

**UNDERSTANDING
EVOLUTION:**
Inheritance & Change

UNDERSTANDING EVOLUTION

CREDITS

WRITER

Matthew Lovering

VIDEO SCRIPT

Matthew Lovering

TEACHER'S RESOURCE BOOK

B. Ellen Friedman, Ph.D.

E. Friedman Consulting

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UNDERSTANDING EVOLUTION

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Evolution is one of the most powerful ideas ever introduced into the study of life. This organizing principle explains the continuous thread of life and the great diversity of living things through over 3 billions years of Earth's history. One of the best skills you can give your biology students is a firm grasp of the meaning of biological evolution. The video *Understanding Evolution* gives you an effective tool to help that happen.

How will you approach this sometimes daunting topic? By combining the preview questions and student activities of this teaching guide with the experience of watching the video, you can bring this topic alive for your students. The program *Understanding Evolution* provides a strong mix of basic concepts reinforced with specific detailed knowledge. Students are given a variety of examples to stimulate their interest and to provide a concrete basis on which to build their understanding. The activities then reinforce and expand this understanding, in order to give students a lasting grasp of this important topic.

Long-term biological change over time, change that is passed from one generation to another – this is evolution. Students watching the video are introduced immediately to the key ideas underlying biological evolution, summarized in four basic points. The program then explores the mechanisms of evolutionary change and the evidence that supports this explanation. The topic is examined at the level of whole populations, of individual organisms of different species and at the molecular level. Students see the essential connection between genetic mutation and evolutionary change.

The color, motion and narration of the video portion of *Understanding Evolution* help students to think through the ideas of evolution in an active way that will stick with them. Once students understand the basic principles of evolution, they can apply their knowledge to current observations and to reports in the news and scientific literature. Student activities in the Teaching Guide offer this opportunity as well as some basic drill and review of the central issues and specific knowledge. The Guide also includes a convenient glossary, suggested strategies for how to use the program to teach evolution and useful reading and website references.

UNDERSTANDING EVOLUTION

LEARNING OBJECTIVES

After viewing the video program *Understanding Evolution* and using the student activities and exercises, your students should be able to:

- recognize that evolution is long-term, heritable change in living systems.
- state the four basic points regarding evolution (genetic variation, role of environmental pressures, adaptation, inheritance over many generations).
- diagram the importance of relative survival of offspring in different populations
- explain the effect of meiosis on genetic variation.
- describe what a mutation is in molecular terms and what role it plays in evolution.
- contrast different patterns of evolutionary change, such as divergent versus convergent evolution.
- explain what an allele is and how the frequency of alleles changes in different populations.
- compare analogous and homologous features.
- use fossil and other evidence to explanation evolutionary change.
- apply this understanding of evolution to new situations they encounter.

Evolution comes alive in the video *Understanding Evolution*. The images are fresh and engaging, and the narration builds a strong and logical train of thought about evolutionary processes. The program opens by posing the question, “Why are there so many different types of organisms?” and then shows how biological evolution has produced diversity across the planet.

An analogy to the changes seen in car models across years of production is used to help students think about form and function. However, the program explains that changes in evolution happen through a very different process. Biological evolution involves random mutation and a process of selection through competition to survive. The video combines animated graphics with live images to illustrate these ideas. The concept of evolution through natural selection is developed in a logical way for students by breaking it down into four key points:

- There are variations in the genes carried by individuals
- Environmental pressures select some individuals and reject others
- The best adapted individuals have genes that allow them to survive
- Genes are passed on to many generations

The environmental pressures come in a variety of forms, such as predation and changes in surrounding conditions. As organisms struggle to survive, some reach an age to reproduce successfully and some do not. Gradually, the genes of those who most often produce offspring become the genes most represented in the population. In other words, these genes best suit the individuals to cope with problems.

The program touches briefly on the history of the scientific idea of evolution by mentioning Charles Darwin and Alfred Russell Wallace who first proposed it. The image of the scientific paper of 1858 and subsequent book (by Darwin) in 1859 remind students of the importance of careful reporting to the scientific community.

