From Slime to Sublime — Evolutionary Paths

Secrets of the Sequence Video Series on the Life Sciences • Grades 9 – 12

Teaching materials developed by **VCU** Life Sciences.

V i r g i n i a   C o m m o n w e a l t h   U n i v e r s i t y

For Classroom Trial Testing

Video Description

"Secrets of the Sequence," Show 141, Episode 2
"From Slime to Sublime" – approximately 10 minutes viewing time

While we are similar to our fellow man in size, shape, and appearance, there are many differences at the molecular level. Gene mutations and the process of natural selection are responsible for who – and what – we are and will become.   The genetic composition of such creatures as butterflies and lobsters are beginning to yield some fascinating insight into how parallel our evolutionary paths may be.

National and State Science Standards of Learning

National Science Education Standards Connection
Content Standard A: Life Science
As a result of their activities in grades 9 - 12, all students should develop:
- understandings about scientific inquiry;
- formulate and revise scientific explanations and models using logic and evidence.

Content Standard C: Life Science
As a result of their activities in grades 9 - 12, all students should develop an understanding of:
- molecular basis of heredity and
- biological evolution.

Content Standard E: Science and Technology
As a result of their activities in grades 9 - 12, all students should develop an understanding of:
- understanding about science and technology.

Content Standard G: History and Nature of Science
As a result of their activities in grades 9 - 12, all students should develop an understanding of:
- nature of scientific knowledge.

Selected State Science Standards Connection
Use http://www.eduhound.com (click on "Standards by State") or a search engine to access additional state science standards.

Virginia
BIO.1 The student will plan and conduct investigations in which:
    e) conclusions are made based on recorded quantitative and qualitative data;
    f) a scientific viewpoint is constructed and defended.
BIO.2 The student will investigate and understand the history of biological concepts, including:
    b) scientific explanations of the development of organisms through time (biological evolution);
    e) the collaborative efforts of scientists, past and present.
BIO.5 The student will investigate and understand life functions of organisms, including:
    a) how structure and function vary between and within kingdoms.
BIO.7 The student will investigate and understand bases for modern classification systems, including:
    0)   structural similarities in organisms;
    e)   systems of classification that are adaptable to new scientific discoveries.
BIO.8 The student will investigate and understand how populations change through time, including:
    a) how natural selection leads to adaptation;
    e) scientific explanations for biological evolution.

Florida
Processes of Life
Standard 1:
    The student describes patterns of structure and function in living things. (SC.F.1.4)
    2. knows that body structures are uniquely designed and adapted for their function.
Standard 2:
    The student understands the process and importance of genetic diversity. (SC.F.2.4)
    2. knows that every cell contains a "blueprint" coded in DNA molecules that specify how proteins
    are assembled to regulate cells.
    3. understands the mechanisms of change (e.g., mutation and natural selection) that lead to
    adaptations in a species and their ability to survive naturally in changing conditions and to
    increase species diversity.

<u>Overview</u>

What's the difference between any two life forms? At the molecular level, the difference between any two organisms is only a few thousand base pairs in their DNA. The first attempts to classify organisms relied primarily on appearance, breaking groups of organism into categories based on common characteristics. In the eighteenth century, Carolus Linnaeus developed a naming system that assigned every organism two names: a genus and a species name. This process, referred to as *binomial nomenclature*, was later expanded by scientists by grouping similar genera into families, families into orders, orders into classes, classes into phyla, and phyla into kingdoms. This is the system in use today, and many of Linnaeus' original names from the eighteenth century are still used. However, today the fast-paced world of genomics is further advancing the understanding of evolutionary history, helping scientists find genetic connections and relationships many people find astounding, and sometimes turning the world of classification on its head. Taxonomy, or the science of placing organisms into a hierarchy based on similarities and differences, is undergoing many changes now that scientists can map out significant sections of an organism's genome. One major theme among most animals is the fact that we share a common body scheme: a central, segmented core and appendages of some sort - this is why we are genetically so similar. The common mouse shares 85% of our DNA; the chimpanzee, 98.5%. The differences are based on different arrangements of the same genetic material – often called genetic mutations.

