Teaching Evolution Resource Kit

Produced for the workshop
"TEACHING EVOLUTION AT RUTGERS"
8 Feb 2006

by

Lena Struwe
Chi-hua Chiu
Karl Kjer
Rebecca Jordan
Jody Hey
Peter Smouse

CONTENTS:

Evolution is the central theory of life and an understanding of evolutionary process and evidence is necessary for considering, not only the history of living things, but also many modern questions. Increasingly evolutionary understanding is required for appreciating basic questions in fields traditionally apart from basic biology and anthropology. For example, major areas of psychology, philosophy, computer sciences, and other fields now require a solid grounding in evolutionary thinking. The information contained in this packet is intended to aid Rutgers University faculty incorporating essential evolutionary themes into their courses.

Available on-line at http://evolru.rutgers.edu/EvolResources.html

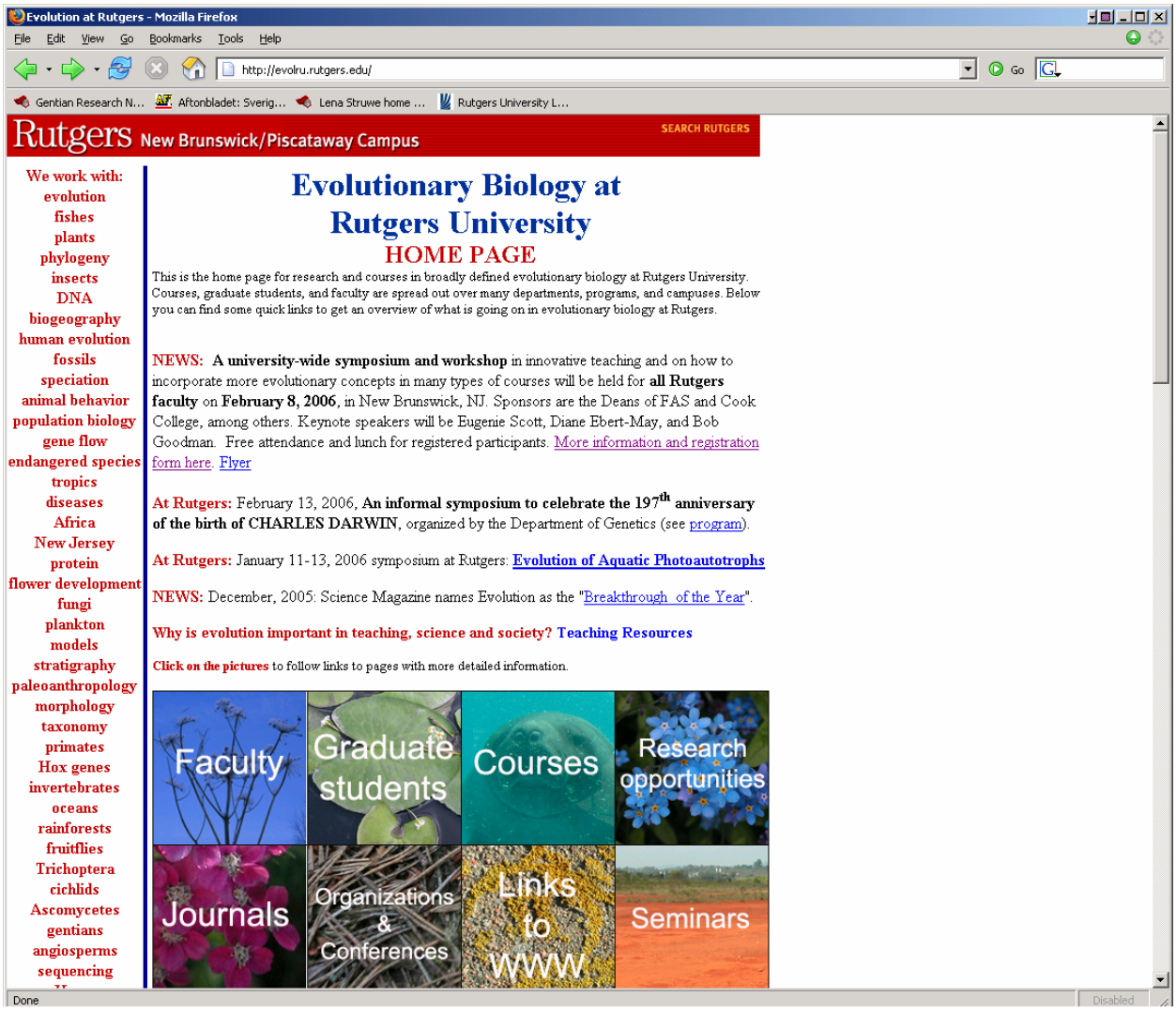
We welcome additions and corrections to this toolkit, and will keep an updated version of it on the web for public access. E-mail changes and new material to Lena Struwe (struwe@aesop.rutgers.edu).

THE STATE UNIVERSITY OF NEW JERSEY
RUTGERS

Evolutionary Biology at Rutgers University

Visit our home page
http://evolru.rutgers.edu

On this site, updated information is listed about:
Faculty
Graduate Students
Courses (both graduate and undergraduate)
Upcoming and recent events
Seminars
Research Opportunities
Journals
Undergraduate Programs
Graduate Programs
Teaching Resources
etc.



COMMON MISCONCEPTIONS OF EVOLUTION

- Evolution is "only a theory"
  - A common public perception is that a theory is characterized by tentative or unsubstantiated ideas. It is important to recognize that 'evolution' in a narrow sense simply means that life has changed over time, and this is taken as fact by most scientists. If by the 'theory of evolution', one is focusing on issues like common descent and natural selection , then the field does have active areas of scientific debate.

- Evolution is a "change in traits" and "speciation and evolution are the same thing"
  - The change that occurs during evolution is not literally a change of one kind of organism into another. Rather it is the accumulation of change in the proportion of traits that are present in a population. Understanding this will move students away from the commonly held notion that evolution acts on species, rather than individuals.. In addition it is important to recognize that evolution need not imply speciation.

- "Humans descended from monkeys"
  - Statements like these reflect a lack of understanding about common ancestry and phylogeny; discussions about macroevolution and phylogenetic inference can aid in clarifying notions of common descent. Humans did evolve from apelike ancestors, and we share these ancestors with chimpanzees.

Mechanisms of evolution (a few notable examples):

- Natural selection acts "for the good of the species"
  - Adaptation mostly results from selection on genes and on organisms - Selection on species also occurs, and it is often debated how much this can lead to complex adaptations. It is also important for individuals to recognize that adaptations do not arise because organisms "needed them" and that adaptations are not strictly a product of chance, but rather are the result of chance mutations and deterministic forces of natural selection.

