beetles
Science and Teaching for Field Instructors

Professional Learning Materials

Adaptation and Evolution

The main focus of this session is developing *adult-level* understanding of evolution for instructors. Unlike most BEETLES professional learning (PL) sessions, this session is science content–focused, doesn't include model student activities, and takes place indoors. It's recommended for staff who have experienced other BEETLES PL sessions and who are open to learning more about what many scientists think is the most essential unifying topic in biological science: evolution. Some of your instructors may already have a deep understanding of the topic, while others may have very little—and they all may have (and teach) *some* inaccurate ideas about the topic. Since evolution is so complex, it's difficult for science educators to not share *some* inaccurate ideas. Although in nature we're surrounded by the fascinating *results* of evolution, instructors and students can't actually witness in the field the *process* of evolution. However, it's interesting and valuable for both instructors and students to try to figure out why the slender salamander has such tiny legs, how the fit between hummingbirds and red cone-shaped flowers came to be, or why whales don't breathe underwater.

This session uses readings to stimulate an exchange of ideas among participants. The discussion-based nature taps into what your instructors already know about the topic and gives them a chance to engage as learners in a productive struggle of ideas with one another. In the session, participants explore how natural selection interacts with genetic variation and reproductive pressure from the environment to produce the changes we see in living things over time. A backbone of the session is a mnemonic device for the critical aspects of the evolutionary process—VISTA: Variation, Inheritance, Selection, Time, and Adaptation. It's not possible to achieve a full understanding of evolutionary science in a three-hour PL session, but by sharing ideas and puzzling through interesting questions, everyone can increase their understanding and curiosity about the topic and become better prepared to teach it. A key goal is for participants to become increasingly motivated to keep digging into the topic of adaptation and evolution so they keep up an ongoing engagement with expanding both their understanding and their teaching of the topic.

Goals for the session:

- **Improve understanding of and increase curiosity about essential ideas related to adaptation and evolution.**
- **Learn to use scientific terms and share concepts accurately with upper-elementary and middle school students.**
- **Recognize some common misconceptions about adaptation and evolution.**
- **Engage in meaning-making conversations about evolutionary theory.**
- **Consider how to make choices about teaching students with different levels of understanding and experience with the topic.**

THE LAWRENCE HALL OF SCIENCE
UNIVERSITY OF CALIFORNIA, BERKELEY

ABOUT BEETLES™

BEETLES™ (Better Environmental Education Teaching, Learning, and Expertise Sharing) provides environmental education programs nationally with research-based approaches and tools to continually improve their programs.

www.beetlesproject.org

Lawrence Hall of Science is the public science center of the University of California, Berkeley. www.lawrencehallofscience.org

Special Acknowledgments:
We are grateful to former BEETLES team member Lynn Barakos for her insights, perspective, and strong foundational work on this session and write-up.

We would also like to thank Dr. Drew Talley for his expertise, knowledge, and advice in this subject area.

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The following programs contributed to the development of these materials by field testing and providing invaluable feedback. For a complete list of contributors and additional partners, please see beetlesproject.org/about/partners/

California: YMCA Camp Campbell, Rancho El Chorro Outdoor School, Blue Sky Meadow of Los Angeles County Outdoor Science School, YMCA Point Bonita, Walker Creek Ranch, Santa Cruz County Outdoor Science School, Foothill Horizons Outdoor School, Exploring New Horizons Outdoor Schools, Sierra Nevada Journeys, San Joaquin Outdoor Education, YMCA Camp Arroyo, Shady Creek Outdoor School, San Mateo Outdoor Education, Walden West Outdoor School, Westminster Woods.

Other locations: Balarat Outdoor Education, CO; Barrier Island Environmental Education Center, SC; Chincoteague Bay Field Station, VA; Eagle Bluff Environmental Learning Center, MN; Great Smoky Mountains Institute at Tremont, TN; Wellfleet Bay Wildlife Sanctuary Mass Audubon, MA; Mountain Trail Outdoor School, NC; NatureBridge (CA, WA, VA); Nature's Classroom (CT, MA, ME, NH, NY, RI); North Cascades Institute Mountain School, WA; NorthBay, MD; Outdoor Education Center at Camp Olympia, TX; The Ecology School, ME; UWSP Treehaven, WI; Wolf Ridge Environmental Learning Center, MN; YMCA Camp Mason Outdoor Center, NJ; and YMCA Erdman, HI.

Photos: Pages 1 and 2 by Kevin Beals. Icons: Backpack by Rémy Médard; Growth by Arthur Shlain; Cut by Nathan Thomson; Outside by Petr Holusa; Park by Antar Walker; Time by Wayne Middleton; & Diversity by Cara Foster all from The Noun Project.

Funding from 2012-2021 for BEETLES publications such as this one has been generously provided by the S.D. Bechtel, Jr. Foundation, The Dean Witter Foundation, Pisces Foundation, the Mary A. Crocker Trust.

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BEETLES™ Professional Learning Materials

Adaptation and Evolution

Contents

TEACHING ABOUT TEACHING

This session has been designed to practice what we preach and is set up to reflect a learning-cycle approach to instruction. In this way, participants experience a version of the learning cycle instructional model while they learn about adaptation and evolution. It's important to maintain the structure of the session so there will be opportunities for participants to struggle a bit with the concepts for themselves before discussing how to teach this concept to students. Unlike other sessions, this presentation includes quite a bit of information delivery. The assumption is that instructors have spent time exploring the topic and, in many cases, also teaching about it before experiencing the session; therefore, they are ready for more concept invention. A significant part of the session is also spent with participants' applying ideas to their teaching.

PRESENTATION OPTION

Want to spend some time outdoors? This entire session is presented indoors, largely due to the need for projecting slides. However, as instructors participate in individual, partner, and small-group work, you might choose to offer that they can conduct this work just outside your building.

TIMING TIP

Keep things moving. The prompts in the session are purposefully designed to generate productive and interesting conversations, but interesting discussions can make it challenging to stay within the estimated time frame. You may need to gently limit some of the discussion and then pick up on the topic at another time, perhaps after staff has had some experience applying what they've learned to teaching.

SESSION OVERVIEW

	Adaptation and Evolution	Activity Locations	Estimated Time
Invitation	**Introducing Evolution** Participants are introduced to evolution as the unifying idea for understanding life on Earth. To access prior knowledge, they discuss an interesting adaptation and how it may have come to be. They are introduced to a useful mnemonic (VISTA) that represents key concepts of evolution theory.	This entire session is presented indoors.	20 minutes
Exploration/Concept Invention	**Diversity and Variation** Instructors look at similarities and differences between major groups of organisms and observe illustrations of homologous structures (similar structures in different organisms) that are evidence of relatedness. Instructors are introduced to a Tree of Life diagram and a Circular Phylogenetic Tree, and they learn the benefits of each way of describing evolution.		30 minutes
Concept Invention	**Inheritance: Discussing Inheritable Traits** The incredible variation in dogs is used to illustrate how a single species can develop a variety of traits. Participants read an article about inheritance and use cards to actively map out or develop a storyline for the content of the article.		15 minutes
Concept Invention/Application	**Selection: Exploring Selective Pressures** Dogs are used once again to explain the results of artificial selective pressure on developing changes within a population. Natural selective pressures are also discussed.		20 minutes
Concept Invention/Application	**Time and Adaptation: Changes Over Deep Time** Articles describe how adaptations such as whale blowholes and giraffe necks can be explained through VISTA concepts, and some common misconceptions are addressed. Participants learn that significant adaptations usually develop over millions of years.		30 minutes

SESSION OVERVIEW (continued)

	Adaptation and Evolution	Activity Locations	Estimated Time
Application	**Putting the Pieces Together: Evolution Puzzlers** The evolution of feathers in birds is used to illustrate how evolutionary biologists think about and explain adaptations. Participants practice applying these concepts by explaining several interesting adaptations.		30 minutes
Application	**Teaching About Adaptation and Evolution** The conversation about instruction begins with discussing a few definitions for *adaptation* and moves on to discussing NGSS learning progressions and aligning activities with different grade levels.		25 minutes
Reflection	**Reflecting and Wrapping Up** Participants reflect on how their understandings have shifted during the session and how they intend to apply it to their instruction.		10 minutes
	TOTAL:		**180 minutes**

LEARNING ABOUT EVOLUTION

We all have much to learn about evolution. Even if your instructors don't specifically teach about the process of evolution with students, it's important to strive for a more accurate understanding about the topic in order to share accurate ideas as much as possible, to avoid sharing or supporting inaccurate ideas that often come up, and to use language that supports accurate ideas. We should all be humble about our understanding, do our best to keep learning more about the topic, and do what we can to avoid inaccuracies.

TEACHING TIPS

Making the session a conversation. As much as possible, this session should feel more like a collaborative conversation and less like merely delivery of content. Throughout the session, it's important to listen to participants' input, making connections between what they say and any relevant concepts (e.g., *Like Alondra was saying about the Lazuli buntings, there is variation within a species.*) Fold examples participants bring up into points made. Be a co-learner, admitting what you don't know and what you are wondering about. Use staff members as resources and collectively make plans to follow the group's questions and find more information to answer those questions after the session.

Students, participants,* and *presenter. In this document, we use the word *students* to refer to the learners your instructors work with. We use the word *participants* to refer to the adult learners participating in the professional learning session. The word *presenter* refers to the person(s) who is presenting the session. Feel free to use other terms if you prefer.

MATERIALS

For the group:
- ❑ projection system/ computer
- ❑ slides
- ❑ copies of *BEETLES Activities for Teaching Adaptation and Evolution* (pages 49–50)
- ❑ copies of any non-BEETLES activities about adaptation and evolution that you already use and have decided to share with your staff
- ❑ paper clips or envelopes (for card sets)

For each participant:
- ❑ journal (or sheet of paper)
- ❑ pencil

Handouts:

For the group, 1 copy of each *Evolution Puzzler*:
- ❑ *The Evolution of the Fiddler Crab's Large Claw* (page 40)
- ❑ *The Evolution of Horse Hooves* (page 41)
- ❑ *The Evolution of Legless Snakes* (page 42)
- ❑ *The Evolution of Blackberries* (page 43)
- ❑ *The Evolution of Dung Ball Rolling Behavior* (page 44)
- ❑ *The Evolution of Monarch Butterfly Migration* (page 45)
- ❑ *The Evolution of the Bee Stinger* (page 46)
- ❑ *The Evolution of Newt Toxin* (page 47)

(continued on next page)

PREPARATION

Before the day of the session:

1. **Prepare to present.** Choose who will present each part of the session. Most important is the ability to lead discussions well, encourage an exchange of ideas, guide the direction of discussion, etc. For suggestions on leading productive discussions, see *Encouraging Student Discussion and Productive Talk* (http://beetlesproject.org/resources/integrating-discussion-instruction/). Also important is having some level of comfort with the content (as well as comfort with being a co-learner with participants). You may want to ask another staff member who is more comfortable with leading discussions or more familiar with the *Adaptation and Evolution* content to lead or assist on specific parts of the session. To prepare, read through the session write-up, slides, handouts, sidebars, and Background Information for Presenters (starting on page 51). The more each presenter is able to "own" the session, the better the presentation. Record notes on a printed version of the session, or however you prefer.
2. **Set up a projection system/review multimedia.** Set up and test the projection system to be sure participants will be able to see items projected during the session.
3. **Make copies of the group materials—adaptation and evolution activities used in your program.** During the session, staff will look at BEETLES adaptation and evolution activities as they discuss how to best teach the topic to students within your program. Decide how many copies of the *BEETLES Activities for Teaching Adaptation and Evolution* handout (pages 49–50) you want to have available for your staff.
   - You may also want to make some copies of non-BEETLES activities about adaptation and evolution that you already use in your program and make them available for your staff to review.
4. **Choose which version of the *Inheritance: How Inheritable Traits Are Made* reading to use.** There are two versions: one that includes information about DNA and proteins (page 34), and one that omits that part and is a bit simpler (page 35). Decide which you think is most appropriate for your staff.
   - Decide if you want each participant to have their own copy of the reading and set of Inheritance Reading Cards, or if you prefer that pairs share a copy of the reading and the card set.
   - Make enough copies of the version of the reading that you chose so each participant or each pair can have their own copy.

PREPARATION (continued)

5. **Make copies of the handouts for participants.** See Materials list at left and right.
   - Make two-sided copies of the *Explanation for Blowholes in Whales (Using VISTA)* article (page 38) and the *Lamarckian Explanation for Giraffe Necks* article (page 39) so each participant can receive one sheet with both articles.
6. **Prepare sets of Inheritance Reading Cards.** Make enough copies of the 2 sheets of the Inheritance Reading Cards (pages 36–37) so each participant can get 1 set. If you prefer that participants work in pairs, make enough copies so each pair can share 1 set. Cut apart the cards and clip together each set or put each set in an individual envelope. There are 24 cards/set.
   - If you have decided to use the simpler version of the *Inheritance: How Inheritable Traits Are Made* reading, participants won't need the following three cards: *Tissue, Organs, Stuff We're Made Of* card; *Proteins* card; and *Messenger* card. You can either remove these cards or have participants set them aside during the activity.
7. **Plan when you might include a break in the schedule or whether you want to divide the session into two shorter sessions.** We suggest a break just after the "Selection: Exploring Selective Pressures" section and before the "Time and Adaptation: Changes Over Deep Time" section. If you have less time available than the 3 hours needed for this session, we strongly recommend against only doing some of the session; instead, we recommend dividing the session into two parts. A good place to pause would be after the end of the "Selection: Exploring Selective Pressures" section. The rest of the session ("Time and Adaptation: Changes Over Deep Time," "Putting the Pieces Together: Evolution Puzzlers," "Teaching About Adaptation and Evolution," and "Reflecting and Wrapping Up") could take place at another time.
8. **OPTIONAL: Make Session Overview to post on the wall.** You may choose to make a Session Overview to post on the wall during this session. Some presenters and participants prefer having it so they can see the trajectory of the session.

Immediately before the session:

1. **Set out handouts near the front of the room.**
2. **Decide where to set up Evolution Puzzler Stations.**

MATERIALS (continued)

Handouts (continued):

For each team of 3–4 participants, 2 copies of one of the following Similarities and Differences sheets (a different handout for each team):

- ❑ *Vertebrate Skeletons* (page 30)
- ❑ *Digestive Systems* (page 31)
- ❑ *Vascular Systems* (page 32)
- ❑ *Cells* (page 33)

For each participant, 1 copy of the following:

- ❑ 1 set of Inheritance Reading Cards, 24 cards/set (or 1 set/pair) (pages 36–37)
- ❑ *Inheritance: How Inheritable Traits Are Made* (whichever version you have chosen to use) or 1 copy for each pair (page 34 or page 35)
- ❑ *Explanation for Blowholes in Whales (Using VISTA)* (page 38)
- ❑ *Lamarckian Explanation for Giraffe Necks* (page 39)
- ❑ *NGSS* Adaptation and Evolution *Learning Progression* (page 48)

YOU ARE HERE:

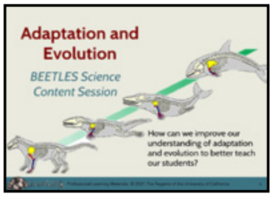
20 minutes

TEACHING NOTES

About Theodosius Dobzhansky. Dobzhansky was a prominent evolutionary biologist in the 20th century and is considered a central figure in the field of evolutionary biology. He was born in the Ukraine and came to the United States as a young scientist to work at Columbia University studying genetics. Ten years later, he published a major work on modern evolutionary synthesis, *Genetics and the Origin of Species*. He also wrote the essay "Nothing Makes Sense Except in the Light of Evolution" in which he criticizes creationists' ideas, arguing that the diversity of species cannot be best explained without considering the ecological interactions between them and the environment. Dobzhansky concluded that scripture and science are two different things: "It is a blunder to mistake the Holy Scriptures for elementary textbooks of astronomy, geology, biology, and anthropology."

Introducing Evolution

1. **Show Slide 1:** *Adaptation and Evolution*. **Introduce the session.**
   a. Welcome participants and make sure everyone is ready to begin.
   b. Share that this session is designed for instructors to improve their understanding about adaptation and evolution.

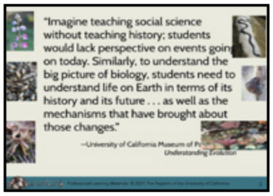


slide 1

2. **Show Slide 2:** *Dobzhansky Quote*. **Introduce quotes related to the topic of evolution. Share:**
   - Let's start with a couple of quotes about evolution.

slide 2

3. **Show Slide 3:** *UCMP quote*. **Share quote from UCMP website:**
   a. The Museum of Paleontology at the University of California, Berkeley, has a highly informative website for teachers of science and evolution.
   b. These quotes capture why evolution and adaptation are key understandings for naturalists and field educators.



slide 3

4. **Share that evolution is often undertaught or oversimplified:**
   a. Some have waged a long campaign against teaching evolution.
   b. As a result, this key idea has often been undertaught or oversimplified.
   c. In environmental education, evolution curriculum is often reduced to only teaching about adaptations, likely because this avoids the term *evolution*, and because the term *adaptation* may not raise as many negative reactions.
   d. Since evolution tends to be undertaught, it's often not understood well, and there are a lot of misconceptions about it.
   e. Unfortunately, when instructors don't have a strong background in the topic, they may reinforce or even mistakenly teach misconceptions.
   f. Since evolution is arguably the most important underlying idea in life science, and since it's undertaught, we can do our students a great service by approaching the topic in a thoughtful manner.
   g. This is especially relevant while exploring an outdoor environment in which we are surrounded by the results of evolution!

5. **Share that the session will focus on a science perspective of life on Earth:**
   a. Science is one extremely useful, evidence-based way of understanding the natural world.
   b. Art, history, and religion are also examples of valuable ways of understanding.

c. Traditional Ecological Knowledge (TEK) is a way of understanding that includes many overlaps with science about the natural world.

d. This session will focus on a scientific way of understanding life on Earth.

