legitimacy of biological evolution and its place in the science curriculum and public thought.

Q: ***What do anti-evolution groups want?***

A: The answer is complicated because many groups hold different beliefs about the history and nature of life on Earth. Groups on one end of the spectrum seek to replace or "balance" the teaching of evolution with a literal biblical interpretation of creation, while others, to sidestep the overtly religious argument, call for teaching the so-called "weaknesses" of evolution. Still others believe that a myriad of ideas, scientifically supported or not, should be taught out of "fairness."

Q: ***I'm frustrated at the amount of time and attention being devoted to the evolution issue, especially when I have so many other demands and challenges in the classroom. Shouldn't we all just keep a low profile and hope the issue goes away?***

A: We understand your frustrations. We've heard from many of you that the dialogue on this issue is causing undue stress and usurping valuable time. Now more than ever, we need the voice of the nation's science teachers to be heard. The stakes are simply too high. We recommend that you use this opportunity to educate and inform students, school leaders, and community members about the nature of science and what it can and can't tell us about the world. Rest assured you are not alone in this effort. NSTA stands ready to support you in any way and is working at the national level to keep evolution—and sound science—in its rightful place in the science curriculum.

Introduction

Research shows . . .

Three research studies offer insight into the controversy surrounding the teaching of evolution. Throughout the book statistics from each of these studies are boxed off and cited under the heading "Research shows . . ."

The first study—a 2006 survey of 1,000 randomly selected individuals conducted by the Coalition of Scientific Societies—focuses on the attitudes of Americans (the general public, not just teachers) regarding science education and the teaching of evolution, creationism, and intelligent design. Attitudes vary depending on the education level, religious background, politics, marital status, race, sex, and size of community of the respondents. Knowing the demographics of your school's community can help you better frame your stance of teaching evolution as a valid scientific explanation.

The second study is by three political science experts at The Pennsylvania State University who surveyed teachers about the teaching of evolution in the 2006–2007 academic year. The researchers found that personal beliefs and college-level courses in evolutionary biology impact teaching practices.

A third study was conducted in 2005 by the Pew Forum on Religion and Public Life, which charges itself with promoting a deeper understanding of issues at the intersection of religion and public affairs. This telephone survey reached a nationwide sample of 2,000 adults.

Research shows...

- Even though nearly half of Americans believe that humans evolved over time, only 26% say they favor teaching evolution only in the public schools while 64% favor teaching creationism along with evolution. Another aspect of the survey revealed that 38% would teach creationism instead of evolution although 49% opposes teaching creationism only. "These findings strongly suggest that much of the public believes it is desirable to offer more viewpoints where controversial subjects in the schools are concerned" (Pew Forum on Religion and Public Life 2005, p. 10).

- In the classroom, 69% of biology teachers spend from 3–5 hours on general evolutionary processes. In addition, about 25% of biology teachers spend at least 1–2 hours on creationism. While some of these teachers address creationism in response to student inquiries or to criticize it, nearly half of that 25% say that creationism is a valid scientific alternative to Darwinian explanations for the origin of species (Berkman, Pacheco, and Plutzer 2008, Table S2).

Supporting Your Efforts

NSTA supports your efforts to teach evolution as a major unifying concept in your biology or life science class, as outlined in its position statement at *www.nsta.org/about/positions/evolution.aspx*. Local curriculum and attitudes can make this endeavor difficult, but we hope the *NSTA Tool Kit for Teaching Evolution* supports you in your current practices and provides new ideas and resources that add depth to your instruction.

Chapter 2: Active Evolution Instruction

Craig Nelson, biology professor at Indiana University and researcher in evolution and evolutionary ecology, asked the following question in his book *The Creation Controversy & The Science Classroom* (Skehan and Nelson 2000, p. 19): "How can we produce a scientifically literate society, especially in areas that are publicly controversial?" He came to the following conclusions:

- "Active learning is even more important for controversial topics than for the rest of science."
- "We too often teach science as a set of conclusions … instead of as a set of processes for thinking critically about alternatives."
- "We have good ways to judge the levels of strength of support for scientific theories and other criteria for comparing them. Helping students understand these ways of judging is integral to teaching science as critical thinking."
- "Public controversies usually rest on disagreements about consequences … If students are to understand why topics such as evolution are controversial, we must help them understand the different views of consequences."

In his book, Nelson also describes effective strategies for teaching evolution and other controversial topics by outlining several problems and giving strategies for how to overcome them. Using evolution instruction as his example, Nelson applies strategies that emphasize critical thinking and that can be adapted to your classroom situation.

Research shows…

- The public's view of the goals of science education may differ from your personal teaching goals. The public rated the following goals of science education as "very important":

Learn how to draw conclusions from evidence	80%
Learn how to think critically	78%
Learn how science is conducted	63%

  (Coalition of Scientific Societies 2007, p. 6)

- Biology teachers whose college-level coursework included at least one class in evolutionary biology devote substantially more class time to evolution than teachers with fewer credit hours in evolutionary biology. The best-prepared teachers devote 60% more time to evolution than the least prepared (Berkman, Pacheco, and Plutzer 2008, Table S6).

Active Evolution Instruction

To help elevate your level of active instruction, this chapter provides a sampling of the kinds of hands-on activities that promote understanding of evolutionary processes. These particular activities are structured according to the BSCS 5E Instruction Model—engage, explore, explain, elaborate, and evaluate. The 5E Model is a teaching sequence that can be used for entire programs, specific units, or individual lessons (Bybee 1997). This chapter also contains print and online resources for new ideas and practical applications that will help you emphasize science process and how evolutionary changes affect us daily.

Showing Evolutionary Relationships With Cladograms

Engage

As you introduce the concept of comparative anatomy reflecting common ancestry, your program or reference materials might suggest a common classification task whereby students group inanimate objects, such as classroom furniture, lab equipment, or backpack contents, according to visible characteristics. However, this kind of task can lead to misconceptions because unlike living things, there is no genetic relationship among the objects used. Different lab groups will develop different classification systems, but as long as the logic is sound, no one system will be any more "correct" than the next.

Instead of this common classification task, show students pictures of organisms that have several common characteristics such as streamlined swimming marine animals—jellyfish, tuna, swordfish, killer whale, dolphin, great white shark, and stingray. Have students group the animals and then ask volunteers to share their grouping criteria. Ask students how the characteristics of the animals are determined (gene interaction) and what processes would have to occur for their characteristics to change (mutation, adaptation). Help students see how a desk, for example, may have different physical characteristics in different circumstances that would lead to alternate classifications. Great white sharks, though, are great white sharks no matter the circumstances and have a definite set of characteristics.

Explore

Have students consider the "relatedness" of a subset of these marine animals. Ask students to consider which animals are more closely or more distantly related. Focus students on the jellyfish, tuna, killer whale, and great white shark. To differentiate among the animals, have students determine whether the animals' skeletons are cartilaginous or bony and whether breathing is accomplished through gills or lungs. Develop a class chart with characteristics listed across the top and the names of the animals down the side (see Table 2). Have students research the characteristics and use symbols such as + and 0 to denote if a character is present in a given animal at any time during its development.