The topic then shifts to go deeper into the mechanisms that underlie biological evolution, beginning with mutation. Animated graphic illustrations show that DNA, the genetic material used for storage of information, must be copied to pass on information to new cells and eventually to offspring. Although the copying process is almost entirely faithful, errors occur. These are mutations. If they occur during meiosis in sexually reproducing organisms, the errors are passed along in the gametes to the offspring. This process (along with recombination in meiotic crossing over) gives the supply of genetic variation that is the source material for evolutionary change. The program does not belabor the molecular details, but it does present a foundation for understanding by describing the molecular basis for mutation.

An example from modern species is given with a graphic showing a species of mollusk (snail) with color and pattern variations in the shell. This example is used to introduce the idea of alleles. The program goes on to show that although many mutations are neutral (and some are harmful) mutations sometimes become advantageous. This benefit results when environmental conditions change: the mutation may confer an advantage in the new situation for those individuals who have the mutant trait. The battle between farmers using chemical insecticides and insects who develop resistance is given as an example.

The frequency of alleles in a population can change, sometimes through chance and sometimes because part of a population is killed (bottleneck) or is isolated (founder effect). Subspecies can develop in these conditions. A colorful example of the emergence of subspecies is shown in the bird known as Crimson Rosella. When subspecies become so different that they can no longer interbreed, they are considered to be two separate species, an example of divergent evolution.

Appearances can be misleading, however. This situation is true of organisms with similar shape or characteristics but which are not closely related. Their similar traits, or analogous structures, reflect a common environmental pressure that has led to similar adaptations in different evolutionary branches. This situation is known as convergent evolution. Moving video footage of sharks and dolphins provides a clear illustration of analogous structures in very different species. Other examples include interesting marsupials with backwards opening pouches.

In cases where structures are homologous – derived from same ancestors even if the function is now different – the evidence can be a powerful clue to lineage. Vertebrates share a similar layout of bones in the arm and hand (pentadactyl or 5-fingered limb). Yet this structure serves a very different role in humans, horses or birds. Images of the skeletal structure reinforce this explanation.

Some structures remain despite the fact that they are no longer needed. Wings in flightless birds are examples of these vestigial structures.

A useful way to track the shared lineage of groups of organisms is to examine their development. A strong example is the similarity of embryos in vertebrate animals such as fish, birds, reptiles and mammals. The early stages are remarkably similar. Only later in development do the specialized cells and tissues begin to distinguish one species from the other.

Another way to investigate evolutionary connections is through molecular similarities. In particular, the degree of similarity in genetic information can be measured through comparing the genetic sequences in the DNA of each species of interest. The video shows laboratory workers loading DNA samples on an electrophoresis gel to identify the sequences. Using techniques such as this, scientists have discovered that the degree of similarity in DNA sequence between humans and our nearest relatives, chimpanzees, is remarkably high – 98%. This information, coupled with knowledge of mutation rate, puts the age of the split between humans and chimpanzees from the ancestral stock at 5-6 million years ago. This split is much more recent than that between human lineage and frog – about 350 million years ago, based on the DNA evidence. Another biochemical comparison is based on protein structure, comparing amino acid sequence to make a “molecular clock”.

Some evidence is present on a larger scale, such as fossils. Fossils are the impressions or casts of dead organisms whose bodies have been replaced by inorganic minerals. Fossils show the structures of ancient life, the other organisms with which they were associated and can provide clues to the time period in which the organisms lived. The latter evidence is based on the ordering of layers in which the fossils are found. In addition, fossils can show a frozen moment in evolutionary time. Such a fossil is the footprint of one of the earliest land animals from 370 million years ago. The image shows the five toes of the foot – the same body plan as we have ourselves. Other fossil stories are told in the horse lineage in North America from 50 million years ago. The video traces the changes from the tiny *Hyrcotherium*. It lived in soft marshy land and had 3 or 4 digits that touched the ground as it walked. From this derived the horse relatives that lived on dry grasslands. Eventually the modern horse evolved with its one exaggerated digit as a hoof to protect it as it walks and runs on hard surfaces.