- Natural selection acts randomly and is the sole driving force of evolution. Sometimes conceived as the environment alone produces changes.
  - These ideas reflect a lack of understanding of the genetic variation integral to natural selection or the processes by which populations can change in the absence of natural selection. In addition, natural selection is not random but a process by which variation in form is sorted out according to reproductive/survival success in that particular environment.
    In addition, there is a tendency to suggest that environmental change alone causes organismal change; lacking an understanding that the environment affects reproduction/survival after the traits arise within a population.

- Natural selection and evolution began after the first organisms, or cells, arose.
  - The predominant theory is that cells and organisms evolved by natural selection from some kind of early replicator or gene

- Natural selection and evolution leads directly to more advanced organisms.
  - Over long periods of time, evolution has lead to more complex organisms. But evolution often leads to less complex forms – e.g. parasites are usually less complex than their ancestors

Recommended scholarly articles on misconceptions about and the teaching of evolution:

Alters, B.J., & C.E. Nelson, "Perspective: Teaching evolution in higher education", Evolution 56: 1891-1901.

Wilson, D.S., "Evolution for everyone: How to increase acceptance of, interest in, and knowledge about Evolution", PLoS Biology 3: 2058-2065.

R. Firenze's works as regular contributions to the Reports of the National Center for Science Education. To learn more, go to: http://www.natcenscied.org/newsletter.asp .

Accessible, informative, apparently mostly accurate, web-based resources on evolution:

The TalkOrigins Archive The central clearing-house for web-based articles on creationism and evolution. This site offers specific commentary about the current controversy, and is a good site to direct those who wish to explore the scientific response to creationism as science, and the "inconsistencies" of evolutionary theory. Most discussions in the newsgroup center on the creation/evolution controversy, but other topics of discussion include the origin of life, geology, biology, catastrophism, cosmology and theology. (http://www.talkorigins.org/)

EvoWikki This URL takes you to an interactive directory of a cross-referenced encyclopedia. Similar to "TalkOrigins" (above), it confronts creationist inconsistencies. (http://www.evowiki.org/index.php/Main_Page)

Understanding Evolution - UC Berkeley An excellent accessible site with an online course, examples, and materials for K-12 Educators. This is "Evolution 101", and will help you and your students bone up on the foundations of evolution theory, its relevance, and history. Includes projects, evolution in the news, and presents the evidence for evolution. (http://evolution.berkeley.edu/)

Also at UC Berkeley is a "Phylogenetics Resources" page with quick links to Societies, Publications, and databases. Particularly extensive is the "software link" where virtually every program imaginable is made available. (http://www.ucmp.berkeley.edu/subway/phylogen.html)

AAAS (American Association for the Advancement of Science): Evolution Resources This site has some nice pages on current issues and perspectives, including essays, state standards, and classic texts. (www.aaas.org/spp/dser/evolution/index.shtml)

AIBS: Evolution This site opens with a directory on "issues in evolution", including essays on evolution theory, new discoveries about species, the fossil record, evolution in action, human evolution and religious beliefs. (http://www.actionbioscience.org/evolution/index.html)

Arizona State University, Institute for Human Origins: Becoming Human [broadband multimedia site, Flash software needed] This site includes a documentary on human origins. There are lesson plans and multimedia exercises, and also a dictionary of terms. (http://www.becominghuman.org)

EvoNet.org A Worldwide Network for Evolutionary Biologists. Search through lists of all the people doing evolutionary research in New Jersey, for example, or find expertise on caddisflies. Has a site on education, including curricula (http://evonet.sdsc.edu/)

Wisconsin Center for Educational Research (Natural Selection modeling) Lesson plans, learning outcomes, and roadblocks to understanding natural selection. (http://www.wcer.wisc.edu/ncisla/muse/naturalselection/index.html)

The National Center for Science Education - A valuable resource for teachers, students, and citizens, with a Teachers Resources page and Links page to many useful websites. Links include sites on the Burgess Shale Fossils, Harvard's evolution site, the Miocene Mammal Mapping Project, Introduction to Ichnology, The e-Skeletons Project, the Paleontology Portal, The complete work of Charles Darwin online, and many museum websites. (http://www.natcenscied.org)

PBS Evolution website An exceptional television documentary covering evolution and controversies. (http://www.pbs.org/wgbh/evolution/darwin/index.html)

NTSA (National Science Teachers Association): Evolution Resources This site includes the NTSA position statement on teaching evolution, and a Q&A section. (www.nsta.org, http://www.nsta.org/evresources)

Areas of Controversy and Debate

Topics of frequent scientific debate

- How do species form? Is complete separation of populations required before the evolution of reproductive isolation? Or not?
- How did life arise?
- What is the best theory for the evolution of ageing (senescence)?
- What is the best way to identify species (or define "species")?
- How and why do eukaryote genomes have introns? Did they arise early in the origin of longer genes, or later?
- How did eukaryotes (organisms with cells with the DNA in a nucleus) evolve?
- Why did sex and recombination evolve?
- What features of large genomes are the result of natural selection, and what are the results of genomic parasites and chance factors?
- What is the true structure of the evolutionary tree of life? (e.g. which major groups of animals are each others closest relatives?).
- Are major evolutionary advances (adaptations) taken in big steps, or lots of little ones? Does evolution take big jumps?

Note these areas of debate are distinct from areas of public debate.

Common areas of public debate on the role of evolution

- Nature versus Nurture Debates
  - What human behaviors have evolved?
  - Questions on validity or viability of 'Evolutionary Psychology'.
  - Which of the apparent differences observed between men and women are the result of natural selection?
  - Did language evolve, or is it the byproduct of a larger brain (Chomsky vs. Pinker).
- Debates on Origins
  - Does the theory of evolution leave a role for God, and if so where?

The Evolutionary Origins of Complex Traits - How does 'design' evolve?

One of the frequent gaps in evolutionary education is on the evolution of complex aspects of organisms. How did ribosomes or human language evolve? How did eyeballs, or rotating flagella evolve?

Many biologists teach about complex features of organisms or cells but do not delve into how those things might have evolved.