Table 2. Characteristics of Selected Organisms

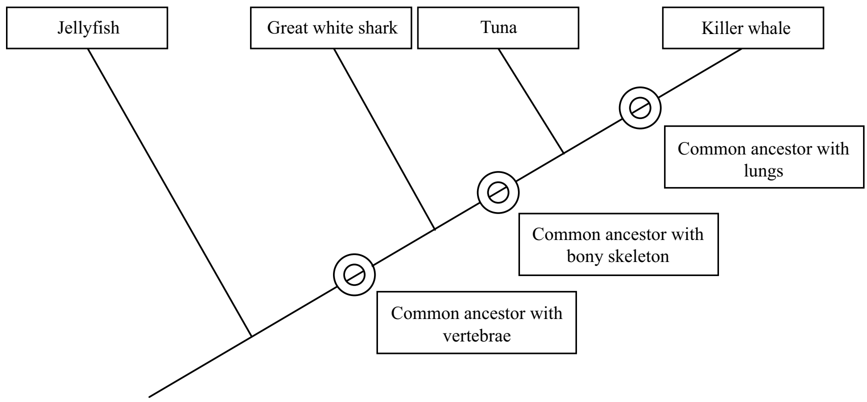
	Vertebrae	Bony skeleton	Lungs
Jellyfish	0	0	0
Tuna	+	+	0
Killer whale	+	+	+
Great white shark	+	0	0

Explain

Tell students that the modern process of classification is based on phylogenies. A phylogeny is similar to a family tree that shows how the various types of organisms in a group are related. Comparative anatomy studies and homologous structures will show characteristics that are the same for all types of organisms in the phylogeny. These characters are the ancestral ones that stem from the common ancestor. Shared derived characters, or ones that differ from the ancestral characters, show the evolutionary pathway. By drawing a diagram of branching lines that connect the groups that share the derived character, the degree of relationship can be inferred. These diagrams look like trees and are called phylogenetic trees or cladograms. (The word *cladogram* originates from the Greek word *klados,* meaning branch or twig.) Reproduce the cladogram shown in Figure 3 (p. 20) for students.

Use the class chart to explain how the cladogram is developed. First, note that all organisms except the jellyfish have vertebrae. Therefore, you

Figure 3. Developing a Cladogram



would designate the jellyfish as the "out-group," and it branches off the cladogram first. The remaining three animals (great white shark, tuna, and killer whale) all descended from an ancestor with vertebrae.

Consider the next characters, the presence of a bony skeleton and lungs. Have students determine which characteristic is shared by all remaining animals except one. The great white shark has a cartilaginous skeleton, whereas the tuna and killer whale have bony skeletons. So the shark is the next animal to branch off the cladogram. Because both tuna and killer whales have bony skeletons, it is most likely that they share a common ancestor with a bony skeleton. Finally, point out that the killer whale has a characteristic that is never present in the other organisms—lungs. Therefore, the killer whale is positioned at the end of this cladogram. In this particular example, lungs cannot be considered a shared derived character because the killer whale is the only animal in the chart displaying the character. Lungs are, however, a derived trait that evolved in the lineage leading to killer whales. Lungs would be a *shared* derived trait if the chart included dolphins because lungs have been inherited from the common ancestor of killer whales and dolphins.

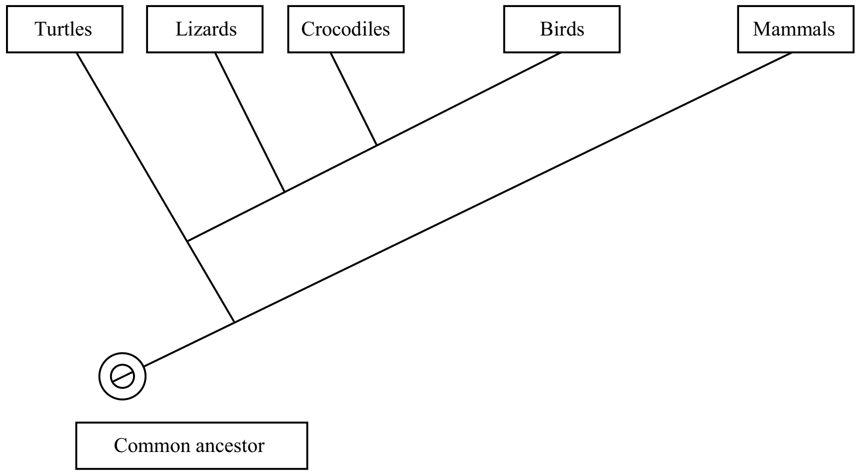
Help students understand how drawing branches from the ancestral line is important. If the organisms were located on the ancestral line it would give the impression that sharks evolved into tuna, which then evolved into killer whales. Although students sometimes misunderstand Darwin's concept of descent with modification, in this model students can see that the "modification" is a derived character that branches from the ancestral line, rather than the "modification" of one group into another. Sharks, tuna, and killer whales descended from a common ancestor, but did not evolve directly from one into the other. Also be sure that students do not think that because the killer whale is at the end of the straight line, it is the common ancestor from which the other types of animals evolved.

The cladogram also shows the relative passage of geologic time. Point out to students that when reading a cladogram, the longer the line, the more distant in the past the event occurred. You might draw the cladogram reversed from right to left, keeping all relative line lengths the same for comparison. Because we read left to right, students may have trouble seeing that the two versions show the same relationship with regard to time—that the common ancestor of tuna and killer whales occurred more recently in geologic time than the common ancestor of tuna, killer whales, and great white sharks.

Cladograms that show several branches can sometimes be confusing to students. Draw the cladogram shown in Figure 4 to spark discussion.

Chapter 2

Figure 4. Interpreting Branches of a Cladogram



Ask students whether birds are more closely related to mammals or to turtles. Help students see that the proximity of the labels is not an indication of relatedness. Instead, students should look at the point of branching.

SCILINKS THE WORLD'S A CLICK AWAY

Topic: Phylogenetic trees

Go to: *www.SciLinks.org*

Code: ETK007

Birds and turtles share a more recent common ancestor than birds and mammals. To clarify, you could draw the same cladogram, but draw the branching from the turtle lineage to the left, which would reverse the order of the labeling but not change the comparative evolutionary relationships of the organisms. On the cladogram, close relationships are shown by a recent fork from the supporting branch. The closer the fork in the branch between two organisms, the closer their relationship. Help students see that birds are most closely related to crocodiles and more closely related to lizards than they are to either turtles or to mammals.

Elaborate

To visualize how characteristics can show evolutionary relatedness, use a set of five nested (large-to-small) self-sealing plastic bags, either for a demonstration or provide one set per lab group. (Six sizes for nesting will be needed by the end of this Elaborate stage.) Make a set of "animal" cards for each set of bags. Label the cards *lamprey, perch, turtle, kangaroo,* and *mouse.* If students are unfamiliar with these animals, have them find pictures and research general characteristics of each.

Also prepare a set of "character" cards using the characteristics in Table 3 for each set of bags (one card per column). If possible, make each character card a different color or add a colored marker symbol for easy reference later. Reproduce Table 3 on a blackboard, white board, or overhead—any means by which students can add to the chart later. You should point out to students that though the characteristics in Table 3 are grouped together, they are inherited independently of one another.

Table 3. Characteristics for Character Cards

Character ○	Character ◊	Character □	Character Δ	Character +
Dorsal nerve cord Notochord Chambered heart	Jaws Paired appendages Vertebral column	Amniotic egg	Three ear ossicles Hair Mammary glands	Placenta

Spread out the five plastic bags from largest to smallest. Near the top, label the bags A through E from largest to smallest. Attach the character card with the characteristics common to the greatest number of organisms [○] to the largest bag (Bag A). Place the organisms with those characteristics inside that bag. (All go into Bag A.) Then attach the character card with characteristics common to the next greatest number of organisms [◊] to the second largest bag (Bag B). From Bag A, take as many organisms that have those characteristics and move them to Bag B. (All except the lamprey go into Bag B.) Repeat until all the character cards and animals have been distributed among the bags (Bag C, [□], lizard; Bag D, [Δ], kangaroo; Bag E, [+], mouse). Now "nest" the bags so they are inside one another and the character and animal cards are visible.