The final story of the video explores the separation of land masses into today’s continents. Geographical distribution of flightless birds hints at the time when the continents were not separated by water. Prior to 120 million years ago, a giant land mass we have named Gondwana formed a super continent. The video also explains some dating methods to measure the age of fossils. These include radioactive dating using potassium-argon and carbon isotopes. A simple but clear explanation of these methods and their different applications for different time periods will help students understand how fossils are analyzed. These examples help students grasp the stunningly great age of the Earth and its inhabitants. The video closes on a last look at the big ideas in biological evolution.

National Science Education Content Standards

The National Science Education Content Standards for biology emphasize the importance of evolution as a major concept for understanding living systems. The video *Understanding Evolution* provides a useful vehicle to teach the concepts described in the standards. For a complete discussion, see an online copy of the standards in print or at this URL:

<http://www.nap.edu/readingroom/books/nses/html/6e.html>

Some of the concepts of biological evolution are summarized here:

1. Species evolve – in other words, as they introduce modifications as they continue through time. How does this happen? Competition for resources and survival acts on genetic variability to select certain offspring (and their genes) as better suited for survival in a particular environment.
2. Diversity results from more than 3.5 billion years of evolution.
3. Fossil evidence, molecular clues and other evidence are consistent with natural selection as an explanation of how evolution occurs.
4. Life on Earth is descended from common ancestors.
5. Biological classification reflects the evolutionary relationships between organisms.

The video and activities present these ideas and offer opportunities to use and reinforces them. Students are particularly encouraged to make the connection between evidence and the observation that (a) evolution takes place (b) natural selection is a useful explanation of the mechanism by which evolution occurs. Ideas of the vast nature of geological / evolutionary time also are reinforced by the video and exercises.

Make it logical: In effectively teaching evolution it is essential to help students construct logical chains of thought, not just memorize facts. The video is useful in this task, because it explains the four key aspects of the topic and then delves deeper into the mechanisms for studying evolution.

Make it active: The activities help students review the material from the video and allows them to reinforce what they have learned and apply it to new situations. Help students see that evolution is an active process that has shaped the living world and continues in modern times.

Don't be afraid: Evolution has been selected by some people out of the many scientific explanations and theories to be the target of attacks – but keep in mind that evolution is not only broadly accepted by scientists, it is the fundamental, organizing principle of biology. Some people confuse the rich and ongoing investigations into the events and mechanisms of evolution as a controversy over the idea of evolution itself – that is not correct. Evolution is the explanation that best fits the evidence in scientific terms. (There are non-scientific approaches to explaining life, but they are not a part of the study of biology, just as music and French literature are not taught in biology. The biology classroom is the appropriate place to learn the scientific explanation, evolution.) Some recommended reading on this topic, including the position statement of the National Academy of Sciences, is given at the end of the Teaching Guide.

You can increase students' ability to pick up ideas from the video by providing some preview questions to spark their interest and get them focused. These questions can be raised and briefly discussed to poll pre-existing ideas, or they can just be raised and left open to pique interest. Suggested preview questions are as follows:

Using Preview Questions

- What is meant by “biological evolution”?
- How does evolution happen?
- What evidence supports these explanations?
- Is evolution going on now?

You can also revisit these preview questions after students view the video so that they can expand and adjust their early ideas about these basic questions.

Another useful strategy is to introduce the preview questions, hold a brief discussion without pushing for complete answers, then pass out selected activities. After students have looked over the activities exercises you selected, view the video. This approach can help students look for specific ideas in the video.

A better approach is to have students hear only the preview questions beforehand and then view the video a second time after students begin work on the exercises.

Encourage students to really toy with the idea of how old the Earth is and how relatively recently the human species has appeared, compared with early bacteria or even the first land animals. Geologic time is not easy to really comprehend.

With regard to some terminology explained in the video, make certain that students do not simply memorize definitions without understanding the significance of the ideas behind the terms. The activities can help with this.

Please ascertain that in the brief explanation of meiosis given in the video that students understand clearly that a sexually reproducing organism such as a human has two copies of each chromosome (diploid). These copies are replicated and paired during meiosis. After replication of DNA but before cell division, there are a total of four copies (but each copy is a double-stranded DNA helix). The “four strands” mentioned in the narration refers to the four copies of each chromosome, not to each strand of double stranded DNA.