Science as one way of understanding—not the only way. There are many different ways of understanding; science is not the only way of understanding, but it is one extremely useful, evidence-based way of understanding the natural world (not the supernatural world). One of the defining characteristics of science is falsifiability. That is, if something can be tested and potentially can be shown to be inaccurate (falsified), then it's considered to be open to scientific examination. If it's not falsifiable, if no test could ever show it to be inaccurate, it's generally not considered to be open to scientific examination. We can test the existence of gravity by dropping things and observing if they fall—gravity is a scientific idea. We cannot test whether something is beautiful or whether there is an afterlife—beauty and the afterlife are not scientific ideas. There are many interesting questions that are appropriate for nonscientific ways of understanding the world. Art, history, and religion are examples of ways of understanding. When teaching evolution, it's important to support students to understand these distinctions. You might offer examples of scientists and thinkers who see different ways of understanding as complementary rather than adversarial. Many scientists who are religious believe in a creator who set up natural selection as a mechanism for life to respond to changing conditions on Earth. We can affirm and respect students' spiritual and religious beliefs by modeling a "both/and" mindset as opposed to an "either/or" view of ways of understanding. If the relationship between religion and science is portrayed as adversarial, or if students feel that their beliefs are being disrespected, they are likely to disregard scientific instruction. One way of acknowledging the ways of understanding that students may bring to the learning experience is to say that this session will focus on a scientific way of understanding life on Earth. For suggestions on how to deal with the kinds of questions that may come up around this issue, see the comprehensive resource developed by the National Science Teachers Association (http://static.nsta.org/pdfs/EvolutionQandA.pdf).

6. **Share that evolution is complex, and it's impossible to fully understand all aspects of evolution through one session, but we can expand our knowledge:**

   a. To prepare for teaching students about evolution, it's helpful to spend time struggling with these concepts and ideas as adults.

   b. This session is designed for instructors to do this.

TEACHING NOTES

Traditional Ecological Knowledge (TEK). BEETLES acknowledges and affirms the validity of Traditional Ecological Knowledge (TEK), as well as the many linkages between ecological restoration and cultural resources and values. The strategies and knowledge that were passed down over generations show a detailed understanding of ecological processes and the connection humans have with those processes. While teaching science, we want to hold in our sight the body of knowledge gained from Indigenous peoples who possess detailed knowledge of the organisms and ecosystems of their homelands. Indigenous cultures have a deep history of observing and understanding the natural world that predates science and includes aspects of what we now define as scientific thinking and investigating. Indigenous cultures have knowledge about the natural world and how to investigate it. TEK is an evolving body of knowledge based on many generations of close observations of ecosystems and includes Indigenous views on ecology, spirituality, and human/animal relationships. Some common goals of outdoor and environmental science educators are to teach science ideas and science approaches related to the outdoors and to support students to understand and connect with their environment. We wish to honor and show respect to TEK and how it has influenced and continues to influence science, how it overlaps with science, and how it differs from scientific approaches. We encourage educators to respectfully integrate aspects of TEK into outdoor science instruction to help students connect with and understand nature. For more on this topic, see the Science as One Way of Understanding, Not the Only Way section (on page 59) in Background Information For Presenters.

TEACHING NOTES

Assessing your participants' prior knowledge. One point of this first activity is for participants to access their prior knowledge about evolution and to engage them in thinking about how adaptations occur. Another important purpose it serves is for the presenter(s) to assess participants' understandings about the topic. By paying careful attention to what they say, you can gain some insight into your group and also into individual participants—what they seem to understand, what they seem to be confused about, and any misconceptions they may have. You can use this information to inform how you teach the session and also what you choose to do with your staff to follow up the session.

Steer participants away from discussing how to teach about adaptation for now. There can be a tendency for instructors to drift into conversations about teaching their students, instead of grappling with the concepts and ideas themselves. Do your best to try to engage participants in communicating their own ideas and thoughts about these concepts and let them know that there will be time later in the session to talk about teaching students.

On the theory of evolution. "The theory of evolution is quite rightly called the greatest unifying theory in biology." —Ernst Mayr, Professor of Zoology, Emeritus, Harvard University

c. Even though I am a presenter of this session, I certainly don't understand everything about evolution, and I hope to expand my own understanding during this session.

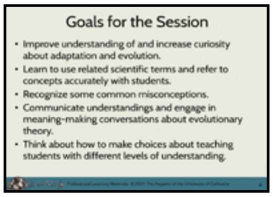
d. I invite everyone here to be open-minded, humble, and ready to engage in some productive struggle over this content.

e. Through collective intellectual engagement and sharing, our understanding about the topic can increase.

f. Hopefully, some of you will develop a lifelong curiosity about the topic, which you may already have!

7. **Show Slide 4:** *Goals for the Session*. **Share session goals:**

- These are goals we will be addressing throughout the session.



slide 4

8. **Show Slide 5:** *Explaining an Interesting Adaptation*. **Ask participants to try to explain an adaptation.**

a. Let's get warmed up on the topic by wrapping our minds around an evolution puzzler.

b. What are some interesting adaptations in nature you can think of?

c. These photos may give you some ideas, but you could also mention any other interesting adaptations.

slide 5

9. **Choose one adaptation for the group to explain while you notice participants' understandings and misconceptions about evolution.**

a. Choose one interesting adaptation brought up by the group and challenge them to try to explain a nonfiction storyline for how that adaptation might have evolved.

b. Ask:

▶ *What could have been going on for that particular adaptation to be developed?*

▶ *What might have been happening in the environment or with other organisms around it?*

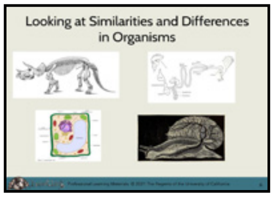
c. Listen to their ideas and ask follow-up questions to get them to share more about the process as they understand it.

d. Take note of evidence of understandings as well as common misconceptions (such as talking about *individual* organisms adapting to the environment).

e. You can refer back to these during the session at appropriate times. (You may also refer back to the specific example of the adaptation that participants chose.)

Diversity and Variation

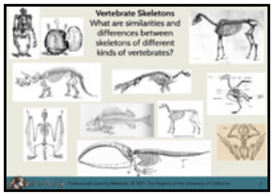
1. **Show Slide 6:** *Looking at Similarities and Differences in Organisms*. **Share the process for looking at diversity, similarities, and differences in features of organisms:**



slide 6

   a. First, we'll look into the incredible diversity of living things.
   b. We'll think about differences, as well as similarities, between some groups of organisms.
   c. Each group of 3–4 participants will look at and discuss different types of structures or features and then report to the whole group.

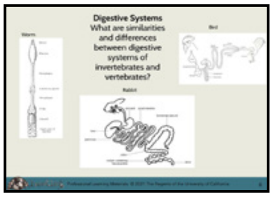
2. **Show Slide 7:** *Vertebrate Skeletons*. **Distribute 2 copies of the *Vertebrate Skeletons* handout to one team and ask, "What are similarities between skeletons of different kinds of vertebrates?"**



slide 7

   a. Distribute 2 copies of the *Vertebrate Skeletons* handout to one team of 3–4 participants.
   b. Share that they'll look at the diagrams and discuss this question with their team.

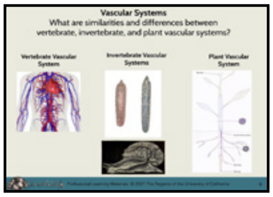
3. **Show Slide 8:** *Digestive Systems*. **Distribute 2 copies of the *Digestive Systems* handout to another team and ask: "What are similarities and differences between digestive systems of invertebrates and vertebrates?"**



slide 8

   a. Choose a different team of 3–4 and distribute 2 copies of the *Digestive Systems* handout to the team.
   b. Remind them to discuss both similarities and differences between the digestive systems.

4. **Show Slide 9:** *Vascular Systems*. **Distribute 2 copies of the *Vascular Systems* handout to the next team and ask: "What are similarities and differences between vertebrate, invertebrate, and plant vascular systems?"**



slide 9

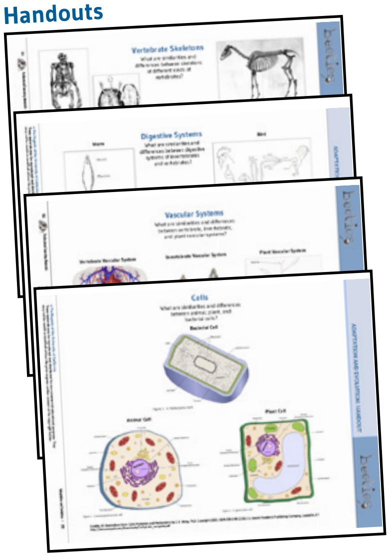
   a. The next team will compare vascular systems of vertebrates, invertebrates, and plants.
   b. Vascular systems are the tissues, tubes, and spaces in organisms through which liquids, gases, nutrients, and wastes are moved through the organism.
   c. Distribute 2 copies of the *Vascular Systems* handout to this team.
   d. Let them know that they will include plants in their comparison discussion.

YOU ARE HERE:

30 minutes

TEACHING NOTES

Similarities and Differences: Handouts



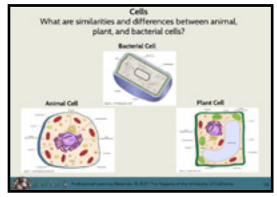
TEACHING NOTES

Other comparisons between groups of organisms. Similarities between reproductive structures can be another interesting comparison to explore.

Homologous structures. Many structures on the comparison sheets are considered homologous structures—similar features shared by different organisms but not necessarily used for the same function, such as finger bones in a human, a bat, and a whale. Homologous structures are evidence of organisms having descended from a common ancestor. The opposite of homologous organs are analogous organs—which do similar jobs in two different groups of organisms, but which are *not* evidence of relatedness. These are things that were not present in the last common ancestor, but evolved separately. An example of an analogous trait would be the wings of bats and birds. Both creatures evolved wings to fly, but the wings evolved independently in each lineage after they separated.

Indigenous perspective on the relationship of humans to other living things. "In the Western tradition, there is a recognized hierarchy of beings, with, of course, the human being on top—the pinnacle of evolution, the darling of Creation—and the plants at the bottom. But in Native ways of knowing, human people are often referred to as "the younger brothers of Creation." —Robin Wall Kimmerer, Distinguished Teaching Professor and Director, Center for Native Peoples and the Environment, State University of New York (SUNY) College of Environmental Science and Forestry. (For more information about Kimmerer, you can find her bio and a link to her many publications at https://www.esf.edu/faculty/kimmerer/.)

5. **Show Slide 10:** *Cells*. **Distribute 2 copies of the** ***Cells*** **handout to the last team and ask: "What are similarities and differences between animal, plant, and bacterial cells?**



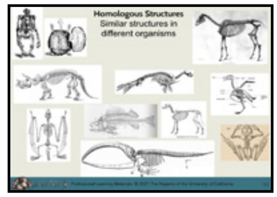
slide 10

   a. Distribute 2 copies of the *Cells* handout to this last team.
   b. Share that they will be looking at similarities and differences between cells of these three groups of organisms.

6. **Give teams a few minutes to look at their sheets, discuss their topics, and then get ready to share out.**

7. **Participants share out and discuss what they learned from each of the comparison handouts.**
   - Ask the following questions, listen to their ideas, and probe for evidence about relatedness between organisms:
     - ▶ *What did you notice?*
     - ▶ *What did you find interesting or surprising?*
     - ▶ *If you were an early biologist and were confronted with this evidence, how do you think it might have affected your understanding and ideas about life on Earth?*

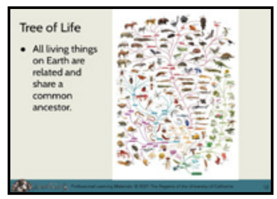
8. **Show Slide 11:** *Homologous Structures*. **Share homologous structures as evidence for relatedness and evolution:**



slide 11

   a. Similar structures in different organisms are called homologous.
   b. Homologous structures were important early evidence for relatedness among living things.
   c. Homologous structures were also early evidence for evolution.
   d. Scientists noticed structures that look similar but had very different functions, such as those shown on the *Vertebrate Skeletons* handout. (You may want to ask for and/or point out an example, such as finger bones in a human, a bat, and a whale.)
   e. This evidence inspired scientists to think about all living things as having a common ancestor.

9. **Show Slide 12:** *Tree of Life*. **Share the Tree of Life diagram:**



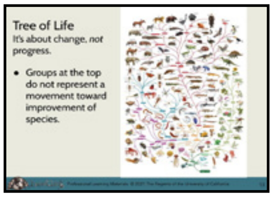
slide 12

   a. This Tree of Life diagram gives an idea of diversity found in different groups of organisms.
   b. This diagram doesn't include many extinct organisms.

c. The beauty of the diagram is that it illustrates how all living things on Earth are related and share a common ancestor. Note the single root at the bottom.

d. This is a key idea in evolution: *Scientific evidence supports the idea that all life evolved from the same ancient organism approximately 3.7 billion years ago.*

10. Show Slide 13: *Tree of Life: Change, not progress***. Share a common Tree of Life misconception about evolution being goal oriented:**



slide 13

a. Some people misunderstand Tree of Life diagrams as showing evolution moving in a direction toward the improvement of life forms, with humans as the ultimate superior species.

b. This is a common misconception about evolution.

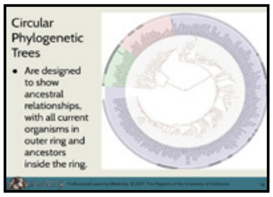
c. If we use these diagrams, we should point out to students that organisms at the top of the tree are not any better or more evolved than those at the bottom.

d. Bacteria, for example, are at the very bottom of the Tree of Life, but they are incredibly successful. They have outlasted many other more complex life forms, can live almost anywhere, and feed on a wide range of things.

e. All organisms on the tree are success stories because they all have lived successfully for a very long time, and most continue to live successfully on Earth.

f. The Tree of Life is about change, not progress. Evolution is not goal oriented.

11. Show Slide 14: *Circular Phylogenetic Tree***. Share how this diagram dispels the anthropocentric view of human superiority:**



slide 14

a. Circular phylogenetic trees show genetic relationships between organisms.

b. This example shows all currently existing organisms placed with equal status on the outer ring.

c. Ancestors are shown inside the ring.

d. These diagrams are meant to show relationships between organisms—without implying a particular direction, intentionality, or hierarchy.

e. Diagrams like this can help dispel the anthropocentric tendency to view humans as superior to other organisms.

12. Share that genetic evidence supports many early understandings about relatedness, but that now we know more about these relationships:

a. Early biologists didn't have genetic evidence to work with, but today's biologists do.

TEACHING NOTES

Tree diagrams. Today, tree diagrams are constructed using evidence from fossils, DNA, shared internal characteristics of organisms, and shared visible characteristics—with the goal of classifying and describing the relatedness of organisms. Tree diagrams are used not only to show evolutionary relationships but also to discover them. Extinct and living species are placed on branches that reflect evidence of their evolutionary history and common ancestry. Two species that are fairly closely related, with a relatively recent common ancestor, are placed on nearby branches that split near the tips of the branches. Less closely related species are placed on tree branches that split from one another nearer to the tree's trunk. This shows that their common ancestor lived a longer time ago.

Dispelling the notion of more evolved or advanced creatures. It's common (but inaccurate) for people to talk about some organisms as being higher up on the Tree of Life, such as humans and primates and, therefore, being more evolutionarily advanced. While there is a tendency for more complex organisms to evolve from simpler ones, this does not mean they are necessarily more advanced. Organisms such as bacteria, for example, are really good at just being bacteria. They have been evolving for much longer than humans, have survived many changes in environmental conditions and resources, and are very successfully adapted.

***Phylogeny* definition.** Merriam-Webster's dictionary defines *phylogeny*: 1: the evolutionary history of a kind of organism. 2: the evolution of a genetically related group of organisms as distinguished from the development of the individual organism.

TEACHING NOTES

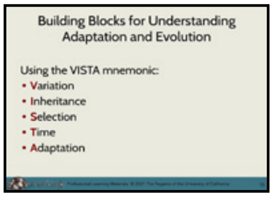
Are viruses alive? Viruses reproduce, carry genetic material, and evolve through natural selection, but they don't have cell structures and other characteristics that other living things have. Some scientists count them as living things, but others think they belong in their own category. Sometimes they are called organisms on the edge of life, and sometimes they're referred to as replicators.

Origins of the VISTA acronym. Niles Eldridge, an evolutionary biologist and curator at the American Museum of Natural History, is credited with developing this acronym as a way to explain Darwin's ideas about the primary mechanisms for the evolution of life on Earth.

About leading content-based discussions. At a number of points, the presenter will ask the group for their ideas and then add information from a list in this write-up. In these moments, it's important not to repeat responses that participants already mentioned but just to add a few more. Otherwise, it may sound as if you haven't really been listening or as if the points you've mentioned are the more correct responses. Try to acknowledge all ideas and be curious about how participants are thinking about the topic so you can strategically and respectfully insert information to extend and deepen their thinking.

b. Much of this evidence supports early understandings about how things are related.
c. But genetic evidence has changed what we know about these relationships.
d. Evolutionary biologists now have a lot of evidence that homologous structures are the result of shared DNA.

13. Show Slide 15: Building Blocks for Understanding Adaptation and Evolution. **Share the VISTA mnemonic representing key evolution concepts:**



slide 15

a. This mnemonic is a helpful way to remember important building blocks for understanding evolution: VISTA = Variation, Inheritance, Selection, Time, Adaptation.
b. It can be used to guide how we teach students about the topic.
c. We'll unpack each of these concepts throughout the rest of the session, using VISTA to help anchor our discussions.

14. Show Slide 16: *VISTA: Variation*. **Revisit VISTA and distinguish diversity from variation. Share:**

slide 16

a. So far, we've been discussing similarities and diversity in different kinds of organisms.
b. For our purposes, diversity refers to differences *between* species.
c. As related to the processes for evolution, variation refers to differences *within* a species or population.
d. These ladybird beetles (ladybugs) are all the same species, but there is variation between them.
e. What are some variations you can see?
f. What are some variations you can't see but you know must be there?
g. Individual organisms can vary in size, coloration, ability to fight off diseases, and countless other traits.

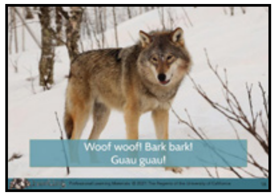
15. Show Slide 17: *VISTA: Variation . . . Genetic variation . . .* **Share that genetic variation is the raw material for evolution:**

slide 17

a. The processes that drive evolution are based on genetic variation among organisms of the same species.
b. We'll now think about what needs to happen for this kind of variation to happen.

