

By Land or Sea — Comparative Anatomy

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

Classroom Tested Lesson

Video Description

“Secrets of the Sequence,” Show 125, Episode 2

“By Land or By Sea – Comparative Anatomy” – approximately 8 minutes viewing time

How has nature, through evolution, used the same genes to create diversity? Researchers have identified a specific family of genes, which are responsible for body segmentation in crustaceans, like lobsters, crabs and shrimp. In humans, this same family of genes is responsible for creating our segments, such as our spine and ribs.

Ward Television

Producer: Fran Victor

Featuring: Nipam Patel, Howard Hughes Medical Institute at University of Chicago

Lesson Author; Reviewers: Beth Richert; Catherine Dahl, Dick Rezba, and Kieron Torres

Trial Testing Teachers: Brooke Williams, Sharon Padgett

National and State Science Standards of Learning

National Science Education Standards Connection

Content Standard C: Life Science

As a result of their activities in grades 9-12, all students should develop understanding of

- Biological evolution
- Behavior of organisms

Content Standard G: History and the Nature of Science

As a result of their activities in grades 9-12, all students should develop understanding of

- Science as a human endeavor
- Nature of scientific knowledge

Selected State Science Standards Connections

Use <http://www.eduhound.com> (click on “Standards by State”) or a search engine to access additional state science standards.

Florida

Processes of Life

Standard 1

The student describes patterns of structure and function in living things. (SC.F.1.4)

1. Knows that the body processes involve specific bio-chemical reactions governed by biochemical principles.
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)

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.

Oklahoma

Process Standard 5

Model - Modeling is the active process of forming a mental or physical representation from data, patterns, or relationships to facilitate understanding and enhance prediction.

1. Interpret a biological model which explains a given set of observations.

Content Standard 2

The Molecular Basis of Heredity - DNA determines the characteristics of organisms.

1. Cells function according to the information contained in the master code of DNA (i.e., cell cycle, DNA to DNA, and DNA to RNA). Transfer RNA and protein synthesis will be taught in life science courses with rigor greater than Biology I.
2. A sorting and recombination of genes in reproduction results in a great variety of possible gene combinations from the offspring of any two parents (i.e., Punnett squares and pedigrees). Students will understand the following concepts in a single trait cross: alleles, dominant trait, recessive trait, phenotype, genotype, homozygous, and heterozygous.

Content Standard 3

Biological Diversity - Diversity of species is developed through gradual processes over many generations.

1. Different species might look dissimilar, but the unity among organisms becomes apparent from an analysis of internal structures, the similarity of their chemical processes, and the evidence of common ancestry (e.g., homologous and analogous structures).
2. 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, which may enhance or limit the survival and reproductive success in a particular environment.

Overview

With the enormous diversity of life on earth, it is remarkable how the same genetic material appears over and over in all species of animals, even sea creatures. This video explains how a complex set of genes called homeotic genes have been found in all these species. Researchers have discovered that these genes are turned on and off in different parts of the body thus controlling how skeletons are formed as repeated patterns, whether they are internal or external. The segments in a human vertebrae are therefore not that genetically different from the segmentation in an aardvark or a lobster. This video also addresses how these species have evolved over millions of years as nature finds new ways to use their genetic material – an example of which is shown by highlighting the continued specialization of appendages in the arthropod family.

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

According to modern evolutionary theory, genes responsible for new traits that help a species survive in a particular environment will usually

1. not change in frequency
2. decrease gradually in frequency
3. decrease rapidly in frequency
4. increase in frequency *

Source: New York - Living Environment Regents Examination

Video Preparation

Preview the video and make note of the locations at which you will later pause the video for discussion.

Before Viewing

1. Distribute Student Handout 1 to each student and have them quickly rate their current knowledge of these topics by checking the appropriate categories.
NOTE: At the end of the lesson students will be asked to revisit this chart and determine which areas their knowledge has increased.
2. Ask: "Why is it easier to see segmentation patterns in some species than others?"
In species that have exoskeletons their segmentation is visible, while in species with internal skeletons their segmentation is hidden.

During Viewing

1. **START** the video.
2. **PAUSE** the video (1.48 minutes into the video) after Nipam Patel says "We're interested in the genes that allow them to specialize these different appendages to do different things."

Ask: "Can you list different uses of appendages in different organisms, and make connections between these functions in crustaceans and similar functions in other organisms?"
3. **RESUME** the video.
4. **PAUSE** the video (6.37 minutes into the video) after the narrator says, "...so just like our cousins..." the human vertebra consists of 33 segments divided into 5 types.