Teaching Notes for Activities

Copymasters for student activities are provided in the next section of this guide. Here we give you specific comments or sample responses for each activities. Please keep in mind that some activities exercises are intended to review the material in the video while others extend that material and bring in new information to enrich the student experience. Many of the exercises would work well in teams.

You may find it is helpful to have students begin their work on the exercises and then re-run the video so that they can look for specific concepts to complete the work.

Activity 1: Evolutionary Diversity

Organisms are found in essentially every part of Earth. Threads traced back would all run together – in other words, there is common descent. Diversity arises through natural selection which favors different traits in different environments.

Activity 2: Molecular Mechanisms

See glossary for definitions. The main idea in this activities is for students to think about the connection between molecular events and evolution. They should recognize inheritance with modification as a key part of evolution – the DNA provides the molecular means for that to happen. It is replicated to pass on information to offspring. Although this information is almost entirely accurate, errors do show up – these are mutations. Mutations can provide the variation in traits that produce a range of adaptive possibilities.

Meiosis provides genetic variation through errors introduced during DNA replication and through recombination. The significance of these changes is that they take place in cells that will produce offspring. Combination of gametes from two individuals is another source of new combinations of alleles. This is a good place to make certain students are clear about the behavior of chromosomes during meiosis.

Activity 3: Raw Material for Evolution

Genetic variation provides the range of traits on which natural selection acts to confer some advantage in particular environmental conditions. Because the traits can be passed along to offspring, long-lasting changes in a population of organisms can occur. If the mutation is in a body cell, it won't be passed on.

Activity 4: Mutation

Mutations can be harmful, beneficial or neutral, depending on what effect the genetic mutation has on the encoded trait. In addition, a change that is neutral or even mildly harmful in one environment may become advantageous if conditions alter.

Mutations are VERY rare events. If not, species would not survive. Student diagrams will vary but should indicate an awareness of the effect of passing on a mutation to offspring. Their relative success will determine the occurrence of the mutant allele (and its physical expression) in subsequent generations.

Activity 5: Mechanism for Change: Natural Selection

For a particular circumstance, not all offspring are equally suited to survive to reproduce.

Having students restate this important idea helps them think about the meaning of the term “natural selection”. Genetic variation provides the range of traits on which natural selection acts.

Activity 6: Extension: Mutation in the News

Student responses will vary; there are many reports of mutations from which to choose. For instance, reports on antibiotic resistance among bacteria are common.

Activity 7: Competition and Evolution

Alleles of those offspring that die before reproduction are gradually reduced in the population. The reverse is that some offspring increase the levels of particular alleles with each generation. When many insects compete for food, some will not survive. However, in the presence of pesticide, competition is essentially removed for the small number of insects who are resistant.

News updates are widespread on the topic of protections against insect pests. New chemicals are used as pesticides, and plants are genetically modified to have their own resistance. Some methods rely on using competitive insect species. Student reports will vary.

Activity 8: Allele Frequencies and Change Part I

Terms defined in glossary. A change in alleles in a population shows that the population is changing and will be able to pass on those changes.

Activity 9: Key Concepts

Students should be able to state in their own words the four main concepts presented in the opening of the video. Inquire what each step means to make certain that students have not simply memorized the statements.

The key steps listed in the video are:

- There are variations in the genes carried by individuals
- Environmental pressures select some individuals and reject others
- The best adapted individuals have genes that allow them to survive
- Genes are passed on to many generations

Activity 10: Allele Frequencies and Change Part II

These terms are defined in the glossary. Keep in mind that a change in allele frequency between generations is a clue that evolutionary change is taking place. Genetic drift refers to random change; bottleneck and founder effects show specific environmental pressures that can significantly alter allele frequency. In the bottleneck, an abrupt decrease in population limits the supply of alleles for the next generations. In the founder effect, geographic isolation can remove some alleles from the pool and over-emphasize others.

Activity 11: Origin of Structure and Function: Different Stories

The terms homologous structures, analogous structures and vestigial structures are given in the glossary.

