**Teacher Notes for Evolution and Adaptations**[[1]](#footnote-1)

This discussion activity is designed to help students understand natural selection by explicitly recognizing that:

* in common experience, the term "adapting" usually refers to changes during an organism's lifetime,
* but in discussing natural selection biologists use the term "adaptation" for a heritable trait that increases fitness.

To help students reconcile their everyday experience with an understanding of natural selection, this activity discusses phenotypic plasticity (the ability of an organism to adapt to different environments within its lifetime). The examples of phenotypic plasticity analyzed in this activity illustrate heritable variation in phenotypic plasticity with effects on fitness (the ability to survive and reproduce). Questions guide students in analyzing how the balance between the advantages and disadvantages of a given trait can change as the environment changes, how phenotypic plasticity can be one way to optimize fitness in a variable environment, and how natural selection can influence the amount of phenotypic plasticity in a population.

This activity is designed to meet Next Generation Science Standards and Common Core State Standards for high school students. This activity is also appropriate for introductory-level college students. As background, students should have a basic understanding of natural selection. The simulation activity, "Evolution by Natural Selection" (available at <http://serendipstudio.org/sci_edu/waldron/#evolution>) provides a suitable introduction to natural selection.

Learning Goals

* Biologists use the term adaptation to refer to a heritable characteristic that is influenced by natural selection. The types of adaptation discussed by biologists are often stable characteristics (e.g. camouflage-colored fur). In contrast, in everyday usage, people refer to an organism adapting to its environment within its lifetime (e.g. a plant growing toward the light).
* Phenotypic plasticity refers to the ability of an organism to adapt to different environments within its lifetime. A phenotypic characteristic is any observable characteristic of an organism (e.g. color or shape). Plasticity means that the phenotypic characteristic can change during an organism's lifetime in response to the environment.
* Natural selection occurs if there is heritable variability in a characteristic that influences fitness (the ability to survive and reproduce in the organism's environment).
* Examples are presented to illustrate that there is heritable variability in at least some types of phenotypic plasticity and that phenotypic plasticity can influence fitness; consequently, natural selection can act to increase (or decrease) the prevalence of phenotypic plasticity in a population.
* The examples presented also illustrate how:
* there may be both advantages and disadvantages to a trait
* the balance between the advantages and disadvantages of a particular trait often varies, depending on the environment
* phenotypic plasticity can be one way to optimize fitness in a variable environment.

This activity will help students to meet the Next Generation Science Standards performance expectation: "construct an explanation based on evidence for how natural selection leads to

adaptation of populations" [[2]](#footnote-2) In accord with A Framework for K-12 Science Education[[3]](#footnote-3), students

will:

* gain understanding of several crosscutting concepts (stability and change; cause and effect;

mechanism and explanation) and one disciplinary core idea (adaptation)

* engage in scientific practices (constructing explanations; reading scientific text, including tables, and explaining the key ideas being communicated).

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

This activity counteracts several common misconceptions about evolution[[5]](#footnote-5):

* The fittest organisms in a population are those that are strongest, healthiest, fastest, and/or largest.
* Natural selection produces organisms perfectly suited to their environments.
* Evolution only occurs slowly.
* Evolution is not science because it is not observable or testable.

Suggestions for Teaching this Activity and Background Information

If you do not have enough time to complete the whole activity, you can use the introduction (section A):

* with section B for an engaging and relatively simple introduction to the topic or
* with section C for a more in-depth introduction to phenotypic plasticity, genetics and natural selection or
* with sections C and D for a more complete discussion of phenotypic plasticity as a heritable trait that influences fitness, including an example of how natural selection has increased phenotypic plasticity in a population.

To maximize student participation and learning, we recommend that you have students work individually or in pairs or small groups to answer the questions in the Student Handout before having a class discussion. You will probably want to have your students work on the questions in each section and then have a class discussion of those questions to ensure student understanding before moving on to the next section.

Section A in the Student Handout introduces the students to basic concepts concerning the meanings of key terms.

The example mentioned in question 1 of a house plant growing toward the light illustrates one type of phenotypic plasticity of plants that contributes to fitness by increasing exposure to light needed for photosynthesis. If you want to introduce your students to additional types of plant phenotypic plasticity in response to light vs. dark, you may want to use the videos of seedling development available at <http://plantsinmotion.bio.indiana.edu/plantmotion/earlygrowth/photomorph/photomorph.html>.