Ask: "Can you list the 5 types of human vertebrae described in the video and review what their functions are?"

- *Cervical: designed to be flexible and strong in order to hold up the head*
- *Thoracic: designed to hold more weight and is attached to the ribs*
- *Lumbar: designed to hold up the majority of the body weight*
- *Sacral: segments are compressed and fused together for support*
- *Coccygeal: forms the tail-like bone at the base of the spine*

5. **RESUME** the video and play to the end.

After Viewing

1. Review how evolution has resulted in increased specialization of appendages of crustaceans using the examples shown in the video.
 - Sea monkey (brine shrimp): *this primitive crustacean shows that all appendages of the thorax are used for swimming*
 - Other crustaceans: *some divergence and evolution beyond the sea monkey resulted in some appendages near the head becoming specialized for feeding*
 - Lobster: *further evolution show appendages becoming specialized not only for feeding but also for snapping at something, tearing food and walking away all at the same time*
 - Stomatopod: *shows further evolution with powerful appendages used for defense and attack.*
2. How do the genes that create segments in arthropods correlate to humans?
Homeotic genes called HOX genes that are found in all species are identified with making different parts of the body different from other parts – this is called regionalization. These genes not only create segmentation in an arthropod but also have been directly linked with how the spine develops in humans. UBX or the ultra bi-thorax gene is one of these HOX genes that is found in all vertebrates but expressed at different levels depending on the evolution of that particular species.

Note: Remind students that crustaceans and humans are both animals. Often students have a misconception that humans are in their own kingdom.

Teacher Notes for the Student Activity: Why is an arm an arm? Why is a leg a leg? - Genes that Determine Body Patterns

Materials

- Student Handout 2: *Why is an arm an arm? Why is a leg a leg? – Genes that Determine Body Patterns* (Copy for each student)
- Student Handout 3: *Background Information on How Genes Determine Body Patterns - Why is an arm an arm? Why is a leg a leg?* (Copy for each student if Internet access is unavailable)
- Color transparency of the diagrams on page 2 of Handout 3

Introduction

Every organism has a unique body pattern. Although specialized body structures, such as arms and legs, may be similar in makeup (for example, both are made of muscle and bone), their shapes and details are different. During the growth of the embryo, arms and legs develop differently due to the actions of special genes, called homeotic genes, which specify how structures develop in different segments of the body.

Procedure

Students will explore the following topics using the Web site

<http://gslc.genetics.utah.edu/units/basics/bodypatterns/> or a printed version (Handout 3) of the information found on that Web site if students do not have access to individual computers.

- How scientists discovered genes that determine body pattern
 - Many organisms have similar sets of homeotic genes
 - Homeotic gene organization is conserved through evolution
 - Mutations in mammalian homeotic genes
 - Homeotic gene mutations may play a role in evolutionary change
1. If sufficient computers are available, have students work individually. If computer access is limited, have students work in small groups to complete this activity. Explain how to navigate through the Web site:
 - Students click on each topic on the main page to read more about the topic in order to answer the questions on Handout 2.
 - Students can click on vocabulary words in color to pop-up a definition.
 - After completing the reading for each topic, students must use the browser's back-button to return to the list of topics so they can select the next bulleted topic.
 2. If computer access is not available, give each student a copy of the Student Handout 3: Background Information on How Genes Determine Body Patterns.
 - The information in Handout 3 will allow students to explore the same topics as on the Web site although the information has been abbreviated somewhat from the Web site:
<http://gslc.genetics.utah.edu/units/basics/bodypatterns/>
 - Make a color transparency of the diagrams on page 2 of Handout 3 to better show students how the strands recombine with both fly and frog DNA. Black and white print copies do not show this well.
 3. Once students have completed this activity, have them briefly fill in the "Rate your Knowledge" Handout 1 for the second time to determine which areas their knowledge has increased.

Answers to Questions on Student Handout 2

1. What is the role of the homeotic gene?

To determine body patterns

2. How did scientists discover genes that determine body pattern?

By studying bizarre mutations in fruit flies they correlated mutations in different genes with transformations in the flies' body patterns.

3. What is a homeotic mutation?

It causes structures in one body segment to be replaced by structures normally found in another segment.

4. In the fruit fly that was studied, what caused the fruit fly to grow a leg where its antenna should have been?

A mutation in a single gene called antennapedia

5. What general principle did Dr. Lewis' work demonstrate?

Every cell in an organism carries within its DNA all of the information necessary to build the entire organism.