Lead students to understand that the characteristics on any given bag are not only characteristics of the animal in that bag, but also of all the other animals in the bags nested within. Any derived character is also a characteristic of those animals nested within that bag, but not of the ones outside it.

Now give students a "frog" card. Have students research the unique character set of this organism (lungs, four limbs) and add that data to Table 3. Ask students where a new bag with these characters would nest within their set (between Bags B and C). Give students an appropriate size bag to insert.

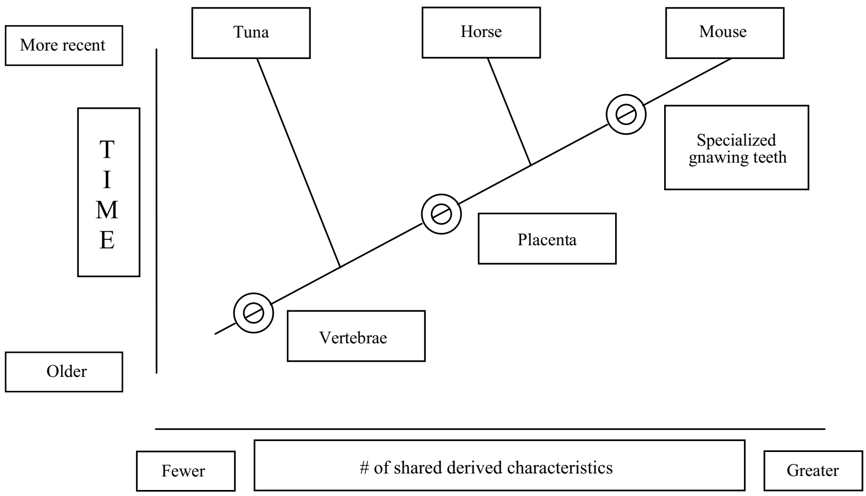
Have students convert their visual Venn diagram of nested bags to a chart similar to the one you made during the Explore stage. Have students list the character sets across the top and the animals down the side. Students should complete the chart using Xs to show whether that organism has that trait or not. Have students compare the total number of Xs for any given animal to its bag's position in the nested arrangement. Use the chart to revisit the concept that any derived character is also a characteristic of those animals nested *within* that bag, but not of the ones *outside* it.

Next, ask students to draw a cladogram using the chart and their nested bags as a guide. Once students have constructed their cladograms, they can map the characters onto the cladograms as in the previous examples. Troubleshoot as students work independently or in small groups ensuring that time is illustrated correctly and the number of shared characteristics increases appropriately. Show the example in Figure 5 (p. 24) to students who are struggling with the material.

Evaluate

Tell students that the Hawaiian Islands are home to at least 800 species of *Drosophila*, or fruit flies. Show students pictures or describe the fragility of fruit flies and how a fruit fly's range would cover a relatively small

Figure 5. Sample Cladogram Emphasizing Time



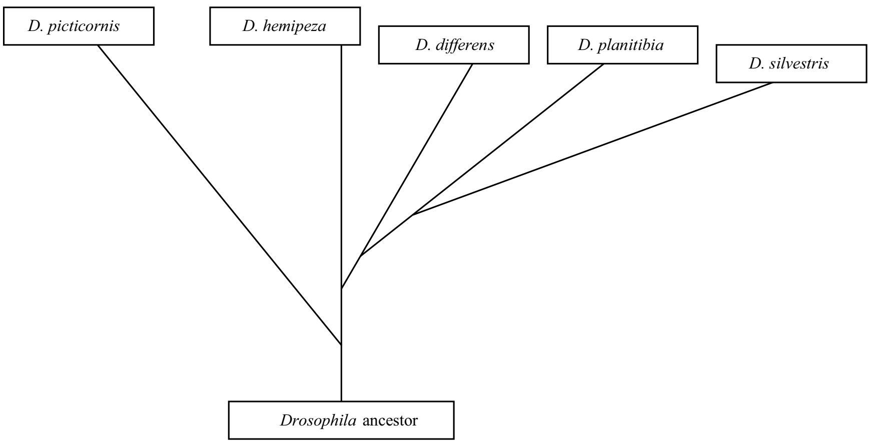
geographic area. Scientists think that one pregnant fruit fly blew ashore on one of the islands several million years ago. This one fruit fly is the common ancestor of the hundreds of species on the islands. Give students the cladogram in Figure 6, developed from the ancestral and shared derived characters of five species of fruit flies. Each species lives on a different island in the chain.

Display a map of the Hawaiian Islands and have volunteers research and share basic facts about the formation of the Hawaiian Islands over a mid-plate hotspot and their ages. Add island names and approximate formation times (Niihau and Kauai formed about five million years ago; Hawaii formed about one half million years ago).

Have students write two to three paragraphs that explain how the islands' formation supports the hypothesis of the evolutionary relationships shown by the cladogram. Writing should reflect an understanding of the relative length of evolutionary history of each species, potential islands that each species lives on, the relative time over which the speciation occurred, and how the islands' origins might have contributed to speciation.

To assess students' responses, use the SAT Reasoning Test Essay Scoring Guide (*http://professionals.collegeboard.com/testing/sat-reasoning/scores/essay/guide*), the Northwest Regional Educational Laboratory's 6+1 Trait Assess-

Figure 6. Hawaiian Fruit Flies



ment Scoring Guide (*www.nwrel.org/assessment/pdfRubrics/6plus1traits.PDF*), or your own state or local writing rubric. Writing activities help students assimilate ideas and provide practice for the writing required on the SAT and state-mandated exams.

Natural Selection and Antibiotic Resistance

Engage

Engage students in a discussion about hand sanitizers and other antibacterial or antimicrobial soaps. Elicit from volunteers how often they use such products and why they use them over more conventional soaps. Draw on students' prior knowledge to develop an operational definition of antibiotic. Continue the discussion, probing for use of antibiotics and antibacterial products to combat illnesses. Ask students to list illnesses that antibiotics effectively fight. Remind them that viral infections such as colds, flu, and most sore throats should not be treated by antibiotics because viruses are not affected by antibiotics. Point out to students that prescriptions for antibiotics specify that all of the prescription must be taken over a specific timeframe. Ask for hypotheses as to why this is the case.

Explore

Set up your favorite predator/prey simulation using multicolored paper dots, toothpicks, jelly beans, or tokens on a colored "environment." Have students demonstrate how a population can shift due to predation. "Prey" are captured (picked up with fingers, forceps, or sticky tape; stabbed with a toothpick; etc.) during a 30-second turn and are not returned to the environment. Students observe the survivors and add "offspring" to the surviving population. For every pair of similar-colored objects not captured, two offspring are born (or added back to the environment). In the event that an odd number of objects survive, students should calculate offspring based on the highest number of pairs that can be formed. The objects that are easy to find will have few survivors and may become extinct due to their low reproduction rate. Those that are difficult to find will survive, reproduce, and increase in total population. After even a few turns, students witness a decline in diversity as the population shifts toward objects that are most similar to the color of their environment.