Some resources on the evolution of things that seem to have been 'designed':

WWW: **The evolution of irreducibly complex systems** by Don Lindsay (http://www.don-lindsay-archive.org/creation/evolve_irreducible.html)

WWW: **"A reducibly complex mousetrap"** by John Mcdonald (http://udel.edu/~mcdonald/mousetrap.html)

WWW: **"Behe and the Blood Clotting Cascade"** by George Acton (http://www.talkorigins.org/origins/postmonth/feb97.html)

WWW: **"The Flagellum Unspun"** by Kenneth Miller (http://www.millerandlevine.com/km/evol/design2/article.html)

Addressing Creationist/ Intelligent Design Controversies

Some thoughts from university professors:
"I have also started emphasizing the controversy. Students, especially nonmajors, have a sense that it is unfair to dismiss the creationist/ID claims without discussion. I agree. I point students to creationist/ID literature (e.g., M. Behe, W. Dembski, J. Wells, P. Johnson) and to works written by evolutionary biologists for the general public (e.g., M. Pigliucci, K. Miller). Contrasting the two sets of literature is a great way to reinforce earlier lectures and activities about the philosophical underpinnings and methods of science. It's also a great way for the students to figure out for themselves what is bogus, what is real, and what the limits are to what we currently know. I can't think of a better way to expose the creationist/ID pseudoscience for what it is. Some are dismissive. Some come in confused and stay confused. Many begin to "get it."
Greg Adkinson, Western Carolina University, gadkison@wcu.edu (quoted with permission)

"I often get an, "oh, I get it now" reaction from students who figure out that evolution is a population-level process and not something that an individual can do. Emphasizing how natural selection, adaptation, and evolution are related and how evolution and speciation are related clears up a whole lot of confusion!! Exposing expressions like "survival of the fittest" and "the strong survive" as misleading sound-bites also gets reactions and seems to help. I am delighted by how open these guys are to evolution once they figure out what the jargon actually means."
Greg Adkinson, Western Carolina University, gadkison@wcu.edu (quoted with permission)

Importance of evolution to society
* Evolution will help solve biological problems for mankind
* social interactions, human behavior
* agriculture, pest control, plant breeding, disease resistance,
* medicine, vaccines, drug-resistance, evolution of diseases
* invasive species, conservation of biodiversity

WWW: **Review of evolution's relevance: UC Berkeley**.
(http://evolution.berkeley.edu/evosite/relevance/index.shtml)

Additional Resources

WWW: **TalkOrigins** Usenet newsgroup devoted to the discussion and debate of biological and physical origins. Most discussions in the newsgroup center on the creation/evolution controversy, but other topics of discussion include the origin of life, geology, biology, catastrophism, cosmology and theology. (www.talkorigins.org)

Booklet: National Academy of Sciences, **Science and Creationism**
(http://www.nap.edu/html/creationism/index.html)

Book: E. Scott, **Evolution vs. Creationism**, University of California Press, 2004.
(http://www.ncseweb.org/evc/)

WWW: M. Behe, Design for Living, New York Times opinion article on Intelligent Design, Feb 7, 2005 (article proposing intelligent design) (http://www.nytimes.com/)

WWW: H. A. Orr, **Devolution: Why intelligent design isn't**, The New Yorker, 30 May 2005.
(http://www.newyorker.com/fact/content/articles/050530fa_fact)

Book: K. Miller's **Finding Darwin's God**: a scientist's search for common ground between God and evolution: Harper Collins Publishers, New York, 1999
(http://www.millerandlevine.com/km/fdg/index.html)

Book: M. Young & T. Edis (eds.), **Why Intelligent Design Fails,** Rutgers University Press
(http://rutgerspress.rutgers.edu/acatalog/____1147.html)

WWW: Astronomy Education Review: "The Challenge of Creationism and Intelligent Design: An Introduction" by A. Fraknoi (The Astronomy Education Review 1(4): 90-94, 2005) [includes great bibliography and list to links, especially about the age of the universe]
(http://aer.noao.edu/AERArticle.php?issue=7&section=4&article=2)

Textbooks and student literature

Evolution textbooks recommended by university faculty for use in undergraduate courses:

Freeman, S. & J. C. Herron, Evolutionary Analysis, 3rd ed., Prentice Hall, 2003.
Futuyma, D. J., Evolution, Sinauer Associates, 2005.
Ridley, M., Evolution. 4th ed., Blackwell Science, 2004.
Smith, J. M., Evolutionary Genetics, 2nd ed., Oxford University Press, 1998.
Stearns, S. & R. Hoekstra, Evolution: an introduction, Oxford University Press, 2005.
Wiley, E.O, D. Siegel-Causey, D.R. Brooks, & V.A. Funk. **The Compleat Cladist.** A work of phylogenetics, available as a pdf. (www.amnh.org/learn/pd/fish_2/pdf/compleat_cladist.pdf)

Consider using popularized texts for your courses:

Burne, D., Get a grip on evolution, Barnes & Noble Books, 2003. [small easy-read book with non-serious layout explaining evolutionary concepts with detail and accuracy]
Dawkins, R., The Ancestor's Tale: A pilgrimage to the dawn of evolution, Mariner Books, 2005.
Dawkins, R., The Blind Watchmaker: Why the Evidence of Evolution Reveals a Universe Without Design, W. W. Norton, 1996.
Dobzhansky, T., 1973, Nothing in biology makes sense except in the light of evolution, American Biology Teacher 35: 125-129.
Gould, S. J., The structure of evolutionary theory, Belknap, 2002.
Mayr, E., What Evolution Is, Basic Books, New York, 2001.

Some thoughts from a university professor:
"The Ancestor's Tale" would make a great text for a basic introduction to evolution. The book goes through the phylogenetic tree of life starting with humans and tells a "tale" about evolutionary biology at each node in the tree, usually relating to the organism that joins. The end result is that he covers most of the basic principles of evolutionary biology without a lot of math and in a clear and entertaining manner. I have thought this would be a good way to introduce freshman majors and non-majors to evolution by assigned readings and discussions of the readings."
Jim Smith, Boise State Univ., jfsmith@boisestate.edu (quoted with permission)

Examples from scientific research

Recent and classic breakthrough discoveries that can be highlighted when teaching evolution

***Agrodiaetus* Butterflies [Rapid Speciation, Reinforcement]**
These butterflies are generally morphologically uniform, but males have major differences in their color patterns on their wings and they have variable chromosome numbers. This study shows that breeding between species will lead to unfit hybrids (reinforcement), thereby keeping species apart. Color differences occur mainly between closely related species that live in the same area.
WWW: Science, **Evolution: Breakthrough of the Year, 2005**.
(http://www.sciencemag.org/cgi/content/full/310/5756/1878)
Article: V. A. Lukhtanov, **"Reinforcement of Pre-Zygotic Isolation and Karyotype Evolution in *Agrodiaetus* Butterflies"**, Nature 436: 385 (2005); Nature, **Editor's Summary**, (http://www.nature.com/nature/journal/v436/n7049/edsumm/e050721-12.html)

Ancient DNA
Article: E. Willerslev, & A. Cooper, "Ancient DNA", Proc Biol Sci 272:3-16 (2005).

