Teacher Notes for "How Eyes Evolved – Analyzing the Evidence"[1]

This analysis and discussion activity focuses on two questions. How could something as complex as the human eye or the octopus eye have evolved by natural selection? How can scientists learn about the evolution of eyes, given that there is very little fossil evidence? To answer these questions, students analyze evidence from comparative anatomy, mathematical modeling, and molecular biology. Students interpret this evidence to develop a likely sequence of intermediate steps in the evolution of complex eyes and to understand how each intermediate step contributed to increased survival and reproduction. These Teacher Notes suggest additions to the Student Handout that can be used to introduce concepts such as the role of gene duplication in evolution and/or homology and analogy.

Before they begin this activity, students should have a basic understanding of natural selection (see e.g. "Evolution by Natural Selection", available at http://serendipstudio.org/sci_edu/waldron/#evolution).

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Learning Goals

Learning Goals Related to National Standards

In accord with the Next Generation Science Standards[2] and A Framework for K-12 Science Education[3]:

- This activity helps to prepare students for the Performance Expectation, HS-LS4-1, "Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence."
- Students will gain understanding of two Disciplinary Core Ideas:
  - LS4.A, Evidence of Common Ancestry and Diversity. "Genetic information provides evidence of evolution. DNA sequences vary among species, but there are many overlaps… "
  - LS4.C, Adaptation. "Natural selection leads to adaptation, that is, to a population dominated by organisms that are anatomically, behaviorally, and physiologically well suited to survive and reproduce in a specific environment.…"
- Students will engage in Science Practices, including:
  - "Constructing Explanations… Apply scientific ideas, principles and/or evidence to provide an explanation of phenomena…"

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[1] By Dr. Ingrid Waldron, Department of Biology, University of Pennsylvania, 2022. These Teacher Notes and the related Student Handout are available at http://serendipstudio.org/exchange/bioactivities/evoleye.

[2] http://www.nextgenscience.org/sites/default/files/HS%20LS%20topics%20combined%206.13.13.pdf

[3] http://www.nap.edu/catalog.php?record_id=13165

    - "Analyzing and Interpreting Data. Evaluate the impact of new data on a working explanation and/or model of a proposed process or system."
    - "Engaging in an Argument from Evidence. Make and defend a claim based on evidence about the natural world… that reflects scientific knowledge…"
- This activity provides the opportunity to discuss the Crosscutting Concepts, including:
    - "Stability and Change. Students understand much of science deals with constructing explanations of how things change and how they remained stable. They quantify and model changes in systems over very short or very long periods of time."
    - "Scale, Proportion, and Quantity. Some systems can only be studied indirectly as they are… too slow to observe directly."
- This activity also illustrates the Nature of Science:
    - Science investigations use diverse methods and do not always use the same set of procedures to obtain data.
    - Science knowledge is based on empirical evidence.

This activity also helps students to meet Common Core English Language Arts Standards for Science and Technical Subjects, including "integrate and evaluate multiple sources of information presented in diverse formats… in order to address a question…" and "write arguments focused on *discipline-specific content*".[4]

Specific Content Learning Goals

- Human and octopus eyes have a nearly spherical shape, with a retina that has many photoreceptor cells that contain light-sensitive molecules and a lens which focuses light to form an image on the retina.
- The comparative anatomy of contemporary animals shows several types of simpler light-sensitive sensory organs, including eye spots and eye cups which provide visual information that is less detailed, but useful for the lifestyle of the animals that have them. This evidence suggests a plausible sequence of steps which would have been favored by natural selection and probably contributed to the evolution of the shape of octopus eyes and human eyes.
- This hypothesized sequence of steps is supported by the results of a mathematical model that starts with a flat layer of photoreceptor cells and shows that repeated selection for small improvements in spatial resolution result in increased curvature of the photoreceptor layer.
- This mathematical model also suggests how the evolution of a lens may have begun with natural selection for repeated small increases in the concentration of transparent proteins that bend light in the opening where light enters the eye; selection favored increased concentration of these proteins to bend light and produce a focused image on the retina.
- The results of this mathematical model also indicate that, under realistic assumptions, both the shape of the eye and the lens could easily have evolved within the very long time periods of animal evolution.
- Molecular evidence indicates that the light-sensitive opsin-retinal molecules found in the light-sensitive sensory organs of almost all animals are evolutionarily descended from a similar molecule that evolved very early in the evolution of animals. In contrast, the diversity of lens proteins in the eyes of different types of animals suggests that these lens proteins evolved independently during the more recent evolution of different animal groups.