16. **Show Slide 18:** *Woof woof! Bark bark! Guau guau!* **Share a familiar example of variation in dogs:**

- For an interesting example of how a variety of traits have developed over time in a single species, we'll take a look at dogs.



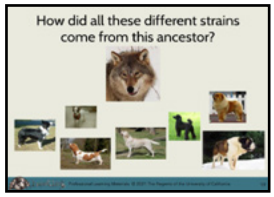
slide 18

17. **Show Slide 19:** *How did all these different strains come from this ancestor?* **Say:**

   a. There are so many wildly different variations within the dog species.

   b. How did we get Saint Bernards, dachshunds, and Chihuahuas from the same wolf-like ancestor?

   c. Accept several answers and probe for explanations and evidence as appropriate.



slide 19

18. **Summarize participants' responses and relate their ideas to artificial selection, tying it into any explanations they offered. Share:**

   a. Over time, people selected dogs with traits they liked and then bred them.

   b. They avoided breeding dogs that had traits they didn't want.

   c. For new types of dogs to persist in the population, two important processes are needed: inheritance and selective pressure.

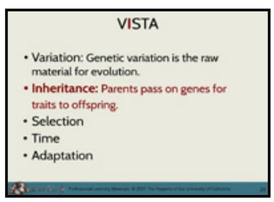
Inheritance: Discussing Inheritable Traits

1. **Show Slide 20:** *VISTA: Inheritance*. **Revisit VISTA and define inheritance. Share:**

   a. Let's explore the "I" in VISTA: inheritance.

   b. Inheritance may be mostly a review for us, but scientists of the past did not understand mechanisms of inheritance.

   c. Many students are familiar with this idea of inheritance: *Parents pass on genes for traits to offspring.*



slide 20

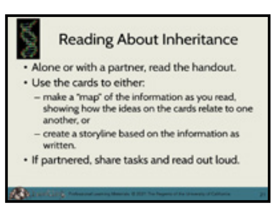
2. **Share the *Inheritance: How Inheritable Traits Are Made* handout and the Inheritance Reading Cards:**

   a. I'm going to distribute a reading on inheritance for you to read (either alone or with a partner).

   b. You'll also get a set of cards to manipulate as you read.

3. **Show Slide 21:** *Reading About Inheritance*. **Share the procedure for the handout and card set:**

   a. To engage you more actively in reading the handout, you'll use cards.



slide 21

TEACHING NOTES

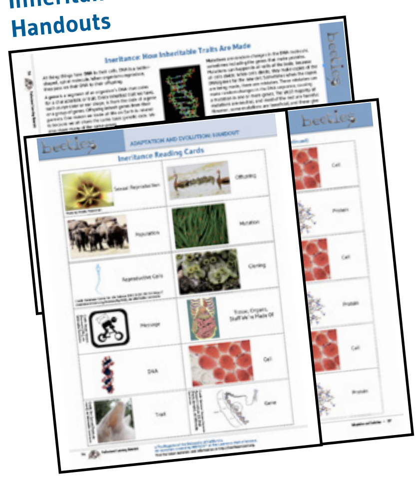
***Woof, woof* or *guau, guau*?** *Guau* is what dogs say in Spanish-speaking countries—at least in the comics! In Spanish slang, *guau* also can mean wow!

Importance of understanding inheritance. A basic familiarity with inheritance and with the role of genes is a key part of understanding the mechanisms for evolution. Knowing that characteristics are passed from parents to young through genes will help students understand how adaptive traits are passed on to surviving generations. Understanding that new variations of organisms are often formed during reproduction will help lay a foundation for understanding that natural selection can only happen when new characteristics are introduced into populations. This idea also helps combat the common misconception that variations happen as a response to changes in the environment. In fact, the variation is always there, but selective pressures, such as changes in the environment, select for certain traits to be more successfully passed on.

YOU ARE HERE:

15 minutes

Inheritance Reading and Cards: Handouts



TEACHING NOTES

More on DNA and reproduction. Almost every cell in the human body has a complete set of genes in its DNA, and each set contains the information needed for the whole body. The exceptions are reproductive cells (which only have half the number of chromosomes) and cells without DNA (such as blood cells as well as some skin and hair cells). In species that reproduce sexually, such as humans, offspring are made from combining the egg cell from the mother (containing copies of half of their DNA) and the sperm cell from the father (containing copies of half of their DNA). Every time an egg and a sperm join, a new combination of genes is created, which means every individual has a unique set of genes. Identical twins are exactly alike genetically because the same fertilized egg has split into two individuals. Species that reproduce asexually, by cloning or budding, also have identical genes because they are exact replicas of the parent organism. Sexual reproduction, along with spontaneous genetic mutation, is the primary mechanism for producing variation within species.

b. Use the cards either to make a map of the information in the reading or to lay out the information in a storyline.

c. Laying out the cards is meant to help you make sense of the ideas for yourself. You won't need to share it with others.

d. OPTIONAL (if you chose to have pairs work together): If you are working with a partner, both you and your partner should share the tasks of reading and manipulating the cards, and you should do the reading out loud.

e. When you've finished, team up with someone else (or another pair, if you worked with a partner) and discuss the main ideas of the article. Try to describe the information in your own words.

4. **Distribute 1 copy of the *Inheritance: How Inheritable Traits Are Made* handout and 1 set of Inheritance Reading Cards to each "team" (individuals or pairs) and have them begin:**

- If you chose to use the simpler version of the reading, three cards won't be needed. If you haven't already removed the following three cards, have participants set them aside: *Tissue, Organs, Stuff We're Made Of* card; *Proteins* card; and *Messenger* card.

5. **Regain the attention of the whole group and briefly discuss what they've learned:**

a. After approximately 10–15 minutes, when it seems that everyone is finished with the reading and sharing their storylines, get everyone's attention.

b. Ask what they found surprising or interesting about the reading.

c. Ask how using the cards helped them make sense of the reading.

d. Share that when students put ideas in their own words, it allows them to clarify their thinking and helps reveal any confusion about the details.

YOU ARE HERE:

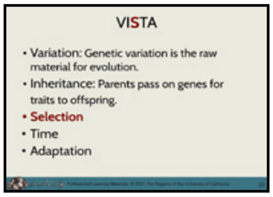
20 minutes

Selection: Exploring Selective Pressures

1. **Show Slide 22:** *VISTA: Selection*. **Revisit VISTA and introduce selection. Share:**

a. For any new genes or traits to end up in a population of organisms, you need another important process to be at work: selection.

b. Let's go back to the example of variation in dogs and take a look at the results of genetic mutation combined with artificial selection.



slide 22

2. **Show Slide 23:** *Short-Legged Mutation*. **Share an example of mutation and selection in dogs:**

a. A random mutation caused the trait of short legs to appear in some dogs.

b. Some humans thought this trait was useful in hunting dogs, because it made them better at chasing burrowing animals.

slide 23

c. So they selectively bred dogs that had this trait.
d. This resulted in the dogs with the mutation for short legs reproducing and making more short-legged offspring.

3. **Show Slide 24:** *Color in Dogs*. **Share how color traits have been artificially selected for in dogs:**
   a. Changes in three different genes cause the color variations found in dogs.
   b. Dogs have been bred to have specific coat colors.

slide 24

4. **Show Slide 25:** *Shar-Pei*. **Share how other traits have been artificially selected for in dogs:**
   a. Four small mutations in the gene that makes a skin protein resulted in the wrinkling of this breed's skin.
   b. Each of these characteristics came from a random mutation that was selected for and spread by humans who bred dogs with those traits.

slide 25

5. **Share that the selection process is *not* random in either artificial or natural selection:**
   a. You may hear people say that the complex features of living organisms could not have been produced by random events.
   b. They are correct in that these events are *not* totally random.
   c. The mutation that produces these traits may be random, but the selection process is not.
   d. We saw in these examples that artificial selection isn't random. People have selected for specific characteristics.
   e. Natural selection isn't random, either. This is an important point!
   f. In natural selection, the conditions the organism lives in select for types of characteristics.
   g. Say:

      ▶ *In natural selection, the traits that persist in a population of organisms are those that provide an advantage in the organism's habitat.*

6. **Ask the group to discuss selective pressures in nature.**
   a. Share: In the case of dogs, humans provided the selective pressure.
   b. Ask:

      ▶ *What are some possible selective pressures found in nature?*

   c. Listen to participants' ideas and ask for specific examples.
   d. Add any of the following that may not have been mentioned:
      - seasonal conditions
      - environmental changes
      - predators, availability of prey or other food

TEACHING NOTES

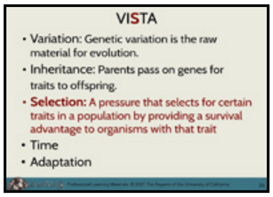
More on natural selection. Natural selection is the process by which organisms with the most favorable genetic adaptations out-compete other organisms in a population and displace the less adapted organisms. Environmental factors in a habitat, such as the temperature or the types of predators, can "select" which individuals of a species survive. But survival is only part of the story. First, there needs to be a population of organisms with more offspring than can possibly survive. These organisms also need to have a variety of genes present in different individuals (due to mixing of genes either during reproduction or from spontaneous mutations). In general, organisms with characteristics that help them be more successful at surviving long enough to reproduce will have more offspring. Over many generations, populations with traits that help them survive in these conditions keep reproducing successfully, and those without those traits don't do as well. Over time, this causes a shift in the genetic makeup of the population in which there will be more individuals that have these adaptations and can pass them on to their offspring. The driving force behind adaptation and evolution is not the desire or needs of a species. It's a combination of evolutionary processes—overproduction, genetic variation, natural selection, and the inheritance of genetically determined traits.

TEACHING NOTES

Kimmerer on the "gifts" and adaptations of strawberries. "I'm a plant scientist, and I want to be clear, but I am also a poet, and the world speaks to me in metaphor. When I speak of the gift of berries, I do not mean that *Fragaria virginiana* has been up all night making a present just for me, strategizing to find exactly what I'd like on a summer morning. So far as we know, that does not happen, but as a scientist I am well aware of how little we do know. The plant has, in fact, been up all night assembling little packets of sugar and seeds and fragrance and color, because when it does so its evolutionary fitness is increased. When it is successful in enticing an animal such as me to disperse its fruit, its genes for making yumminess are passed on to ensuing generations with a higher frequency than those of the plant whose berries were inferior. The berries made by the plant shape the behaviors of the disperser and have adaptive consequences." —Robin Wall Kimmerer

- sexual selection
- disease
- changes in climate
- reproductive advantages that increase an organism's success in finding a mate

7. **Show Slide 26:** *VISTA: Selection*. **Share a formal definition for *selection*:**



slide 26

   a. Say:

      ▶ *Selection is a pressure that selects for certain traits in a population by providing a survival advantage to organisms with that trait.*

   b. When there is competition for resources, it can create survival advantages for organisms with certain traits, such as a bird having a strong beak that can crack open hard seeds.

   c. This process is often referred to as survival of the fittest, but:

      ▶ *The fittest individual is not necessarily the strongest, fastest, or biggest. An organism's fitness includes its ability to survive, find a mate, produce offspring—and ultimately to pass on its genes to the next generation.*

   d. What are some organism examples you can think of that are "fit" for survival but are not the strongest, fastest, or biggest? (Listen to a few of their examples.)

Break

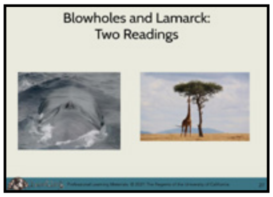
If you are dividing the session into two shorter sessions, this is a good time to stop. If you aren't, this is also a good time for a short break.

Time and Adaptation: Changes Over Deep Time

YOU ARE HERE:

30 minutes

1. **Show Slide 27:** *Blowholes and Lamarck*. **Share readings:**

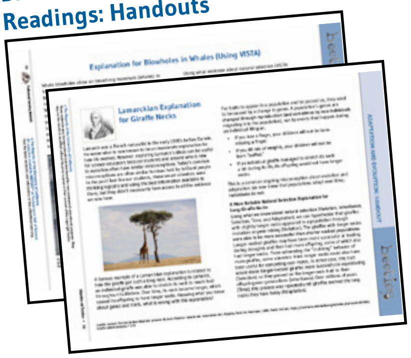


slide 27

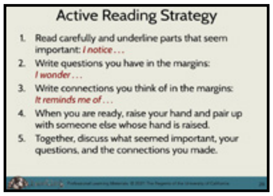
   a. To apply some of what we've discussed so far, we have two readings:
      - a natural selection (VISTA) explanation for blowholes in whales
      - an (inaccurate) Lamarckian explanation for giraffe necks

   b. Distribute 1 copy of the two-sided handout to each participant.

Blowholes and Lamarck Readings: Handouts



2. **Show Slide 28:** *Active Reading Strategy*. **Share the active reading process:**



slide 28

   a. Read the description of active reading.

   b. This is a useful strategy to help readers engage more actively with text.

c. It's very similar to the *I Notice, I Wonder, It Reminds Me Of* routine for engaging students with nature.

d. When you finish both readings, pair up and discuss the reading with a partner.

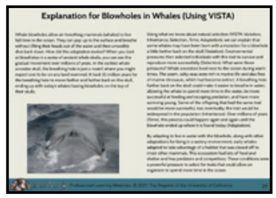
e. Together, see if you can answer any of your questions or clarify the connections you made.

3. **Allow time for participants to read and discuss the article:**

   a. Facilitate the active reading process as necessary.

   b. When it seems that everyone has finished reading and has had time to discuss, get the attention of the whole group.

4. **Show Slide 29:** *Explanation for Blowholes in Whales (Using VISTA)*. **Discuss the article about whale evolution.**

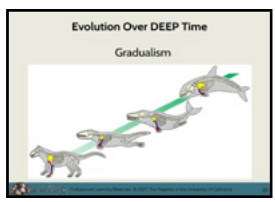


slide 29

   a. Ask participants to share their responses to the first article.

   b. If they don't bring it up themselves, point out that this article introduces the extremely long time it usually takes for changes like this to take place in populations of organisms.

5. **Show Slide 30:** *Evolution Over DEEP Time*. **Share evidence of long periods between blowhole changes:**



slide 30

   a. If we take a close look at the dates on these fossil skulls, there are at least 5 million years between each step shown in the evolution of the whale blowhole—a total of 35 million years!

   b. There may have been smaller changes that happened during the time during which these fossils were formed, but we don't have fossils showing those changes.

6. **Briefly share the controversy over the pace of evolutionary changes:**

   a. Scientists don't actually know a typical rate for evolution because fossil evidence shows that changes in life-forms have happened at different rates.

   b. Sometimes, these changes happen over very long periods of time (gradualism), but they also happen in shorter bursts after long periods with little change (punctuated equilibrium).

   c. Some significant changes have been found in fossils dated less than 100,000 years apart.

   d. But many significant changes found in fossil records show gradual transitions, such as the whale blowhole, happening over millions of years.

TEACHING NOTES

Survival of the "good enough." The process of natural selection is relatively simple but can be misunderstood. It's tempting to think of it as a force driving each new species to become more advanced or even perfected. Saying things such as *An organism is perfectly adapted.* can support these misconceptions. Species don't need to be perfect to survive. Think about imperfections such as genetic diseases humans have or how some plants are susceptible to certain types of pests. There are many examples of structures in very successful organisms that are not perfect. For example, whales live mostly underwater, but they evolved from land animals and still have lungs inherited from their ancestors. Instead of being perfectly adapted to breathe in their habitat, they have to keep returning to the surface to get oxygen. They are good enough! We're all highly imperfect, but we're survivors. Realistically, natural selection should not be called survival of the fittest, but rather survival of the good enough to pass on their genes.

What is meant by *deep time*? When we use the term *deep time* in relation to evolutionary theory and adaptation, we are referring to a multimillion-year time frame that is most often used to describe geological events that have occurred since the formation of our planet approximately 4.6 billion years ago. Changes in populations of organisms usually take place over millions of years.

Common misconception about a connection between embryonic development and the history of evolution. After reading the whale blowhole article, you may hear participants quoting the phrase *ontogeny recapitulates phylogeny*. This catchy phrase, which was popularized in the 1800s by Ernst Haeckel, represents the now-debunked Biogenetic Law, which claims that evolutionary history is repeated during embryonic development.

7. **Show Slide 31:** *What might make evolution happen more quickly?* **Brainstorm some factors that might make changes happen more quickly in populations:**

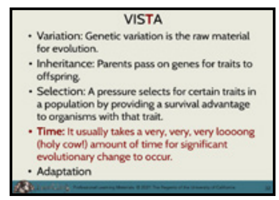
slide 31

   a. Ask participants to think of factors that might cause evolutionary changes to happen more rapidly in populations.

   b. Listen to their ideas. Then, add any of the following that may not have been mentioned:

      - **Catastrophic events** can quickly kill off many individuals in a population and drastically change the conditions in their habitat.
      - **Geographic isolation**, such as populations living on islands, can separate a subpopulation from the larger gene pool and may produce rapid changes.
      - **Drastic gene mutations** can cause dramatic changes in a population and are sometimes produced by sexual recombination.
      - Organisms with a **high reproductive rate**, such as bacteria and viruses, also have more rapid evolutionary changes.

8. **Show Slide 32:** *VISTA: Time*. **Share the role of time, using the VISTA acronym:**



slide 32

   - The most significant changes in organisms have occurred over a very long period of time.

9. **Show Slide 33:** *Lamarckian Explanation for Giraffe Necks*. **Discuss Lamarckian article.**

slide 33

   a. Ask participants to share responses to the second article.

   b. Ask if any of these ideas make anyone think differently about ideas that have been talked about earlier in the session.

   c. If any participants' ideas about adaptations shared earlier in the session were based on Lamarckian thinking, take time to address them here, if participants do not do so themselves.

10. **Discuss inaccuracies in some student statements and lack of intention in evolution. Share:**

   a. Students often use Lamarckian explanations for adaptations, saying things such as.

      - *Predators could break a bird's shell, so it built a stronger shell and survived better.*
      - *The animal needed or wanted to run from predators, so it developed longer legs.*

   b. What is inaccurate about those statements? (Listen to participants' ideas.)