Section B on cephalopod camouflage introduces your students to a dramatic and interesting example of phenotypic plasticity and also provides suggestive evidence that phenotypic plasticity can contribute to fitness and be influenced by natural selection.

Students will need to watch the video before answering the questions. We recommend that you show this video in your classroom or assign students to watch it at home and answer question 2. You may also want to show your students the "raw footage" available at the link shown on the website with the video. If there is no feasible way for your students to view this video, you will probably want to omit Section B.

Cephalopod camouflage shows phenotypic plasticity in color, pattern and texture. This phenotypic plasticity appears to play an important role in helping these soft-bodied animals to avoid predation and probably also contributes to success of cephalopods in hunting prey. Comparison of different species of cephalopods largely confirms the correlations expected on the basis of the hypothesis that natural selection for the ability to produce complex patterns of visual camouflage is stronger for species that are active in well-lit, visually complex environments. As noted in the Student Handout, species that can produce more complex patterns of visual camouflage have more chromatophores per square millimeter and more brain tissue devoted to control of chromatophores; these observations suggest underlying anatomical characteristics that may have been subject to natural selection for greater capability for this type of phenotypic plasticity.

A useful background source is "Color Change in Cephalopods", available at <http://www.thecephalopodpage.org/cephschool/ColorChangeInCephalopods.pdf>

Section C discusses research concerning phenotypic plasticity in the amount of melanin deposited in the carapace of Daphnia. Melanin can be deposited in the new carapace formed before each molt. The Daphnia discussed in this section molt approximately every three days, so changes in pigmentation can occur quite frequently. If you want to describe molting of the exoskeleton as arthropods grow, you may want to refer to the brief introduction with a video available at <http://en.wikipedia.org/wiki/Arthropod_exoskeleton>.

Experiments on laboratory-raised clones of Daphnia from lakes with no fish demonstrate that Daphnia exposed to UV light during development deposit more melanin in their carapace; this has the advantage of reducing damage due to UV light.[[6]](#footnote-6) In the natural environment, the amount of UV light varies in different seasons and locations, and Daphnia can optimize their fitness by producing more melanin when exposed to more UV light (to protect against DNA damage), but producing less melanin when there is less UV light (to conserve resources in order to maximize reproduction). Thus, the balance between the advantages and disadvantages of producing more melanin varies due to seasonal and location variation in the amount of UV light; phenotypic plasticity in the amount of melanin production allows Daphnia to optimize their melanin production in a variable environment.[[7]](#footnote-7)

Phenotypic plasticity in melanin production was not observed in laboratory-raised clones of Daphnia from lakes with fish that are visual predators that eat Daphnia. Fish predation selects for lighter Daphnia that are harder for the fish to see and devour, and this selection for lighter Daphnia has apparently been strong enough to override any advantage due to more melanin in the carapace in response to UV light exposure.

Researchers have shown that the Ddc gene contributes to phenotypic plasticity in Daphnia from lakes with no fish, but not in Daphnia from lakes with fish. For the Daphnia from lakes with no fish, the molecular basis of phenotypic plasticity in melanin production is as follows. Exposure to UV light during development results in less mRNA from the Ddc gene and thus less of the Ddc protein which inhibits melanin production. Thus, exposure to UV light during development results in less inhibition of melanin production and therefore darker exoskeletons. For Daphnia from lakes with fish, UV light exposure does not influence the amount of expression of the Ddc gene (presumably due to a mutation in the regulatory DNA for this gene). Thus, Daphnia from lakes with fish no longer display phenotypic plasticity in melanin production in response to differences in UV light exposure.

This section illustrates how phenotypic plasticity can be a heritable trait that influences fitness. When the environment changes so that phenotypic plasticity decreases fitness, natural selection can reduce the prevalence of phenotypic plasticity and increase the prevalence of a stable trait that increases fitness in the new environment (transparent carapace, which reduces fish predation).

We suggest that you introduce the following points in this section (and in section D) and then reinforce these points in your discussion of the question in section E. The importance of melanin production and carapace pigmentation provides an example of the broad range of characteristics that contribute to fitness; this can help to counteract the common misconception that evolutionary fitness is determined only by strength, speed, size and health. In addition, the evidence suggests a substantial change in the regulation of melanin production within 50-90 years after the introduction of fish; this counteracts the common misconception that evolution only occurs slowly. Rapid evolution of new traits is facilitated by Daphnia's short generation time – females reach sexual maturity within 8-10 days.

