In this hands-on, minds-on activity, students learn about the two ways that evolution produces similarities: (1) inheritance from a shared evolutionary ancestor (homologous characteristics) and (2) independent evolution of similar characteristics to accomplish the same function (analogous characteristics). Students use these concepts to analyze the similarities and differences between bat and squirrel skeletons and between bat and insect wings. In the laboratory investigation, students observe the external anatomy and locomotion of earthworms, mealworms, and crickets. Students use these observations and the concepts they have learned to figure out which two of these animals are more closely related evolutionarily.

Before your students begin this activity, it will be very helpful if they are familiar with natural selection. For this purpose, I recommend “What is natural selection?” (https://serendipstudio.org/exchange/bioactivities/NaturalSelectionIntro).

If your lab period is 40-50 minutes long, I recommend that you complete class discussion of questions 1-9 before the lab period, so you will have enough time for the laboratory investigation.

Learning Goals
In accord with the Next Generation Science Standards:

- Students prepare for the Performance Expectation MS-LS4-2. “Apply scientific ideas to construct an explanation for the anatomical similarities and differences among modern organisms … to infer evolutionary relationships.”
- Students learn the Disciplinary Core Idea, LS4.A. “Anatomical similarities and differences between various organisms living today …, enable the reconstruction of evolutionary history and the inference of lines of evolutionary descent.”
- Students engage in the Scientific Practices:
  - “Analyze and interpret data to determine similarities and differences in findings.”
  - “Apply scientific ideas, principles, and/or evidence to construct an explanation for real-world phenomena, examples, or events.”
- This activity provides the opportunity to discuss the Crosscutting Concept, “Patterns can be used to identify cause and effect relationships.”

Additional Learning Goals
Students will understand:

- the distinction between similarities due to inheritance from shared evolutionary ancestors (homologous characteristics) and similarities due to independent evolution of similar characteristics to accomplish the same function (analogous characteristics)
- the relationship between form and function.

Equipment and Supplies for each 6-9 students in your largest class:

- 5 live earthworms (e.g., *Lumbricus terrestris*)
- 5 live mealworms (larvae of *Tenebrio molliert*)
- 5 live crickets (e.g., *Acheta domestica*)

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1 By Dr. Ingrid Waldron, Department of Biology, University of Pennsylvania, © 2021. These Teacher Preparation Notes and the related Student Handout, are available at http://serendipstudio.org/exchange/bioactivities/EvolSimil.

These animals can be purchased online or from local pet store (e.g., Petco). You can reuse the animals all day but, depending on how many classes you teach, you may want to buy replicate sets to ensure freshness and mobility for each class. If you will not be using the animals right away, make sure they are stored in containers with holes punched in the lids or screens on top to allow gas exchange. Instructions for care of the animals can be found in the following sources:

- mealworms – [https://www.fossweb.com/mealworm](https://www.fossweb.com/mealworm)
- crickets – [https://www.flinnsci.com/api/library/Download/87e4d66b70df4826992dfd252d78e14d](https://www.flinnsci.com/api/library/Download/87e4d66b70df4826992dfd252d78e14d)

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### Display containers:

- 2 medium sized plastic containers (volume ~2-4 cups)
- 1 gallon-sized plastic bag (Ziploc or with tie)
- 2 plastic trays or plates + paper towels

### Magnifying glasses or hand lenses (2-4)

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### Optional:

- 2 dissecting microscopes
- 2 rulers
- 1 glove for each student (If you don’t provide gloves, make sure that the students wash their hands after handling the animals.)

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**For each 6-9 students, set up 3 stations.**

1. Place 5 mealworms in one of the display containers.
2. Place 5 earthworms on a damp paper towel in one of the display containers and cover them with a damp paper towel so they stay moist and active.
3. Crickets are best viewed in a sealed plastic bag that has been expanded to full volume (either the bag they come in from the pet store or a 1-gallon plastic storage bag with a few crickets). However, you cannot keep the crickets in a sealed bag overnight and must store them in a different covered container with a screen on top or holes in the lid. Be careful the crickets don’t jump away during transfer.

