

Teacher Notes for "Natural Selection and the Peppered Moth"¹

In this minds-on analysis and discussion activity, students interpret evidence concerning natural selection in the peppered moth. The evidence includes (1) the genetic basis for the different color forms of peppered moths, (2) mortality differences between the color forms in different environments, and (3) a history of correlated changes in the environment and the proportion of moths with each color form. This activity will help students to consolidate a scientifically accurate understanding of the process of natural selection. (This activity is very similar to the last section of the hands-on activity “Evolution by Natural Selection” (https://serendipstudio.org/sci_edu/waldron/#evolution).)

Before students begin this activity, they should have a general familiarity with natural selection and genetics. For this purpose, I recommend:

- “What is natural selection?” (<https://serendipstudio.org/exchange/bioactivities/NaturalSelectionIntro>)
- either “Introduction to Genetics – Similarities and Differences between Family Members” (<https://serendipstudio.org/exchange/bioactivities/geneticsFR>) or “Genetics” (https://serendipstudio.org/sci_edu/waldron/#genetics).

Learning Goals

In accord with the Next Generation Science Standards²:

- Students will gain understanding of two Disciplinary Core Ideas:
 - LS4.B Natural Selection. "Natural selection occurs only if there is both (1) variation in the genetic information between organisms in the population and (2) variation in the expression of that genetic information – that is, trait variation – that leads to differences in performance among individuals. The traits that positively affect survival are more likely to be reproduced, and thus are more common in the population."
 - 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. That is, the differential survival and reproduction of organisms in a population that have an advantageous heritable trait leads to an increase in the proportion of individuals in future generations that have the trait and to a decrease in the proportion of individuals that do not. Adaptation also means that the distribution of traits in a population can change when conditions change."
- Students will engage in several Scientific Practices:
 - Analyzing and Interpreting Data: “Evaluate the impact of new data on a working explanation and/or model of a proposed process or system.”
 - Constructing Explanations and Designing Solutions: “Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects.”
- This activity provides the opportunity to discuss the Crosscutting Concepts:
 - Cause and effect: Mechanism and explanation – “In grades 9-12, students understand that empirical evidence is required to differentiate between cause and correlation and to make

¹ By Dr. Ingrid Waldron, Department of Biology, University of Pennsylvania, © 2024. These Teacher Preparation Notes and the Student Handout for this activity are available at <https://serendipstudio.org/exchange/bioactivities/NaturalSelectionMoth>.

² Quotations are from <https://www.nextgenscience.org/> and <http://www.nextgenscience.org/sites/default/files/HS%20LS%20topics%20combined%206.13.13.pdf>

claims about specific causes and effects. They suggest cause and effect relationships to explain and predict behaviors in complex natural and designed systems. They also propose causal relationships by examining what is known about smaller scale mechanisms within the system.”

- Stability and Change – “Students understand much of science deals with constructing explanations of how things change and how they remain stable. They quantify and model changes in systems ...”

This activity helps to prepare students for the Performance Expectations³:

- HS-LS4-4, "Construct an explanation based on evidence for how natural selection leads to adaptation of populations."

Additional Content Learning Goals

- Since (1) individuals with an adaptation are more likely to survive and reproduce and (2) parents pass their alleles to their offspring, the allele(s) that result in an adaptation tend to become common in the population.
- Natural selection does *not* cause changes in an individual. Instead, natural selection results in changes in the frequency in a population of an adaptation and the allele(s) that result in the adaptation.
- The effects of natural selection are more easily observed when the environment changes, so natural selection results in changes in the frequency in a population of an adaptation and the allele(s) that result in the adaptation.

This activity counteracts several common misconceptions about evolution.⁴

- Natural selection involves organisms trying to adapt.
- The "needs" of organisms account for the changes in populations over time (goal-directed or teleological interpretation).
- The fittest organisms in a population are those that are strongest and/or fastest.

Background Biology and Instructional Suggestions

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

If your students are learning online, I recommend that they use the Google Doc version of the Student Handout available at <https://serendipstudio.org/exchange/bioactivities/NaturalSelectionMoth>. To answer questions 1, 2a, 2b and 7, students can either print the relevant pages, draw on them, and send pictures to you, or students will need to know how to modify a drawing online. To answer online, they can double-click on the relevant drawing in the Google Doc to open a drawing window. Then, they can use the editing tools to answer the questions.

You may want to revise the Word document or Google Doc to prepare a version of the Student Handout that will be more suitable for your students. If you use the Word document, please

³ This activity is designed for high school students, but it can be adapted to help middle school students prepare for the Performance Expectations, MS-LS4-4, "Construct an explanation based on evidence that describes how genetic variations of traits in a population increase some individuals' probability of surviving and reproducing in a specific environment." and MS-LS4-6, "Use mathematical representations to support explanations of how natural selection may lead to increases and decreases of specific traits in populations over time."