Bird flu and influenza evolution
The 1918 flu epidemic killed 20-50 million people worldwide, and in 2005 DNA sequenced from exhumed victims showed that this virus started as a pure avian strain, only occurring in birds. Studies showed how the virus had evolved with only a few mutations to infect humans as well. This increases the concern over the current bird flu threat.
WWW: Science, **Evolution: Breakthrough of the Year, 2005**.
(http://www.sciencemag.org/cgi/content/full/310/5756/1878)
Article: T.M. Tumpey et al., **"Characterization of the Reconstructed 1918 Spanish Influenza Pandemic Virus"**, Science 310: 77 (2005).
(http://www.sciencemag.org/cgi/content/abstract/310/5745/77)
Article: J. Kaiser, **"Resurrected Influenza Virus Yields Secrets of Deadly 1918 Pandemic",** Science 310: 28 (2005). (http://www.sciencemag.org/cgi/content/summary/310/5745/28)
Article: M. Enserink, **"Pandemic Influenza: Global Update"** Science 309: 370 (2005).
(http://www.sciencemag.org/cgi/content/summary/309/5733/370)
Article: D. Normile, **"Genetic Analyses Suggest Bird Flu Virus Is Evolving"** Science 308: 1234 (2005). (http://www.sciencemag.org/cgi/content/summary/308/5726/1234a)

Chromosome evolution
Article: A. Coghlan, **"Chromosome evolution in eukaryotes: a multi-kingdom perspective"**, Trends Genet. 21: 673-682 (2005).
Article: Z. Cheng et al., "**A genome-wide comparison of recent chimpanzee and human segmental duplication"**, Nature 437: 88-93 (2005).

Cichlid fishes [Rapid Speciation in Vertebrates]
Article: Kocher, T.D., **"Adaptive evolution and explosive speciation: The cichlid fish model"**, Nature Reviews Genetics 5: 288-298 (2004).
(http://www.nature.com/nrg/journal/v5/n4/full/nrg1316_fs.html)
Article: Kocher, T.D., **"Evolutionary biology, Ghost of speciation past"**, Nature 435: 29-30 (2005).
(http://www.nature.com/nature/journal/v435/n7038/full/435029a.html)

Co-evolution between different species

Article: C. A. Machado et al., "**The coevolutionary history of the fig-fig wasp mutualism: new insights from neotropical species**", Proc Natl Acad Sci U S A (2005).

Concrete evidence for common ancestry
Allowing students to view scientific evidence for macroevolution can help promote critical thinking skills and will provide insight into the inferential processes used by scientists.
WWW: Theobald, D., **"The scientific case for common descent"**, The Talk.Origins Archive, January 2006.

Ecology, evolution, and biogeography interaction
An excellent review paper arguing for closer interaction between these fields were published by Wiens & Donoghue (2004). The current distribution of species is dependent both on ecological limitations and past evolutionary events. A model is presented that can explain why the tropics have more species based on phylogenetic studies, not necessarily ecological factors.
Article: Wiens, J. J. & M. J. Donoghue, "**Historical biogeography, ecology, and species richness"**, Trends in Ecology and Evolution 19: 639-644 (2004).

Efficacy of selection
Resources on microevolution can help students understand natural selection during real-time scales.
Article*:* **Genetica*:* volume 112-113**. The entire volume dedicated to microevolution, available online.
Article: Hendry, A.P. & M.T. Kinnison, "**An introduction to microevolution**: rate, pattern, process", Genetica 112-113: 1-8, Nov 2001.

European black caps (warbler birds) [sympatric speciation = within-the-same area speciation, temporal segregation]
Two different populations in the same area differ in their migration routes and arrival times to breeding grounds in Germany and Austria, resulting in separation into two, geographically overlapping populations that later might lead to two different species.
WWW: Science, **Evolution: Breakthrough of the Year, 2005**.
(http://www.sciencemag.org/cgi/content/full/310/5756/1878)
Article: S. Bearhop et al., **"Assortative Mating as a Mechanism for Rapid Evolution of a Migratory Divide"** Science 310: 502 (2005) (http://www.sciencemag.org/cgi/content/abstract/310/5747/502)

European corn borers (insects) [sympatric speciation = within-the-same area speciation]
Within the same field, two races of a species of corn borer is dividing into two different populations based on their food plant, one eats corn and the other mugwort and hops. The different races emit different pheromones so they nearly only mate (95%) within their own race.
WWW: Science, **Evolution: Breakthrough of the Year, 2005**.
(http://www.sciencemag.org/cgi/content/full/310/5756/1878)
Article: T. Malausa et al., **"Assortative Mating in Sympatric Host Races of the European Corn Borer"** Science 308: 258 (2005) (http://www.sciencemag.org/cgi/content/abstract/308/5719/258)

EVO-DEVO: birds
Article: A. Abzhanov et al. . "**Bmp4 and morphological variation of beaks in Darwin's finches**", Science 305:1462-1465 (2004).

EVO-DEVO: insect wings
Article: S. D. Weatherbee et al., **"Ultrabithorax function in butterfly wings and the evolution of insect wing patterns"**, Curr Biol. 9:109-115 (1999).

Flower development and evolution – MADS-box genes
One of the most important gene families for flower development are the MADS-box genes, and several studies have highlighted how gene duplication and function has changed over millions of years during the evolution of higher plants. This accounts for important differences in morphology that are linked to other processes such as pollination and speciation.
Article: S. Kim et al., "**Phylogeny and diversification of B-function MADS-box genes in angiosperms: evolutionary and functional implications of a 260-million-year-old duplication**", American Journal of Botany 91: 2101-2118 (2004).

Fruit type evolution of potatoes and tomatoes in Solanaceae
By looking at the evolutionary relationships within the large tomato/tobacco plant family Solanaceae, which also includes eggplant, peppers, and potatoes, S. Knapp showed that berries had arisen several times independently.
Article: S. Knapp, "**Tobacco to tomatoes: a phylogenetic perspective on fruit diversity in the Solanaceae**", J. Exper. Botany 53: 2001-2022 (2002).

Gene-transfer in parasitic plants
The parasite *Rafflesia* has acquired its mitochondrial genome from its host-plant through horizontal gene transfer.
Article: C. Davis & K. J. Wurdack, "**Host-to-Parasite Gene Transfer in Flowering Plants: Phylogenetic Evidence from Malpighiales**", Science 305: 676-678 (2004).

Geology, extinctions, and evolution

Article: A. K. Behrensmeyer**, "Atmosphere. Climate change and human evolution",** Science 311: 476-478 (2006).
Article: P. G. Falkowski et al., "**The rise of oxygen over the past 205 million years and the evolution of large placental mammals",** Science 309: 2202-2204 (2005).
Article: G. H. Miller et al., "**Ecosystem collapse in Pleistocene Australia and a human role in megafaunal extinction",** Science 309:287-290 (2005)

Hawaiian crickets [Rapid Speciation]
Species of Hawaiian crickets are only separated by different male courtship songs. These insects show the highest speciation rate for arthropods, with similar rates to African cichlids (fishes).
WWW: Science, **Evolution: Breakthrough of the Year, 2005**.
(http://www.sciencemag.org/cgi/content/full/310/5756/1878)
Article: T.C. Mendelson & K.L. Shaw, **"Sexual Behaviour: Rapid Speciation in an Arthropod",** Nature 433: 375 (2005). (http://www.nature.com/nature/journal/v433/n7024/abs/433375a.html)

HIV-evolution [rapid evolution, using phylogenetic methods to trace origin]
Lab exercise: "**A viral mystery".** A case of dentist to patient transmission that was unraveled using phylogenetic analysis of the viruses. Developed by David Baum, Univ. of Wisconsin – Madison (see Appendix 1).