For each station 1 and station 2, have 1 or 2 hand lens or magnifying glasses available and possibly a ruler and/or a dissecting microscope.

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### Instructional Suggestions and Biology Background

To maximize student participation and learning, I suggest that you have your students work individually or in pairs to complete each group of related questions and then have a class discussion after each group of questions. In each discussion, you can probe student thinking and help them develop a sound understanding of the concepts and information covered before moving on to the next group of related questions.

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A key is available upon request to Ingrid Waldron ([iwaldron@upenn.edu](mailto:iwaldron@upenn.edu)). The following paragraphs provide additional instructional suggestions and background information – some for inclusion in your class discussions and some to provide you with relevant background that may be useful for your understanding and/or for responding to student questions.

The anchoring phenomena for this activity are the similarities and differences shown in figures and observed in the laboratory investigation. The driving question is “What are the evolutionary processes that result in the similarities and differences?”
Squirrels are familiar to most students, and a squirrel skeleton shows enough resemblance to a human skeleton for most students to readily identify many of the bones. Squirrels’ tails appear to have multiple functions, including communication and helping with balance during locomotion.

The figure below may aid the interpretation of the bat skeleton shown in the Student Handout. Both squirrels and bats are mammals, but squirrels are in the order Rodentia and bats are in the order Chiroptera.

Questions 1d and 2b provide the opportunity to discuss how natural selection results in “form matches function”. For question 2b, students should propose that natural selection favored the differences between bat and squirrel skeletons as bat and squirrel ancestors evolved different modes of locomotion. The fossil record provides little insight about intermediate stages in the development of bat flight, but the main hypothesis is that wing precursors initially evolved for gliding, followed by muscle attachments that allowed steering, and finally wings that the animal could flap to produce powered flight.

The main components of bones are a mineral, hydroxyapatite (Ca_{10}(PO_4)_6(OH)_2), and the protein, collagen. In contrast, insect exoskeletons are made of the polysaccharide, chitin (see figure) and proteins. The thicker parts of an exoskeleton provide protection and support and also points of attachment for the insect’s muscles. At the joints, the exoskeleton is thinner and flexible. The exoskeleton is relatively impermeable to water, so it prevents insects from drying out.

If your students are not familiar with molting, you may want to show them the very brief time lapse movie of a cicada molting out of its exoskeleton available at

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3 A similar evolutionary sequence of adaptive steps is analyzed in "How Eyes Evolved – Analyzing the Evidence" (https://serendipstudio.org/exchange/bioactivities/evoeye).
As discussed in questions 4 and 5, insects and bats are descended from different evolutionary ancestors that had very different types of skeletons. In these evolutionarily distant groups, natural selection had very different raw materials to shape into wings. This explains why insect and bat wings are made of very different components.

This figure shows a cross-section of an insect wing with a thin “wing membrane” and the thicker supporting “veins”. The exoskeleton is labeled as “cuticle”. (The tracheae are tubes for gas exchange. Insects have an open circulatory system in which blood is not confined to blood vessels, so the blood moves through body cavities.)

This figure shows a mammalian bone. Bat wings are supported by bones that are thinner and lighter than most mammalian bones. (Bone marrow has many blood vessels. Red marrow contains blood stem cells that can become red blood cells, white blood cells, or platelets. Yellow marrow is mostly fat.)

**Homologous** structures are observed in evolutionarily related species and have been inherited from a common evolutionary ancestor. This figure shows the homologous bones of the forelimbs of tetrapods, including mammals, amphibians, reptiles and birds. This is part of the evidence that all tetrapods share an evolutionary ancestor with similar forelimb bones.⁴ Although the same bones are present in most tetrapod forelimbs, the shapes and proportions are quite different to serve different functions in different animals. This nicely illustrates Darwin’s famous evolutionary “descent with modification”.

Analogous structures share the same function, but they had separate evolutionary origins. Natural selection produced similar structures to accomplish the same function. For example, insect wings and bat wings have a similar wide thin structure, as a result of natural selection to accomplish flight. (This type of independent evolution of similar characteristics is called convergent evolution.) Analogous structures typically have different component parts. For example, bat wings are made up mainly of bones and skin, whereas insect wings are made up mainly of exoskeleton.