[4] http://www.corestandards.org/

- The similarity of the light-sensitive molecules in all animals is an example of homology (similarity due to common descent). The similar structure and function of lenses with transparent proteins in octopus eyes and human eyes is an example of analogy (similarity due to convergent evolution for a similar function).
- This activity illustrates the varied types of evidence that can be used to learn about evolution, even when there is little or no fossil evidence. Taken together, the three types of evidence analyzed suggest a sequence of multiple small steps favored by natural selection which probably contributed to the evolution of key features of human and octopus eyes.

Instructional Suggestions and Background Information

To maximize student learning and participation, we recommend that you have students work in pairs to answer each group of related questions. Student learning is increased when students discuss scientific concepts to develop answers to challenging questions; furthermore, students who actively contribute to the development of conceptual understanding and answers to questions gain the most.[5] After pairs of students have worked together to answer a group of related questions, we recommend that you have a class discussion to probe student thinking and help students develop a sound understanding of the concepts and information covered.

If you use the Word version of the Student Handout to make changes for your students, please check the PDF version to make sure that the figures and formatting in the Word version are displaying correctly on your computer.

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

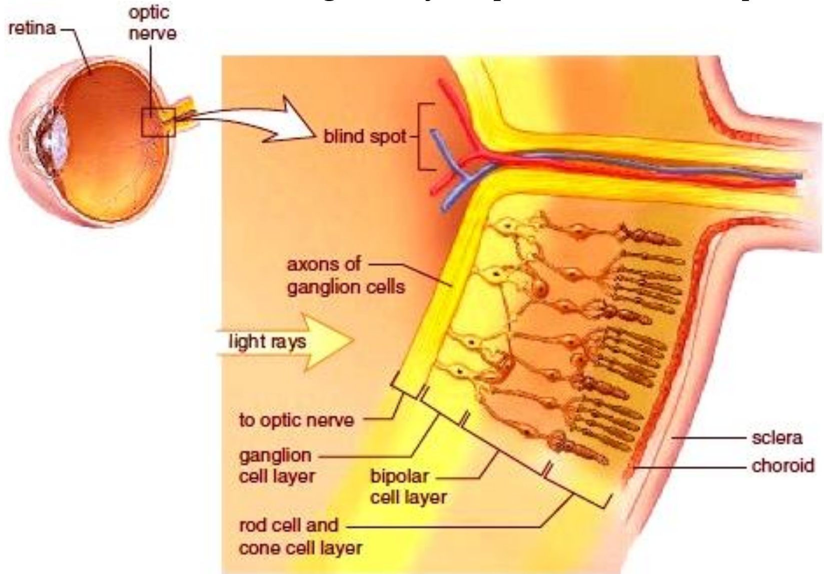
Page 1 of the Student Handout shows and describes several important similarities between the camera-like eyes in humans and octopuses. If your students are not familiar with the structure and function of a vertebrate eye, you may want to:

- have your students complete an eye dissection (https://sites.google.com/site/biologypd/home/evolution)
- provide some additional information (see e.g. https://www.allaboutvision.com/resources/anatomy.htm and https://www.merckmanuals.com/home/eye-disorders/biology-of-the-eyes/structure-and-function-of-the-eyes).

You may want to mention that there are some significant differences in structure between human and octopus eyes. For example, in the human eye, but not the octopus eye, light must pass through blood vessels and nerve cells to reach the photoreceptors in the retina, and there is a blind spot where the optic nerve fibers cross the retina to exit the eye (see figure below). Another difference is that in the human eye muscles adjust the focus by changing the shape of the lens, whereas in the octopus eye muscles adjust the focus by changing the position of the lens. If you discuss these differences, you may want to point out to your students that, although many features of the human eye are adaptations that contribute to visual acuity, other features represent

[5] https://education.asu.edu/sites/default/files/the_role_of_collaborative_interactions_versus_individual_construction_on_students_learning_of_engineering_concepts.pdf

disadvantages. The advantages and disadvantages of the vertebrate eye illustrate the general principle that the results of evolution are generally adaptive, but less than perfect.



a. Drawing of retina

(From http://encyclopedia.lubopitko-bg.com/images/Structure%20and%20function%20of%20the%20retina.jpg)