Explain

Connect students' exploration to their discussion of antibacterial soaps and antibiotics. Guide them to understand that the overuse and misuse of these products enables natural selection to act on bacterial populations resulting in shifts to populations of bacteria resistant to a given antibiotic. Review their hypotheses from the earlier discussion, noting that research shows that a shortened course of antibiotics will kill only the most vulnerable bacteria, while allowing relatively resistant bacteria to survive.

Students may wonder how bacteria evolve so quickly. Describe that at the most basic level, the process of evolving resistance happens quickly for two main reasons:

- Bacteria have large population sizes. Any population is relatively likely to include an individual that happens to carry a gene for resistance.
- Bacteria have short generation times. A population in a patient can evolve from a susceptible state to a resistant one quickly.

Another unusual factor comes into play as well. In a process called *horizontal gene transfer,* bacteria can pass gene copies to one another directly, even to an entirely different species of bacteria.

SciLinks — THE WORLD'S A CLICK AWAY

Topic: Antibiotic resistance

Go to: *www.SciLinks.org*

Code: ETK 008

Many resources, such as the following, describe the process of and health concerns about antibiotic resistance:

Centers for Disease Control and Prevention ***(www.cdc.gov/ncidod/eid/vol7no3_supp/levy.htm):*** Triclosan is the active ingredient in many antibacterial soaps and it inhibits the production of fatty acids. Research into the particular cellular site on which triclosan acts shows that resistant mutants of *Escherichia coli* (*E. coli*) appeared with low-, medium-, and high-level resistance. They all had a mutation on one gene that enabled the resistant strains to produce essential fatty acids even in the presence of triclosan. In comparison with the wild-type *E. coli*, mutants required up to 100 times more triclosan to show even minimal inhibition of fatty acid biosynthesis.

Although triclosan's high concentration in soaps (2,500 μg/ml) seems to be high enough to kill even resistant bacteria, tests show this is not the case. A 90% death rate in wild-type *E. coli* requires exposure to 150 μg/ml of triclosan in soap for two hours at 37°C. Mutants required two to four times that. Ironically, triclosan was more effective by itself as soaps seemed to decrease triclosan's effectiveness. Mutant strains survived in triclosan soaps diluted with as little as three parts water. Most important, the time, temperature, and amount needed to kill the bacteria greatly exceeded the average five-second hand washing performed by most people.

World Health Organization (***www.who.int/mediacentre/factsheets/fs194/en/*****):** When infections become resistant to first-line antimicrobials, treatment has to be switched to second- or third-line drugs, which are nearly always more expensive and sometimes more toxic. For example, drugs needed to treat multidrug-resistant forms of tuberculosis are more than 100 times more expensive than the first-line drugs used to treat nonresistant forms. In many countries, the high cost of such replacement drugs means that some diseases can no longer be treated. Most alarming are diseases where resistance is developing for virtually all currently available drugs. Even if the pharmaceutical industry were to step up efforts to develop new replacement drugs immediately, current trends suggest that some diseases will have no effective therapies within the next 10 years.

Mayo Clinic (***www.mayoclinic.com/health/antibiotics/FL00075*****):** To halt the spread of antibiotic resistance: understand when antibiotics should be used, take antibiotics exactly as prescribed, never take an antibiotic without a prescription, don't pressure a doctor for antibiotics when you have a viral infection, and protect yourself from infection in the first place.

Elaborate

For years it was commonplace to have students prepare agar plates, transfer bacteria from the human body and surfaces of objects in the classroom, and add antibiotic discs to show the effect of antibiotics on bacteria growth. Students would then observe any resistant colonies forming in the clear zone around the desks. Now, however, that practice is discouraged. The December 2007 issue of *NSTA Reports* advises against such an activity, because whenever students create bacterial cultures in schools, it is almost inevitable that rich colonies of staphylococcus (along with streptococcus and other pathogens) will be produced (Texley and Kwan 2007). Placed in an optimal medium for 24 hours, a single cell might produce a colony of 10^9 cells/ml by the next day. Instead of having students work with bacteria and antibiotics, show them images that you can find online or in text materials.

Promote critical thinking by giving students the generation times of common pathogens and asking them to hypothesize how the difference in times might affect population shifts (Table 4). Or share with students data on observation of antibiotic resistance (Table 5). Have students research common ailments each antibiotic was used for and hypothesize why resistance was relatively quick or slow to evolve.

As an alternative, students can work with microbes that can live under extreme hypersaline conditions (Schneegurt, Wedel, and Pokorski 2004). The high salt content of the media eliminates the need for sterilization and aseptic techniques, and rules out the possibility of culturing bacterial pathogens. Staphylococcus

Medium for Halotolerant Bacteria

Mix and boil the following ingredients until the agar or gelatin dissolves:

- 50 g (5 tsp) iodine-free table salt (NaCl)
- 1.25 g ($\frac{1}{8}$ tsp) salt substitute
- 0.5 g ($\frac{1}{8}$ tsp) all-purpose plant food
- 5 g ($\frac{3}{4}$ tsp) unsulphured molasses
- 3.75 g (1 $\frac{1}{2}$ tsp) agar-agar or 33.6 g (12 tsp) gelatin
- 180 ml ($\frac{3}{4}$ cup) tap water

After cooling the mixture to about 45°C (baby-bottle temperature), add the following:

- 50 ml (10 tsp) of milk solution—2.5 g (1$\frac{1}{2}$ tsp) instant nonfat dry milk in 50 ml (10 tsp) tap water
- 20 ml (4 tsp) vitamin solution—dissolve 1 multivitamin tablet in 50 ml (10 tsp) tap water with low heat (<45°C) and decant or filter
- 1.5 ml (5 drops) antifungal preparation (1% clotrimazole solution)

is relatively halotolerant, but it does not grow above 15% (w/v) salinity. High-salt concentrations of 25% or more, and the addition of magnesium (as magnesium sulfate in Epsom salts to 1%), will often enrich for haloarchaea—brightly colored red or pink organisms that depend on high-salt concentrations for growth. Therefore, salt concentrations of 20% to 25% (w/v) should be used in this activity. "Salty Microbiology" in the September 2004 issue of *The Science Teacher* provides a good source of background information on where to find halotolerant species, as well as the medium recipe of approximately 250 ml (1 cup) provide in the sidebar.

Table 4. Pathogenic Bacteria Generation Times

Pathogen	Condition	Generation time
Escherichia coli O157:H7	diarrhea	20 minutes
Staphylococcus aureus	infections	30 minutes
Mycobacterium tuberculosis	tuberculosis	870 minutes
Treponema pallidum	syphilis	1980 minutes

Table 5. Resistance to Antibiotics

Antibiotic	Year first used	Year resistance observed
Penicillin	1943	1946
Streptomycin	1943	1959
Tetracycline	1948	1953
Erythromycin	1952	1988
Methicillin	1960	1961
Ampicillin	1961	1973

Make an analogy between how the extreme environment selects for individuals that can tolerate a higher salt concentration than the rest of the population and those that are no longer affected by antibiotics (Schneegurt, Wedel, and Pokorski 2004).

You might also have students conduct internet research to find out about the activities and education efforts of various government and health agencies. As an example of the varied resources available, see the video program developed by the National Institutes of Health that gives a practical application to evolutionary processes in bacteria at *http://science.education.nih.gov/supplements/nih1/diseases/default.htm*.