6. What is a homeobox?

A sequence of about 180 nucleotides within a large sequence of DNA

7. If the following words were homeotic genes, what would the homeobox be in each gene? ___EAT___

Underline the homeobox in each of the following 'homeotic genes':

WEATHER
WHEAT

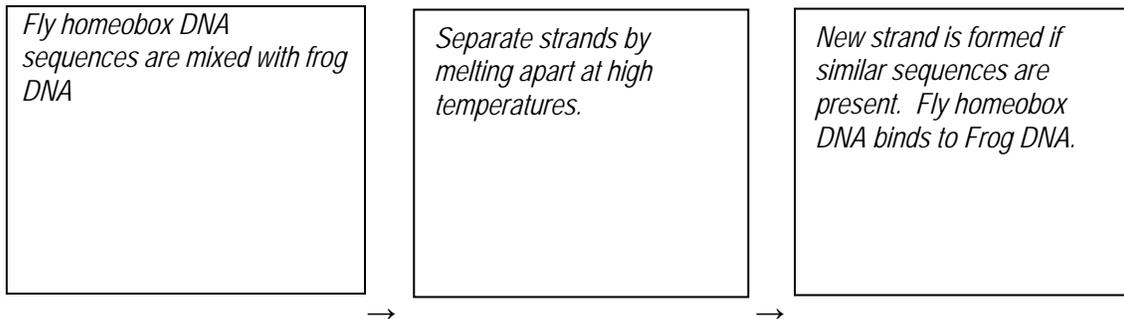
BEAT
FEATHER

SWEATER
ANTEATER

8. Several research groups, led by Bill McGinnis, Michael Levine and Walter Gehring, examined the following question, "Do organisms other than fruit flies also have homeotic genes that regulated body patterning?" What was the first step of their investigation?

They examined the DNA from a variety of animals for sequences similar to the homeobox

9. Diagram the three-step process they used to find the homeobox in different organisms.



10. What did the researchers find?

Every animal tested had homeobox sequences in its DNA.

11. Homeobox sequences found in most mammalian genes are very similar to those in fruit flies. These sequences have been conserved throughout evolution without much change. What does 'conserved' mean?

Retained – they have remained within the DNA throughout evolutionary time.

12. What are genes in different organisms that share similar sequence and function called?

Homologous

13. How is amount of evolutionary time and the extent to which gene sequence and organization are conserved between organisms related?

The extent of conservation of gene sequence and organisms diminishes as evolutionary time passes.

14. What can gene organization tell us about evolutionary relationships between organisms?

The tighter the genes cluster, the more likely those genes will be inherited by the next generation as a linked group.

15. What is a paralog?

Genes that correspond to each other in each duplicated cluster.

16. If a scientist wanted to mutate a specific gene to see what impact it would have on the organism, what difficulties might they encounter in making a conclusion?

The effects of the mutation may be hidden by the normal functions of other genes in the same paralogous group.

17. Natural homeotic mutations can be an effective means for evolutionary change. How might a homeotic mutation be helpful to a species?

It might lead to an advantage; they may be able to capture food more easily or be more attractive thus benefiting reproduction.

18. When might a homeotic mutation be harmful to a species?

If the organism becomes less effective in getting food or becomes unattractive, the mutation might lessen the organism's chances to reproduce.

Student Handout 1: Rate Your Knowledge – Comparative Vertebrate Anatomy

Rate your knowledge for each of the concepts by placing an “X” in the category that reflects your level of understanding before viewing the video. After you have completed the lesson you will rate your knowledge of these concepts again, but this time you will place an “O” in the appropriate category. Then total the number of X’s and O’s for the “I know it” column for a comparison of what you already knew and what you have learned from this lesson.

	I Know It	I Think I Know It	I Don't Know It
Crustaceans			
Arthropods			
Exoskeleton			
Endoskeleton			
Body Segments			
Appendages			
Cervical Vertebrae			
Thoracic Vertebrae			
Lumbar Vertebrae			
Sacral Vertebrae			
Coccygeal Vertebrae			
Divergence			
Convergence			
Evolution			
Homeotic genes			
Mutations			
Homeobox			
Nucleotides			
Paralog			
Paralogous			
DNA			
Specialization			
Embryo			
Gestation			
Development			
Phylogeny			
Ontogeny			
Comparative Anatomy			
Total:	X's _____ O's _____		

Student Handout 2: Why is an arm an arm? Why is a leg a leg? - Genes Determine Body Patterns

In this activity you will explore the genes that regulate how body structures develop in different segments of the body.