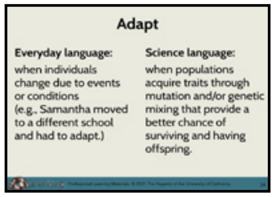
TEACHING NOTES

Can evolution be observed? Evidence of evolution surrounds us, but can the actual process of an organism evolving be observed? When new species evolve, it's called macroevolution. Macroevolution tends to take a very long time, which makes it hard to observe. But we can observe organisms in the process of forming new species, such as the apple maggot fly that is just beginning the long process of separating into different species. There are also some shorter examples of new species forming, such as two new species of American goatsbeard wildflowers that have formed within a 50-year period. Evolution that happens within species is called microevolution. Microevolution works through the same mechanisms as macroevolution (mutations, genetic drift, migration, and natural selection), but the term *microevolution* refers to smaller evolutionary changes that can happen over shorter timescales at the population level within a species. For species that reproduce quickly, such as bacteria, microevolution can be observed in a matter of minutes or even hours! So these kinds of microevolutionary changes are easily observable.

Acquired versus inherited characteristics. Not all characteristics come from the genes of an individual, and these kinds of characteristics can't be inherited or passed on. Acquired characteristics come from an individual organism's experience and interactions with its environment. Injuries such as a broken bone, learned skills such as riding a bicycle, and temporary changes such as a person's haircut are characteristics that do not necessarily affect one's genes. Some characteristics are more difficult to categorize as acquired or inherited because they may be partially the result of genes and partially environmental. Language in humans is a good example of this. Through our genes, we inherit brains that can process and produce language, but we have to acquire language by being taught specific words and symbols.

c. There are no intentions behind natural selection, only survival advantages that allow individuals with specific traits to reproduce more.

11. Show Slide 34: *Adapt*. **Share confusion from the everyday use of the word *adapt*:**



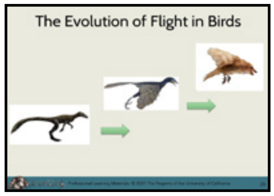
slide 34

a. Part of the confusion around understanding adaptation and evolution is that the word *adapt* has both an everyday meaning and a scientific meaning.

b. When this common, everyday definition is confused with the science definition, it can reinforce the inaccurate idea that an individual organism can adapt during its lifetime and pass on those adaptations to its offspring.

Putting the Pieces Together: Evolution Puzzlers

1. Show Slide 35: *The Evolution of Flight in Birds*. **Share evolution of birds from dinosaurs:**



slide 35

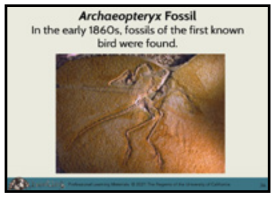
a. 200 million years ago, there were no birds.

b. Now, birds are the most diverse terrestrial vertebrate, and there are almost 10,000 species.

c. We now know that birds descended from dinosaurs.

d. We also know that the dinosaur ancestor of birds had scales, not feathers.

2. Show Slide 36: *Archaeopteryx Fossil*. **Share:**



slide 36

a. This is a fossil of an early bird, and you can see feather-like structures.

b. It's about the size of a large raven.

3. Show Slide 37: *Archaeopteryx—CGI Model*. **Share that *archaeopteryx* is considered a link between dinosaurs and birds because of the combination of feathers, teeth, and bony tail:**

slide 37

a. From this and other fossils, scientists think *archaeopteryx* had feathers, as shown in this model.

b. It also had teeth and a long bony tail, like dinosaurs.

c. Since it has features common to both birds and dinosaurs, and because it appeared shortly before birds did, it's considered a link between them.

d. In fact, scientists now consider birds to be theropod dinosaurs.

TEACHING NOTES

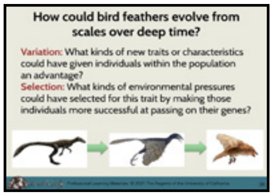
Adaptations are the result of evolution in a species, not in a single individual. An organism does not "decide" to produce adaptations. Species do not develop adaptations because they want or need them. Instead, certain genetic changes enable organisms to survive and reproduce better than others and to pass on these changes to future generations. These characteristics then become new adaptations of the species.

YOU ARE HERE:

30 minutes

TEACHING NOTES

4. **Show Slide 38:** *How could bird feathers evolve from scales over deep time?*



slide 38

5. **Share that participants will now apply VISTA to their own tentative explanations for the evolution of feathers:**
   - **a.** Think about the aspects of evolution described in VISTA, especially variation and selection, as you come up with a possible nonfiction storyline for bird evolution.
   - **b.** Ask:
     - ▶ *How do you think the scales of a dinosaur could have evolved, over deep time, into bird feathers?*
   - **c.** Try to brainstorm different explanations to compare, like scientists do.

6. **Participants find a partner to discuss the question.**
   - **a.** Have participants pair up and briefly discuss some possible explanations for how this might have happened.
   - **b.** Share: Use your best evidence and reasoning and keep your explanations as realistic as possible.
   - **c.** Give pairs just a few minutes to discuss the question.

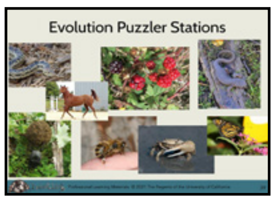
7. **Briefly share out some explanations with the whole group while you probe, coach, and model, as needed:**
   - **a.** Have a couple of volunteers share their tentative explanations and remind them to include as many aspects of VISTA as they can.
   - **b.** Since this is meant to be a model of how to apply VISTA to come up with explanations for evolution puzzlers, do what you can to help participants do it fully and help them break down their ideas, as necessary.
   - **c.** If they don't share their thinking about the evidence, reasoning, and elements of VISTA they used, remind them to do this. For example:
     - **Participant:** We think there was a dinosaur that had longer scales that allowed it to run a little bit faster.
     - **Presenter:** So, you're saying that you think there was a variation, such as a mutation for longer scales, which allowed it to run faster? How do you think that might have been passed on?
     - **Participant:** It could outrun predators and catch more prey. So, it could survive and have more young, and some of them would have it, too.
     - **Presenter:** So in your explanation, the ability to outrun predators and catch more prey was a selective pressure that helped it have more offspring that could carry that same trait, which would make them be more successful, too?

Avoid focusing on coming up with a "correct" answer. It's impossible to be absolutely certain of what happened millions of years ago that eventually led to the adaptations we see in organisms today. The purpose for engaging in the evolution puzzlers, starting with the bird feather question, is to show how scientists use what they know about the process of evolution to hypothesize about past (and future) events that they can't witness themselves. It's also fun and interesting to do! As new evidence comes to light, evolutionary scientists may change their explanation.

8. **Briefly share some different explanations that scientists are currently debating for how feathers evolved:**
    - **a.** Scientists have come up with different explanations, similar to yours.
    - **b.** Some have used evidence that early feathers were downy to explain that feathers first evolved for warmth and then later evolved further for flight.
    - **c.** Others have used evidence that these dinosaurs were able to shake their tail feathers to explain that they first evolved for sexual attraction.
    - **d.** These ideas are both explanations that can be justified with evidence.
    - **e.** These ideas are still being debated by scientists.

9. **Evolution works with what an organism already has, so adaptations are not perfectly designed but tend to be jury-rigged.**
    - **a.** These examples show how adaptations often have been jury-rigged through evolution from structures that originally had different uses:
        - Feathers that evolved for warmth or sexual attraction are then used for flight.
        - Snake venom evolved from saliva.
        - Mammary glands in mammals evolved from sweat glands.

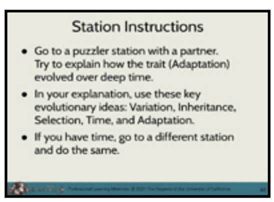
10. **Show Slide 39:** *Evolution Puzzler Stations*. **Share evolution puzzlers:**



slide 39

    - **a.** Now you'll act like evolutionary biologists and come up with tentative explanations for how different adaptations have evolved in organisms that are living today.
    - **b.** Again, use aspects of VISTA to put together a reasonable, evidence-based, nonfiction storyline of how these adaptations might have developed.

11. **Show Slide 40:** *Station Instructions*. **Share the procedure and timing for the Evolution Puzzler Stations:**



slide 40

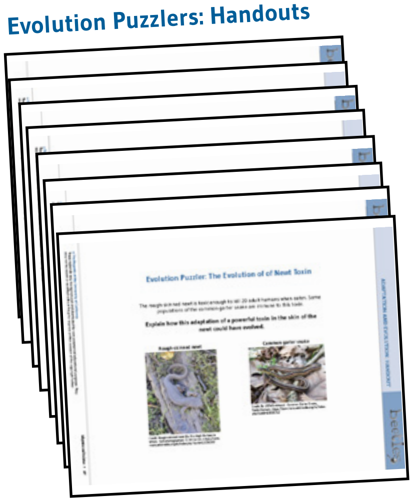
    - **a.** Go to your first station with a partner and try to come up with an evidence-based explanation for the adaptation described there.
    - **b.** Use VISTA to make sure you are including all important aspects of evolution.
    - **c.** Ask yourself:
        - ▶ *What kinds of pre-existing structures might have been modified into a trait they now have?*
        - ▶ *What kind of trait might have appeared as a result of genetic variation?*
        - ▶ *How could that trait have been selected for through environmental or reproductive pressure?*

TEACHING NOTES

Provide a scientific definition of *theory*. Sometimes, science educators challenge their students to come up with scientific theories to explain something. Often, evolution deniers dismiss evolution as just a theory. Both these examples show a misunderstanding of the scientific use of the word. In everyday usage, *theory* can mean a guess. However, in science, it refers to the opposite—ideas that have lots of supportive evidence. "In science, a theory is not a guess or an approximation but an extensive explanation developed from well-documented, reproducible sets of experimentally derived data from repeated observations of natural processes." —National Association of Biology Teachers (NABT) Statement on Teaching Evolution, 1995.

Should we still use the term *reptile*? We now know that the birds we see today share a common ancestor with (and are, therefore, most closely related to) the group of organisms formerly called reptiles. In fact, they all descended from dinosaurs and are part of the same genetic branch, or clade (Theropoda). Although *reptile* or *reptilia* are no longer considered accurate terms, and *amniota* or *sauropsida* are considered more accurate, many biologists still use the term *reptile*, particularly when communicating with the general public.

Evolution Puzzlers: Handouts



TEACHING NOTES

Not all characteristics of a species are considered adaptations. In fact, adaptations are only those characteristics that have evolved through the process of natural selection because they provide a survival advantage to the population. Other characteristics exist just because they are carried over from past generations. For example, the wings of flightless birds are not considered adaptations in those species because they no longer help the animal survive, so they can't be selected. But when introducing the concept of adaptation to youth, this level of detail is likely not worth discussing.

d. Then, try to think of a different explanation. You'll have a total of 15 minutes.

e. If there's time, you can go to more stations.

12. Participants spend about 15 minutes trying to solve evolution puzzlers.

a. Spread out the *Evolution Puzzler* sheets and allow participants to pair up and choose a station at which to start.

b. Circulate as participants discuss to make sure they understand directions and are applying VISTA.

13. Bring the group together to share some of their ideas.

a. Ask:

▶ *What are some of your explanations for these adaptations?*

b. As participants share a few explanations, help them make connections to the VISTA concepts.

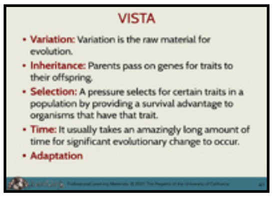
c. Ask others to add on to or gently critique explanations.

d. If there is time, probe further by asking:

▶ *What was an adaptation you struggled to explain?*

▶ *Was there any additional evidence you would have liked to have to better explain what happened?*

14. Show Slide 41: *VISTA*. **Revisit VISTA and share how participants might want to guide students in puzzling similarly over found organisms:**



slide 41

a. You can try this sort of evolution puzzler–approach with your students whenever you notice an interesting adaptation with an organism in the field.

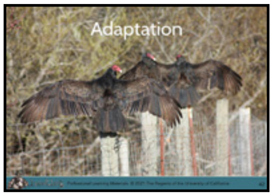
b. Notice that we have added definitions to all the ideas listed here, except for *adaptation*.

YOU ARE HERE:

25 minutes

Teaching About Adaptation and Evolution

1. Show Slide 42: *Adaptation*. **Brainstorm a definition for *adaptation*:**



slide 42

a. Since adaptation is often the focus for teaching students about evolution in outdoor science, it's worth taking time to discuss how to best approach the topic.

b. Thinking about everything we've discussed so far about evolution, how might you now define *adaptation*? (Accept several responses and point out any differences or nuances participants provide.)

c. There's a lot of potential for misunderstanding, so it's important to think about how we phrase this for our students.

2. **Show Slide 43:** *Adaptation Definition #1*. **Share pros and cons of UCMP's definition of *adaptation*:**

slide 43

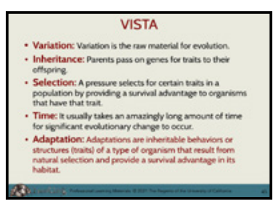
   a. This is a definition from the Museum of Paleontology at the University of California.
   b. What are some advantages to using this definition? [*Feature* refers to both structures and behaviors. It emphasizes the natural selection process.]
   c. A disadvantage might be that the definition is not very useful for students who don't understand natural selection.

3. **Show Slide 44:** *Adaptation Definition #2*. **Share a second definition of *adaptation*:**

slide 44

   a. This definition might be better for students who are unfamiliar with natural selection.
   b. Ask for advantages or disadvantages of this definition. Bring up the following, if participants don't:
      - Instead of *features*, it breaks down the word into *structures and behaviors* to help students remember that adaptations can be either or both.
      - It emphasizes the relationship between the environment in which an organism lives—its habitat—and the potential survival advantage.
      - It would be more informative (and longer) if it ended with the words *and pass on their genes*.
   c. Evolutionary biologists have to think about the environmental conditions when they are trying to figure out whether specific features of organisms are adaptations.

4. **Show Slide 45:** *VISTA with Adaptation Definition*. **Share usefulness of different definitions with different students:**



slide 45

   a. This is another workable definition to use with students who have already discussed some of the ideas behind natural selection, such as inheritance and survival.
   b. Any of these definitions can be useful, appropriate, and accurate, depending on the background and grade level of your students.

5. **Brainstorm a list of adaptation and evolution activities. Share:**
   a. We've pushed our own thinking about these important ideas in biology.
   b. Now, we'll move on to how we might help students develop an understanding of adaptation and evolution.

TEACHING NEWS

Populations adapt, individuals don't. When discussing adaptations of particular species, it's important to keep emphasizing that we should refer to the group of organisms' adaptations and not an individual organism's traits or characteristics.

Avoid using terms such as *designed to* or *engineered for* when talking about adaptations. Based on scientific understandings, the adaptive characteristics of species are not designed; instead, they are the result of natural selection, and science instructors should avoid using words that imply intentional design. If students bring up beliefs implying intentional design, respectfully acknowledge other ways of understanding and say that during this class, the focus will be on the scientific way of understanding life on Earth.

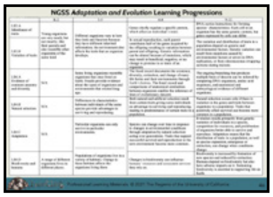
About intelligent design and adaptations. One of the arguments against intelligent design is that adaptations are often highly imperfect pre-existing features that have been jury-rigged for a different purpose. For example, sweat glands for cooling the body evolved into mammary glands for feeding young. The wolf behavior of licking the mouth of alpha wolves to show subservience probably came from a behavior of young wolves licking to encourage parents to regurgitate food. In ants and bees, the ovipositor for laying eggs evolved into a stinger for defense. See Background Information for Presenters (starting on page 51) for more on exaptations.

TEACHING NOTES

What does the BEETLES acronym stand for? It could be *Bringing Expensive Education To Lemurs, Emus, and Stink Bugs*. But it's not. It actually stands for *Better Environmental Education, Teaching, Learning, and Expertise Sharing* . . . and it's certainly not expensive; it's free!.

6. **Distribute adaptation and evolution–related activity write-ups.**
    a. Distribute the write-ups for any non-BEETLES adaptation-related or evolution-related activities currently used in your program.
    b. Distribute 1 copy of the *BEETLES Activities for Teaching Adaptation and Evolution* handout to each participant, as well as any copies of BEETLES activities you prepared.

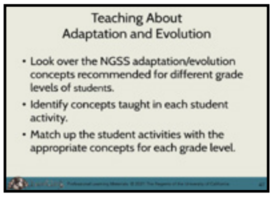
7. **Show Slide 46:** *NGSS Adaptation and Evolution Progression*. **Distribute the *NGSS* Adaptation and Evolution *Learning Progression* handout and share:**



slide 46

    a. Scientists and science educators who worked on the Next Generation Science Standards (NGSS) chose important concepts related to adaptation and evolution that all students should have the opportunity to learn as part of their public education.
    b. This chart shows how each of these six concepts could be developed over the grade-level spans of K–2, 3–5, 6–8, and 9–12.
    c. We'll take a look at how the activities we listed might be used to teach about these concepts at each grade span.

8. **Show Slide 47:** *Teaching About Adaptation and Evolution*. **Share:**



slide 47

    a. First, look over the concepts on the chart and think about how they are related to the VISTA concepts we've been discussing.
    b. Next, your group will try to identify related concepts in the student activities.
    c. Finally, you'll work on matching up the activities with particular grade-level concepts to help you make decisions about when to use them.

9. **Participants work in small groups to discuss adaptation and evolution concepts and how and when to teach them.**
    a. Circulate and assist small groups in reading the learning progression chart and making sense of the concepts in each grade level.
    b. Answer any questions about how the NGSS concept statements relate to the ideas they've been discussing in the session.

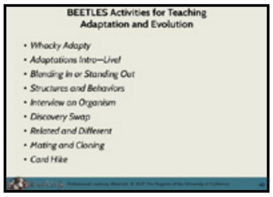
10. **Briefly share ideas for teaching about adaptation and evolution.**
    a. After small groups have had about 15 minutes to discuss, call on volunteers to describe their thinking about how to teach about adaptation and evolution with students.
    b. Ask:

    ▶ *Were there any new opportunities for teaching about adaptation and evolution that you discovered?*

TEACHING NOTES

▶ *Did you talk about how you might modify any of the activities you discussed?*

11. Show Slide 48: ***BEETLES Activities for Teaching Adaptation and Evolution*. Share BEETLES adaptation activities and connections to guidelines:**



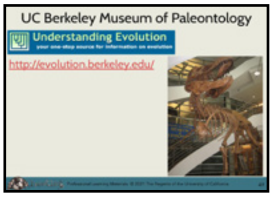
slide 48

a. These BEETLES activities build from a basic introduction of adaptations in organisms to more complex ideas.

b. Make connections as appropriate between BEETLES student activities and any guidelines for teaching about adaptation that have been discussed.