Human evolution [common ancestry]
The DNA of humans is about 96% the same as chimpanzees, if you include 'junk DNA' regions. If you include only regions you can align for human and chimp, the similarity is about 99%. The average protein differs by less than 2 amino acids. In total there are 40 million differences between the two genomes. The chimp genome was sequenced in 2005.
WWW: Science, **Evolution: Breakthrough of the Year, 2005**.
(http://www.sciencemag.org/cgi/content/full/310/5756/1878)

Article: The Chimpanzee Sequencing and Analysis Consortium, **"Initial Sequence of the Chimpanzee Genome and Comparison with the Human Genome"**, Nature 437: 69 (2005). (http://www.nature.com/nature/journal/v437/n7055/abs/nature04072.html)
Article: Z. Cheng et al., **"A Genome-Wide Comparison of Recent Chimpanzee and Human Segmental Duplications"**, Nature 437: 88 (2005). (http://www.nature.com/nature/journal/v437/n7055/abs/nature04000.html)
WWW: Nature **Web Focus, the chimpanzee genome** [with list of additional articles]. (http://www.nature.com/nature/focus/chimpgenome/index.html)

Language evolution in humans
For general reading nothing beats Pinkers (1994) book.
Book: S. Pinker, **The Language Instinct**, W. Morrow and Co., New York, 1994.
Article: W. Enard, et al., "**Molecular evolution of FOXP2, a gene involved in speech and language**". Nature 418:869-872 (2002).
Article: J. Zhang, et al., "**Accelerated protein evolution and origins of human-specific features: Foxp2 as an example**", Genetics 162: 1825-1835 (2002).
Article: S. E. Fisher & G. F. Marcus, "**The eloquent ape: genes, brains and the evolution of language**", Nature Reviews Genetics 7: 9-20 (2006). (Recent review on genes and language evolution)

Language and culture evolution
Article: R. Mace & C. J. Holden, "**A phylogenetic approach to cultural evolution**", Trends in Ecology & Evolution 20: 116-121 (2005). The authors use phylogenetic methods to study cultural and language interchanges through history.

Lice and the origin of human clothing
By dating the origin of body lice, the time of the origin of human clothing could be assessed. Clothes and body lice appears to have arisen in Africa about 70 000 (plus minus 40 000) years ago.
Article: R. Kittler et al., "**Molecular evolution of *Pediculus humanus* and the origin of clothing**", Current Biology 13: 1414-1417 (2003).

NJ geology and fossil plants from NJ
USGS, **Geology of the New York City region**, Atlantic Coastal Plain [Central and South New Jersey], Newark Basin, and Valley and Ridge Province (NJ Highlands).[map of field locations] (http://3dparks.wr.usgs.gov/nyc/index.html)
Article: Crepet & Nixon, "**Exceptionally rich deposits of angiosperm floral, fruit, and leaf remains from the Late Cretaceous of New Jersey**", American Journal of Botany 85: 1273-1288. (1998) [About the 90 million year old flowers of the **Sayreville sand pits**, which also have yielded amber]. (http://www.amjbot.org/cgi/content/full/85/9/1273 ; http://3dparks.wr.usgs.gov/nyc/parks/loc49.htm)

Protein evolution
Review article: C. Chothia, "**Evolution of the Protein Repertoire**", Science 300: 1701-1703 (2003).
Article: B. S. Chang et al., "**Recreating a functional ancestral archosaur visual pigment",** Mol. Biol. Evol. 19: 1483-1489 (2002)

Radiometric dating of rocks
Article: R. Wiens, "**Radiometric Dating – A Christian perspective**". Good introductory article about the different radiometric dating techniques. (http://www.asa3.org/ASA/resources/wiens2002.pdf)
WWW: **Clair Patterson.** Add a historical perspective by focusing on the work of this researcher. (http://evolution.berkeley.edu/evolibrary/article/0_0_0/history_23)

Sex and the Single Guppy [natural selection, adaptation]
Developed through a PBS partnership based on John Endler's work.
WWW: **PBS Evolution program; Natural Selection simulation: Sex and the Single Guppy** (http://www.pbs.org/wgbh/evolution/sex/guppy/low_bandwidth.html)

Sticklebacks (fishes) [adaptation]
Stickleback populations that became isolated in inland lakes after the last Ice Age in Europe have independently lost their armor plates since they no longer have marine predators. However, these independent losses are due to the same preexisting DNA defect, that was rare in the ocean, but now is common in the lake populations, showing fast adaptations to new environments.
WWW: Science, **Evolution: Breakthrough of the Year, 2005**. (http://www.sciencemag.org/cgi/content/full/310/5756/1878)
Article: P.F. Colosimo et al., **"Widespread Parallel Evolution in Sticklebacks by Repeated Fixation of Ectodysplasin Alleles"**, Science 307: 1928 (2005). (http://www.sciencemag.org/cgi/content/abstract/307/5717/1928)
Article: G. Gibson, **"The Synthesis and Evolution of a Supermodel"**, Science 307: 1890 (2005). (http://www.sciencemag.org/cgi/content/summary/307/5717/1890)

Sunflowers [hybridization, adaptation, speciation]
Loren Rieseberg has studied the speciation of sunflowers through hybridization, chromosome changes, and new ecological niches. Hybrid species have been shown to be ecologically different from parent species, taking on new ecological niches.
WWW: **Rieseberg lab home page**. (http://www.bio.indiana.edu/~rieseberglab/)
Article: L. H. Rieseberg et al., "**Major ecological transitions in annual sunflowers facilitated by hybridization"**, Science 301: 1211-1216 (2003); Science Perspectives, Science 301: 1189-1190. (2003);
Article: C.R. Linder & L.H. Rieseberg, "**Reconstructing patterns of reticulate evolution in plants"**, American Journal of Botany 91:1700-1708 (2004).

Survival of the fittest is not necessarily good for the species
Example of fittest organisms succeeding, and yet leading to low population fitness. Parthenogenetic animals can have a twofold advantage of reproduction. A mutation that allows a female to produce only daughters that are clones of herself can swiftly replace an entire sexual population. However the population is reduced long-term chance of persistence.
Article: R. L. Dunbrack, et al., "**The Cost of Males and the Paradox of Sex - Experimental Investigation of the Short-Term Competitive Advantages of Evolution in Sexual Populations**", Proceedings of the Royal Society of London Series B-Biological Sciences 262: 45-49 (1995).

Symmetry in flowers in the African violet family
There are several recent studies where gene expression and phylogenetic studies has been interlinked to explain the evolution of particular characters, this is one example.
Article: Smith, J. F., et al., "**Evolution of GCYC, a Gesneriaceae homolog of CYCLOIDEA, within subfamily Gesnerioideae (Gesneriaceae)**", Molecular Phylogenetics and Evolution 31: 765-779 (2004).