The Student Handout gives some important clues for distinguishing homologous vs. analogous characteristics. These clues illustrate the Crosscutting Concept, “Patterns can be used to identify cause and effect relationships” (in this case, evolutionary cause and effect). For example, multiple detailed similarities suggest inheritance from a shared evolutionary ancestor as the cause of these similarities.

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⁴ Molecular similarities indicate that all living things (including bacteria, plants, and animals) had a shared evolutionary ancestor (http://ircamera.as.arizona.edu/NatSci102/NatSci/images/convergent.htm).
Laboratory Investigation
In the laboratory investigation of earthworms, mealworms and crickets, students combine observation of the external structure and behavior of these three animals with the concepts they learned in the earlier pages to figure out which two of these animals are more closely related.

This figure shows many details of earthworm anatomy. The parts that are most relevant for this activity are the circular and longitudinal muscles in the body wall, the segments which can each change shape, and the bristles (setae). Earthworms do not have antennae or legs and their scattered eyes are microscopic, so not visible to the naked eye. Your students may notice and inquire about the clitellum, which secretes material that makes the cocoon which surrounds the eggs and fertilizing sperm when they are released by the hermaphroditic earthworm after copulation.

The slimy feel of the earthworm is due to mucus which keeps the body surface moist for gas exchange. The mucus also lubricates the earthworm as it moves through the soil.
The figures below show how an earthworm moves, using:
- waves of alternating contractions of the circular and longitudinal muscles in the body wall of each segment,
- the “hydrostatic skeleton” provided by the fluid-filled segments, and
- the setae that grip the surface for segments that have the longitudinal muscles contracted.

When the longitudinal muscles of a segment of the earthworm body are contracted, the segment gets shorter and fatter, and the setae or bristles grip the ground. When the circular muscles of a segment are contracted, the segment is elongated.

Compare the numbered segments in diagram 2 with the same segments in diagram 1 to see how:
- contraction of the circular muscles in segments 1-3 elongated these segments which pushed the head forward
- the contractions of the longitudinal muscles in segments 4-7 shortened these segments which pulled the rest of the body forward.

Videos that show earthworm locomotion include:
- “Earthworm (Lumbricus) Locomotion” [https://www.youtube.com/watch?v=0Texxu3p7I8](https://www.youtube.com/watch?v=0Texxu3p7I8)
“Movement in Earthworms” [https://www.youtube.com/watch?v=Kq1QDMWXBNM](https://www.youtube.com/watch?v=Kq1QDMWXBNM). A 4.5-minute informative and amusing video about earthworms is “The Amazing World of Earthworms in the UK” ([https://www.youtube.com/watch?v=9ZHTerOJYMA](https://www.youtube.com/watch?v=9ZHTerOJYMA)).

As shown in the figure below, mealworms have short legs and antennae and tiny eyes. Mealworms prefer a dry habitat, such as stored grain. They can extract the water they need from their food and from cellular respiration, which produces water from the metabolism of glucose.

In mealworms, as in other insects, gas exchange occurs in multiple tiny tubes called tracheae. The tracheae are guarded by spiracles which can open and close as needed for gas exchange vs. preserving body moisture.

This figure shows the external anatomy of a female cricket. (The cerci are sensitive to air currents, including sound.)

As discussed in question 19, the similar long narrow shape of earthworms and mealworms is not due to recent shared evolutionary ancestors, but rather represents convergent evolution to a form that is well-adapted to a burrowing lifestyle. Similarly, the small or microscopic eyes also represents an adaptation to the burrowing lifestyle.

Once your students have correctly identified the evolutionary relatedness of mealworms and crickets in response to question 21, you may want to show them the lifecycle of mealworms/darkling beetles (see the figure below and the 3-minute video, “The Unseen Incredibleness of Mealworms”, https://www.youtube.com/watch?v=P4w2cuH9h4). The larval stages (mealworms) are specialized for eating and growing, and the adult stage (beetle) is specialized for reproduction and dispersal.