12. Wrap up the discussion and describe any follow-up actions you have planned for implementing changes or additions to your activity write-ups.

13. Show Slide 49: ***UC Museum of Paleontology*. Share references for more information about teaching evolution:**



slide 49

a. The Understanding Evolution website from the University of California Museum of Paleontology is a very useful source for doing further research into this important topic.

b. The information found on the site is designed to help educators be more accurate and clear when teaching about evolution and adaptation.

Reflecting and Wrapping Up

YOU ARE HERE:

10 minutes

1. Show Slide 50: ***Reflection*. Participants write reflections in their notebooks.**

slide 50

a. Read the reflection prompts.

b. Allow 5–10 minutes for participants to write their thoughts in their journals or on a blank sheet of paper.

TEACHING NOTES

APPLYING SESSION TO INSTRUCTION

The session is not over! A critical phase of learning anything new is application—when the learner takes new knowledge and applies it. There is some application included in the session; however, as with all professional learning for instructors, the rubber meets the road (or trail) when instructors apply what they've learned to their instruction and when they keep thinking and discussing with their peers. If you want your instructors to keep developing their understandings about adaptation and evolution and applying it to their instruction, they'll need ongoing support from you. Below are a variety of follow-up activities and discussions to let you dig deeper into the topic and help you facilitate thoughtful implementation.

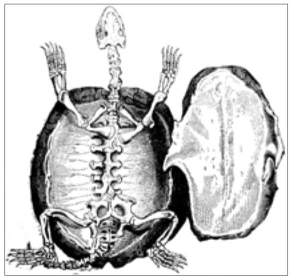
- **Staff brainstorm what they and you can do to encourage more accurate and coherent instruction around the topic of adaptation and evolution.** After the session reflection, your staff recorded ideas they have about implementation into their instruction. You can tap into these, as well as other ideas, through a brainstorm of what they plan to do and how you can support them in doing it.
- **Instructor observations.** If you do observations of instructors, discuss how you might incorporate elements from this session into the observations, such as paying attention to how experiences help students build their understandings about evolution.
- **Continuing a discussion.** If there was a topic that came up during discussion that you had to cut off, and it seems like your staff is still interested, set aside some time to continue the discussion.
- **Researching questions.** You might ask volunteers to do deeper research into aspects of evolution that your group found confusing and report back to the group.
- **Assign your staff a reading related to the ideas in this session.** Tell them to take notes as they read. Have them pair up with someone else and compare their notes and ideas. Then, bring this discussion into the whole group. Here are some suggested readings:
    - Understanding Evolution website from the University of California Museum of Paleontology (http://evolution.berkeley.edu/). This website is rich with many articles on aspects of evolution. You could assign staff to browse through the site and read about whatever interests them, or you might assign all staff to read one or more particular articles and then discuss them as a group (https://evolution.berkeley.edu/evolibrary/article/0_0_0/evo_51).
    - *Science Matters: Achieving Scientific Literacy* by Robert M. Hazen and James Trefil. NY: Anchor Books.
- **Addressing people who question the theory of evolution.** In addition to learning more about evolution, it may be useful for instructors to look into information and suggestions for ways to address the concerns of

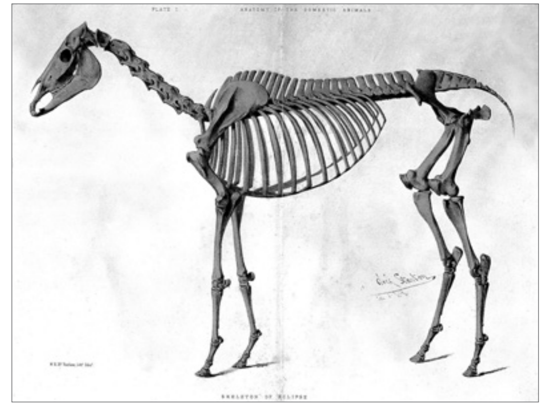
people who question the theory of evolution. For suggestions, see this comprehensive resource developed by the National Science Teachers Association (NSTA): An NSTA Q&A on the Teaching of Evolution (http://static.nsta.org/pdfs/EvolutionQandA.pdf).

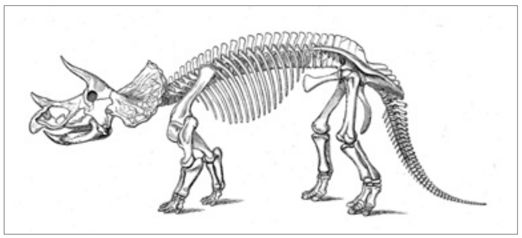
- **Use VISTA concepts to further examine any activities used to teach about adaptation and evolution in your program.** Come up with guidelines for how and when to teach using particular activities.
- **Addressing common misconceptions.** Have instructors discuss some common misconceptions about adaptation and evolution by referring to the Common Relevant Misconceptions section (beginning on page 57) in Background Information for Presenters. Instructors can also refer to any misconceptions they collect from their own students. Brainstorm possible ways to challenge students.

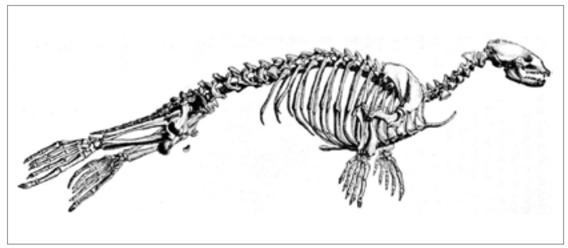
Vertebrate Skeletons

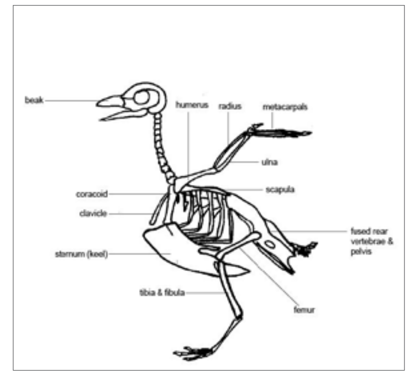
What are similarities and differences between skeletons of different kinds of vertebrates?

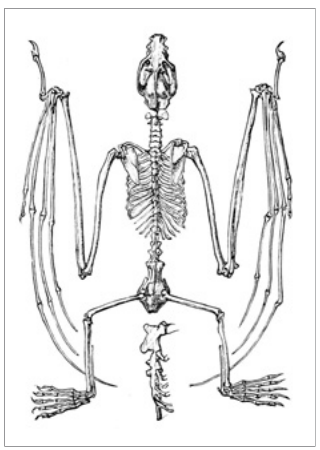


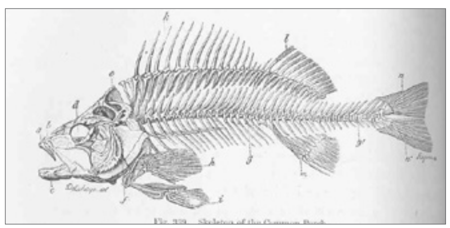


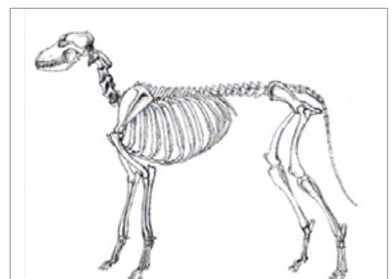


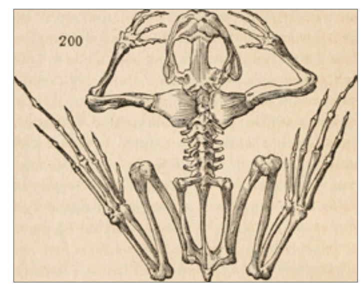


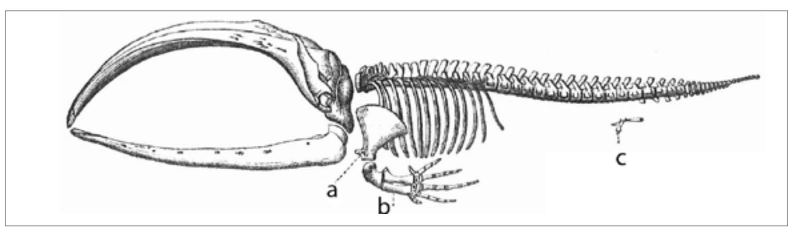







Dog Skeleton (after Ellenberger)



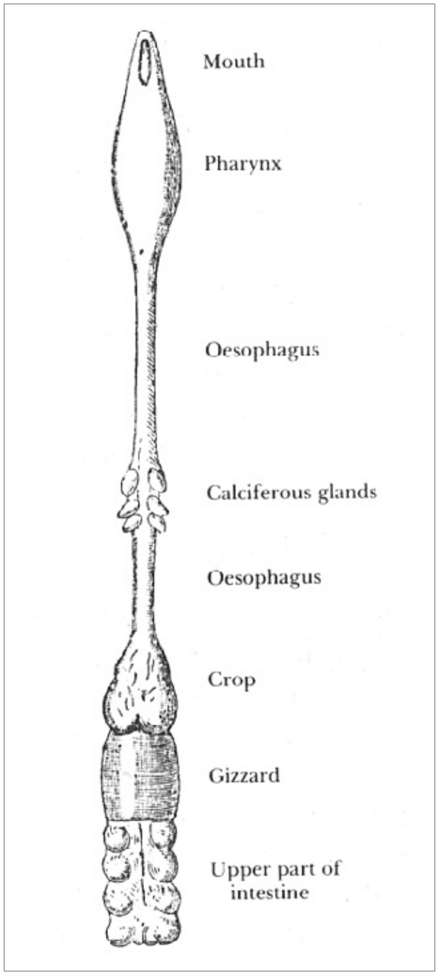


Credits (top, left to right): Gorilla: Gorilla skeleton Brehms Tierleben. 1888. Alfred Brehm/public domain; Turtle: Skeleton of a turtle. Anonymous. Public domain; Horse: Skeleton of Eclipse (a horse). Wellcome Library, London/CC BY (https://creativecommons.org/licenses/by/4.0); Triceratops: Triceratops prorsus old. Public Domain. By O.C. Marsh; Seal: Cambridge Natural History Mammalia Fig 227. Frank E. Beddard/ public domain; Bird: Anatomy and physiology of animals Birds skeleton. By Ruth Lawson. Otago Polytechnic. The original uploader was Sunshineconnelly at English Wikibooks./CC BY (https://creativecommons.org/ licenses/by/3.0); Bat: PSM V09 D563 Skeleton of flying fox. Unknown author/Public domain; Fish: Skeleton of the Common Perch. By Charles Bevalet - Fibuier, Louis (1868) Ocean World: Being a Descriptive History of the Sea and its Living Inhabitants, Category: New York: D. Appleton & Co., Public Domain, *Freshwater and Marine Image Bank* https://commons.wikimedia.org/w/index.php?curid=42981385; Dog: Lateral View of a Dog Skeleton. By Wilhelm Ellenberger and Hermann Baum - University of Wisconsin Digital Collections[1], Public Domain, https://commons.wikimedia.org/w/index.php?curid=2844510, Frog: Animal and vegetable physiology, considered with reference to natural theology (1836). Internet Archive Book Images/No restrictions; Whale: Whale skeleton. Meyers Konversionlexikon/Public domain.

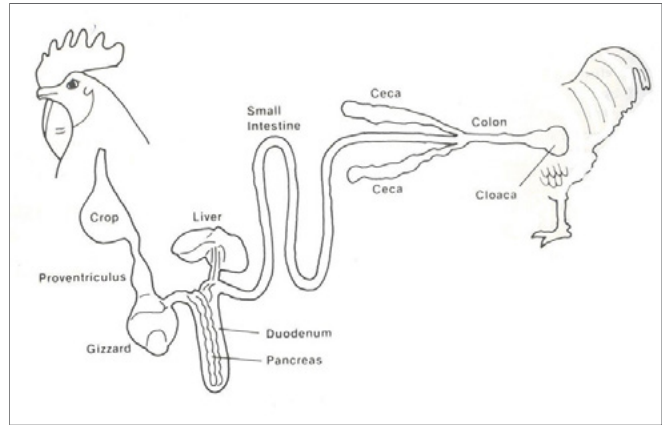
Digestive Systems

What are similarities and differences between digestive systems of invertebrates and vertebrates?

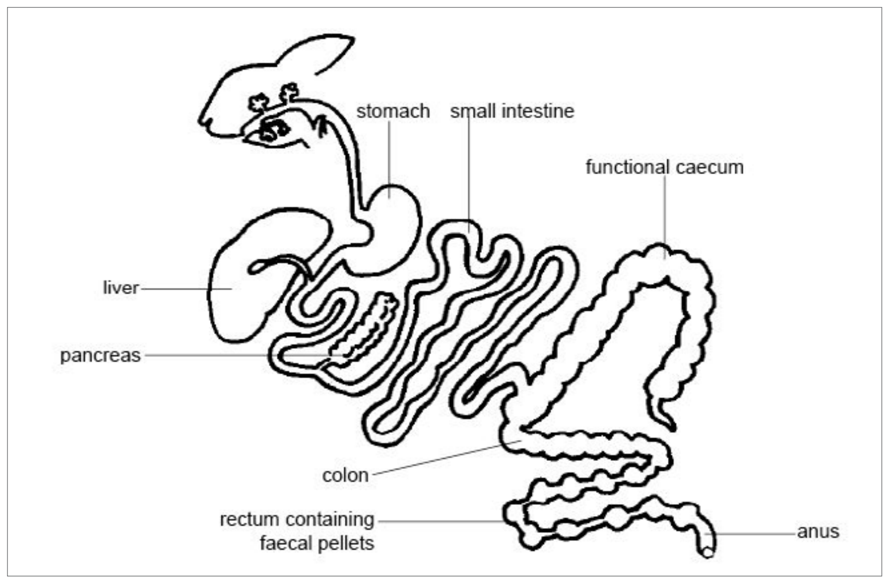
Worm



Bird



Rabbit

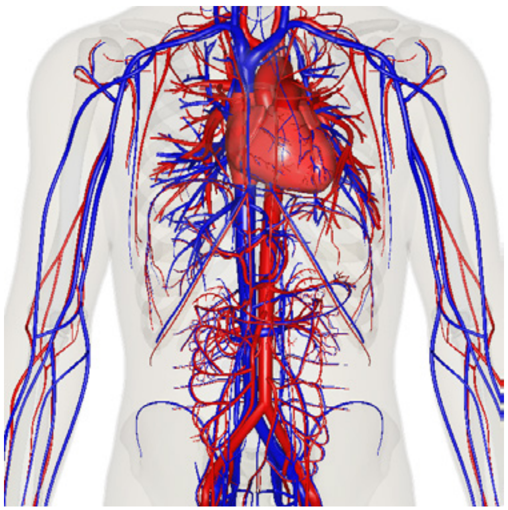


Credits: Worm: Vegetable Mould and Worms figure 1 (English labels). Diagram of the alimentary canal of an earthworm (Lumbricus). Unknown author/Public domain; Bird: Bird Gastro System. ErikBeyersdorf / CC BY-SA (https://creativecommons.org/licenses/by-sa/3.0); Rabbit: Anatomy and physiology of animals Gut of a rabbit. By Ruth Lawson. Otago Polytechnic. The original uploader was Sunshineconnelly at English Wikibooks. - Transferred from en.wikibooks to Commons by Adrignola using CommonsHelper., CC BY 3.0, https://commons.wikimedia.org/w/index.php?curid=13673351

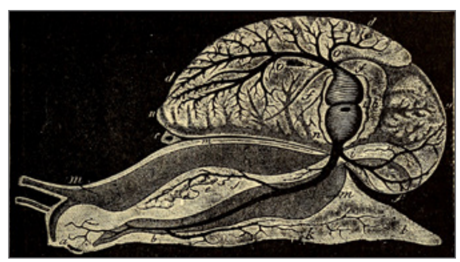
Vascular Systems

What are similarities and differences between vertebrate, invertebrate, and plant vascular systems?

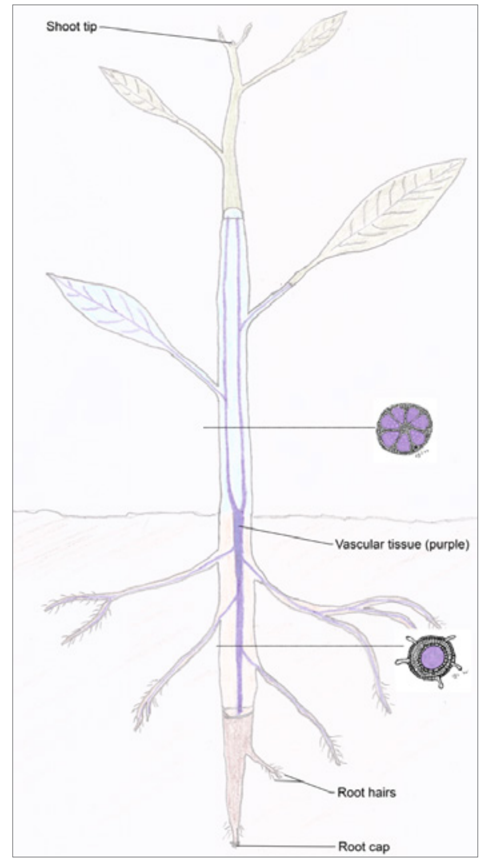
Vertebrate Vascular System



Invertebrate Vascular System



Plant Vascular System



Credits: Cardiovascular: Depiction of the heart, major veins and arteries constructed from body scans. Public Domain, https://commons.wikimedia.org/w/index.php?curid=35786381; Worm: *Fascola gigantica*. Thomas Spencer Cobbold (1828–1886)/Public domain; Snail: Comparative zoology, structural and systematic: for use in schools and colleges Year: 1883 (1880s). Authors: Orton, James. 1830-1877; Birge, E. A. (Edward Asahel), 1851-1950. Internet Archive Book Images/No restrictions; Plant: Plant vascular. CKRobinson / CC BY-SA (https://creativecommons.org/licenses/by-sa/4.0)

Cells

What are similarities and differences between animal, plant, and bacterial cells?