Procedure

If you have Internet access

- 1) Log on to the Internet and carefully type in the following URL in the address bar at the top of the screen: <http://gslc.genetics.utah.edu/units/basics/bodypatterns/>.
 - Click on the first of the five topics on the main page to learn more about this topic
 - After you have read the information on the first topic, use your browser back-button to return to the main page.
 - Click on the remaining bulleted topics and continue as described above
- 2) Use the information provided on the Web site to help you answer the questions listed below. Words that appear in color on the Website are linked to a definition. Click on any that you do not understand.

If you **do not** have internet access

- 1) Read Student Handout 3: Background Information on How Genes Determine Body Patterns
- 2) Using the information from the Handout and the video, answer the following questions individually or in groups as directed by your teacher.

Questions:

1. What is the role of the homeotic gene?

2. How did scientists discover genes that determine body pattern?

3. What is a homeotic mutation?

4. In the fruit fly that was studied, what caused the fruit fly to grow a leg where its antenna should have been?

5. What general principle did Dr. Lewis' work demonstrate?

6. What is a homeobox?

7. If the following words were homeotic genes, what would the homeobox be in each gene? _____

Underline the homeobox in each of the following 'homeotic genes':

WEATHER
WHEAT

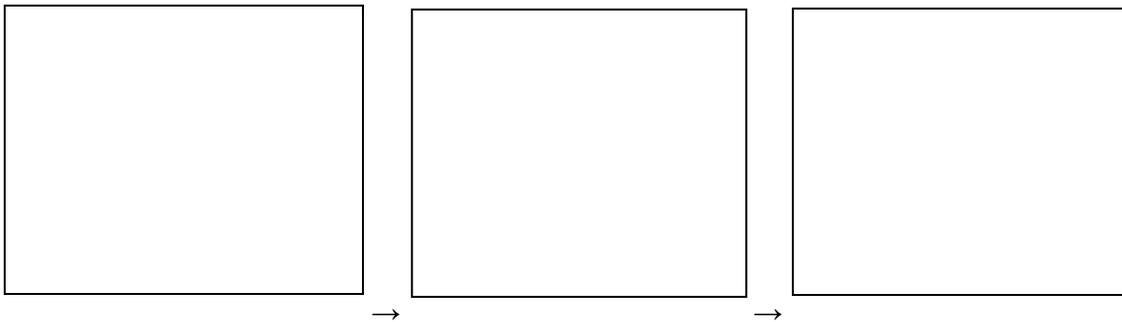
BEAT
FEATHER

SWEATER
ANTEATER

8. Several research groups, led by Bill McGinnis, Michael Levine and Walter Gehring, examined the following question, "Do organisms other than fruit flies also have homeotic genes that regulated body patterning?"

What was the first step of their investigation?

9. Diagram the three-step process they used to find the homeobox in different organisms.



10. What did the researchers find?

11. Homeobox sequences found in most mammalian genes are very similar to those in fruit flies. These sequences have been conserved throughout evolution without much change. What does 'conserved' mean?

12. What are genes in different organisms that share similar sequence and function called?

13. How is amount of evolutionary time and the extent to which gene sequence and organization are conserved between organisms related?

14. What can gene organization tell us about evolutionary relationships between organisms?

15. What is a paralog? _____

16. If a scientist wanted to mutate a specific gene to see what impact it would have on the organism, what difficulties might they encounter in making a conclusion?

17. Natural homeotic mutations can be an effective means for evolutionary change. How might a homeotic mutation be helpful to a species?

18. When might a homeotic mutation be harmful to a species?

Student Handout 3: Background Information on How Genes Determine Body Patterns (If Internet access is not available.)

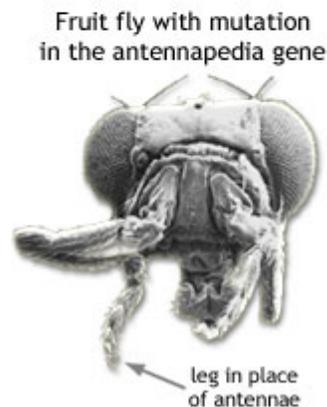
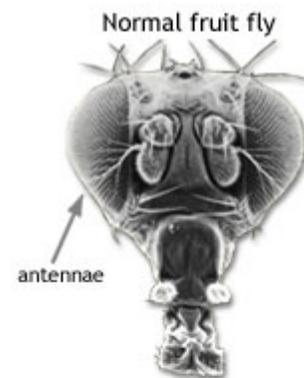
If Internet access to <http://gslc.genetics.utah.edu/units/basics/bodypatterns/> is not available, read the following information that has been selected from the Web site. Every organism has a unique body pattern. Although specialized body structures, such as arms and legs, may be similar in makeup (for example, both are made of muscle and bone), their shapes and details are different. During growth of the embryo, arms and legs develop differently due to the actions of special genes, called homeotic genes, which specify how structures develop in different segments of the body.