Activity 12: Evolutionary Relationships

These examples come from the video. Students should recall that both are large animals that live in the ocean, swimming through the waters with their streamlined bodies. The shape of the body and tail, fins and flippers make them efficient and powerful swimmers. Looking more closely the student sees that the shark (unlike the dolphin) has fluttering gills used for breathing. Both animals have eyes to detect prey; less obvious is their sense of hearing and smell. Strong jaws are used to catch prey and for defense.

The video pointed out that the pectoral fin looks and functions in a similar way, but in the shark it is made of cartilage, while in the dolphin it is a limb with bones similar to those in other vertebrates. These are analogous structures.

Differences (besides that noted for the pectoral fin) include the difference in breathing (lungs versus gills). If students know that the dolphin is a mammal, they may also realize that it nurses young.

Students could use a variety of diagrams to show relative closeness of the trios of organisms. A branched line diagram is one useful approach. Whatever the layout, the diagram should convey these connections:

- Group 1: Dolphin and shark are both animals and much closer to each other than to the sunflower plant.
- Group 2: Dolphin and whale are both mammals and much closer to each other than either is to the shark (You could challenge students on this response and ask where the sunflower would be relative to the other grouping.)
- Group 3: As in the previous response, the two mammals (dolphin and seal) are closer to each other than either is to the shark.

Activity 13: Hands Down!

This fun exercise lets students quickly demonstrate how they can think about evolution and adaptation, using a familiar subject. Their responses will vary but might include a caption calling out:

- The fingers, which are jointed and good for grasping,
- The opposable thumb that improves grasp,
- Nails that are related to the claws of some animals and to the horse’s hoof (they serve as protection)
- The lack of webbing (life on land)
- Overall structure that used to be good for support in walking
- They might indicate hair or skin (protective role)

Activity 14: Make Your Own Comparisons

This exercise lets students look outside the examples in the video and use a surprising example, the beak of the octopus. There are many online images of finches and octopuses, or you could use a guidebook for birds. Some websites particularly useful for seeing the octopus beak are found at:

<http://rbcml.rbcm.gov.bc.ca/programs/expert/octopus/>

Images of octopus beak:

<http://marine.alaskapacific.edu/octopus/specimens/beakocto.html>

Students should recognize that some features have similar name, appearance or function yet the large difference in other features (lack of skeleton in octopus, etc.) show that the structures in question are not derived from direct common ancestor. They are analogous. Additional evidence in addition to more details of physiology, anatomy, and reproductive behavior would be the use of molecular (DNA sequence) evidence.

Activity 15: Evolution Today

The importance of this activity is for students to apply what they have learned and to gain experience using reliable scientific reports. They should reference their sources.

Activity 16: Geological Time

The exercise gives students a chance to do a little math to help themselves fully realize the huge expanse of geologic time and the stunningly recent appearance of humans and chimpanzees. It is also a chance to emphasize the importance of noticing units in numerical data: the human-chimpanzee split is listed in millions of years while the age of the planet is in billions. Writing the values as scientific notation may help.

The fraction of human-chimpanzee split over total age is about 1.3×10^{-3} or .0013. That is just over a tenth of one percent.

Dating methods rely on the decay of a radioactive isotope to a nonradioactive one (such as potassium-40 to argon-40 or carbon-14 to carbon-12). Carbon dating is used for more recent time periods than is the potassium-argon system.

Activity 17: Geology and Evolution

The video described the super continent of Gondwana that broke up to form several modern continents. The process of continental drift (shifts in Earth's crust) produced the separation. The result was the isolation of species, including the flightless birds found on several continents (for example the New Zealand Kiwi and the geographically distant African Ostrich). The fact that these species are flightless lessens the chance that they simply migrated between land areas over the seas.

Activity 18: Fossils: Stories in Time

Student responses will vary. There are many fine examples, including the dinosaur fossils that are so often in the news. Students should be able to explain that a fossil is an impression or cast in which organic material is replaced by inorganic minerals. Soft bodied organisms are not generally represented in the fossil record. Single-celled organisms can leave fossils. Stromatolite mounds are built of bacterial remains.

The video gave an example of a footprint impression being preserved as a fossil, capturing a moment in time, in the stride of the organism.

The location of the fossil geographically, the layer of earth in which it is found and the other types of fossils found near by are all clues to the life and evolution of the organism whose body produced the fossil evidence.