Bacterial Cell

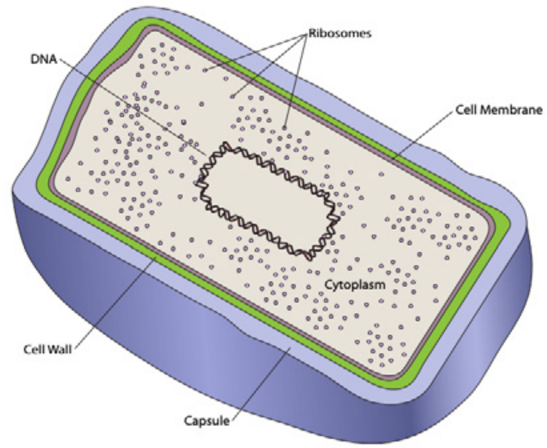


Figure 1. A Prokaryotic Cell.

Animal Cell

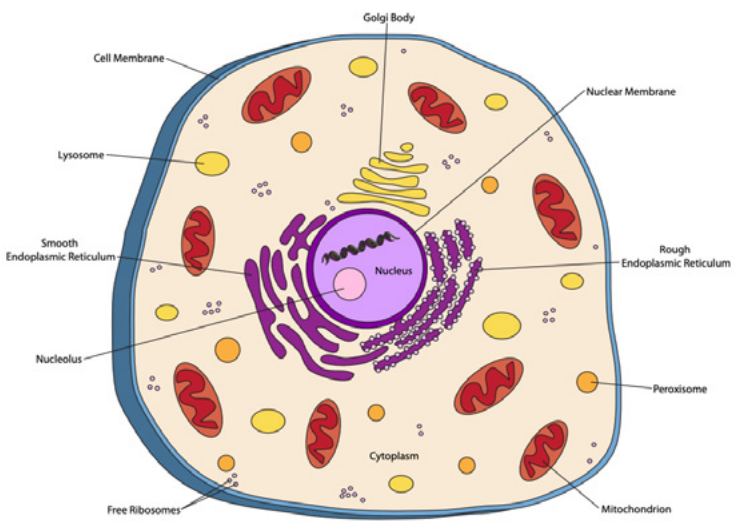


Figure 2. A prototypical animal cell.

Plant Cell

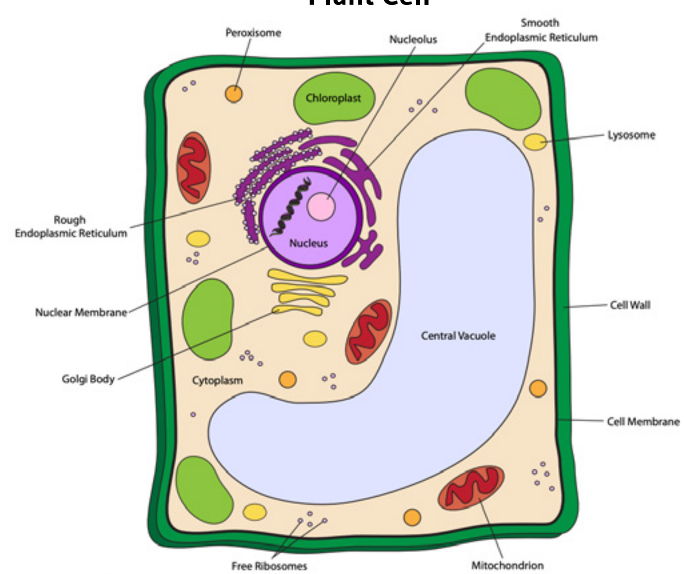


Figure 3. A typical plant cell.

Credits: All illustrations from: Cells: Molecules and Mechanisms by E. V. Wong, Ph.D. Copyright 2009, ISBN 978-0-9852261-1-4 Axolotl Academic Publishing Company, Louisville, KY http://www.axopub.com/Downloads/Cells/cells_complete.pdf

Ineritance: How Inheritable Traits Are Made

All living things have **DNA** in their cells. DNA is a ladder-shaped, spiral molecule. When organisms reproduce, they pass on their DNA to their offspring.

A **gene** is a segment of an organism's DNA that codes for a characteristic or trait. Every inherited trait we have, such as eye color or ear shape, is from the code of a gene or a group of genes. Offspring inherit genes from their parents. One reason we know all life on Earth is related is because we all share the same basic genetic code. We also share many of the same genes.

DNA does a lot of interesting things. One of the main things it does is help cells make **proteins**. A single strand of DNA has thousands of genes, each of which codes for a unique type of protein. What a protein does is determined by its size and shape. Two kinds of proteins are **structural proteins** and **messenger proteins**.

Structural proteins, along with other biochemicals, combine to make the structures of living cells. Cells make up the tissues and organs of living things. **Proteins** make up much of the "stuff" our bodies are made of.

gene > > protein > > cell > > tissue > > organ

Messenger proteins "tell" cells what to do. They are messengers for many biochemical reactions in cells (along with other important messenger molecules). Insulin and oxytocin are both proteins that tell your body to do certain things.

Changes in genes that make proteins can cause a cascade of effects in cells and tissues. This is because changes in structural proteins, messenger proteins, and other kinds of proteins can result in different physical traits in an organism and/or different ways that cells function.

Mutations are random changes in the DNA molecule, sometimes including the genes that make proteins. Mutations can happen in all cells of the body, because all cells divide. When cells divide, they make copies of the DNA/genes for the new cell. Sometimes when the copies are being made, there are mistakes. These mistakes can make random changes in the DNA sequence, causing a mutation in one or more genes. The *vast* majority of mutations are neutral, and most of the rest are harmful. However, some mutations are beneficial, and these give the organism an advantage. Mutations that happen in reproductive cells—such as sperm, pollen, eggs, and spores—can be passed on to offspring. These changes can add to the genetic variation in a population. In organisms that reproduce through cloning, mutations in body cells can also be passed on to offspring.

Sometimes, a single mutation may have a large effect on a population. However, in most cases, evolutionary change is based on the accumulation of many mutations.

Sexual reproduction can also introduce new gene combinations into a population. Reproductive cells, such as sperm and egg, from two "parent" organisms combine to form the embryo of the offspring. Offspring get half the DNA from one parent and half from the other. When DNA from parents is put together in new combinations, new traits can sometimes show up. This genetic shuffling (or recombining) is an important source of genetic variation.

mating insects

Gene flow is the movement of genes from one population to another (through migration or territorial expansion) and is also an important source of genetic variation. For example, there may be two populations of the same species of beetle that are far apart and, over time, have evolved some different genes. If one or more beetles from one group mates with beetles from the other group, their different genes will be combined in their offspring.

Credits: A section of DNA. The bases lie horizontally between the two spiraling strands. By Zephyris, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=6285050; Insects: *Oncopeltus fasciatus* 3893.jpg Davefoc, CC BY-SA 4.0 <https://creativecommons.org/licenses/by-sa/4.0>, via Wikimedia Commons

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Ineritance Reading Cards

Photo by Amelia Rosenman

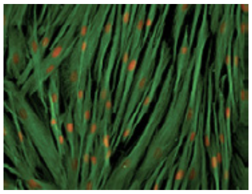
Sexual Reproduction

Credit: Black Bellied Whistling Duck Family by Matthew Paulson, CC BY-NC-ND 2.0. https://www.flickr.com/photos/matthewpaulson/5807008008/

Offspring

Credit: Front Line by James Marvin Phelps, CC BY-NC 2.0. https://www.flickr.com/photos/mandj98/3908249882/

Population



Credit: Science daily #41: They build us, we are made of them by Sergei Golyshev, CC BY-NC 2.0. https://www.flickr.com/photos/29225114@N08/8658765020/

Mutation

Credit: Database Center for Life Science (DBCLS) [CC-BY-3.0 (http://creativecommons.org/licenses/by/3.0)], via Wikimedia Commons

Reproductive Cells

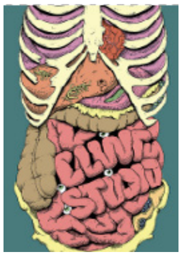
Credit: *Marchantia polymorpha* with conceptacles by George Shepherd, CC BY-NC 2.0. https://www.flickr.com/photos/gjshepherd/3559651042/

Cloning

Credit: Jesper Hansen (Denmark) [FAL], via Wikimedia Commons

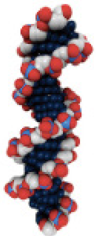
Message

Credit: Buxo by Pedro Henrique Corrêa, CC BY-NC 2.0. https://www.flickr.com/photos/pedrohcorrea/6517297305/



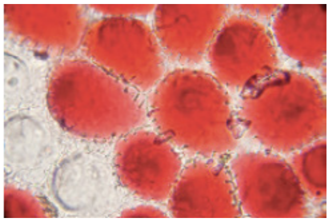
Tissue, Organs, Stuff We're Made Of

Credit: DNA by Enzymlogic, CC BY-NC 2.0. https://www.flickr.com/photos/101755654@N08/9735192821/



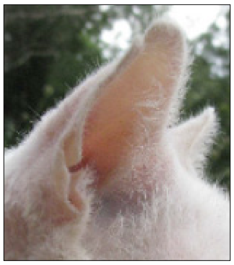
DNA

Credit: Red geranium petal cells by Umberto Salvagnin, CC BY-NC 2.0. https://www.flickr.com/photos/kaibara/4966621857/



Cell

Credit: Jim Conrad [Public domain], via Wikimedia Commons



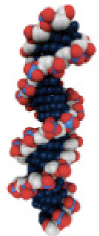
Trait

Credit: National Human Genome Research Institute ([1] (file)) [Public domain], via Wikimedia Commons

Gene

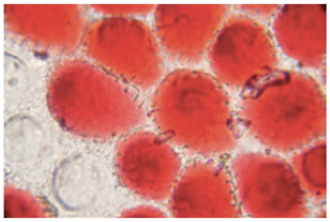
Ineritance Reading Cards (continued)

Credit: DNA by Enzymlogic, CC BY-NC 2.0. https://www.flickr.com/photos/101755654@N08/9735192821/



DNA

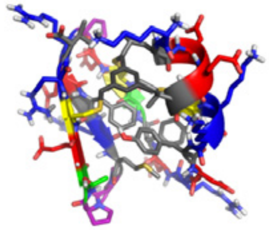
Credit: Red geranium petal cells by Umberto Salvagnin, CC BY-NC 2.0. https://www.flickr.com/photos/kaibara/4966621857/



Cell

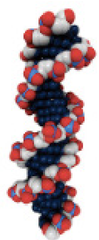
Non-Reproductive Cell

Credit: Towards Breakthroughs in Protein Structure Calculation and Design (sticks_tbmb_peptide) by Argonne National Laboratory, CC BY-NC 2.0



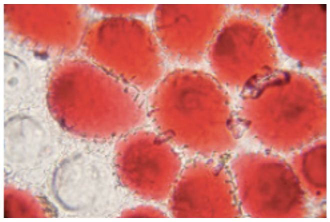
Protein

Credit: DNA by Enzymlogic, CC BY-NC 2.0. https://www.flickr.com/photos/101755654@N08/9735192821/



DNA

Credit: Red geranium petal cells by Umberto Salvagnin, CC BY-NC 2.0. https://www.flickr.com/photos/kaibara/4966621857/



Cell

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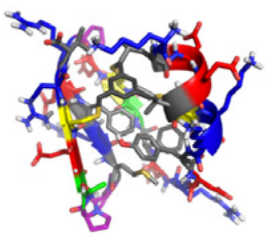
Credit: Towards Breakthroughs in Protein Structure Calculation and Design (sticks_tbmb_peptide) by Argonne National Laboratory, CC BY-NC 2.0



Protein

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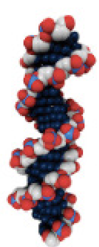
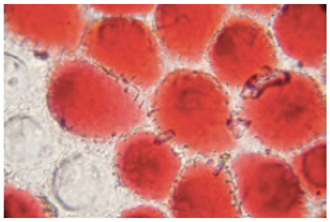


DNA

Credit: Red geranium petal cells by Umberto Salvagnin, CC BY-NC 2.0. https://www.flickr.com/photos/kaibara/4966621857/



Cell

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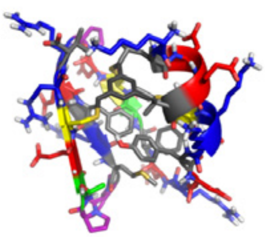
Credit: Towards Breakthroughs in Protein Structure Calculation and Design (sticks_tbmb_peptide) by Argonne National Laboratory, CC BY-NC 2.0



Protein

Explanation for Blowholes in Whales (Using VISTA)

Whale blowholes allow air-breathing mammals (whales) to live full time in the ocean. They can pop up to the surface and breathe without lifting their heads out of the water and then smoothly dive back down. How did this adaptation evolve? When you look at blowholes in a series of ancient whale skulls, you can see the gradual movement over millions of years. In the earliest whale ancestor skull, the breathing hole is just a nostril where you might expect one to be on any land mammal. It took 35 million years for the breathing hole to move farther and farther back on the skull, ending up with today's whales having blowholes on the top of their skulls.

Credit: The blowholes of the Blue Whale. By NOAA Fisheries (TBjornstad 11:21, 18 April 2007 (UTC)) - Protected Resources Division, Southwest Fisheries Science Center, La Jolla, California, Public Domain, https://commons.wikimedia.org/w/index.php?curid=1965067

Using what we know about natural selection (VISTA: Variation, Inheritance, Selection, Time, Adaptation), we can explain that some whales may have been born with a mutation for a blowhole a little farther back on the skull (Variation). Environmental pressures then selected individuals with this trait to survive and reproduce more successfully (Selection). What were those pressures? Whale ancestors lived next to the ocean during warm times. The warm, salty seas were rich in marine life and also free of marine dinosaurs, which had become extinct. A breathing hole farther back on the skull could make it easier to breathe in water, allowing the whale to spend more time in the water, be more successful at feeding and escaping predation, and have more surviving young. Some of the offspring that had the same trait would be more successful, too; eventually, the trait would be widespread in the population (Inheritance). Over millions of years (Time), this process could happen again and again until the blowhole ended up where it is found today (Adaptation).

By adapting to live in water with the blowhole, along with other adaptations for living in a watery environment, early whales adapted to take advantage of a habitat that was closed off to most other mammals. This ecosystem had lots of food and shelter and few predators and competitors. These conditions were a powerful pressure to select for traits that could allow an organism to spend more time in the ocean.

Lamarckian Explanation for Giraffe Necks

Lamarck was a French naturalist in the early 1800s, before Darwin. He wrote what is now known to be an inaccurate explanation for how life evolved. However, exploring Lamarck's ideas can be useful for science educators because students and anyone who is new to evolution often have similar misconceptions. Today's common misconceptions are often similar to ideas held by brilliant people in the past! Just like our students, these smart scientists were thinking logically and using the best information available to them, but they didn't necessarily have access to all the evidence we now have.

A famous example of a Lamarckian explanation is related to how the giraffe got such a long neck. According to Lamarck, an individual giraffe was able to stretch its neck throughout its lifetime to reach food. Over time, its neck became longer, which caused its offspring to have longer necks. Knowing what you know about genes and traits, what is wrong with this explanation?

For traits to appear in a population and be passed on, they need to be caused by a change in genes. A population's genes are changed through reproduction (and sometimes by new individuals migrating into the population), not by events that happen during an individual lifespan.

- If you lose a finger, your children will not be born missing a finger.
- If you lift lots of weights, your children will not be born "buffed."
- If an individual giraffe managed to stretch its neck a bit during its life, its offspring would not have longer necks.

This is a common ongoing misconception about evolution and adaptation. We now know that *populations* adapt over time; individuals do not.

A More Reliable Natural Selection Explanation for Long Giraffe Necks

Using what we know about natural selection (Variation, Inheritance, Selection, Time, and Adaptation), we can hypothesize that giraffes with slightly longer necks appeared in a population through mutation or gene mixing (Variation). The giraffes with longer necks were able to be more successful than shorter-necked populations. Longer-necked giraffes may have been more successful at feeding during droughts and then had more offspring, some of which also had longer necks. From witnessing the "clubbing" behavior of male giraffes, some scientists think longer necks could also have been useful for competing over mates. In either case, this trait would make longer-necked giraffes more successful in reproducing (Selection), so they passed on the longer-neck trait to their offspring over generations (Inheritance). Over millions of years (Time), this process was repeated until giraffes evolved the long necks they have today (Adaptation).

Credits: Lamark: Portrait de Jean-Baptiste Lamarck. By Jules Pizzetta - Galerie des naturalistes de J. Pizzetta, Paris: Ed. Hennuyer, 1893, Public Domain, https://commons.wikimedia.org/w/index.php?curid=657682; Giraffe: safaritravelplus / CC0

Evolution Puzzler: The Evolution of the Fiddler Crab's Large Claw

Male fiddler crabs have one very large claw and one small claw. They use the small claw for picking up food. They use the large claw for fighting other males and for waving around to attract females.

Explain how the adaptation of this large claw could have evolved.

Credit: Fiddler crab 0. Wilfredor / CC0

Evolution Puzzler: The Evolution of Horse Hooves

Ancestors of the horse lived on open grasslands. Somewhere along the way, they began walking and running on their toes. Pre-horse toes eventually evolved into the hooves found on modern horses.

Use this evidence and the photos below to explain how the adaptation of hooves could have evolved.

Credit: Mountain horse 2. tuchodi. Flickr

Credit: By Alex brollo - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=876946

Evolution Puzzler: The Evolution of Legless Snakes

Modern snakes have no legs. But there is evidence that ancestors of snakes did have legs.

What could be a possible explanation for snakes developing the adaptation of having no limbs?

Credit: Gopher Snake (9096387429). National Park Service from USA / Public domain

Evolution Puzzler: The Evolution of Blackberries

Blackberry bushes produce sweet fruit that contain their seeds.

Explain how the adaptation of blackberries having their seeds contained in sweet fruit could have evolved?

Credit: Kevin Beals

Evolution Puzzler: The Evolution of Dung Ball Rolling Behavior

Many dung beetles roll a ball of dung away from where it was found and lay their eggs inside it. This brooding ball provides food for their hatching young.