Evaluate

To demonstrate their understanding of the causes and concerns of antibiotic resistance, have students develop a public service campaign to educate consumers about overuse and misuse of antibiotics and antibacterial soaps. They might develop press releases, posters, cartoons, computer presentations, or videos. Their campaigns should be informative but might also include humor or elements of art. Have students choose an audience such as elementary students, high school graduates, or the elderly as the target of their messages about evolution in bacteria and health concerns about antibacterial resistance. As a reminder, you can assess student campaigns with the tools listed earlier in the cladogram activity (p. 24).

Using Ring Species to Demonstrate Human Evolution

Engage

Elicit from students a definition of species and have them relate how speciation can occur through geographic isolation. Prompt them to discuss populations that become separated by a physical barrier or a range so big that populations become isolated in certain portions of it. Remind students that groups of organisms become separate species as characteristics determined by and mutations within their genetic makeup promote survival in their environment.

SCILINKS® THE WORLD'S A CLICK AWAY

Topic: Human evolution

Go to: *www.SciLinks.org*

Code: ETK009

Explore

Introduce the concept of a ring species, or one that occurs when a single species becomes geographically distributed in a doughnutlike pattern over a large area. This is a phenomenon in which variety of a species gradually change around a physical barrier. The species form a ring such that the two ends of the loop are different enough to be reproductively isolated even though elsewhere in the loop adjacent populations do interbreed. Two well-studied examples are salamanders in the *Ensatina eschscholtzii* group, distributed in mountains along the west coast of North America, and greenish warblers *(Phylloscopus trochiloides)*, small, insect-eating songbirds in the forests of Central and Northern Asia and Eastern Europe.

Demonstrate a ring species distribution by having the class form a ring around a row of desks. The row of desks represents a mountain range for the salamanders and a desert for the warblers. Give each student one of a series of paint chips that gradually vary in hue from one color to another distinct color. Use color families that differ from human skin tones, such as greens and blues. Make an analogy between the gradual change in the colors of the paint chips and the gradual changes in the populations that led to two different species. Scientists hypothesize that the species (color) near the center of the range (series of colors) is the founder or ancestral species to both "ends."

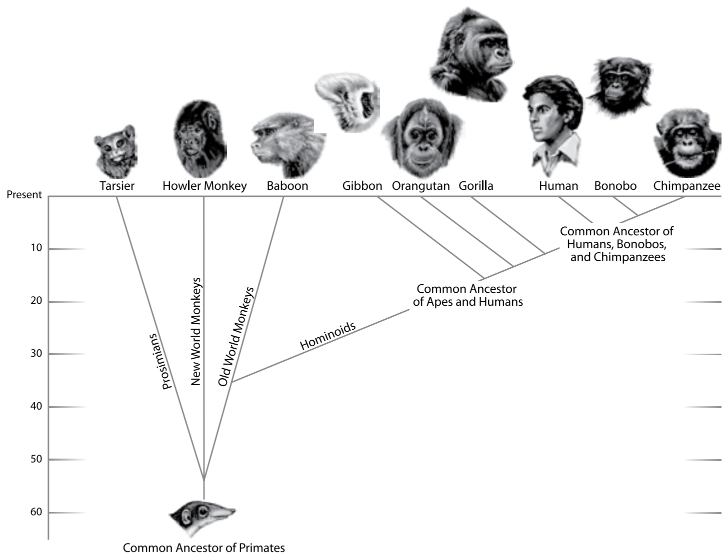
Explain

Show students Figure 7 (p. 32)—the cladogram showing the relationship among humans and different species of apes. Point out to students how the cladogram shows that these separate species did not evolve from one into the other, but from separation of populations of a common ancestor. Adapt the ring species demonstration to show the relationship of humans and chimpanzees and to emphasize that humans did not "descend" from apes but rather from a common ancestor.

Have the class form a ring again, with the same color paint chips used in the previous activity. Describe for students how this ring is not formed in "space" (around a mountain range or desert) but in "time" (over millions of years). Then have students move from a loop to a "V" shape. Students should compare this new shape to the cladogram in Figure 7 and draw the conclusion that the apex of the "V" is the closest common ancestor and the distance along each branch of the student "V" represents time.

Help students understand that gradual variations over time along both halves of the loop constitute evolution along the routes to human and chimpanzees. In this case, the intermediates have gone extinct and the ring is discontinuous in the present. However, as the intermediate forms of salamanders are present in the "space" example, over time, intermediate forms of humans and chimpanzees existed.

Figure 7. Primate Evolutionary Tree



Source: Biological Sciences Curriculum Study (BSCS). 2005. *The nature of science and the study of biological evolution.* Colorado Springs, CO: BSCS. © 2005 by BSCS. All rights reserved. Reprinted with permission.

Elaborate

Have students compare phenotypes of humans and chimpanzees with baboons, with which they share a much earlier common ancestor, to discern both common and differing structures and behaviors. This task will give students a feel for how many similarities exist between humans and chimpanzees.

Students should then apply their knowledge of DNA to understand the molecular basis for those similarities. Tell students that Svante Pääbo, the director of the Max Planck Institute for Evolutionary Anthropology in Germany, was the first to extract DNA from fossil humans and compare it with living humans and chimpanzees. From this data he estimates that humans and Neanderthals had a common ancestor one half million years ago. Pääbo and his colleague, Henrik Kaessmann, then traced the ancestry of humans and chimps to find out when they shared a common ancestor by using a segment of human DNA about 10,000 nucleotides long from the X chromosome. By counting, they discovered that humans and chimps aver-

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Code: ETK006

aged only about 100 differences out of 10,000 nucleotides on that length of DNA—a difference of about 1%. The scientists concluded from this data that the common ancestor of humans and chimps existed in Africa about five to six million years ago. Use the activities on pages 34 through 39, from *Virus and the Whale: Exploring Evolution in Creatures Small and Large* (Diamond 2006), to show what DNA comparisons can tell us about evolutionary relationships.

Evaluate

To evaluate student understanding of DNA, ask them to write a short news story about humans and chimpanzees as an "assignment" for their local newspaper. In their articles, students should tell their readers about how new DNA studies of humans and chimpanzees suggest they are close relatives. As a reminder, you can assess student writing using the tools listed earlier in the cladogram activity (p. 24).

Q: ***I cannot accept the fact that I am descended from an ape; therefore, I do not support the theory of evolution.***

A: Evidence does not support the assertion that humans evolved from an ape. Evidence does, however, indicate that modern apes and humans are closely related and are descendents of a common ancestor.

It's Molecular Time

DNA is no ordinary stuff. DNA carries the recipe for assembling proteins into living organisms. This long molecule also acts like a clock, helping scientists estimate how long two species have been separated from a common ancestor. When DNA makes a copy of itself, it isn't always perfect. Mistakes can happen. One nucleotide (Adenine, Thymine, Cytosine, or Guanine) might be missing, duplicated, or two nucleotides might switch positions. Scientists like Svante Pääbo have discovered that these mistakes (mutations) accumulate at a regular rate over millions of years, like the steady tick of a clock. Scientists can use this knowledge to date different copies or generations of DNA. This is what scientists call the "molecular clock."

See if you can tell time using the molecular clock method. First, compare copies of tiny segments of DNA for differences (mutations) in the nucleotides. Then use the mutation rate to date the copies.

Work With a Partner

Each team will need:

- Generations of Copies sheet
- scissors

1. Down to DNA

a. Below is a short segment of DNA that is nine nucleotides long. The first line of nucleotides is from a living organism. The second line is from a close ancestor. Underline the nucleotide in the ancestor DNA line that is different from the living DNA. This difference in the DNA code is a mutation site.