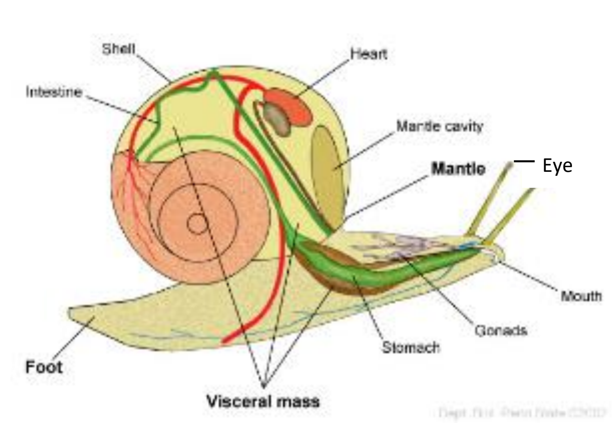
After you discuss question 1, I recommend that you have a class discussion of the two "main questions" for the activity to get students thinking about these questions and to solicit their ideas.

Questions 2-3 provide the opportunity to reinforce student understanding of the process of natural selection and how natural selection could contribute to the evolution of eyes.

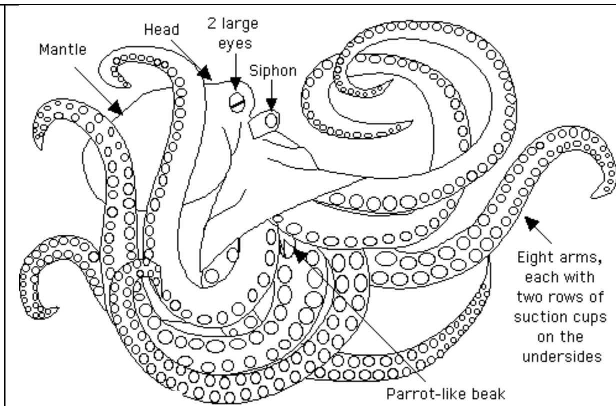
Evidence from Comparative Anatomy

This section introduces the use of comparative anatomy to suggest how complex structures could have evolved. It is important to note that comparative anatomy uses evidence from contemporary animals that are *not* the ancestors of octopuses or humans. Nevertheless, this evidence suggests a possible evolutionary sequence: flat eye spot → → → indented eye cup → → → spherical shape with a lens. The evidence from comparative anatomy also indicates that each stage could increase fitness, so each stage could be favored by natural selection.

The examples shown on page 3 of the Student Handout are all from mollusks. Information about mollusks is available at https://eol.org/docs/discover/mollusks and https://www.vims.edu/cbnerr/_docs/discovery_labs/MOLLUSCS.pdf.



Snail



Octopus

Evidence from the comparative anatomy and development of chordate visual organs suggests that very early chordates had an eye cup with the function of detecting shadows and/or light levels for the regulation of circadian rhythms. A lens and other features of complex eyes developed during later stages of vertebrate eye evolution ("Evolution of the vertebrate eye: opsins, photoreceptors, retina and eye cup", Nature Reviews Neuroscience 8, pages 960-75; "Evolution of the Eye", *Scientific American*, July, 2011, pages 64-6).

Before question 5 concerning the advantages of an eye cup, you may want to have your students explore the effects of light coming from different directions using a flashlight and an opaque bowl and disk. This will help your students understand how an eye cup can provide information about the direction light is coming from, but an eye spot cannot. Information about the direction light is coming from can be useful for directing locomotion, e.g. moving away from light and toward a dark hiding space.

After question 5 and before page 4 of the Student Handout, we recommend that you show one of these two videos concerning vision with an eye cup and vision with a lens:

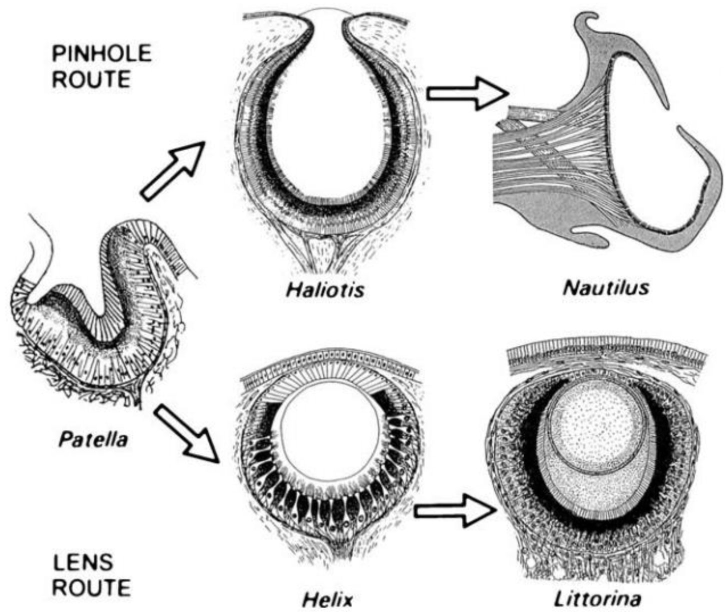
- https://www.pbslearningmedia.org/resource/tdc02.sci.life.evo.nilssoneye/evolution-of-the-eye/#.Xj7WIshKg2w (4 minutes)
- https://www.yout-ube.com/watch?v=Nwew5gHoh3E (14 minutes).

Either of these videos will provide a good context for the discussion of the advantage of a lens on the top half of page 4 of the Student Handout. (To reinforce student understanding of what a blurry image looks like, you might want to show the video at https://www.youtube.com/watch?v=SAUJYv5pOxQ concerning adjustable lens glasses.)

As discussed on page 4 of the Student Handout, the lens in the human or octopus eye bends light to form a focused image on the retina. The ability to form an image is more important for active predators like an octopus than for a limpet that scrapes algae off of a rock. This illustrates the general relationships among the lifestyle of an organism, the usefulness of complex visual information for this lifestyle, and the type of light-sensitive sensory organ the organism has.

A pinhole eye can also produce an image. A major disadvantage of a pinhole eye is that very little light gets into the eye, so the image is dim. This probably explains why pinhole eyes are rare in contemporary animals.

Examples from mollusks that illustrate two different ways of evolving an eye that can form an image

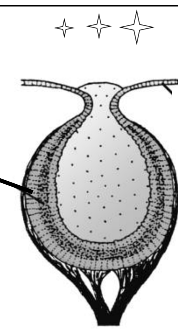


(http://www.isaiadis.com/blog/wp-content/uploads/switch to Microsoft Word general/Evolution_of_the_Eye.pdf)

If you want your students to understand how a pinhole eye can form an image, you could include the following optional question on page 4 of the Student Handout.

8. A pinhole eye has a narrow opening for light. In this diagram of a pinhole eye, draw the pathways of light from each star in the visual stimulus to the photoreceptor cells that would be stimulated by the light waves from each of these stars.

Visual stimulus:



(http://commons.wikimedia.org/wiki/File:Haliotis_pinhole_eye.png)

Notice that the light from each spot in the environment stimulates photoreceptors in a different part of the retina. In this way, the pinhole eye can form an image which provides relatively detailed visual information about the environment. However, very little light enters the pinhole, so the image is dim.

A Mathematical Model

The mathematical model starts with a flat layer of photoreceptor cells and shows that repeated small random changes and selection for improvements in the ability to provide more detailed visual information results in increased curvature of the photoreceptor layer.[6] This finding provides support for the previously discussed hypothesis based on comparative anatomy about how eye shape may have evolved.

In addition, the mathematical model proposes a reasonable hypothesis about how the lens could have evolved, beginning with selection for increasing concentrations of transparent proteins

[6] For each generation in this mathematical model there were small random variations in the model eye which mimicked the effects of random mutations. The specific criterion used for selection was an improvement in spatial resolution, where spatial resolution measures the extent to which light coming from different parts of the environment stimulates different photoreceptor cells. Eyes with better spatial resolution provide more detailed visual information.

where light enters the eye; selection favors increased concentrations of transparent proteins that bend light to produce a focused image on the retina. The figure showing lens evolution on page 5 of the Student Handout shows greater concentrations of protein at the center of the lens; this corresponds to the gradient of refractive index seen in most biological lenses (including in octopus and human eyes); these graded-index lenses reduce aberration.

This mathematical model also demonstrates that, with reasonable assumptions, natural selection for better spatial resolution could produce the postulated changes in shape and the evolution of the lens in a relatively short time period in evolutionary terms. This is compatible with evidence that indicates that complex eyes have evolved independently multiple times. It should be mentioned that additional generations would probably be required to develop the additional features of complex octopus and human eyes (e.g. muscular control of pupil diameter, lens focus and gaze direction).