This lesson introduces students to the concept of taxonomy and the advancements that have been made that allow scientists to find more exact relationships among organisms. The students will have the opportunity to develop a phylogenetic tree based on common genetic sequences. In addition, depending on their level of understanding of amino acid sequences, they will examine the DNA sequences for the cytochrome c gene in various organisms and see how the percent differences in these sequences relate to the evolution of that organism. This is the process by which molecular clocks are built.

## Testing: A sample multiple choice item from State Standardized Exams

Scientists can use the amino acid sequence in proteins to determine the evolutionary relationships of primates. Of the following, which primate is least closely related to humans?

Human	SER	THR	ALA	GLY	ASP

A. Gorilla	SER	THR	ALA	GLY	ASP
B. Baboon:	ASN	THR	THR	GLY	ASP
C. Chimp:	SER	THR	ALA	GLY	ASP
*D. Lemur:	ALA	THR	SER	GLY	GLU

(Source: North Carolina Sample Test Items – Biology)

Before Viewing

- Have 5 volunteers come to the front of the room. Tell the students to take a minute to observe the 5 volunteers.
- Ask**:** "Come up with a way to divide the group into two smaller groups based on one characteristic." (Response: The students might choose gender, hair color, shoe type, etc.)
- Physically separate the volunteers into two groups based on the chosen characteristic.
- On the board, above the groups, record the characteristics - girls, not girls; tennis shoes, no tennis shoes. Don't lead them - it's important that they pick their own.
- Choose one of the two sub-groups. Have the class divide this group in a similar manner.
- Physically separate this group into two smaller groups.
- Separate the last group into individuals. Each of the five volunteers should be separated from the others based on individual characteristics. The characteristics that have been written on the board should create a classification scheme similar to the one below.

VOLUNTEERS

Boys   Not Boys

Brown   Not Brown   Brown   Not Brown
Hair   Hair   Hair   Hair
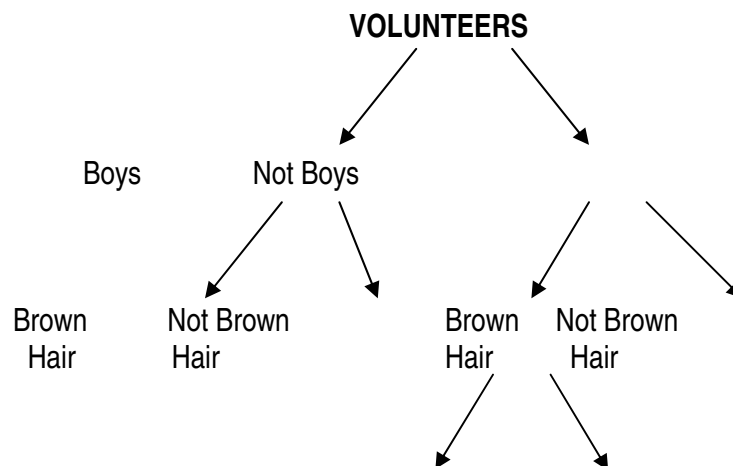
Tennis   Not Tennis
Shoes   Shoes

1) Use the classification scheme to identify a particular volunteer. When you reach the end of the classification scheme, write that student's name underneath. Do this with each volunteer. If done properly, each student will have his or her own unique location. No two volunteers should occupy the same location.

2) Ask: "If we did this again in a month, which characteristics could we still use?" *Response: gender.* Explain that often obvious features such as hair color are the least reliable when classifying. Shoes will change; even hair color may be different in a month. Classification has to be made using information that is least likely to change.

3) Explain how geneticists are looking for similarities between organisms that go much deeper than how the organisms look externally. In living organisms, the most reliable information is DNA. Scientists are now studying the similarities that exist between molecules that can be found in all organisms to help us understand how organisms have changed over time.