LIVING DNA

A	C	A	T	A	T	T	A	C

ANCESTOR DNA

A	T	A	T	A	T	T	A	C

Pages 34 through 39 from Diamond, J., ed. 2006. *Virus and the whale: Exploring evolution in creatures small and large.* Arlington, VA: NSTA Press.

The letters represent nucleotides:

A = Adenine

T = Thymine

C = Cytosine

G = Guanine

2. Sorting Out Sequences

a. Cut out all the sequences of DNA from the Generations of Copies sheet.

b. You have a nine-nucleotide sequence from a section of DNA similar to what you might find from a living human. Look for the sequence with the label living DNA.

c. Now find the closest ancestor. It is the sequence that differs by only one nucleotide. The remaining sequences you have cut out are each older ancestors. Each older ancestor has more mutations or differences.

d. Sort the sequences in order from the living human (the present) to the oldest ancestor (longer and longer ago).

3. Consider This

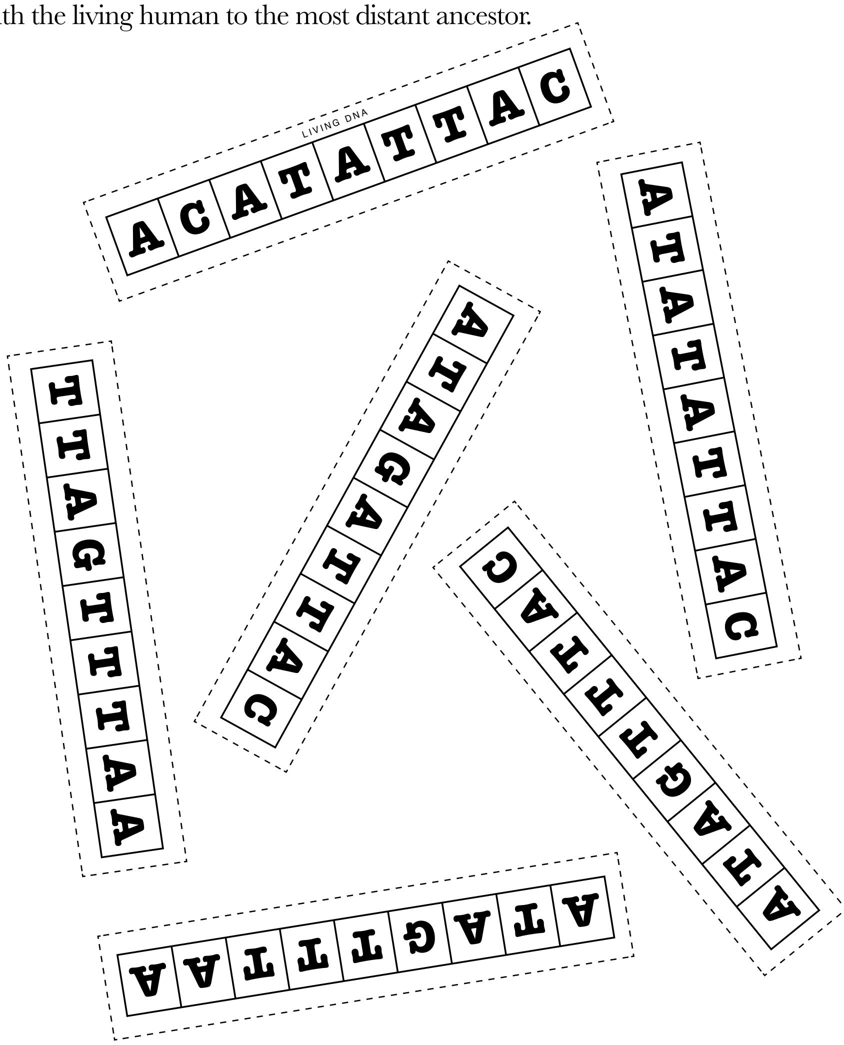
Now make the DNA tell time. Assume that the rate of mutation in this DNA segment is one difference for every 10,000 years.

a. Based on the rate of mutation, how many years different are the oldest and the newest DNA segments?

b. How long ago did the oldest ancestor live?

Generations of Copies

Below is a sequence of nucleotides from DNA that is similar to what you might find from a living human (Living DNA). The rest are sequences from five different ancestors. Cut out the sequences and sort the sequences starting with the living human to the most distant ancestor.



Mutations Up Close

Scientists like Pääbo line up the DNA sequences of different species. They compare the nucleotides A, T, C, G, letter for letter, and count the differences. The differences are the number of mutations in the DNA code that have accumulated over time. The more differences that accumulate between species, the longer the species have been evolving separately.

The genetic code of humans and chimps is billions of letters long. Working out a method for comparing DNA sequences between the two species is one of the problems that genetic scientists must solve. Today this is your challenge too. Only about 1% of the DNA in the chimp and human genes is different. Can you pinpoint the differences?

Work With a Partner

Each team will need:

- Chimp vs. Human DNA Sequences sheets, parts 1 and 2 (taped together)
- scissors