This mathematical model is described in Nilsson and Pelger (1994) *Proc. Royal Soc. London B* 256:53-58. Nilsson has made a video that explains the major steps in the evolution of eye shape and the lens (available at https://www.yout-ube.com/watch?v=duBW9QabXfw). You may want to show this video to help your students understand the first two sections of the Student Handout.

Students may have trouble understanding that results of mathematical models can be evidence. Therefore, you may want to discuss how models can indicate whether a hypothesized process can produce the predicted results. In this case, the model shows how, under realistic assumptions, natural selection could produce the shape and lens of a human or octopus eye in less than 400,000 generations. It may be helpful if you can refer students to other experiences with models that demonstrate likely outcomes of biological processes, e.g.:

– simulations of natural selection (see e.g. "Evolution by Natural Selection", available at https://serendipstudio.org/sci_edu/waldron/#evolution)
– mathematical models of population growth (see e.g. "Population Growth – Exponential and Logistic Models Versus Complex Reality", available at https://serendip.brynmawr.edu/exchange/bioactivities/pop)

The following evidence indicates that the overall spherical shape and lens of octopus and human eyes evolved independently during the evolution of Mollusks and the evolution of Chordates.

- Contemporary mollusks have a wide variety of types of light-sensitive sensory organs, including simple eye spots or eye cups in many types of mollusks. This indicates that the common ancestor of all mollusks almost certainly did not have spherical eyes with a lens. This is one important part of the evidence that the shared ancestor of mollusks and vertebrates did not have spherical eyes with a lens.
- The results of the mathematical model indicate that, under realistic assumptions, natural selection could produce the basic shape and lens of the octopus or human eye in a relatively short time (within 400,000 generations). This is a much shorter time span than the more than 500 million years since mollusk and vertebrate evolution diverged. This supports the hypothesis that eyes could have evolved independently in mollusks and vertebrates.
- Further evidence of the independent evolution of eye shape and lens in the evolutionary ancestors of octopuses and humans is provided by the following observation. Although the basic structure of human and octopus eyes is similar, there are significant differences in both the development and the structure of these eyes, including major differences at the cellular and tissue levels (see page 3 of these Teacher Notes and additional information available at http://www.mapoflife.org/topics/topic_7_Camera-eyes-of-cephalopods/).

Molecular Evidence

As background for the discussion of molecular evidence, your students should have a basic understanding of genes as segments of DNA that code for proteins (see e.g. "Introduction to the Functions of Proteins and DNA", https://serendipstudio.org/exchange/bioactivities/proteins).

The molecular evidence indicates that opsin proteins originated very early in animal evolution (after the evolutionary ancestors of sponges diverged and before the evolutionary ancestors of Cnidaria diverged from the evolutionary ancestors of Bilateria). The evolution of opsin proteins appears to have begun with gene duplication. If you want to discuss gene duplication with your students you can insert the following below question 11 on page 6 of the Student Handout:

- The molecular evidence suggests that a mistake during cell division resulted in duplication of a very ancient gene for a protein with an amino acid sequence similar to opsin. After that, one of the copies of this duplicated gene had a mutation that changed a key amino acid to produce an opsin protein which can combine with retinal to form a light-sensitive molecule.
- This resulted in a very ancient animal that had two similar genes with different functions:
  - one gene that coded for the original protein
  - a mutated gene that coded for an opsin protein in a light-sensitive molecule.

12. Explain why gene duplication can be a crucial initial step in the evolution of a new gene for a new protein with a new function (e.g. the opsin protein in light-sensitive molecules).

This information and question introduce students to the important role that gene duplication has played in evolution. Gene duplication can occur as a result of unequal crossing over. Once a gene has been duplicated, one copy of the gene can preserve its original function and the other copy of the gene can be mutated to produce a protein that serves another function. Gene duplication can occur repeatedly to produce a family of related genes; for example, humans have several different opsin genes which code for light-sensitive molecules that respond preferentially to different wavelengths of light; this provides the basis for color vision. Gene duplication has occurred for other proteins that are active in the retina and has made a significant contribution to the evolution of eyes. In general, gene duplication has been a major source of genetic material for evolutionary innovation. For example, in mice, one very large family of duplicated gene includes 1296 genes for proteins involved in olfactory reception.