During Viewing

1) Start the video.
2) Pause the video (3.30 minutes into the video) after the computer explanation of mutations in biological evolution.
   Ask: "Can you think of any examples of biological mutations that allow certain members of a species to survive in their environments."
   Response: polar bears (hair color and temperature tolerance), or Sherpas of Tibet who are able to live at very high altitudes.
3) Resume the video**.**
4) Pause the video (4.50 minutes into the video) when the scientist says, "… novelty in animals is the using of genes in new places in the body."
   Ask: "Can you list different forms of appendages and write them on the board?"
   Response: legs/feet, arms/hands, ears, nose, elephant's trunk, tails (mammals, birds, reptiles, fish), flippers, fins. Stress again that the commonality of all these features represents a significant portion of our shared DNA. It is the genetic mutations that cause the specialization of these parts that makes us unique.
5) Resume the video and play to the end.

After Viewing

Choose between the following 2 activities based on your students' understanding of amino acid sequences. The first activity continues with the concept of a traditional "tree of life" classification scheme while the second activity includes calculations to set up a "molecular clock" and determine accurate rates at which organisms have evolved.

Teaching Notes for Student Activity #1: Tree of Life

1) Explain to students that they will conduct an activity in which they will create a classification scheme or "phylogenetic tree" similar to the one they developed at the beginning of class. The diagram will separate 16 organisms into specific places based on sequences of DNA. In most cases, characteristics are added; in certain instances, a characteristic has been deleted. The goal is to find the 'organism' who is the ancestor of all the other organisms. The 'oldest' organism will be the one with the fewest groupings - represented in this activity by letters. Through the process of evolution and natural selection, new organisms advance through the addition of new DNA sequences – represented by additional letters.

2) Show the students a picture of a phylogenetic tree. You can find one at: http://tolweb.org/tree/phylogeny.html. It should be easy for the students to find the base of the tree (CEF) and to break the trunk into its first two branches. After that, the task becomes more difficult. Advanced classes may be able to finish this activity without guidance.

   a. Explain to the students that they will conduct an activity in which they will create a classification scheme similar to the one they developed at the beginning of class.
   b. Distribute the handout, Tree of Life
   c. Read through the directions as a class.
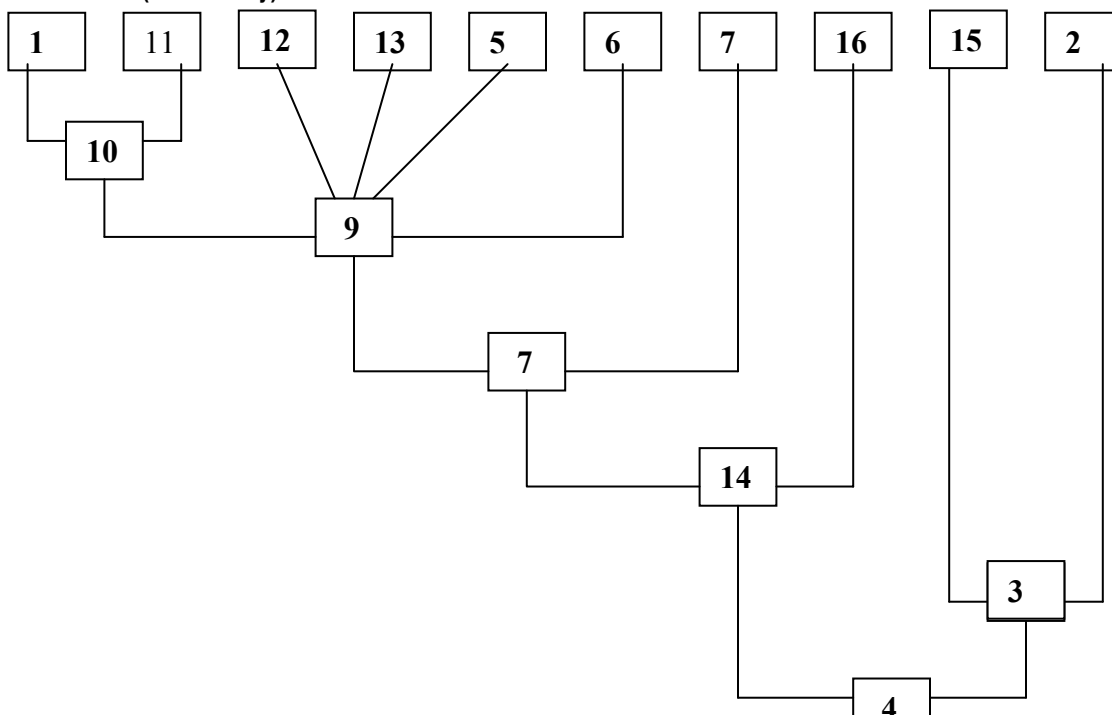   d. Break into groups two or three to complete the assignment.