Tree-thinking and phylogenies
Introducing tree thinking (how to read a tree, how a tree is not a ladder, the idea the evolution is ongoing, that living species are not ancestors, etc.) can been helpful. It can work as an organizing scheme for parts of the same course or other courses.

Article: D. Baum et al., "**The Tree-thinking Challenge"**, Science 310: 979-980 (2005).
Lab exercises: Science, **Tree-thinking quizzes I and II**, [excellent examples for courses, view in color] (http://www.sciencemag.org/cgi/content/full/310/5750/979/DC1)

Virus-tracking among cattle and other animals during an outbreak
Using phylogenetic analysis, the source or transmitter of virus can be analyzed using evolutionary methods. This example investigated pseudorabies virus strains in Illinois in 1989.
Article: T. L. Goldberg, "**Application of phylogeny reconstruction and character-evolution analysis to inferring patterns of directional microbial transmission**", Preventive Veterinary Medicine 61: 59-70 (2003).

Relationships of organisms (phylogenetics)

Comparative studies – how closely related are these organisms?
For comparative studies, put organisms also in evolutionary context: - OK, they are different, but how closely related are there and how much of the difference is inherited from different or common ancestors? This is important for ecology, environmental sciences, physiology, molecular biology, neurology, etc. To find phylogenetic information for particular organisms, try these resources:

Evolution of Life
WWW: **Tree of Life** web site, a collaborative effort of biologists from around the world. The project provides information about the diversity of organisms on Earth, their evolutionary history (phylogeny), and characteristics. You can navigate through the tree of Life on this website (http://tolweb.org/tree/)
WWW: **UC Berkeley: Life on Earth project** (http://www.ucmp.berkeley.edu/alllife/threedomains.html)
Article: S. Baldau, "**The Deep Roots of Eukaryotes**", Science 300: 1703-1706 (2003).
Article: M. J. Benton & F. J. Ayala, "**Dating the Tree of Life**", Science 300: 1698-1700 (2003).
Review article: P. J. Keeling et al., "**The tree of eukaryotes**", Trends in Ecology and Evolution 20: 670-675.

Microbes, Protists, etc.
Article: T. M. Wassenaar, "**Bacteria: More than pathogens**", Action Bioscience (July 2002). (http://www.actionbioscience.org/biodiversity/wassenaar.html)

Animals:
WWW: **Tree of life: Metazoa** (http://tolweb.org/tree?group=Animals&contgroup=Eukaryotes)
WWW: **AnimalDiversity Web** (http://animaldiversity.ummz.umich.edu/site/index.html)
WWW: Nature magazine: **Chimpanzee genome resources** Features articles and research on chimps. (http://www.nature.com/nature/focus/chimpgenome/index.html)

Insects:
WWW: **Iowa State Entomology Index of Internet resources** includes image galleries, keys, teaching resources and software. (http://www.ent.iastate.edu/List/)
WWW: **Digital dragonflies**. The site contains detailed scans of living dragonflies. (http://www.dragonflies.org/)
WWW: **Orthoptera species file online**. Look up images of grasshoppers and crickets and hear their songs. This is a good example of what a museum can do with its dead bugs. (http://www.tettigonia.com/)

Fungi:
WWW: **Tree of Life: Fungi** (http://tolweb.org/tree?group=Fungi&contgroup=Eukaryotes)
WWW: **UCMP Berkeley's introduction to the Fungi** (http://www.ucmp.berkeley.edu/fungi/fungi.html)
Textbook: G. M. Mueller et al., Biodiversity of Fungi, Elsevier Academic Press, 2004.
Article: Lutzoni et al., "**Assembling the fungal tree of life: progress, classification, and evolution of subcellular traits"**, Amer. J. Bot. 91: 1446-1480, 2004. (http://www.amjbot.org/cgi/reprint/91/10/1446)

Plants:

WWW: **Tree of Life: Green plants** (http://tolweb.org/tree?group=Green_plants&contgroup=Eukaryotes)

WWW: **Botany and Plant Systematics**, on-line Subject Research Guide at Rutgers Libraries, http://www.libraries.rutgers.edu/rul/rr_gateway/research_guides/plant_systematics/plant_systematics.shtml

Textbook: Plant Systematics by Michael G. Simpson, Elsevier Academic Press, 2005.

Textbook: Plant Systematics, a phylogenetic approach, W. Judd et al., ed. 2, Sinauer.

Articles: **The October 2004 issue of American Journal of Botany** was dedicated to The Tree of Plants, and includes a variety of review articles, including algae, fungi, evolution of plant development, fossils, reticulate evolution, ferns, dinoflagellates, red and green algae, and plastid evolution. (http://www.amjbot.org/content/vol91/issue10/)

Review article: E. M. Friis et al., "**When Earth started blooming: insights from the fossil record**", Current Opinion in Plant Biology 8: 5-12 (2005).

Examples and ideas for specific course topics

Certain course topics such as evolution, anthropology, genetics, geology, systematics, etc., are not listed here since they already are evolutionarily to a large degree. For those courses, examples and resources can be drawn from many areas below.

For resources in the form of researchers soinf ecvolutionary research within Rutgers, please see **EVOLUTION at Rutgers** web page. (http://evolru.rutgers.edu)

Agriculture, agronomy, animal and plant sciences
* evolution of DDT resistance
* evolution of herbicide resistance
* domestication of crops and animal
* breeding, artificial selection vs. natural selection
* hybridization of species, polyploidization in plants
* pollination mechanisms and their evolution, co-evolution with pollinators
* Improvement of wild crops into larger, tastier fruits
* Deselection against toxic compounds in food products (example cassava)

Example: evolution of corn and wheat
Example: evolution of fleshy tomatoes from dry capsules (fruit-type evolution in Solanaceae; see Example list in this toolkit).
Example: Fig and fig wasp co-evolution (see Example list in this toolkit).
Review article: I. Denholm et al., "**Insecticide resistance on the move**", Science 297: 2222- 2223(2002).

Art, art history, fashion
* evolution of symmetry and asymmetry in living organisms
* evolution of pigments and coloring patterns
* Biological illustration, accuracy and invention

Example: Haeckel
Example: Evolution of clothes and lice (see Example list in this toolkit).

Behavior
Examples: cricket, black cap, and corn borer studies (see Example list in this toolkit).

Biology introductory courses:
- Start with the large and familiar – elephants, turkeys, cows, and oaks, then go deeper into cells, molecules and microcosms to explain science. This grabs the attention and pulls them into the subject.
- Make it relevant to the students' own lives and interests, talk about evolution of resistance to antibiotics, bird flu, anything sex-related, and psychoactive plants, dogs, and parasites are also popular.
- Introductory biology is often taught from a structure-function approach, but instead information such as animal organ systems and plant structures and their functioning could be placed in a phylogenetic context.
- If you can get them to understand that birds ARE Dinosaurs, they begin to grasp phylogenetic taxonomy.
- Understanding that chimps are more closely related to humans than they are to gorillas is a good introduction to phylogenetics as well, since "body covered with black hair" is a plesiomorphy, or ancestral condition.
- Bring in a stick (full of twigs). Hold it in your left hand. Break a piece off in with your right hand. You now have a monophyletic group in your right hand, and a paraphyletic group in your left.