Explain how this behavioral adaptation of the dung beetle could have evolved.

Credit: An earth-boring dung beetle working. By Rafael Brix - own photograph, reload of wrong named image, CC BY 2.5, https://commons.wikimedia.org/w/index.php?curid=921903

Evolution Puzzler: The Evolution of Monarch Butterfly Migration

North American monarch butterflies fly hundreds to thousands of miles south from late summer through autumn and return north during the spring months.

Explain how this migratory behavioral adaptation of butterflies could have evolved.

Credit: Cliff1066 - IMG 1893 (by). Cliff from Arlington, VA (Outside Washington DC), USA / CC BY (https://creativecommons.org/licenses/by/2.0)

Evolution Puzzler: The Evolution of the Bee Stinger

Female bees are the only ones in a colony that can sting; male drones do not have stingers. Queen bees also have stingers, but they use them only to kill potential rival queens as they emerge from their cells

What's a possible explanation for the adaptation of bees having stingers?

Credit: Stechende Biene 12a. Waugsberg / CC BY-SA (http://creativecommons.org/licenses/by-sa/3.0/)

Evolution Puzzler: The Evolution of Newt Toxin

The rough-skinned newt is toxic enough to kill 20 adult humans when eaten. Some populations of the common garter snake are immune to this toxin.

Explain how this adaptation of a powerful toxin in the skin of the newt could have evolved.

Rough-skinned newt

Credit: Rough-skinned newt (By The High Fin Sperm Whale - Self-photographed, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=12036399

Common garter snake

Credit: By USFWSmidwest - Common Garter Snake, Public Domain, https://commons.wikimedia.org/w/index.php?curid=69205712

NGSS *Adaption and Evolution* Learning Progressions

	K-2	3-5	6-8	9-12
LS3.A Inheritance of traits	Young organisms are very much, but not exactly, like their parents and also resemble other organisms of the same kind.	Different organisms vary in how they look and function because they have different inherited information; the environment also affects the traits that an organism develops.	Genes chiefly regulate a specific protein, which affect an individual's traits.	DNA carries instructions for forming species' characteristics. Each cell in an organism has the same genetic content, but genes expressed by cells can differ
LS3.B Variation of traits			In sexual reproduction, each parent contributes half of the genes acquired by the offspring resulting in variation between parent and offspring. Genetic information can be altered because of mutations, which may result in beneficial, negative, or no change to proteins in or traits of an organism.	The variation and distribution of traits in a population depend on genetic and environmental factors. Genetic variation can result from mutations caused by environmental factors or errors in DNA replication, or from chromosomes swapping sections during meiosis.
LS4.A Evidence of common ancestry and diversity	N/A	Some living organisms resemble organisms that once lived on Earth. Fossils provide evidence about the types of organisms and environments that existed long ago.	The fossil record documents the existence, diversity, extinction, and change of many life forms and their environments through Earth's history. The fossil record and comparisons of anatomical similarities between organisms enables the inference of lines of evolutionary descent.	The ongoing branching that produces multiple lines of descent can be inferred by comparing DNA sequences, amino acid sequences, and anatomical and embryological evidence of different organisms.
LS4.B Natural selection	N/A	Differences in characteristics between individuals of the same species provide advantages in surviving and reproducing.	Both natural and artificial selection result from certain traits giving some individuals an advantage in surviving and reproducing, leading to predominance of certain traits in a population.	Natural selection occurs only if there is variation in the genes and traits between organisms in a population. Traits that positively affect survival can become more common in a population.
LS4.C Adaptation	N/A	Particular organisms can only survive in particular environments.	Species can change over time in response to changes in environmental conditions through adaptation by natural selection acting over generations. Traits that support successful survival and reproduction in the new environment become more common.	Evolution results primarily from genetic variation of individuals in a species, competition for resources, and proliferation of organisms better able to survive and reproduce. Adaptation means that the distribution of traits in a population, as well as species expansion, emergence or extinction, can change when conditions change.
LS4.D Biodiversity and humans	A range of different organisms lives in different places.	Populations of organisms live in a variety of habitats. Change in those habitats affects the organisms living there.	Changes in biodiversity can influence humans' resources and ecosystem services they rely on.	Biodiversity is increased by formation of new species and reduced by extinction. Humans depend on biodiversity but also have adverse impacts on it. Sustaining biodiversity is essential to supporting life on Earth.

Credit: NGSS, Appendix E, page 6. http://www.nextgenscience.org/sites/default/files/resource/files/AppendixE-ProgressionswithinNGSS-061617.pdf

BEETLES Activities for Teaching Adaptation and Evolution

Whacky Adapty

In this Adaptation Name Game, students sit or stand in a circle and play a version of tag that represents how certain structures and behaviors help organisms survive in their habitat. This game helps students learn one another's names while lightly introducing students to what adaptations are.

Adaptations Intro—Live!

This activity is a brief introduction to adaptations as the group observes a live organism together. Students start out observing an organism's structures and trying to figure out which structures might help it survive in its habitat and which structures are inheritable. Then, they do the same with behaviors, attempting to figure out which behaviors are behavioral adaptations.

Blending In and Standing Out

This activity focuses on how organisms' patterns and colors help them blend in with or stand out in their environment and how this helps them survive. Students observe the main colors in the landscape and then search for plastic animals hidden there, noticing which animals blend in with their surroundings and which stand out. Then, students discuss what made the animals blend in or stand out, constructing explanations for how this could help the animals survive. Students learn four categories for color and pattern adaptations: camouflage, mimicry, warning, and attraction. Students apply these concepts as they search for real organisms in the area and then discuss how patterns and coloration might help the organisms survive in their habitat.

Structures and Behaviors

This activity helps students develop a definition of *adaptation* that includes both behavioral and structural adaptations and gives students the experience of applying that definition to an organism in the local ecosystem. Pairs of students find an organism and then observe and record its structures and behaviors. Students apply the lens of adaptations as they come up with explanations for how their organisms' structures and behaviors might help them survive in their habitat. In a group discussion, students consider the relationship between organisms' structures and possible functions.

Interview an Organism

This activity gives students the opportunity to enter the world of an organism. Students slow down and have a "conversation" with an organism of their choosing, asking questions that can be answered through more observation while paying attention to its surroundings and the scale of its world. This helps take students to the next level of observing and questioning as they learn to ask themselves questions that lead them to make deeper observations. Students search for interesting organisms and observe them. Each pair of students chooses an organism to study, comes up with questions about the organism's appearance and structures, and then attempts to answer each question through observation. Students then move on to more probing questions about the organism's relationships to other organisms and how its structures and behaviors help it survive in its habitat.

BEETLES Activities for Teaching Adaptation and Evolution (continued)

Discovery Swap

In pairs, students explore an ecosystem, collecting and examining many organisms. They then choose one organism to study through drawing and through recording observations and questions in writing. They also use tools such as field guides or identification keys (if you have them) to identify and further research their organisms. Students think about the structures their organisms have and about how those structures might help it survive in its habitat. One member of each pair stays with their organism, while the other member circulates to check out the other organisms. Students discuss their discoveries, questions, and ideas with one another. After a few minutes, those who have been circulating switch roles with their partners who have been staying with their organisms, so everyone has a chance to look at other organisms and share about their own organisms.

Related and Different

Students search for two somewhat closely related organisms (e.g., two kinds of insects or a spider and an insect) to compare using Venn diagrams. Students then debate which two organisms studied by a team are most closely related and support their ideas with evidence and reasoning. Finally, they interpret a Tree of Life diagram to see how living things on Earth share common ancestors.

Mating and Cloning

This activity is meant to follow the activity *Related and Different*. Students compare individuals of the same type and recognize diversity. Discussing where this diversity comes from leads students to think about how parents pass on their traits to their young. Using *Field Guide to Mating in Flowering Plants and Conifers*, students explore evidence of plant reproduction and realize that there are plants mating all around them! A final discussion focuses on advantages and disadvantages of sexual (mating) and asexual (cloning) reproduction.

Card Hike

Students slowly move along a planned trail alone (but not far from others), reading cards placed along the trail. The activity includes a set of cards on the theme of adaptations. The Adaptations Cards introduce thoughtful adaptations content and interesting tidbits of information that can get students to think about their surroundings through an adaptations perspective. The cards also direct students to engage with their surroundings through sensory experiences and inspiring quotes. This activity works well as a conclusion to an adaptations-themed field experience.

BACKGROUND INFORMATION FOR PRESENTERS

> "The theory of evolution is quite rightly called the greatest unifying theory in biology." —Ernst Mayr, Professor of Zoology, Emeritus, Harvard University

Understanding the theory of evolution is more than just describing the change over time in organisms since life began 3.7 billion years ago. Throughout this session, we emphasize the important cornerstone ideas of evolution that are captured in the VISTA acronym—Variation, Inheritance, (natural) Selection, (deep) Time, and Adaptation. What follows here is a consolidation of the information provided in the session itself, as well as many of the content-related sidebar notes and some additional information. Read this section to refresh your understanding and to prepare for presenting the session.

Content Knowledge

Diversity and Variation

Diversity refers to the differences between organisms within ecosystems, between species, and within species. Biodiversity—a measure of the differences within and between different species in an ecosystem—is a prized aspect of a healthy habitat. This diversity can be appreciated by looking at a Tree of Life diagram and also by comparing features of different species outdoors. In the BEETLES student activity *Related and Different*, students make Venn diagrams of characteristics of similar species and use overlapping characteristics as evidence of relatedness. It can be fascinating to compare characteristics of similar species (e.g., by looking at the variety of shapes of antennae in insects) and then propose ideas for how these differences could be advantageous.

Variation can be thought of as the "palette" of characteristics that the process of natural selection uses to "paint" the different forms of life found on Earth. The more variation there is in the features of a species of organisms, the more possibilities there are for different adaptations to help it survive in the wild. Variation can be seen by closely observing and comparing individual organisms of a species outdoors. In the BEETLES activity *Mating and Cloning*, students notice variation in members of a species and try to figure out which features are inherited and which are not.

While there is an amazing array of variation found in living creatures, the other side of the coin is noticing the similarities. The Tree of Life can also be useful for examining and discussing similarities and relatedness between all living things. For example, all living organisms are made up of cells, and many groups share other structural features such as groups of vertebrates that have four limbs. The physical similarities between different groups of organisms are a key piece of evidence for the relatedness between species and can be traced back to one original ancestral life-form. In *Related and*

Different, students also look for evidence of relatedness between species. Several of the defining structures on the comparison sheets used in this session are considered homologous features. This means that these structures are shared by different organisms, but they don't necessarily perform the same function in each one. Homologous structures are traits and features whose origin can be explained by descent from a common ancestor. The opposite of homologous organs are analogous organs, which are different structures that do similar jobs in two different groups of organisms. These are characteristics that were not present in the last common ancestor but evolved separately. An example of an analogous trait would be the wings of bats and birds, which evolved independently in each lineage after they separated. After diverging from ancestors with forelimbs that were not used as wings (terrestrial mammals and theropod dinosaurs, respectively), both bats and birds developed a similar adaptation for flight. The characteristic of having wings is not an indication of relatedness in this case. It only reflects the fact that the development of wings aided in the survival of both ancestors of these species in their particular habitats, resulting in both groups evolving this characteristic.

Inheritance

Inheritance explains how we know that all life forms are related, because they share DNA (deoxyribonucleic acid). This is why a basic familiarity with inheritance and the role of genes is a key part of understanding the mechanisms for evolution. Knowing that characteristics (traits) are a result of the genes passed from parents to their young helps students understand how adaptations are passed on to surviving generations. Most cells in the human body contain a complete set of genes that have the information needed for the whole body. The exceptions are reproductive cells (which have only half the number of chromosomes) and cells without DNA (such as blood cells and some skin and hair cells). In species that reproduce sexually, such as humans, an offspring is made from combining the egg cell from the mother (containing copies of half of her DNA) and the sperm cell from the father (containing copies of half of his DNA). This combined set of DNA from both the mother and the father makes up the full complement of genes needed by the new individual. Every time an egg and sperm join, a new combination of genes is created. This means that sexual reproduction makes it so that each individual organism has a unique set of genes. Identical twins are the exception. They are exactly alike genetically because they are the result of one fertilized egg splitting into two separate individuals. Species that reproduce asexually, by cloning or budding, also have identical genes since they are exact replicas of the parent organism. This is why sexual reproduction (along with spontaneous genetic mutation and genetic flow between migrating populations) is seen as an important mechanism for producing variation among species.

DNA includes lots of genes. Each gene has information on how to make the specific proteins that make up a characteristic or trait. Genes are the codes used for protein synthesis in all cells. A gene is a special segment of DNA that contains a sequence of A's, C's, T's, and G's (the four nucleotides, that is, not the entire strand of DNA) that provides information for making specific proteins that can result in a characteristic or trait. A single strand of DNA contains thousands of genes that function as unique protein recipes. Humans have about 20,000 genes altogether. Some genes are small, only about 300 nucleotides long, while others are well over a million nucleotides long. Sequences of nucleotides (base pairs) occur on the DNA molecule code for amino acids, which then combine in cells to form specific proteins. These proteins, created in each cell of the body, can direct the multitude of choices that are made as organisms develop and grow.

Gaining an awareness that new variations in organisms can be caused by changes in DNA that happen during either sexual reproduction or spontaneous mutations will help lay a foundation for understanding that natural selection depends on those new characteristics regularly popping up in populations. This idea also helps combat the common misconception that variations happen as a response to changes in the environment. Variations in DNA are always present due to the recombining and/or mutation of DNA, but selective pressures, such as changes in the environment, create the conditions that select for certain traits being successfully passed on as adaptations.

Biologists use many kinds of evidence to decide which species are most closely related as well as to uncover evolutionary relationships. Constructing tree diagrams and circular phylogenetic trees is an evidence-based process that relies heavily on genetic analysis. Scientists use a combination of evidence from fossils, DNA analysis, shared internal characteristics of organisms, and shared visible characteristics to classify and describe the relatedness of organisms. Species are then placed on branches that represent the evidence of their evolutionary history and common ancestry. Both extinct species and living species are often placed on tree diagrams. Two species that are fairly closely related, having had a relatively recent common ancestor, are typically placed on nearby branches that split near the ends of the branches. Less closely related species are placed on branches that split from one another nearer to the trunk of the tree. In other words, when the split between species is closer to the trunk of the diagram, this shows that their common ancestor lived farther in the past. In this way, cladograms and circular phylogenetic tree diagrams are a record of the genetic changes that have happened in different populations of organisms over long periods of time, resulting in the diverse species that exist on the planet today.

Selection

Natural selection is the process by which organisms with the most favorable genetic adaptations outcompete less adapted organisms in a population. Environmental factors in a habitat, such as the temperature or the types of predators, can influence which individuals of a species survive. But survival is only part of the story. First, there needs to be a population of organisms that have more offspring than can possibly survive. This population of organisms also needs to have a variety of genes present in different individuals (due to mixing of genes either during reproduction or from spontaneous mutations). Some organisms with characteristics that help them to be more successful at surviving to reproduce will have more offspring. Over many generations, populations with traits that are suited to survival in these conditions continue to reproduce successfully, while those without those traits don't do as well. Over time, this causes a shift in the genetic makeup of the population, with the result that there are more individuals that have these adaptations and can pass them on to their offspring. The driving force behind adaptation and evolution is not the desire or needs of a species. Instead, it's a combination of evolutionary processes: overproduction, genetic variation, natural selection, and the inheritance of genetically determined traits.

Some students may say that the purpose for the development of new species through adaptation has ultimately been to produce humans, and, generally speaking, organisms have evolved from less complex to more complex (i.e., from single-celled to multicellular organisms). It is true that human body processes are *more complex* at the cellular level than in the humans' ancestors, but biologically speaking, they are not actually more advanced than in any other living organism. There is no aim to evolution. It happens automatically as certain organisms have more offspring that survive in particular habitats. This is why scientists don't refer to the organisms higher up on the Tree of Life, such as humans and primates, as being more evolutionarily advanced. In fact, there are organisms on Earth that have been evolving for much longer than humans—bacteria, for example—that have survived many changes in environmental conditions and resources and are therefore very successfully adapted. To quote one educational resource, "Evolution is a tinkerer, not an engineer." It's important to clearly communicate to students that the process of evolution does not have the goal of producing better organisms from more primitive ones. Some students may incorrectly think that the ultimate purpose for the development of new species through adaptation has been to produce humans.

Time

The incredible variety of living things currently found on Earth did not appear overnight; instead, it developed over the span of geologic history. When we use the expression *deep time* in relation to evolutionary theory and adaptation, we are referring to the multimillion-year time frame that is most often used to describe geological events that have occurred since the formation of our planet some 4.6 billion years ago. Changes in populations of organisms usually take place over millions of years.

About molecular clocks. Scientists use several methods to determine the dates of fossils, including: stratigraphy (looking at the layers of rock), radiometric dating (measuring the radioactive decay of particular elements), and more recently, the use of a DNA-based molecular clock (looking at changes in DNA base pairs). For the past 40 years, evolutionary biologists have been investigating the possibility that some evolutionary changes happen in a clock-like fashion. Over the course of millions of years then, mutations may build up in any given stretch of DNA at a reliable rate. For example, the gene that codes for a component of hemoglobin experiences base changes at a rate of 0.56 changes per base pair per billion years. If this rate is reliable, the gene could be used as a molecular clock. When a stretch of DNA does indeed behave like such a clock, it becomes a powerful tool for estimating the dates of lineage-splitting events. For example, imagine that a length of DNA found in two species differs by four bases, and we know that this entire length of DNA changes at a rate of approximately one base pair per 25 million years. This means that the two DNA versions differ by 100 million years of evolution and that their common ancestor lived 50 million years ago. This means the two species must have descended from a common ancestor that lived at least 50 million years ago.

Biologists and paleontologists agree that life on Earth has evolved over great periods of time and that all species share a common ancient ancestor. However, they do not necessarily all agree about the pace of evolution—whether it occurs gradually (gradualism) or through spurts of rapid change (punctuated equilibrium). This question is extremely difficult to answer with any certainty because the fossil record is incomplete, and we can't easily replay what happened in the distant past.