Additional molecular evidence indicates that light-sensitive organs evolved very early in animal evolution. For example, different versions of the Pax6 gene play a crucial role in activating the multiple genes involved in the formation of very different types of eyes, including vertebrate eyes and the compound eyes of Drosophila and other insects (https://insaneinthecellmembrane.wordpress.com/2015/06/04/beginning-to-see-when-did-eyes-evolve/).

Scientists have been surprised to discover that many different proteins are found in the lenses of different types of animals and many of these lens proteins are also produced in other parts of the body where they have different functions (e.g. as enzymes or as heat shock proteins that serve as chaperone proteins that can stabilize other proteins). Scientists have concluded that, during the evolution of the lens, natural selection favored mutations in the regulatory DNA sequences[7] of

[7] Regulatory DNA sequences include promoters, promoter-proximal elements, enhancers and silencers.

selecting analysis the genes for these various proteins so these genes were transcribed in both the cells in the original location in the body (where the protein continues to serve its original function) and in the cells of the developing lens (where higher concentrations of the protein bend light). This illustrates the important general principle that a mutation in the regulatory DNA sequence of a gene often has provided the basis for natural selection to produce new adaptations.[8]

The evolution of some lens proteins has involved both gene duplication and mutations in one copy of the gene. These include mutations in the:

- coding DNA which provides the instructions for the sequence of amino acids in a protein
- regulatory DNA sequences where transcription factors can bind to regulate the rate of transcription.

Mutations in the coding DNA result in a lens protein which is similar to, but somewhat different from the related protein (e.g., an enzyme or heat shock protein). Mutations in the regulatory DNA sequence of a gene can result in protein production in additional types of cells. For example, mutations in a regulatory DNA sequence could result in protein production in the opening where light enters the eye. If this protein was transparent and bent light to produce a sharper, more focused image on the retina, then natural selection would favor this mutation in the regulatory DNA sequence. Consequently, over time, this mutation and production of the protein in the opening where light enters the eye would become widespread in the population.

Related resources are:

- A student-friendly discussion of the molecular biology of eyes (https://learn.genetics.utah.edu/content/senses/toolkit/)
- an activity about the evolution of the Pax6 gene (https://www.nsta.org/ncss-case-study/do-you-see-what-eye-see).

Conclusions

This section includes several questions designed to stimulate students to integrate the information in the previous pages of the Student Handout and develop a more in-depth understanding of the evolution of eyes. If you would like to include the concepts of analogy and homology, you could add the information and questions in this box to page 7 of the Student Handout.

Evolution results in two different kinds of similarity: • Homology refers to similar characteristics which are the result of common descent from a shared ancestor. • Analogy refers to similar characteristics which are the result of convergent evolution, i.e. similar characteristics which evolved independently as a result of natural selection for a similar function. **14a.** Octopus and human eyes both have similar light-sensitive molecules that contain opsin proteins. Is this similarity due to homology ___ or analogy ___? What evidence supports your answer? **14b.** Octopus and human eyes both have transparent proteins in their lens. Is this similarity due to homology ___ or analogy ___? What evidence supports your answer?

[8] For example, this was the basis for evolution of lactose tolerance due to lactase persistence (see e.g. https://serendipstudio.org/exchange/bioactivities/proteins).

Helpful introductions to homology and analogy are available at https://evolution.berkeley.edu/evolibrary/article/similarity_ms_01 and https://evolution.berkeley.edu/evolibrary/article/evo_09. Some of the criteria that scientists use to distinguish between similarities due to common descent and similarities due to convergent evolution are:

- If a gene and the protein it codes for are widespread in a phylogenetic group and if the gene has a similar nucleotide sequence in the different members of this phylogenetic group, this indicates that the gene was probably present in the evolutionary ancestor of this group, so similarities in the protein in different members of the phylogenetic group are probably due to common descent.
- If two organisms with a similar trait also display similarities in many other traits, then it is more likely that these organisms are closely related evolutionarily and the similar trait is due to common descent. Conversely, if the close evolutionary relatives of one or both of the organisms do not share this similar trait, it is more likely that the trait evolved independently and the similarity is due to convergent evolution.
- If a similar morphological trait has a similar developmental origin, then it is more likely that this similar trait is due to common descent.