1. How Did Scientists Discover the Genes That Determine Body Pattern?

Scientists discovered these genes by studying bizarre mutations in fruit flies. They correlated mutations in different genes with transformations in the flies' body patterns. These types of mutations, called homeotic mutations, cause structures in one body segment to be replaced by structures normally found in another segment.

One research group, led by biologist Ed Lewis, studied fruit flies that had legs growing out of their heads in place of antennae! They found that a mutation in a single gene, called *Antennapedia*, made this transformation happen. Scientists believe that this mutation changes not only the antennal structure, but makes that entire segment of the fruit fly's body develop as if it were a different segment.

Dr. Lewis's work demonstrated that antennal cells carry all of the information necessary to become leg cells. This is a general principle: every cell in an organism carries, within its DNA, all of the information necessary to build the entire organism.



While studying the DNA sequences of many genes that control body pattern, researchers found that each contains a similar stretch of about 180 nucleotides within its sequence. They named this stretch a homeobox and classified all genes containing it as homeotic genes. The homeobox is only a portion of each gene. For example, if the following words were homeotic genes, the underlined letters would represent the homeobox:

together, theoretical, gathering, bother

3. Many Organisms Have Similar Sets of Homeotic Genes?

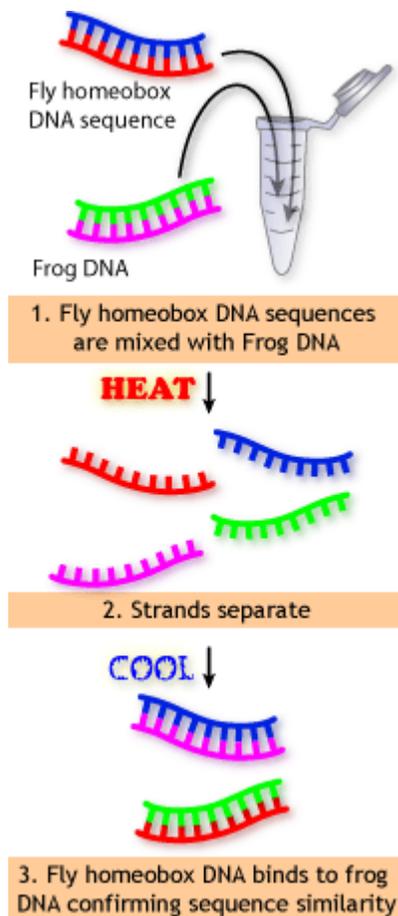
NOTE: If this page is not in color on your Handout, you will need to refer to the color transparency of this page displayed by your teacher.

Researchers were curious to know whether organisms other than fruit flies also had homeotic genes that regulated body patterning. Several research groups, led by Bill McGinnis, Michael Levine and Walter Gehring, examined this question.

First, they looked through the DNA from a variety of animals for sequences similar to the homeobox. They took advantage of the fact that DNA is double stranded, meaning that DNA is composed of two separable strands, connected by A-T and C-G base pairs.

The two strands in DNA can be melted apart at high temperatures. Once separated, the strands are free to pair with other DNA molecules in the same mixture. If the two original strands are the only molecules in the mixture, then they will re-pair with each other, reforming the original double-stranded DNA molecule. If other DNA molecules with similar sequences are present in the mixture, then new double-stranded DNA molecules will be formed using different combinations of single strands.

To see whether other animals contain homeobox sequences in their DNA, the researchers mixed fruit fly homeobox DNA sequences with DNA from other animals, such as frogs. They heated the mixture to separate the DNA strands, then allowed the mixture to cool slowly. The slow cooling process allows DNA molecules with complementary sequences to find each other and pair together. Then they observed whether double stranded DNA sequences had formed between the fruit fly and frog DNA. Finally, they isolated the frog sequences that had base paired with the fruit fly homeobox DNA and determined the frog DNA sequence.



