Instructors’ notes
The theory of evolution articulates elegantly a series of inferences from a vast collection of observations and evidence. We present some of those evidences here to stimulate in our students the sorts of scientific reasoning necessary to understand the presence and origin of diversity of life on the planet.

There are three parts to this lesson. The first part supplies specimens showing various examples of homologous, analogous, and vestigial structures. By observing these structures, students can see some of the physical traits of organisms that can be used to support inference about their evolutionary past. The second part is a virtual lesson using a selection of sites to highlight other structures in support of the theory of evolution. These examples display atavistic, viral-encoded, and sub-optimal structures. The third part provides some reading to students, giving them a scientific view on some of the difficult misconception in circulation today. The readings address two ideas: irreducible complexity and transitional forms.

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<th>NGSS addressed in this lesson:</th>
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<td><strong>HS-LS3-2</strong> Make and defend a claim based on evidence that inheritable genetic variations may result from (1) new genetic combinations through meiosis, (2) viable errors occurring during replication, and/or (3) mutations caused by environmental factors.</td>
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<td><strong>HS-LS4-1</strong> Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.</td>
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Evolutionary Evidence and Inferences

Part 1: Structural Evidence

This lab activity was designed to provide you with opportunities to make inferences and draw conclusions about evolution and the common ancestry of various animals based on their anatomical characteristics and comparative anatomy. You will be given tasks to accomplish or questions to answer at each of the stations.

Refer to the definitions below to address how we gain evidence about the different types of structures you will see.

**Homologous structures:** Homologous structures can be identified in that they originate from the same part of the embryo, have the same basic structural organization, and have the same relative anatomical position or placement on the body. Homologous structures may or may not have the same function, and they may or may not have the same superficial appearance, although they often do. All of these characteristics can best be explained by the organisms in question sharing a common ancestor.

**Analogous structures:** Analogous structures on different organisms may have the same superficial appearance and perform a similar function, but do not share the other similarities seen in homologous structures. The structural similarities in analogous traits are superficial because they serve a similar function. A careful examination of these traits will reveal that they have different developmental origins, different types of structural organization, and anatomical positions that cannot be considered the same. This suggests that analogous structures do not support descent from a common ancestor, but that similarly functioning structures developed in more distantly related species.

**Vestigial structure:** Vestigial structures have no function, or have only an extremely limited or nonessential function in comparison to homologous structures found in another species. Quite often vestigial structures are much reduced in size. Small size, however, is not what makes a structure vestigial. Although a vestigial structure has little or no function in the organism that possesses it, this same structure can be found in its completely functional form in another species. These structures give us information about an organisms’ evolutionary history, as well as evidence of descent from common ancestry with modification.
As you go through the different stations assembled in the lab, pay particular attention to sighting homologous, analogous and vestigial structures. Use these examples in an explicit explanation of the evolutionary relatedness of the specimens.

Station 1 (vertebrate skeletons)

Materials: Skeletons of several vertebrate species (e.g., human, mole, bat, turtle, rabbit, dog, and monkey).

Task:
Examine the skeletons on display. Do the organisms on display share a common ancestry? Support your answer with three different lines of evidence.

Station 2 (horse leg, pig leg, and human leg)

Materials: The skeletal hind leg of a horse, a pig, a goat, and a human.

Task:
Examine the skeletal hind legs displayed at this station. Do all of the organisms on display share a common ancestry? Support your answer with three different lines of evidence.

A close examination of the horse leg reveals something of its evolutionary history. Look for structures that provide evidence that ancestors to the horse used their limbs differently than the modern horse? Explain your answer citing specific evidence.

Station 3 (eels and salamanders)

Materials: One preserved freshwater or marine eel, one preserved congo eel (*Amphiuma means*), and one preserved salamander such as a tiger salamander.

Task:
Examine the three preserved specimens on display and determine which two are most closely related. Using specific anatomical structures, provide evidence for your answer.

Station 4 (wings and shells)

Materials: The shell of an armadillo and the shell of a turtle. The wing of a bird and the wing of a butterfly.

Task:
Examine the armadillo shell and turtle shell, as well as the two examples of wings. Do the organisms on display share a common ancestry? Support your answer with three different lines of evidence.
Station 5 (vertebrate embryos)

Materials: Pictures of vertebrate embryos, including a human embryo, house cat embryo, and spotted dolphin embryo.