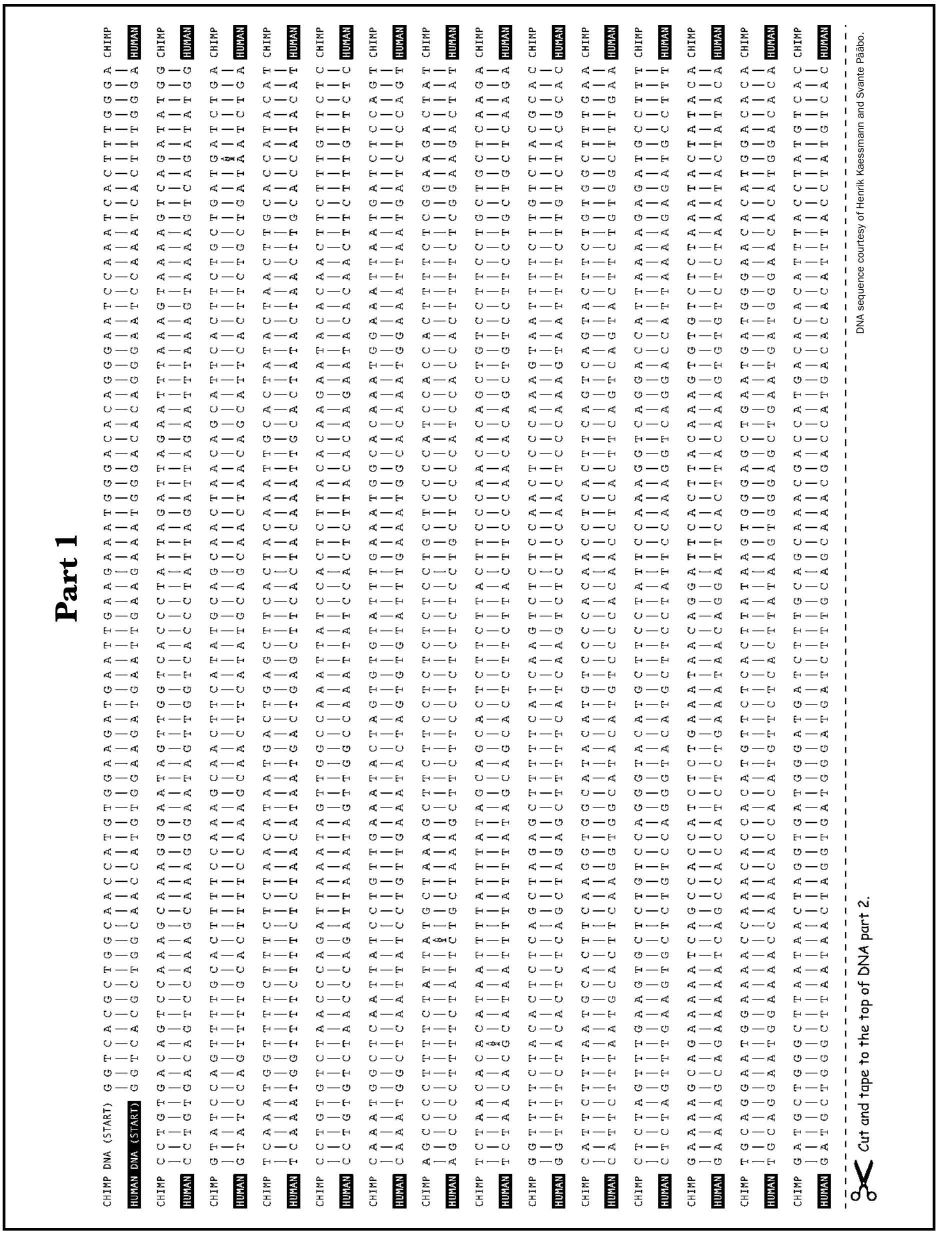
1. Comparing DNA

a. Compare the Chimp vs. Human DNA Sequences. The sequences are located on the X chromosome, and they are called Xq13.3. These are the small sections of the DNA that Svante Pääbo and his group use to make chimp/human comparisons. Look for any differences (mutations) between the chimp and human sequences.

b. How to read the chart:

- In the chart you will find the same stretch of DNA (about 2,700 nucleotides long) for a chimpanzee (top) and a human (bottom).
- The vertical lines show where the DNA is the same for chimps and humans.
- A tiny Pääbo figure shows where there's a difference in the chimp and human DNA.

c. How many Pääbos can you find?


Part 1
CHIMP DNA (START)
HUMAN DNA (START)
Cut and tape to the top of DNA part 2.
DNA sequence courtesy of Henrik Kaessmann and Svante Pääbo.

Part 2

Line up the columns of nucleotides on DNA part 1 with DNA part 2. Then tape the bottom of DNA part 1 to this line.

CHIMP T T A T G T A G G A A G A C C A A C A G T T G A G G T T T G C C T G T G A C T G A G G G T T T T T T G G G A C A T A G T A T T T T C A G T G C T A A A CHIMP

HUMAN G T A T G T A G G A A G A C C A A C A G T T G A G G T T T G C C T G T G A C T G A G G G T T T T T T G G G A C A T A G T A T T T T C A G T G C T A A A HUMAN

CHIMP A A T T G A G C A A T T T T G A A G A C T G C T T G A G G A G T C A A A G A T G A T T T C A T T T A T A A A A C A T G A A A T G T T A T A A A A A A G CHIMP

HUMAN A A T T G A G C A A T T T T G A A G A C T G C T T G A G G A G T C A A A G A T G A T T T C A T T T A T A A A A C A T G A A A T G A T A T A A A A A A G HUMAN

CHIMP A T C C A T T A A C C T A T T T C T T A T T C C A A T A T T T T T C A A T T T T G T A C T A T C T G C C A A C C C T C A T C A A T T C C T A A C T C T CHIMP

HUMAN A T C C A T T A A C C T A T T T C T T A T T C C A G T A T T T T T C A A T T T T G T A C T A T C T G C C A A C C C T C A T C A A T T C C T A A C T C T HUMAN

CHIMP T T C C A G A A A C C T T C A A T A T C T A A A T G C T T C C A T T T C T C C T A G T C T C A C A T A G C A T C C T C C C T C A T C T T A T T T C C T CHIMP

HUMAN T T C C A G A A A C C T T C A A T A T C T A A A T G C T T C C A T T T C T C C T A G T C T C A C A T A G C A T C C T C C C T C A T C T T A T T T C C T HUMAN

CHIMP C A T T C T C C T G C T G C A C C A G C C T G G C A A G G C C C T A A T C G C A G G T T A A G T C C A C A A C A G G T T T T C T T T C T T A C T A T C CHIMP

HUMAN C A T T C T C C T G C T A C A C C A G C C T G G C A A G G C C C T A A T C G C A G G T T A A G T C C A C A A C A G G T T T T C T T T C T T A C T A T C HUMAN

CHIMP C T A A A A T T A T T T T C C T C T A C C C T C T T T T T A C A T G A A C C T G A T T A G T A T C T T C T C C T A T T C C C A T G G T G G C T A A T C CHIMP

HUMAN C T A A A A T T A T T T T C C T C T A C C C T C T T T T T G C A T G A A C C T G A T T A G T A T C T T C T C C T A T T C C C A T G G T G G C T A A T C HUMAN

CHIMP T T G T T T T A G C C C T C A G C T C A A A G A G T A A A T T G A G A T T A T T A G G T G A G A A G A A A T C A A C T T C A T C T A C T G T C C T T T CHIMP

HUMAN T T G T T T T A G C C C T C A G C T C A A A G A G T A A A T T G A G A T T A T T A G G T G A G A A G A A A T C A A C T T C A T C T A T T G T C C T T T HUMAN

CHIMP T G A A T T A T C A C A C T C T T C T A A C C T C C C T C A G G T T T C T C T T T C A T T G A T T G T T C C C T T T C A C T C C T A G A A A A T C A T CHIMP

HUMAN T G A A T T A T C A C A C T C T T C T A A C C T C C C T C A G G A T T C T C T T T C A T T G A T T G T T C C C T T T C A C T C C T A G A A A A T C A T HUMAN

CHIMP C T T A T T C T A G C T C T T T G T T G C C T T C C T G C C C T T C T C T C C A T A G T T G T T T A C A C C A G C T T T T C C T C A C T T T A T A T C CHIMP

HUMAN C T T A T T C T A G C T C T T T G T T G C C T T C C T G C C C T T C T C T C C A T A G T T G T T T A C A C C A G C T T T T C C T C A C T T T A T A T C HUMAN

CHIMP T T A C C C A G A A A G A G G T G A G A A T A G A A T T C C C A G T G C C T C C A A T G C C A G C C T T A C A G A A G T A A T T A C T C T T G G T A C CHIMP

HUMAN T T A C C C A G A A A G A G G T G A G A A T A G A A T T C C C A G T G C C T C C A A T G C C A G C C T T A C A G A A G T A A T T A C T C T T G G T A C HUMAN

CHIMP T C A C T T G A A A G A A G G G T A T G T T G G T G A G T G C C A A A T C C T G A A G G G A A T G A C C A G C A T A G A G T T T T A A C C T A A T A A CHIMP

HUMAN T C A C T T G A A A G A A G G G T A T G T T G G T G A G T G C C A A A T C C T G A A G G G A A T G A C C A G C A T A G A G T T T T A A C C T A A T A A HUMAN

CHIMP G C C A T A A A A A G A A T G A G A T C A T T T C C T T T G C A G G G A C A T G G A T G G A G T T G G A A G C C A T T A T C C T T A G C A A T C T A A CHIMP

HUMAN G C C A T A A A A A G A A T G A G A T C A T T T C C T T T G C A G G G A C A T G G A T G G A G T T G G A A G C C A T T A T C C T T A G C A A T C T A A HUMAN

CHIMP T G G T G A G A A A C A A G A A A C A T T G G A G T C T G T T G G G A G C T G T T G G G T G A G A G A G A G C A T C A G G A A G A A T A G C T A A T G CHIMP

HUMAN T G G T G A G A A A C A A G A A A C A T T G G A G T C T G T T G G G A G C T G T T G G G T G A G A G A G A G C A T C A G G A A G A A T A G C T A A T G HUMAN

CHIMP A A C C C T G C A C A T C C T G C A C A T G T A C C C C T A A A C T T A A A A T A A A A G T T G A A G A A A A T A T G G CHIMP DNA (END)

HUMAN A A C C C T G C A C A T C C T G C A C A T G T A C C C C T A A A C T T A A A A T A A A A G T T G A A G A A A A T A T G G HUMAN DNA (END)

DNA sequence courtesy of Henrik Kaessmann and Svante Pääbo.