Materials
Handout: Tree of Life
For each pair of students:
- a sample phylogenetic tree
- large sheets of paper or newspaper
- marking pen
- scissors

Tree of Life (Answer key)

<u>Teaching Notes for Student Activity # 2:</u>
<u>Making a Molecular Clock</u>

Explain to the students that they will be examining the techniques that geneticists use to determine the similarities and differences between various life forms by forming a phylogenetic tree based on amino acid sequences in a molecule that can be found in nearly all life forms.

<u>Student Activity #1: Tree of Life</u>

In this activity you will create a phylogenetic tree; a classification scheme or diagram that separates organisms based on sequences of DNA similar to the example your teacher has. The goal is to find the organism who is the ancestor of all other organisms.

The table below has 16 different organisms. In most cases, characteristics are added; in certain other cases, a characteristic has been deleted.

Copy the tree diagram on a large piece of paper. Cut out the organism "codes". Move them around to help you figure out where they go. Each code has a number (ACEF and QACEF appear twice). Once you have figured out the tree, write the number in the appropriate box on your worksheet.

1	QCEFPO	9	QACEFP
2	BDCEF	10	QCEFP
3	DCEF	11	QCEFPG
4	CEF	12	QACEFPS
5	QACEFPD	13	QACEFPV
6	QACEFPP	14	ACEF
7	QACEF	15	DCEFR
8	QACEF	16	ACEF

Tree of Life
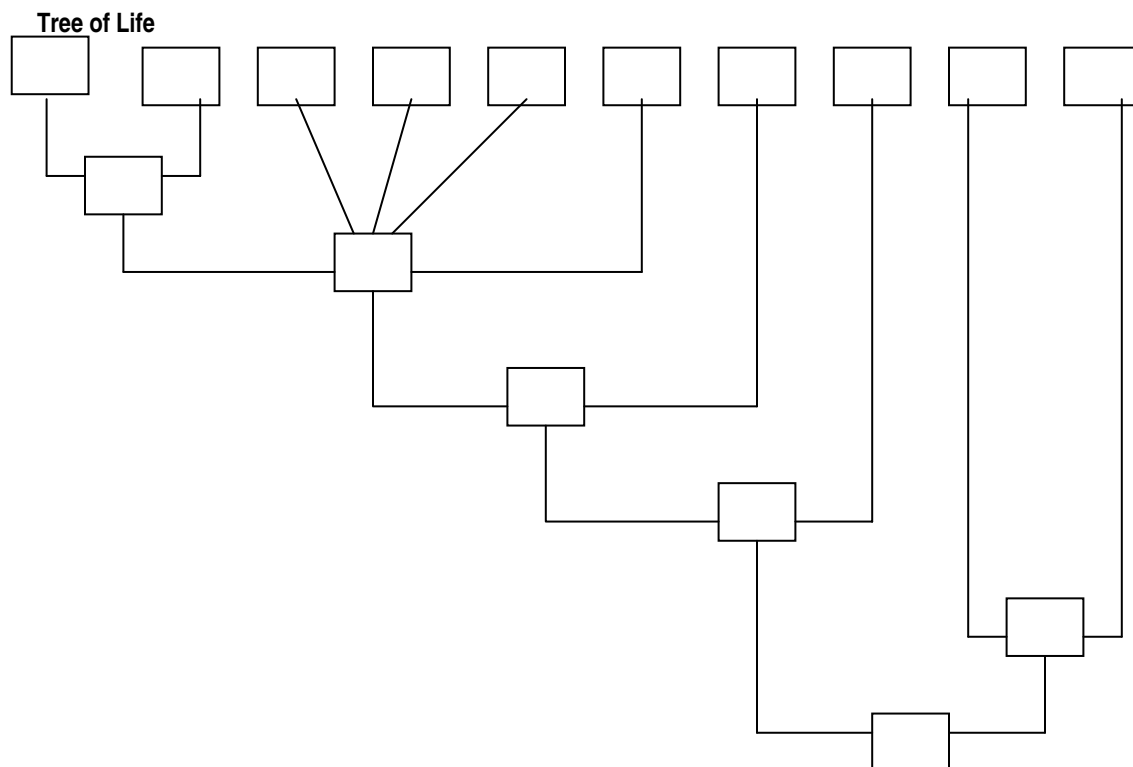
Student Handout # 2: Making a Molecular Clock