STUDENT ACTIVITIES

NAME: _____

ACTIVITY 1
EVOLUTIONARY DIVERSITY

In the video you saw a variety of life forms. Using what you learned from the video and what you already know from other sources, answer these questions.

Of the organisms shown in the video, which did you find the most interesting or unusual?

In what parts of Earth is life found?

If you traced back the thread of each life story of each species on Earth today, where would all the threads lead?

How does biological evolution produce diversity in living things?

NAME: _____

ACTIVITY 2
MOLECULAR MECHANISMS

We can see visible clues about evolution by looking at the diversity among species alive today and by looking at fossils. However, some of the events that lead to evolution occur at a molecular level. Describe these events by answering the following questions.

Briefly define these terms by explaining what they have to do with evolution:

DNA

mitosis

meiosis

mutation

NAME: _____

ACTIVITY 3

SKETCHING MEIOSIS

Draw a sketch to show the steps in meiosis:

- (a) In a cell, there are two copies of each chromosome, one from each parent
- (b) the DNA in the chromosomes is replicated – now there are four copies of the DNA (each is a double-stranded helix, but you can represent each DNA molecule as a single long chromosome)
- (c) two rounds of cell division occur
- (d) One of the four key points that the video stated about evolution is that genes vary

NAME: _____

ACTIVITY 5
MUTATION

Are mutations helpful, harmful or neutral? Explain, giving specific examples.

About how often do mutations occur? In other words, are mutations rare events or do they happen frequently?

Draw a diagram to show how a mutation in a single organism could lead to an evolutionary shift in the population.

NAME: _____

ACTIVITY 11
ALLELE FREQUENCIES
AND CHANGE PART II

Describe what is meant by the term “Genetic Drift”

What is the Bottleneck Effect?

Explain how the Founder Effect brings about a change in frequency of alleles:

NAME: _____

Define these terms and give an example of each:

Homologous structures:

Analogous structures:

Vestigial structures:

NAME: _____

ACTIVITY 13
EVOLUTIONARY RELATIONSHIPS

Dolphins and sharks both are found in ocean waters, sometimes in the same location. Think about seeing them moving in the video. How does their structure help them live in their watery home?

Compare the pectoral fin of a shark and dolphin. Is this an analogous or homologous structure? Explain.

Recall from the video some key differences in sharks and dolphins:

For each group of organisms, provide a simple diagram to compare their relative degree of relatedness to one another. In other words, in each set of organisms, who is closest and who is the farthest apart in evolutionary history? Be prepared to explain your reasoning.

Dolphin – shark – sunflower

Dolphin – shark – whale

Dolphin- shark – seal

NAME: _____

ACTIVITY 14

HANDS DOWN!

On this sheet, sketch or trace your hand. Then label the parts to show how the structure has been shaped by evolutionary process. Include a written explanation as needed.

NAME: _____

ACTIVITY 15

MAKE YOUR OWN COMPARISONS

House finches and goldfinches are two species of birds that both have hard beak structures that they use to break open seeds for food.

An octopus, which is a boneless mollusk, has a very different appearance than a bird. They also have a hard beak-like structure used to kill or crack apart their food.

(You may find it useful to consult a guidebook to birds or sea life or to look online to find a picture of each species.)

What similar function does the beak serve in finches and in the octopus?

What differences are you aware of between these organisms?

Is the beak in each case an analogous structure or a homologous structure between these species? Explain.

You have observed the appearance of the beak in each case and obtained information about its function. What additional evidence would help you decide if the beaks are analogous or homologous structures?

If the beaks are found to be analogous, what does that tell you about the evolution of these organisms?

NAME: _____

ACTIVITY 16

EVOLUTION TODAY

Many reports tell of fossil finds that include creatures now extinct, such as huge dinosaurs. Is evolution just a process of the ancient past, or is it an active process that is occurring today? Prepare an oral or written report to answer this question, using examples from news reports.

NAME: _____

ACTIVITY 17
GEOLOGIC TIME

The DNA sequences of humans differ from that of chimpanzees by only about 2%, showing a recent split from the ancestral organisms. The date of the split is about 5-6 million years ago.