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5 For a brief summary of additional information about crickets, see http://www.enchantedlearning.com/subjects/insects/orthoptera/Cricket.shtml.

6 You may want to contrast the type of development in mealworms/Darkling beetles (complete metamorphosis) vs. in crickets (incomplete metamorphosis). Complete metamorphosis is observed in insects where the larval stages look completely different from the adult (e.g. mealworms or caterpillars) and the transformation from the largest larva to the adult occurs in a pupa. Incomplete metamorphosis is observed in insects like crickets where the young resemble the adults, although they lack wings; each molt produces a larger insect with more nearly adult body proportions, and the final molt produces an insect with wings and mature reproductive organs.
It may be helpful to know the classification of the animals included in this activity (see table below). Evolutionary relatedness is judged based on homologous characteristics that often are not obvious from the outside, so animals that have very different external appearance may be grouped in the same phylum (including larval forms such as mealworms and caterpillars which are grouped with other insects in the Arthropod phylum). In contrast, animals that look similar but have very different internal anatomy may be grouped in different phyla (e.g. mealworms, earthworms and other segmented worms, flatworms, and roundworms).

<table>
<thead>
<tr>
<th>Phylum</th>
<th>Subphylum</th>
<th>Class</th>
<th>Subclass</th>
<th>Order</th>
<th>Animal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annelids</td>
<td></td>
<td>Clitellates</td>
<td>Oligochaetes</td>
<td>Haplotaxida or Lumbriculida</td>
<td>Earthworms</td>
</tr>
<tr>
<td>Arthropods</td>
<td>Insects</td>
<td>Pterygota</td>
<td>winged insects</td>
<td>Coleoptera</td>
<td>Mealworms</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Orthoptera</td>
<td>Crickets</td>
</tr>
<tr>
<td>Chordates</td>
<td>Vertebrates</td>
<td>Mammals</td>
<td>Eutheria</td>
<td>Rodents</td>
<td>Squirrels</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Chiroptera</td>
<td>Bats</td>
</tr>
</tbody>
</table>

The figure below provides an overview of the phylogenetic tree of animals. Notice that exoskeletons and segmentation are not shown as key phylogenetic developments; this is because both exoskeletons and body segments appear to have evolved independently several times.\(^7\)

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\(^7\) All of the animals in this activity are bilaterally symmetric, an early evolutionary development. Bilaterally symmetric animals typically have a concentration of sensory organs at the head end, which allows the animal to gather information about the environment it is moving toward. –
Related Activities

- The analysis and discussion activity, "How Eyes Evolved – Analyzing the Evidence" (https://serendipstudio.org/exchange/bioactivities/evoeye), focuses on two questions. How could something as complex as the human eye or the octopus eye have evolved by natural selection? How can scientists learn about the evolution of eyes, given that there is very little fossil evidence? To answer these questions, students analyze evidence from comparative anatomy, mathematical modeling, and molecular biology. Students interpret this evidence to develop a likely sequence of intermediate steps in the evolution of complex eyes and to understand how each intermediate step contributed to increased survival and reproduction. Students also identify examples of homology (similarity due to common descent) and analogy (similarity due to convergent evolution).

- The online activity, “All in the Family” (https://whyy.pbslearningmedia.org/resource/tdc02.sci.life.evo.allinthefamily/all-in-the-family/) provides a challenging and sophisticated introduction to homology, analogy and related evolutionary concepts for high school or college students.
Sources of Student Handout Figures

- Insect Head – adapted from [http://faculty.valenciacollege.edu/tklenk/bio2labs/bio2labs/GrasshopperLab.htm](http://faculty.valenciacollege.edu/tklenk/bio2labs/bio2labs/GrasshopperLab.htm)
- Earthworm – [https://res.cloudinary.com/dk-find-out/image/upload/q_80,w_1920,f_auto/DCTM_Penguin_UK_DK_AL645784_zcau0r.jpg](https://res.cloudinary.com/dk-find-out/image/upload/q_80,w_1920,f_auto/DCTM_Penguin_UK_DK_AL645784_zcau0r.jpg)