- Tree-thinking is crucial to all evolutionary understanding (see Example list in this toolkit).

Some thoughts from university professors:
"I have also placed more emphasis on distinguishing biological evolution from topics that aren't actually part of biological evolution. Specifically, I bring in some cosmology to explain that biological evolution is not a theory about the origin of the universe, some biochemistry to explain that biological evolution is not a theory about the origin of life, and some geochemistry to explain how radiometric dating is used as a tool in the study of biological evolution. I also spend more time now presenting evidence of evolution from paleontology, biogeography, and molecular biology. I also point out some of the major questions that lack answers (e.g., holes in our understanding of the genetic and developmental mechanisms)."
Greg Adkinson, Western Carolina University, gadkison@wcu.edu (quoted with permission)

"We have an advantage here at BYU [Brigham Young University] in that we know the religious mindset of most of our students. So I started by first dispelling the myth that scientists are atheists. This, I think, is an important misconception to deal with, especially for evolutionary biologists. Second, I listed seven different "tenets of creationism" from the creation research center's homepage that go totally against Mormon doctrine. So after this first 20 minutes, students who thought they were creationists (many of them) now can no longer count themselves creationists because they don't believe all these creationist ideas. So now I have them where I want them ... THINKING (for a change)."
Keith Crandall, Brigham Young University, Keith_Crandall@byu.edu (quoted with permission)

"Bio students are fed a litany of facts from their first grade-school classes. Evolution provides an opportunity to base learning on inquiry and hypothesis-driven predictions. Darwin's Origin is a great example for how the scientific method works. He allows that creation theory could make predictions about expected design features. He contrasts those predictions with predictions from Lamarckian transformism and his descent with modification. Getting the students to derive their own predictions is difficult, but important for learning how science works by falsifying competing hypotheses."
David Fitch, New York University, david.fitch@nyu.edu (quoted with permission)

Chemistry
* protein evolution
* natural product chemistry, phytochemistry
* medicinal plants, ethnobotany
* evolution of chemical defenses

Computational Biology
* calculation of phylogenetic relationships, tree-building
* population genetics
* modeling of processes

Ecology
* evolution of adaptation
* how much of environmental responses are due to inherent factors?
* environmental niches and their role in speciation

Ecological processes can be dependent of or interact with evolutionary processes. For an example of this, see Wiens & Donoghue's review article, on plant species richness in the tropics (see Example list in this toolkit).

Example: Stickleback loss of armor (see Example list in this toolkit).

Example: Sunflower speciation (see Example list in this toolkit).

Genomics
Review Article: J. A. Eisen & C. M. Fraser, "**Phylogenomics: Intersection of Evolution and Genomics**", Science 300: 1706ff (2003).

History, political science
* reaction to the publication of Darwin's "Origin of Species" locally
* historical researchers and explorers
* impact of evolutionary research on teaching and politics

Language
* evolution of languages on Earth
* evolution of speech in humans
Examples: Language evolution, genes that affect development of language (see Example list in this toolkit).

Medicine, human health
* Antibiotic resistant strains of bacteria [Question for students: Why shouldn't you take antibiotics whenever you feel like you might be getting sick?]
* AZT resistance of HIV virus inside one individual [rapid evolution, affects individuals]
Examples: 1918 influenza and bird flu studies (see Example list in this toolkit).
Example: Evolution of clothes and lice (see Example list in this toolkit).

Molecular Biology
Book: Caroll, S. B., Endless Forms Most Beautiful: The New Science of Evo Devo and the making of the Animal Kingdom, W. W. Norton & Company, 2005.

Organismal Survey courses (Herpetology, Invertebrates, Vascular Plants, Insects, etc)
These can be done from a phylogenetic perspective, using tree-thinking, evolution of derived characters, and phylogenies to give students a visual backbone to categorize and understand biodiversity and the evolution within a group. At Rutgers, this is done in the Plant Systematics class taught by Lena Struwe. See Tree of Life resources in this toolkit for more information.

Pathology, parasitology, plant pathology, weed science
Example: corn borer study (see Example list in this toolkit).

Philosophy
* evolution in the context of history
* philosophy of science

Physiology
This is often taught from a structure-function approach, but instead information such as animal organ systems and plant structures and their functioning could be placed in a phylogenetic context.

Plant Molecular Biology
Comparative gene expression and gene evolution can highlight evolutionary processes and how the genotype and phenotype has evolved.
Example: symmetry in flowers in the African violet family (see Example list in this toolkit).
Example: Horizontal gene transfer in plants (see Example list in this toolkit).
Example: MADS box gene evolution and flower development (see Example list in this toolkit).

Psychology

Dr. Hal Herzog, Western Carolina University, bases most of his teaching on evolutionary principles. He studies the interactions of humans with animals, and one of his favorite teaching topics is the prevalence of particular dog breeds based on human preferences. He has shown that breed popularity over time follow a pattern called cultural drift, which is similar to random genetic drift in biological evolution.

WWW: **Hal Herzog research home page.** (http://wcuvax1.wcu.edu/~herzog/research.html)

WWW: newsobserver.com, **Hot dogs follow fashion.** (http://www.bio.indiana.edu/~hahnlab/MediaFiles/Dog Breeds/News-Observer.html)

Article: Herzog, H., et al., **"Random drift and large shifts in the popularity of dog breeds",** The Royal Society Biology Letters (2004). (http://wcuvax1.wcu.edu/~herzog/royalsociety.pdf)

What do your students understand and how do you know this?

Many faculty wait until the summative examination to determine that their students do not understand a particular concept. Consider instead providing assessment prior to the exam, or even prior to instruction. This can be as easy as giving your students your test at the beginning of the unit. There are several ideas for Classroom Assessment Techniques (see reference below). There are also specific types of assessment tools like the CINS—Conceptual Inventory of Natural Selection (referenced below).

Once we know what our students do not understand, how can we change their conceptions? This can be difficult.

Some general strategies that you might want to consider:

1. Increasing the relevance of the material—draw connections between a fuzzy concept and one students understand clearly.

2. Encourage students to make predictions about an outcome, instead of being passive observers—have the students predict outcomes that would occur if their conception were supported by evidence and be sure to incorporate reflective abstraction where learners can think about their thinking.

3. Stress consistency in thinking across several tasks—this will allow them to develop a method for thinking (metacognition, see teaching articles below)

An expansion of the ideas above might be a type of **problem-based learning**—for this you would pose a problem that is somewhat fuzzy and allow students to suggest means to address the problem. This will allow them to discuss their current conceptions. Have them list and prioritize strategies. Have them conduct investigations, and analyze the result. Reinforce this by having them present their result and self-assess.