Another important general point is illustrated by the multiple conflicting selection pressures on the amount of melanin in the exoskeleton (protection against UV light damage tends to favor increased melanin production vs. fish predation and the costs of making melanin tend to favor decreased melanin production). Multiple conflicting selection pressures are common, and this is one reason why the traits of an organism, although generally well-adapted to their environment, are not "perfect". When there is environmental variation in multiple conflicting selection pressures, phenotypic plasticity can be an adaptive solution.

The research evidence in this section is from a 2010 PNAS paper by Scoville and Pfrender which is available at <http://www.pnas.org/content/107/9/4260.full>. A useful overview of Daphnia biology is provided in "Introduction to *Daphnia* Biology", available at <http://www.ncbi.nlm.nih.gov/books/NBK2042/>.

Section D analyzes research on a different type of phenotypic plasticity in a different species of Daphnia in a different environment. Specifically, the researchers investigated phenotypic plasticity in how deep in the water Daphnia swim in response to "fish smell".[[8]](#footnote-8) The advantages of swimming lower in the water are greater when fish predators are present, and as expected, some Daphnia swim lower in the water in response to fish smell. This type of phenotypic plasticity allows Daphnia to avoid fish predation, but still have the benefits of swimming higher in the water during seasons when there is little fish predation. This type of phenotypic plasticity was observed primarily in the descendents of Daphnia that grew in the pond during the period when there was considerable fish predation.

The research evidence supports the conclusion that, when the pond was stocked with planktivorous fish (from 1973 through the early 1980s), there was strong natural selection against Daphnia that consistently swam near the surface of the water (due to substantial predation on these Daphnia). Correspondingly, there was an increase in the prevalence of phenotypic plasticity in swimming depth, which appears to have been a useful adaptation to maximize Daphnia survival and reproduction both during the summer when fish predation is high and at other seasons when fish predation is lower. Some of the Daphnia from the time period with high predation consistently swam lower in the water, which suggests that this may be an alternative behavioral adaptation to high predation. The dramatic changes in swimming depth between 1970-2 and 1976-9 illustrate how rapidly natural selection can occur.

The research evidence in this section is from *PNAS* 98 (11): 6256-6260, 2001 (available at <http://www.pnas.org/content/98/11/6256.full>). To enhance student understanding, many complexities have been omitted from the description provided in the Student Handout.

The final paragraph of this section revisits the potential confusion between the everyday meaning of adapting to an environment vs. evolutionary biologists' usage of adaptation as a heritable characteristic that has become common in the population as a result of natural selection. These two concepts can be reconciled by understanding the examples presented of phenotypic plasticity as an adaptation.

Section E, Question 12 asks students to reflect on some of the implications of the examples in the previous sections for a general understanding of evolution (see discussion of sections C and D in these Teacher Notes).

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

1. By Drs. Ingrid Waldron and Jennifer Doherty, Dept Biology, Univ. Pennsylvania, 2013. These Teacher Notes and the related Student Handout are available at <http://serendipstudio.org/exchange/bioactivities>/evoadapt. [↑](#footnote-ref-1)
2. Standard HS-LS4-4 from Next Generation Science Standards (available at <http://www.nextgenscience.org/hsls-ire-interdependent-relationships-ecosystems>) [↑](#footnote-ref-2)
3. Recommended crosscutting concepts, disciplinary core ideas, and scientific practices are from A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (available at <http://www.nap.edu/catalog.php?record_id=13165> ). [↑](#footnote-ref-3)
4. From [http://www.co fleck in… Science, restandards.org/](http://www.corestandards.org/) [↑](#footnote-ref-4)
5. These misconceptions are excerpted from *Misconceptions about evolution*, available at <http://evolution.berkeley.edu/evolibrary/misconceptions_teacherfaq.php> [↑](#footnote-ref-5)
6. This phenotypic plasticity is similar to human tanning which also results in increased melanin production and a darker surface color that helps to protect against damage that can be caused by the UV light in sunlight. However, the specific physiology differs. [↑](#footnote-ref-6)
7. It should be mentioned that melanin production is generally observed in Daphnia that live in the Arctic or mountain lakes where they are exposed to more intense UV light. [↑](#footnote-ref-7)
8. We have used the imprecise term "fish smell" for ease of student comprehension. The more correct term would be fish kairomone (the chemicals found in water that fish are swimming in or have swum in). It appears that fish kairomone stimulates chemoreceptors in Daphnia antennules and this is one way that Daphnia detect the presence of fish. [↑](#footnote-ref-8)