More Resources

Internet

Staying up-to-date on topics such as evolution is a lot easier with the internet, but sometimes there is too much of a good thing. If you Google the word *evolution,* for example, you get more than 170,000,000 hits.

To narrow down the list with reliable, vetted sources, log into NSTA's SciLinks (*www.scilinks.org*) and use the codes provided throughout this book. In addition, here are a few favorite evolution websites from the SciLinks search team:

- Understanding Evolution *(http://evolution.berkeley.edu/evolibrary/home.php)* is a comprehensive site from the University of California Museum of Paleontology. The information provided on the site could be the basis for a complete course, study group, or self-study project on evolution. The teacher link in the right margin is a tremendous resource that directs readers to a searchable database of lesson ideas and to a link called "conceptual framework," which provides essential questions to help you organize a unit on evolution. You might start by clicking on the Evolution 101 *(http://evolution.berkeley.edu/evolibrary/article/evo_01)* link for a tutorial on evolution that would be appropriate for students as well.
- Evolution *(www.pbs.org/wgbh/evolution)* from PBS is another good source. Even if you don't have access to the video, the web-based resources are very good and visually stunning.
- NSTA has compiled a set of internet resources pertaining to evolution *(www.nsta.org/publications/evolution.aspx)*. NSTA provides a comprehensive list of links to the above websites, position papers on evolution, and additional resources and articles.
- Have you read any of Darwin's writings? Darwin's *On The Origin of Species* (*www.literature.org/authors/darwin-charles/the-origin-of-species*) is not an easy read, but it is the primary source for evolution. The website has links to his other works as well.
- In case the Galápagos Islands are not on your future travel itinerary, *Galápagos Education* (*www.nsta.org/publications/interactive/galapagos*) on the NSTA website is a great collection of background information, classroom investigations, and resources for teaching evolution.

- Teach Evolution and Make it Relevant (*www.evoled.org/default.htm*) pulls together resources from several websites into teaching units that may give you ideas on how to organize your instruction.
- Evolution and the Nature of Science Institutes (ENSI) (*www.indiana.edu/~ensiweb*), began in 1987 with the goal of improving the teaching of evolution in high school biology courses. ENSI encourages teachers to teach evolutionary thinking in the context of a more complete understanding of modern scientific thinking, with quality evolution instruction resources over the internet.
- *The TalkOrigins Archive* (*www.talkorigins.org*) is a collection of articles and essays that provide mainstream scientific responses to questions regarding the evolution/creation controversy, the origin of life, geology, biology, catastrophism, cosmology, and theology.

Books

For a broader look at topics in the evolution/creation controversy, consider curling up with one of the following books:

About the debate

- Alters, B. J., and S. M. Alters. 2001. *Defending evolution in the classroom: A guide to the creation/evolution controversy.* Sudbury, MA: Jones and Bartlett.
- Bybee, R. W. 2004. *Evolution in Perspective. The Science Teacher's Compendium.* Arlington, VA: NSTA Press.
- National Academy of Sciences and Institute of Medicine. 2008. *Science, evolution, and creationism.* Washington, DC: The National Academies Press.
- Scott, E. C. 2005. *Evolution vs. creationism: An introduction.* Berkeley: University of California Press.

About the science

- Carroll, S. B. 2005. *Endless forms most beautiful: The new science of evo devo and the making of the animal kingdom*. New York: Norton.
- Palumbi, S. R. 2001. *The evolution explosion: How humans cause rapid evolutionary change*. New York: Norton.

About science and faith

- Collins, F. S. 2007. *The language of God: A scientist presents evidence for belief*. Waterville, ME: Wheeler.
- Miller, K. R. 1999. *Finding Darwin's God: A scientist's search for common ground between God and evolution*. New York: Cliff Street Books.

About classroom support

- BSCS. 2005. *The nature of science and the study of biological evolution*. Colorado Springs, CO: BSCS
- Diamond, J., et. al. 2006. *Virus and the whale: Exploring evolution in creatures small and large.* Arlington, VA: NSTA Press.
- Skehan, J. W., and C. Nelson. 2000. *The creation controversy and the science classroom*. Arlington, VA: NSTA Press.

Journals

NSTA journals also offer a number of relevant and insightful articles focusing on the topic of evolution. These articles are available online at *www.nsta.org/store.*

Science Scope

- Sandro, L., J. M. Constible, and R. E. Lee, Jr. 2007. Extreme arthropods. *Science Scope* 30(9): 24–32.

The Science Teacher

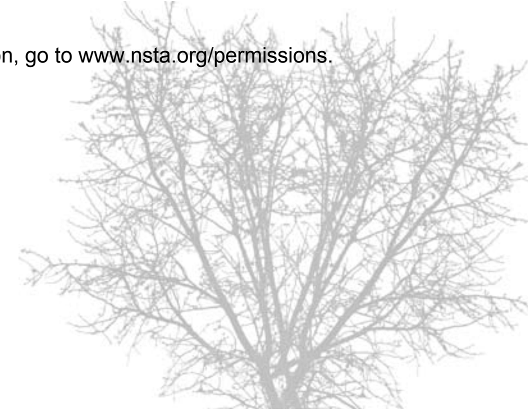
- Hess, L. 2006. Speak up! *The Science Teacher* 73(8): 10.
- Moore, M. 2004. State standards and evolution. *The Science Teacher* 71(6): 41–44.
- Parrott, A. N. 2005. From DNA to disorder. *The Science Teacher* 72(5): 34–39.
- Scalice, D., and K. Wilmoth. 2004. Astrobiology. *The Science Teacher* 71(10): 34–36.
- Scotchmoor, J., and A. Janulaw. 2005. Understanding evolution. *The Science Teacher* 72(9): 26–28.
- Schneegurt, M. A., A. N. Wedel, and E. W. Pokorski. 2004. Salty

microbiology. *The Science Teacher* 71(7): 40–43.
- Tieman, D., and G. Haxer. 2007. The discovery of *jelly bellicus. The Science Teacher* 74(2): 30–35.
- Walsh, J. 2007. Ring species through space and time—A class demo. *The Science Teacher* 74(9): 62–64.

Journal of College Science Teaching

- Benson, K. E. 2004. My brother's keeper: A case study in evolutionary biology and animal behavior. *Journal of College Science Teaching*. 34(2): 40–45.
- Gregg, T. 2007. Intelligent design: Jonathan Wells and the tree of life. *Journal of College Science Teaching* 36(6): 10–11.

Chapter 2



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