Evolutionary biologists caution that the distinction between homology and analogy is more complex and ambiguous than previously appreciated. Homoplasy refers to a character shared by multiple species, but not present in their common ancestor; homoplasy can be due to convergent evolution (independent evolution of a similar feature using different genetic and developmental systems) or parallel evolution (evolution of similar features that occurs independently but uses the same underlying genetic and developmental systems). Evolutionary biologists believe that homology, convergent evolution, and parallel evolution have each played a major role in the evolution of eyes. As discussed above, opsins illustrate the role of homology, and lenses with transparent proteins illustrate the role of convergent evolution. An example of parallel evolution is provided by the Pax6 gene; this gene is involved in regulating the development of almost all animal eyes, but Pax6 acts via somewhat different gene networks which have evolved independently and in parallel in different groups of animals.

Question 15 asks students to develop a scientific argument (including evidence and reasoning) for the claim that "Over many generations, the complex octopus eye probably evolved from a simple eye spot in the evolutionary ancestors of all animals except sponges." Discussion of student answers to this question will naturally develop into a general discussion about how the evidence analyzed in this activity supports hypotheses about the key steps in the evolution of human eyes and octopus eyes. The molecular evidence provides strong support for the conclusion that light-sensitive molecules arose early in the evolution of animals. Comparative anatomy and the results of mathematical modeling support the hypothesis that the shape of human and octopus eyes evolved by gradual increases in curvature of a layer of photoreceptors. Mathematical modeling suggests how the lens probably began to evolve through gradual increases in the concentration of transparent proteins. Molecular evidence supports the conclusion that the evolution of lens proteins followed different paths in different groups of animals and was more recent than the evolution of opsins. Thus, students will see how multiple types of evidence help scientists to understand a probable sequence of steps in the evolution of eyes.

This would be a good time to discuss the Crosscutting Concept that "Some systems can only be studied indirectly as they are too small, too large, too fast, or too slow to observe directly." The information in this learning activity also illustrates the Nature of Science principle that "Science investigations use diverse methods and do not always use the same set of procedures to obtain data." [9]

The evolution of the eye is relevant to a larger debate concerning "irreducible complexity", which has been proposed as one reason to accept intelligent design. If you would like your students to discuss irreducible complexity, you can add the following at the end of the Student Handout.

Irreducible complexity refers to the idea that a complex biological structure such as our eye could not have evolved by natural selection because isolated individual components of the complex structure would not have had any useful function. The irreducible complexity argument proposes that a simple structure and subsequent intermediate evolutionary steps would not have had an adaptive advantage, so a complex structure like the human eye could not have evolved by natural selection.

Challenge Question. Based on the evidence concerning the evolution of eyes, do you agree or disagree with the irreducible complexity argument? Provide evidence and arguments to support your answer.

Additional Resources

The Student Handout omits several relevant topics, some of which are addressed by the optional additional questions presented above and others of which are discussed in the following resources.

- A student-friendly discussion of color vision is available at http://www.the-scientist.com/?articles.view/articleNo/41055/title/The-Rainbow-Connection/.
- Interesting information about the diversity of different types of eyes (including the compound eyes of arthropods) is provided in "Eye Evolution" (available at https://learn.genetics.utah.edu/content/senses/eye/).
- Fossil evidence for the very early evolution of compound eyes in arthropods is described in "Complexity and Diversity of Eyes in Early Cambrian Ecosystems" (available at https://www.nature.com/articles/srep02751). The evidence from this study indicates that sophisticated eyes evolved primarily in actively mobile hunters or scavengers.

Additional Recommended Resources for teaching and learning about evolution are summarized at https://serendipstudio.org/exchange/bioactivities/evolrec.

Sources for Figures in the Student Handout

– page 1 – http://dl0.creation.com/articles/p087/c08774/Human-octopus-eye.png

– page 3 – "Diagram of eye evolution" by Matticus78 at the English language Wikipedia. Licensed under CC BY-SA 3.0 via Commons - https://commons.wikimedia.org/wiki/File:Diagram_of_eye_evolution.svg#/media/File:Diagram_of_eye_evolution.svg and https://external-preview.redd.it/4eGGBMltOvDesGmWX3Yd8wHnYGoX0vEk3clt1nU6oKM.jpg?auto=webp&s=f907b5e259eabd53e6b171eed9d3cd0314fc8a2d

– page 5 – https://qph.fs.quoracdn.net/main-qimg-89a59978c7ef2d08c79d59d745edbb50-c

– page 6 – https://schoolbag.info/biology/living/living.files/image595.jpg

The other figures were created by the author.

[9] http://www.nextgenscience.org/sites/default/files/HS%20LS%20topics%20combined%206.13.13.pdf