The Earth is about 4.5 billion years old. For what percentage of that time have humans existed as a separate lineage from chimpanzees?

What is potassium-argon dating?

What is potassium-argon dating?

How can radiocarbon dating and potassium-argon dating be used as an effective combination in studying evolution?

NAME: _____

ACTIVITY 18
GEOLOGY AND EVOLUTION

The video explained that the modern continents were not always in their current shape and location.

What is Gondwana?

Describe the large geologic events that put the continents where they are today.

How does the modern distribution of flightless birds relate to the geologic history of continents?

NAME: _____

As you respond to these questions, use examples from the video and from outside sources.

What are fossils?

How do fossils provide evidence about the evolutionary history of organisms?

How can a fossil provide a “snapshot of a moment in time”?

FACT SHEETS

Alleles: Slightly different forms of the same gene.

Analogous structures: Biological structures that serve a similar function but that are not closely related in evolutionary history.

Bottleneck effect: A shift in the total frequency of alleles in a population that results from a severe reduction in population numbers. The small number of survivors may not comprise the full range of allele combinations that were originally present.

Convergent evolution: Evolutionary change in organisms such that they come to resemble each other more closely, although they are not directly related evolutionarily. Convergent evolution may result from exposure to similar environmental pressures.

Darwin, Charles: One of the first scientists to formally propose, with substantial evidence, the idea of biological evolution as the origin of species.

Divergent evolution: Gradual separation and changes among organisms that were once closely related or belonging to the same species. For example, as subspecies stay isolated by a geographical barrier for a very long time, the differences between them may grow so large that they no longer can interbreed.

DNA: Abbreviation for deoxyribonucleic acid, the storage molecule for genetic information.

Evolution: Genetic change in a population (changes in the allele frequency) over time that results from natural selective pressures acting on genetic variation in the population.

Homologous structures: Structures that are similar because they are derived from the same ancestral stock, that is, they are closely related in an evolutionary sense.

Gametes: The cells produced for sexual reproduction. Sperm and egg cells are gametes. They have half the normal complement of genetic information.

Genetic drift: Changes in the frequency of alleles that result from random chance.

Gondwana: A super continent from which continental drift broke away modern continents (Antarctica, Africa, India, South America, Australia).

Meiosis: Special cell division process in sexually reproducing organisms in which produces sex cells or gametes. They have half the normal complement of genetic information. After DNA replication and pairing of homologous chromosomes, there are two rounds of division resulting in 4 haploid cells (gametes) for each original diploid cell.

Mitosis: Process of cell division in which the genetic material (DNA) is copied before a cell divides, providing a normal complement of DNA for each daughter cell. For example, a diploid cell gives rise to two diploid cells.

Mutation: Error in the genetic information (DNA) that can be copied and passed on to new cells or to new organisms (if it occurs in the reproductive cells). Mutations are one source of genetic variation, the raw material of evolutionary change.

Natural selection: A mechanism for biological evolution. Natural selection refers to the process through which certain offspring are more suited to survive and consequently more likely to contribute their genetic makeup to the next generation.

Pentadactyl limb: Limb with five digits such as that found in vertebrate animals.

Species: A unit of classification based on evolutionary relationships. Specifically, a species is a group of organisms that are very similar and can interbreed.

Variation (genetic): differences in inherited traits in a population. Genetic variation provides the raw material for evolutionary change as some individuals may have an advantage for survival in response to particular environmental conditions.

Vestigial structures: Inherited structures that are no longer needed. If the underlying genetic information continues to be passed on to offspring, the useless structures remain and sometimes offer clues to earlier connections between species.

Wallace, Alfred Russell: Scientist who proposed an explanation of biological diversity through evolution at the same time that Charles Darwin made a similar proposal to the scientific community.

These interesting articles and books are listed in chronological order. They represent only a small sample of the many publications about on-going work in the study of evolution.

Books

Diamond, Jared, *The Third Chimpanzee*. HarperCollins Publishers, New York, 1992.

Farrington, Benjamin, *What Darwin Really Said*. Schoken Books, New York, 1966.

National Academy of Sciences (position statement) *Science and creationism – A View from the National Academy of Sciences*. National Academy Press, Washington, D.C. 1999.

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