Task: Examine the pictures of the human, house cat, and spotted dolphin embryos on display. As adults these species look very different from one another. Do the organisms on display share a common ancestry? Support your answer with three different lines of evidence.
Part 2: More about structures

Atavisms
The sketch below shows a whale skeleton. However, this skeleton is unusual, because in the red circle is a bone that is normally part of a hind limb structure in vertebrates, a limb that the whale does not normally have. The structure circled does not have any function in the whale. It is not seen in this whale's parents, offspring, or other family members, nor is it found in any other whales in the population.

Read more about atavisms in the link below:
https://www.nature.com/scitable/topicpage/atavism-embryology-development-and-evolution-843

Thoroughly describe one example of atavism described on the website (not the whale bone).

Why do we consider this bone in the whale to provide an example of an atavistic structure and not a vestigial one?

How might this structure have developed in this particular whale?

How do you think this structure might have been lost as the organism diverged from common ancestors to other vertebrates?

How does the presence of atavistic structures support the evolution of a species from common ancestry with another species?

Viruses in genome:
How have viruses impacted mammalian (and specifically human) evolution?

Infiltration of viruses into the host genome does not actually occur that often, so why does this help provide evidence of common ancestry across many species?

**Sub optimal structures:**
The link below discusses how inefficient or suboptimal structures actually give good supporting evidence for evolution of species. The basic premise is that evolutionary processes modify structures, genes, etc. that already exist. This is called exaptation: enhancing survival and reproductive success of a species through modification of structures.

Read more about this subject in the link below:

http://www.talkorigins.org/faqs/comdesc/section3.html#molecular_inefficiency

In particular, read about morphological inefficiency (section 3.5 & 3.6), and summarize these lines of evidence.

“The enzyme RuBisCO has been described as a "notoriously inefficient" enzyme as it is inhibited by oxygen, has a very slow turnover and is not saturated at current levels of carbon dioxide in the atmosphere. The enzyme is inhibited as it is unable to distinguish between carbon dioxide and molecular oxygen, with oxygen acting as a competitive enzyme inhibitor. However, RuBisCO remains the key enzyme in carbon fixation.”

Knowing that carbon fixation is essential for creation of sugars that are converted into usable energy, why does it make sense that despite its inefficient structure, RuBisCO is highly conserved (similar) across many organisms?

What might have to happen in a cell in order to overcome that inefficiency?

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**Part 3: Arguments for Evolution’s Explanatory Power**
Some of the difficulties that people have in understanding of the theory of evolution are not based in willful disagreement of the science, but in a lack of knowledge of specific examples that address the misconceptions that they have. Two examples of just this sort of misconception are regularly offered against the theory of evolution from those in support of non-scientific explanations of how organisms came to be the way that they are today. You will see that much of the literature surrounding these explanations does directly support the theory of evolution of species through descent from common ancestry.

**Irreducible complexity:**
Irreducible complexity of a structure is a common challenge to the theory of evolution. An irreducibly complex structure is so complex, that its development through evolutionary means cannot be imagined. View the following:

https://www.youtube.com/watch?time_continue=315&v=W96AJoChboU

One of the arguments from irreducible complexity proposes that for these complicated structures, any change in the structure or part of the structure would cause it to be non-functional. What are some arguments in response to this assumption?

Scientifically, although irreducible structures exist, we don’t use their existence as evidence against evolution. Pick one example (the eye, beetle, or flagella) and explain how these structures might have evolved into their current complex natures.

What might happen if you DO remove parts from an irreducibly complex system?

**Transitional Forms:**
One of the struggles that people have when conceptualizing how an evolutionary process creates such a huge diversity of organisms is understanding how one lineage can evolve into new types of species. It might be hard, for example, to understand how fish-like creatures turned into the types of four limbed organisms (tetrapods) that walk on land. Transitional forms are one of the best pieces of evidence that show how these changes can occur. Despite some people’s misconceptions (or non-scientific arguments) we have discovered quite a number of examples of transitional forms, one of the most famous being Tiktaalik. View the following:

https://evolution.berkeley.edu/evolibrary/news/060501_tiktaalik

Describe a few features of tiktaalik that supported its label as a transitional form. What information does this fossil give us about the history of biological life?

When we make discoveries in evolutionary research, just like in all science fields, they are not just left to rest indefinitely. What updates to the information on tiktaalik have
been uncovered? How has this new information added to our understanding of history of biological life? Be explicit in your explanation.