Charles Darwin's theory of Natural Selection explains the environmental influences that produce macroscopic changes in populations over time. Modern-day geneticists are now applying the principles of Natural Selection to the microscopic realm -- namely, how have the molecules common to all life forms changed over time and how do these changes explain evolutionary relationships between life forms? In this activity, you will compare the amino acid sequences of a protein found in four organisms. You will use this information to build a model of a molecular clock and determine when divergent evolution might have occurred among these organisms.

By comparing the structures of organisms, scientists are able to draw evolutionary relationships among them. Genetic researchers are now able to use the amino acid sequence of proteins to draw similar conclusions. One such protein being studied is *cytochrome c*. This protein is found in the mitochondria of such varied organisms as yeast and humans. Its role is that of an electron carrier during respiration.

When human cytochrome c is compared to the cytochromes of other animals, there are many similarities and a few differences. When the amino acids of cytochromes are compared, the similarities between the sequences are called "homologies." The differences in the sequence are called "substitutions." Figure 1 shows the amino acid sequences for the first 50 amino acids in the cytochromes of 4 different organisms.

Figure 1
First 50 Amino Acids in Cytochrome C

	1	6	11	16	21	26	31	36	41	46
Human	GDVEK	GKKIF	IMKCS	QCHTV	EKGGK	HKTGP	NLHGL	FGRKT	GQAPG	YSYT A
Turtle	GDVEK	GKKIF	VQKCA	QCHTV	EKGGK	HKTGP	NLNGL	IGRKT	GQAEG	FSYTE
Shark	GDVEK	GKKVF	VQKCA	QCHTV	ENGGK	HKTGP	NLSGL	FGRKT	GQAQG	FSYTP
Fruit Fly	GDVEK	GKKLF	VQRCA	QCHTV	EAGGK	HKVGP	NLHGL	IGRKT	GQAAG	FAYT N

Amino acid key:
G - Glycine; A - Alanine; V - Valine; L - Leucine; I - Isoleucine;
M - Methionine; F - Phenylalanine; W - Tryptophan; P - Proline; S - Serine;
T - Threonine; C - Cysteine; Y - Tyrosine; N - Asparagine; Q - Glutamine;
K - Lysine; R - Arginine; H - Histidine; D - Aspartic acid; E- Glutamic acid

The number of amino acid substitutions between two organisms shows the differences between the organisms themselves. The greater the number of substitutions between two organisms, the longer ago the two organisms diverged from a common ancestor. Scientists believe that cytochrome c has evolved at a fairly constant rate. This rate of change is the basis for a "molecular clock." This rate of mutation can be a helpful tool in trying to determine how organisms have evolved.