The following conclusions were made:

- Every animal tested had homeobox sequences in its DNA.
- Homeobox sequences found in most mammalian genes are very similar to those in fruit flies. These sequences have been conserved throughout evolution without much change.
- Gene sequences maintained over evolutionary time are thought to be especially important to the basic development of even distantly related organisms. Genes in different organisms that share similar sequence and function are called homologous.

4. Homeotic Gene Organization is Conserved through Evolution

The extent to which gene sequence and organization are conserved between organisms gives us clues about the amount of evolutionary time that has passed since the two organisms diverged from one another. For example, the homeotic gene clusters in the flour beetle (*Tribolium*) and the fruit fly (*Drosophila*) are very similar. In contrast, the homeotic gene clusters in these two insects differ greatly from those in the mouse. The presence of homeotic gene sequences in animals as different as insects and mammals suggests that this type of gene has a crucial function in many, and perhaps all, animals. In studying the effects on evolution scientist have determined that those homeotic genes that cluster tightly on one chromosome (called tight linkage), as is found on the flour beetle, are more likely to be inherited by the next generation as a linked group. The homeotic genes of the fruit fly are broken into two clusters on the same chromosome but the mouse has four homeotic gene clusters, all similar but on different chromosomes suggesting the homeotic cluster has been duplicated four times.

4. Mutations in Mammalian Homeotic Genes

Homeotic genes in mammalian genomes appear to have been duplicated over evolutionary time. If you line them up using DNA sequence as a guide, you can see that the genes' organization is conserved but with each duplication, it appears that most are incomplete, missing some fraction of the genes that were present in the ancestral gene cluster. However, the genes that are retained and correspond to each other in each duplicated cluster are called paralogs. Paralogs have similar and often overlapping functions in the animal. For this reason it is difficult to study the function of a homeotic gene by making a mutation in the gene and studying its effects as the effects may well be hidden by the normal functions of other genes in the same paralogous group. To remove the function provided by a group of paralogs, a mutation must be made in every gene in the group. Then dramatic effects can be observed.

5. Homeotic Mutations Could Be Involved In Evolutionary Change

Organisms can survive and reproduce even with homeotic gene mutations that produce differences in body shape. This means that homeotic mutations can be an effective means for evolutionary change. For example, in a mammal, a single homeotic mutation might produce an arm that is shorter, or longer, or broader. Regardless, it will probably still look and work like an arm.

A change in body shape might lead to an advantage for an organism. For example, the mutation may allow it to capture food more effectively or be more attractive in some way. If this is the case, then the mutant organism may have greater reproductive fitness. Its genes may be preferentially passed along to the next generation, thus influencing the course of evolution.

Additional Resources

Because Web sites frequently change, some of these resources may no longer be available. Use a search engine and related key words to generate new Web sites.

Resources for Developmental Biology:

- <http://www.bio.umass.edu/biology/karlstrom/KarlstromLab.html> Movie of Zebrafish Development - fish development from one cell to the formation of the pre-backbone by R. Karlstrom and D. Kane, courtesy of the Max- Planck Institute for Embryology
- <http://www.ucalgary.ca/UofC/eduweb/virtualembryo/> Leon Browder's Virtual Embryo
- <http://www.luc.edu/depts/biology/Movies> Bill Wasserman's Developmental Biology Page - source of informative links on developmental biology in a variety of organisms
- <http://www.visembryo.com/> The Visible Embryo - the first four weeks of human development, explanations and images
- <http://worms.zoology.wisc.edu/frogs/welcome.html> Jeff Hardin's Amphibian Embryology Tutorial - lots of info and many pictures, explanation of amphibians as developmental models
- <http://zygote.swarthmore.edu/> Scott Gilbert's excellent site, ZYGOTE, an up-to-date review of developmental biology. Also see his list of other links, arranged by topic.

Resources for Evolutionary Theory:

- <http://www.ucmp.berkeley.edu/history/evolution.html> History of The Theory of Evolution - University of CA Berkeley
- <http://www.kheper.net/evolution/evolution.htm> Evolution Resources - Kheper
- <http://home.wxs.nl/~gkorthof/index.htm> Was Darwin Wrong? - The Critics of Evolution

Genomic Revolution The Web site to the government-funded Human Genome Project with links about genomics, the history of the project, and more.

http://www.ornl.gov/sci/techresources/Human_Genome/education/education.shtml

Secrets of the Sequence Videos and Lessons

This video and 49 others with their accompanying lessons are available *at no charge* from www.vcu.edu/lifesci/sosq