The 5E method

Also popular is the **5E method**. To see an example of how this strategy is used, go to:
http://www.pbs.org/wgbh/evolution/educators/course/session6/index.html
Engage—generate a question or have them state a conception; assess their understanding.
Explore—allow students to interact with the material in a loosely guided format; provide them with opportunities that allow them to consider different angles of the problem.
Explain—a step when students can begin to make sense of their conceptions based on their exploration. Between exploring and explaining, students are challenging their own conceptions. If they've properly set up the exploration, then their explanations are likely to be evidence-based. If students are moving too far off track, guided inquiry might be more appropriate.
Elaborate— a phase when the student is able to apply the learning and reinforce newly held conceptions.
Evaluate—occurs when the student and instructor assesses performance and moves with a new plan of action.

The key here is that students establish thinking strategies that allow themselves to articulate and test their own conceptions in a self-correcting process through which the instructor is able to guide the student to a more widely accepted, evidence-based notion.

General References on Undergraduate Teaching and Conceptual Change

D'Avanzo, C. 2003. Research on learning potential for improving college ecology teaching. Frontiers in Ecology and the Environment 10: 533-540.
D'Avanzo. C. 2003. Application of research on learning to college teaching: ecological examples. Bioscience 53: 1121-1128.
Handelsman J, et al. 2004. Scientific teaching. Science 304: 521-522.
Ebert-May D, et al. 2004. Pathways to scientific teaching. Frontiers in Ecology and the Environment 6(2): 323.
Ebert-May D, et al.. December, 2003. Disciplinary research strategies for assessment of learning. Bioscience 53(12): 1221-1228.

Assessment tips:

Angelo, T.K. & P. Cross. 1993. Classroom assessment techniques: A handbook for college teachers. Jossey-Bass.

CINS:

Anderson, D.L. et al. 2002. Development and evaluation of the conceptual inventory of natural selection. Journal of Research in Science Teaching 39: 952-978

K-12 Evolution Education Resources

We have only listed a limited amount of resources here, please see Web Resources in this toolkit for additional resources.

Resources

WWW: **Treehouses** on the **Tree of Life**, pages designed for K-16 learners, teachers and the young at heart. Tree of Life is a collaborative effort of biologists from around the world. The project provides information about the diversity of organisms on Earth, their evolutionary history (phylogeny), and characteristics. (http://tolweb.org/tree/home.pages/treehouses.html)
WWW: **Lesson plans in Evolution: UC Berkeley**. (http://evolution.berkeley.edu/evosite/search/search.php)
WWW: New Jersey Department of Education: **Core Curriculum Content Standards, Science**, grade K-12. (http://www.state.nj.us/njded/cccs/s5_science.htm)

APPENDIX 1

A viral mystery

Used in a General Biology class.

In this case study, you take on the role of the investigator attempting to understand a large number of HIV cases among patients in an isolated community who have no known risk factors. The names and places are fictionalized, but the molecular data and the basic situation are real.

The medical community is surprised by a cluster of cases of AIDS in the village of Burton-on-the Water, near Oxford, England. Most worrying, six individuals are identified who are HIV-positive but lack known risk factors. Careful study shows that apart from living in the same community, these individuals have the following in common.

- All individuals have lived in the area for at least five years including the unusually wet and buggy spring of 2001
- All of the individuals share the same oral surgeon, Dr. Gary Gladstone, who has risk factors and recently died of AIDS.
- All of the individuals visited the local optometrist during the last four years. The optometrist, Hilda Henderson, is a haemophiliac and is HIV-positive.
- Apart from the oral surgeon and the optometrist all but one of the individuals are friends with at least one local person who is HIV-positive and has risk factors (“local controls”). However, no local control has had contact with more than one of the six infected individuals.
- Five individuals have children who go to the same school
- Five individuals share the municipal water supply
- Four of the individuals share the same butcher
- Four individuals go to the same hair salon
- Three individuals frequent the same public house (Tavern)
- Three individuals attend the same church

Based on these considerations and what you know about the transmission of the human immunodeficiency virus develop at least two alternative hypotheses to explain the six unexplained cases. For the 2-3 most plausible hypotheses consider what kind of data could help you distinguish among them.

Molecular Data

Viral DNA was extracted from the patients (i.e., infected individuals with no risk factors) and a short stretch of the viral DNA was sequenced from two randomly chose viruses per patient. Additionally, the oral surgeon, the optometrist and four other local HIV+ individuals with known risk factors were sequenced as controls (LCa-LCd). These data were aligned and are prepared as a matrix.

Before analyzing these data make sure you understand how the data were collected. Why include more than one viral sequence per patient? Why were the oral surgeon and optometrist included? Why were some local controls included? Why are no HIV-negative individuals included?

Identity	Name	Abbrev.	HIV status	Risk factors?
Oral Surgeon	Gary Gladstone, D.D.S.	GG	positive	yes
Optometrist	Hilda Henderson	HH	positive	yes
Patient	Alison Archer	AA	positive	no
Patient	Bertrand Bigelow	BB	positive	no
Patient	Chloe Clemens	CC	positive	no
Patient	Donna Delgado	DD	positive	no
Patient	Erica Elsworthy	EE	positive	no
Patient	Flynn Faulkner	FF	positive	no
Local control	Local control A	LCa	positive	yes
Local control	Local control B	LCb	positive	yes
Local control	Local control C	LCc	positive	yes
Local control	Local control D	LCd	positive	yes

Use Se-Al to look at the 24 sequences and consider the following questions. What do these letters stand for? How did the differences among them arise? Why are they at all similar? Why do some sequences have gaps? Why are the gaps in groups of three? How was it determined where to put the gaps? Can determined which sequences are from the most virulent virus? Why/why not?

By visual inspection, can you see any patterns? Are the two sequences from a single individual generally more similar that the sequences from different patients? Why?

Are the sequences from some pairs of individuals more similar to one another than the other pairs? Why might you expect this?

If you want to conduct a phylogenetic analysis of these data using the computer program PAUP (Phylogenetic Analysis Using Parsimony), read the associated handout for information.

A Challenge

Some of the patients choose to sue the estate of the oral surgeon, Gary Gladstone, for infecting them with HIV. Your TA will assign you to be the scientific consultant for either the defendant's or plaintiff's legal team. Your aim is to develop a brief with two sections: (a) What case is the opposing side likely to make and how will they justify this case based on scientific data? (b) What scientific arguments can you make to undermine that case?

Once the case starts it is decided that one scientist from the plaintiff's team will be allowed to make a statement and be cross-examined by a representative of the defendant's team, and vice versa. After hearing these arguments the jury will decide whether the oral surgeon is responsible for infecting these patients, "beyond a reasonable doubt."