Procedure

1.   Compare each organism's cytochrome in Figure 1 to human cytochrome. Record the position of each amino acid substitution and the total number of substitutions in Table 1.
2.   To calculate the percent of difference for each cytochrome from human cytochrome, divide the number of substitutions for each organism by the total number of amino acids in the sequence (50). Enter these percentages in Table 1. These percentages are the differences between human cytochrome c and the cytochrome of each organism.

Table 1

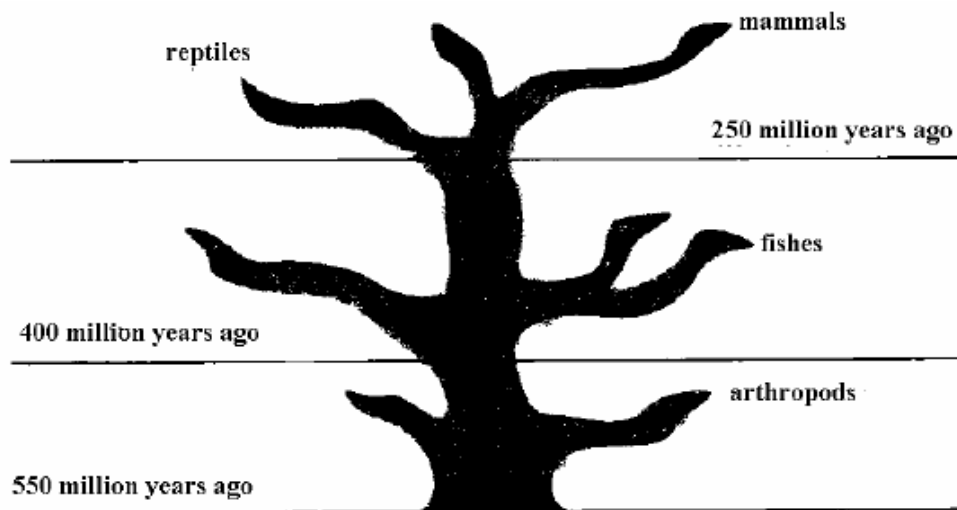| Human vs.	Positions of Substitutions	Number of Substitutions	Percentage of Difference
Turtle			
Shark			
Fruit fly			

Figure 2

Approximate Dates of Divergence

Figure 2 shows the approximate time of divergent evolution of reptiles, fish, and insects. These data are based on the fossil record. Use the percent difference from Table 1 to calculate the average percent change of cytochrome c per million years. To do this for each organism, divide the percent change from Table 1 by the number of million years from that organism's point of divergence (from Figure 2). Average the three quotients. This number represents the average amount of change in cytochrome c that has occurred over each of the one million years of the last 500 million years. Record your findings in Table 2 below.

Table 2

Percentage of Change per 1 Million Years

Reptiles	
Fishes	
Insects	
Average percentage	

Use the average percent from Table 2 to answer the following questions:

1) Using the divergence data below, calculate the expected percent difference for cytochrome c among the following organisms:
a) crustaceans, 450 million years: _____% difference
b) cartilaginous fishes, 350 million years: _____% difference
c) amphibians, 280 million years: _____% difference

2) What percent change should be expected if yeast diverged 800 million years ago?
_____

3) How would this molecular clock be useful in determining the time of divergent evolution for organisms that don't leave fossils?
_____
_____

*This activity was adapted from the activity "Making a Model Molecular Clock," Prentice-Hall **Biology**, **Prentice-Hall, Inc., 1987.***

Additional Resources
http://www.science.gmu.edu/~hgeller/ astrobiology/AbEvolvlect.doc
Sample phylogenetic tree; provides features of such trees.

http://aleph0.clarku.edu/~djoyce/java/Phyltree/intro.html
Explains Phylogeny and Reconstructing Phylogenetic Trees.

http://tolweb.org/tree/phylogeny.html
The Tree of Life is a collaborative web project, produced by biologists from around the world.