Adaptation

Adaptations are features of populations of organisms that improve their function and ability to survive and reproduce in their habitat. Adaptations are the result of evolution in a species, not through changes in a single individual. An organism does not "decide" to produce adaptations. Nor can a species develop adaptations over the course of a few months or years. Species do not develop adaptations because they want or need them, so these are not accurate scientific terms to use when describing the features of organisms. Certain genetic changes enable organisms to survive and reproduce and to pass on these changes to future generations. These characteristics then become new adaptations of the species. Populations as a whole can be said to adapt as a result of changes either in habitat or in the adaptations of other species in their habitat. However, this is because the conditions for survival have changed and, as a result, different variants in the population of the species have been more successful in reproducing.

An important distinction for understanding both the mechanisms for heredity and its role in evolution is the notion of acquired versus inherited characteristics. Not all characteristics come from the genes of an individual. Some, such as bigger muscles from working out or scars from wounds, are acquired characteristics. Acquired characteristics cannot be inherited or passed on. They come from an individual organism's experience and interactions with its environment. Injuries such as a broken bone, learned skills such as riding a bicycle, and temporary changes such as a haircut are characteristics that do not necessarily affect one's genes. Some characteristics are more difficult to categorize as acquired or inherited because they may be partially the result of one's genes and partially environmental. Language in humans is a good example of this. Through our genes, we inherit brains that can process and produce language, but we have to acquire language by being taught specific words and symbols.

Not all characteristics of a species are considered to be adaptations. In fact, adaptations are only those characteristics that have evolved through the process of natural selection because they give a survival advantage to the population. Other characteristics exist because they are merely carried over from past generations. For example, the wings of flightless birds are not considered adaptations in those species because they no longer help the animal to survive and, therefore, cannot be "selected." It's not easy to know whether a characteristic of an organism is an adaptation just by observing it. This is why it's so important to provide opportunities for students to try to explain, or at least to make a case for, how a particular structure or behavior helps the organism to survive in its habitat.

Adaptations do not need to be perfect; they just need to be good enough. One of the arguments against the explanation of intelligent design is that adaptations are often highly imperfect pre-existing features that have been jury-rigged for a different purpose. For example, sweat glands for cooling the body evolved into mammary glands for feeding young. The wolf behavior of licking the mouth of alpha wolves to show subservience probably came from a behavior of young wolves licking to encourage parents to regurgitate food. In ants and bees, the ovipositor for laying eggs evolved into a stinger for defense. In evolutionary science circles, these are all referred to as *exaptations*, although some use the older term *preadaptations*. Every stage in the evolution of the eye, on the other hand, seems to have been for sight, so it is an adaptation, not an exaptation. Some argue that it's very difficult to separate exaptations from adaptations. With students, though, it's probably best to just stick to the term *adaptations* and not worry about this distinction. In his book *Darwin's Dangerous Idea: Evolution and the Meanings of Life* (Simon & Schuster, 1995), the philosopher Daniel C. Dennett wrote: "If you go back far enough, you will find that every adaptation has developed from predecessor structures, each of which had some other use or no use at all." This idea of structures and behaviors being modifications from structures and behaviors with different purposes can be a more advanced adaptation puzzle for students to ponder.

Here are some useful definitions of *adaptation*, from simple to more complex:

- **Simple definition of *adaptation*:** a feature produced by natural selection for its current function
- **Definition of *adaptation* including more detail:** inheritable behaviors or structures that help a type of organism survive in its habitat
- **Most accurate definition of *adaptation*:** inheritable behaviors or structures (traits) of an organism that result from natural selection and provide a survival advantage in its habitat

Epigenetics

Epigenetics is the study of changes in gene expression/phenotype (observable physical traits and biochemical characteristics) that occur without a change in DNA. In our teaching materials, we've described the introduction of new traits in a population as coming from mutations in the DNA of reproductive cells that are passed on from parents to individual offspring and not from events that result from an individual's interactions with its environment. While environmental factors can, in fact, lead to changes in an organism's traits due to changes in gene expression rather than in mutation, these changes are not typically thought to be capable of being passed on to offspring. However, recent research in the field of epigenetics has revealed that this isn't always the case. In some cases, environmental factors can indeed lead to changes in gene expression that, even though they aren't the result of mutations, can be inherited by offspring. In a way, it is still genes coding for the trait, but they are turned on or off, depending on what is happening in their environment. Experimental studies have suggested that environmental conditions such as stress, hunger, addiction, anxiety, depression, and fear conditioning can all create epigenetic changes that get passed down to offspring. These studies have significant implications for our understanding of evolution. Changes to the genome resulting from random mutation take many generations to lead to new traits that, if adaptive, become more common in a population. In contrast, epigenetic changes can happen rapidly among many organisms at once in response to signals from the environment, and such changes may be inherited by offspring. While epigenetics is advancing our understanding of gene expression and inheritance, the field is relatively new, and its role in shaping evolutionary changes is not well understood. At this point in students' development of an understanding of natural selection and evolution, the complexity of epigenetics can confuse them and contribute to misconceptions. For these reasons, we have chosen not to include this topic in our teaching materials.

Common Relevant Misconceptions

Misconception. An individual organism can adapt.

More accurate information. This is the most common misconception about adaptations. In common English, the word *adapt* means something an individual does. For example, when someone moves to a new school, they adapt by making new friends. However, in scientific usage, populations of organisms adapt over generations, but individuals don't. Adaptations are inherited structures or behaviors; they're not things an organism acquires during its lifetime. If a person works out a lot and develops big muscles, that person's children will not inherit big muscles, so it's not an adaptation. An adaptation must be something an organism is born with, such as long legs. If longer legs help organisms run faster, survive, and have more offspring than organisms with shorter legs, then longer legs may eventually become an adaptation and spread through the population.

Misconception. If a population or organism tries hard enough, it will adapt to its environment.

More accurate information. Adaptations come from random genetic mutations. While most genetic mutations are harmful to organisms, every once in a while a mutation will help an organism have a survival advantage and produce more offspring. The offspring that inherit the beneficial trait will also have more offspring. Evolution doesn't happen just because an organism "wants" an adaptation; instead, it works through random trial and error. Genetic mutations randomly happen, and beneficial ones are passed on to the next generation.

Misconception. Survival of the fittest means only the strongest organisms will survive.

More accurate information. The term *fitness* has nothing to do with physical strength in the context of evolution. In biology, fitness refers to how successful an organism is at reproducing and passing on its genes. When we think about evolutionary success, fitness is more important than survival. Bacteria, mayflies, and mice are all examples of organisms with short life spans but high reproductive fitness. One way to think about the term *survival of the fittest* is that the traits that improve an organism's fitness will survive in future generations of a species. Coloration is a good example of an adaptive trait that can increase fitness but has nothing to do with physical strength.

Misconception. All structures on organisms are adaptations.

More accurate information. Structural adaptations are beneficial structures inherited from one generation to the next. They are not traits that are the result of the environment or the way an organism has lived. For example, if you dye your hair and it helps make you superbly successful, this trait will not be passed on to your children. Thus, your chic coif is not an adaptation.

Misconception. All behaviors are adaptations.

More accurate information. Behavioral adaptations are beneficial behaviors inherited from one generation to the next. They are instinctual behaviors, such as when mosquito larvae dive below the surface in response to a shadow passing over or when ants follow a trail of formic acid. The organisms aren't thinking about the situation and choosing a behavior, and they didn't learn it from parents or other individuals. They are instinctively reacting. It's a little harder to think of human behaviors that are adaptations since our brains are complex, and most of our behaviors are acquired. Shivering in response to cold is an adaptation, but putting on a jacket is a learned response.

Misconception. If two organisms look the same, they must be closely related; if two organisms look different, they are distantly related.

More accurate information. Historically, biologists estimated the relatedness of organisms based on their outward appearance. However, biologists are now making more accurate estimates of relatedness by comparing organisms' DNA. Genetic studies have shown that similar-looking organisms aren't always closely related. For example, although crocodiles and lizards have been historically placed in the reptile group, biologists have learned that crocodiles are actually more closely related to birds than they are to lizards. Many other organisms that look very different from one another may be more closely related than they appear. If you just look at them, it's hard to believe that Chihuahuas and Great Danes are both the same species, but DNA, plus our knowledge of canine history, provide evidence that they are.

Science as One Way of Understanding, Not the Only Way

All cultures have a deep history of observing, investigating, and living closely with the natural world that predates modern "science." Humans have always gathered knowledge about the natural world in ways that are similar to current scientific thinking and in other ways that differ from scientific thinking. The ecological knowledge that is obtained by Indigenous peoples and by science are both valid, with each having roots that are based on philosophical foundations, methods of validation, and communities of respected experts. Traditional Ecological Knowledge (TEK) refers to an evolving body of knowledge based on hundreds or thousands of years of close observations of ecosystems by Indigenous people. Indigenous Knowledge (IK) has been used to refer to the local knowledge of Indigenous peoples or to the unique, local knowledge of a particular cultural group. TEK includes Indigenous understandings of ecology, spirituality, and human relationships with living and nonliving things. The ways of constructing, organizing, using, and communicating knowledge that have been practiced by Indigenous peoples for centuries have many similarities with current science practices (Lambert, 2003).

There are many different ways of understanding. Science is one way. When teaching science, it's important for instructors to acknowledge and value the many ways that students come to understand their world. If students feel their religion, spirituality, or cultural knowledge are being ignored or disrespected, they might disregard scientific instruction. Often (though not always), these varied ways of understanding are complementary. The holistic nature of TEK or IK allows for practical applications in science that are balanced with spiritual practices that encompass intellectual, physical, affective, and spiritual domains of learning.

The Venn diagram (on the next page) is an attempt to illustrate the characteristics of science and TEK that overlap and those that distinguish them from one another.

Resources about synergies and distinctions between TEK and science.
To begin your learning:
Books:
- *Braiding Sweetgrass* by Robin Kimmerer
- *Decolonizing Methodologies* by Linda Tuhiwai Smith
- *Wisdom Sits in Places* by Keith Basso
- *Traditional Ecological Knowledge: Learning from Indigenous Practices for Environmental Sustainability* by Melissa Nelson & Daniel Shilling

Research papers:
- "On the Role of Traditional Ecological Knowledge as a Collaborative Concept: A Philosophical Study" by Kyle Whyte
- "Local Understandings of the Land: Traditional Ecological Knowledge and Indigenous Knowledge" by Roy C. Dudgeon and Fikret Berkes
- "The Earth's Blanket: Traditional Teachings for Sustainable Living" by Nancy Turner
- "Elaborating Indigenous Knowledge in the Science Curriculum for the Cultural Sustainability" by Rif'ati Dina Handayani, Insih Wilujeng, and Zuhdan K. Prasetyo
- "Indigenous Environmental Education for Cultural Survival" by Leanne Simpson
- "Culture Shapes How Children View the Natural World" by Jason G. Goldman https://www.scientificamerican.com/article/culture-shapes-how-children-view-the-natural-world/
- "Children's Play with a Forest Diorama as a Window into Ecological Cognition" by Karen Washinawatok, Connie Rasmussen, Megan Bang, Douglas Medin, Jennifer Woodring, Sandra Waxman, Ananda Marin, Jasmine Gurneau, & Lori Faber https://www.tandfonline.com/doi/abs/10.1080/15248372.2017.1392306

Other resources:
- "The Onondaga Nation's Vision for a Clean Onondaga Lake: An offer of biocultural restoration." https://www.onondaganation.org/land-rights/onondaga-nations-vision-for-a-clean-onondaga-lake/

(continued on next page)

For continued learning:

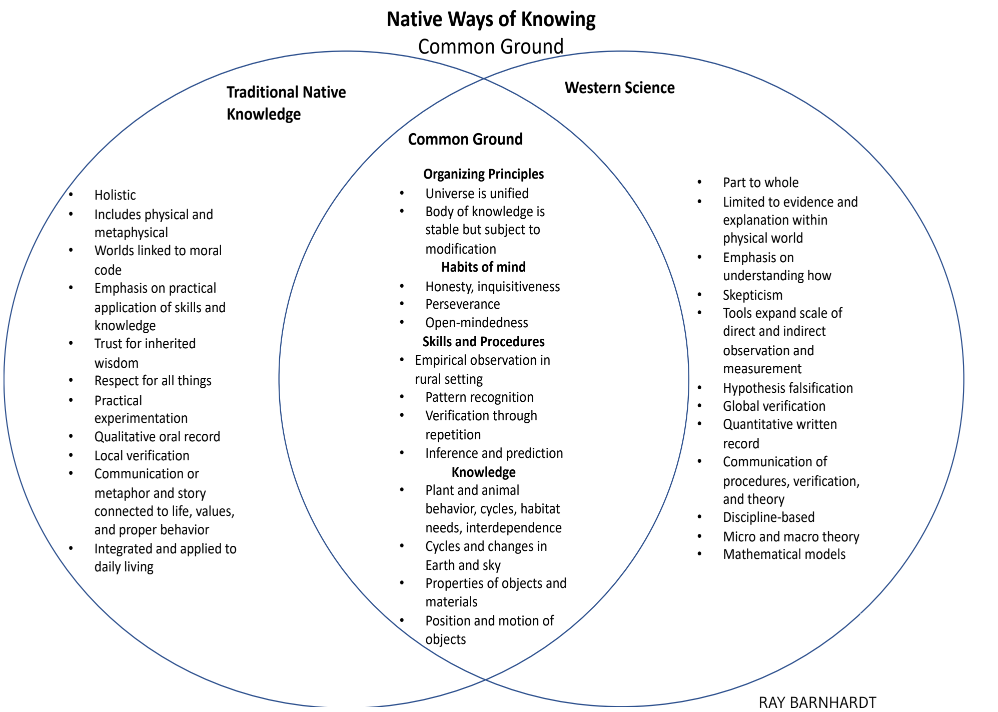
Books:

- *Indigenous Methodologies* by Margaret Kovach
- *Gathering Moss* by Robin Kimmerer
- *A Sand County Almanac* by Aldo Leopold
- *Tending the Wild: Native American Knowledge and the Management of California's Natural Resources* by M. K. Anderson
- *Sacred Ecology: Traditional Ecological Knowledge and Resource Management* by Fikret Berkes
- *Recovering the Sacred: The Power of Naming and Claiming* by Winona LaDuke
- *Original Instruction* by Melissa Nelson

Research papers:

- "Local Understandings of the Land: Traditional Ecological Knowledge and Indigenous Knowledge" by Roy C. Dudgeon and Fikret Berkes
- "Indian Time: Time, Seasonality, and Culture in Traditional Ecological Knowledge of Climate Change" by Samantha Chisholm Hatfield, Elizabeth Marino, Kyle Powys Whyte, Kathie D. Dello, & Philip W. Mote
- "Weaving Traditional Ecological Knowledge into Biological Education: A Call to Action" by Robin Kimmerer
- "Native Knowledge for Native Ecosystems" by Robin Kimmerer
- "Searching for Synergy: Integrating Traditional and Scientific Ecological Knowledge in Environmental Science Education" by Robin Kimmerer
- "An Emerging Decolonizing Science Education in Canada" by Glen Aikenhead and Dean Elliott
- "Discovering Indigenous Science: Implications for Science Education" by Gloria Snively and John Corsiglia
- "Coming to Know: Weaving Aboriginal and Western Science, Knowledge, Language and Literacy in the Science Classroom" by Gloria Snively and Lorna Williams
- "Western Science and Traditional Knowledge: Despite Their Variations, Different Forms of Knowledge Can Learn from Each Other" by Fulvio Mazzocchi

(continued on next page)



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Annie Sorrell and her cohort of graduate students from the Center for Native Peoples and the Environment (at State University of New York, College of Environmental Science and Forestry) offered these additions to the Venn diagram above:

Traditional Ecological Knowledge	**Western Science**
• approach nonliving relationships as relatives/kin	• approach nonliving relationships as resources
• decision-making is based on seven generations	• decision-making is guided by term limits, fiscal years, and an Individual's lifetime
• focus is on journey and process	• focus is on destination, goals, and outcome
• focus on relationships (research projects include consideration of how decisions will affect the community; involvement in a research project should consider all relationships: species, people, and land)	• focus on individuals (decisions are guided by self-interest, what a researcher might achieve individually from their participation in the activity or research)
• species/places are our relatives, they may give us gifts	• species/places are resources humans have a right to use or manage
• increase positive relationships, tend the land, consider reciprocity, re-Indigenize	• stop relationships, passive recreation (e.g., photography) vs. actively tending the land, colonizing another place to meet needs ("sacrifice zones")

Connections to Other BEETLES Sessions

Adaptation and Evolution is one of two professional learning sessions focused on participants learning adult instructor-level science content, rather than on how to teach outdoor science. The other science content-focused session is *Matter and Energy in Ecosystems*.

Research papers (continued):

- "Beyond the 'Ecological Indian': Environmental Politics and Traditional Ecological Knowledge in Modern North America" by Gregory D. Smithers
- "Integrating Traditional Ecological Knowledge with Western Science for Optimal Natural Resource Management" by Serra Hoagland
- "Restoration and Reciprocity: The Contributions of Traditional Ecological Knowledge" by Robin Kimmerer
- "Learning as You Journey: Anishinaabe Perception of Social-Ecological Environments and Adaptive Learning" by Iain Davidson-Hunt and Fikret Berkes
- "Indigenous Knowledge for Biodiversity Conservation" by Madhav Gadgil, Fikret Berkes, and Carl Folke
- "Cultural Keystone Species: Implications for Ecological Conservation and Restoration" by Ann Garibaldi and Nancy Turner
- "Protecting Restorative Relationships and Traditional Values: American Indian Tribes, Wildlife and Wild Lands" by Linda Moon Stumpff
- "How Might Native Science Inform 'Informal Science Learning'?" by Brian McKinley Jones Brayboy and Angelina E. Castagno
- "Defining 'Science' in a Multicultural World: Implications for Science Education" by William W. Cobern and Cathleen C. Loving
- "Indigenous Knowledge in the Science Curriculum: Avoiding Neo-Colonialism" by Ann Ryan
- "Out of Place: Indigenous Knowledge in the Science Curriculum" by Elizabeth McKinley and Georgina Stewart
- "Conversations on Cultural Sustainability: Stimuli for Embedding Indigenous Knowledges and Ways of Being into Curriculum" by Renae Acton, Peta Salter, Max Lenoy, and Robert (Bob) Stevenson
- "Re-Examining the Importance of Indigenous Perspectives in the Western Environmental Education for Sustainability: From Tribal to Mainstream Education" by Doreen Vikashni Chandra

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