⁴ Most of these misconceptions are excerpted from Misconceptions about evolution, available at http://evolution.berkeley.edu/evolibrary/misconceptions_teacherfaq.php

check the format by viewing the PDF.

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.

On page 1 of the Student Handout, if you have trouble finding the speckled peppered moth in the figure on the left, it may help to know that it is near the lower left-hand corner, with its head upward.⁵

As discussed on the bottom of page 1 of the Student Handout, the allele for the dark form (melanism) is dominant relative to the allele for the speckled form. These two alleles are the most common alleles in the populations studied.⁶

Question 3 reinforces student understanding of the conditions required for natural selection to occur, as discussed in “What is natural selection?” (<https://serendipstudio.org/exchange/bioactivities/NaturalSelectionIntro>).

In question 4, students predict the effects of changes in air pollution in regions of England that became industrialized. In question 5, these predictions are compared with the data in the graphs on the top of page 3 of the Student Handout; these graphs provide representative data for an industrial region of England. These graphs show the trends in the proportion of peppered moths that were dark and the prevalence of the allele for melanism (which was estimated from the data on the trends in phenotypes). In these graphs, the total width of the shaded line represents 99% confidence intervals, and the width of the darkest part of the line indicates 50% confidence intervals. Questions 4-5 introduce the importance of changes in allele frequency as part of the process of natural selection.

I suggest that, at this point in the activity, you reinforce student understanding of natural selection of peppered moth color forms by showing them the 4-minute video, “Natural Selection Song: The Ballad of the Peppered Moth” (<https://www.youtube.com/watch?v=uV5-FKT16r0>). I suggest that you stop the video at 3 minutes and 31 seconds, before the part about Kettlewell and Majerus, which is not relevant for high school students.

A goal of question 6 is to counteract the common misconceptions that:

- The “needs” of organisms account for the changes in populations over time (e.g. “the peppered moths needed to become speckled so they would not be eaten by birds”).
- Evolution involves individuals trying to adapt and changing during their lifetime (e.g. “Most of the peppered moths became dark”).

Question 7 primes students to understand the graph on the top of page 4 of the Student Handout. A quick glance at the graphs on the top of pages 3 and 4 of the Student Handout could suggest that during the second half of the twentieth century the trends were much faster in England than in the US. If this misimpression arises, you will probably want to challenge your students to

⁵ For middle schoolers, after question 1, you may want to introduce the information and hunting game, available in “Peppered Moths – Natural Selection in Action” (<https://askabiologist.asu.edu/peppered-moths-game/>).

⁶ Evidence for England indicates that the mutation that resulted in the dark form of the peppered moth occurred around 1820. This single origin of the melanic allele in peppered moths contrasts with other types of moths where melanic forms appear to have been present as polymorphisms in preindustrial rural regions.

figure out whether this is true; if necessary you can give them a hint to compare the scales for the X axis in the two figures.

Taken together, the graphs on pages 3-4 of the Student Handout illustrate the following important points.

- Different characteristics are adaptations in different environments.
- Environmental changes that are subsequently reversed may result in evolutionary changes that are similarly reversed.
- Natural selection typically requires multiple generations (although this was partly due to gradual changes in the environment).
- In response to similar environmental changes, natural selection can result in similar trends in the characteristics of different populations.

Discussion of student answers to question 8 should include the important point that natural selection is occurring continuously, although it is more difficult to see the effects of natural selection when population characteristics are already well-suited to a stable environment (which can be observed for ~1800-1850 and ~1900-1950 in the graphs on page 3 of the Student Handout and for the rural regions in the graph on page 4 of the Student Handout). In rural regions, natural selection kept the frequency of the dark form of the peppered moth very low and, in stable polluted environments, natural selection kept the frequency of the speckled form of the peppered moth low. The effects of natural selection can be seen more easily when environmental changes result in natural selection for a different characteristic (which can be observed for ~1850-1900 and ~1950-2000 in industrial regions). These points lead naturally to a discussion of this Crosscutting Concept: Stability and Change – “Students understand much of science deals with constructing explanations of how things change and how they remain stable.”

There has been some controversy concerning the cause of the trends in the speckled and dark forms of the peppered moth (see "Industrial Melanism in the Peppered Moth, *Biston betularia*: An Excellent Teaching Example of Darwinian Evolution in Action", *Evo Edu Outreach* (2009) 2:63-74). Some aspects of this controversy have been beneficial since they have identified flaws in some of the earlier research and stimulated improved research which has provided strong evidence for the importance of natural selection due to predation by birds on peppered moths (see e. g. <http://rsbl.royalsocietypublishing.org/content/roybiolett/8/4/609.full.pdf>).

Bats are also important predators on adult male peppered moths (the females fly very little so they are less subject to bat predation). However, unlike birds, bats are not visual predators and are equally likely to eat speckled or dark peppered moths. The caterpillars of the peppered moth are also subject to predation, and these caterpillars have a different type of camouflage that is independent of the adult dark vs. speckled forms. When caterpillars molt, they can change color to match the color of the twigs that they live on.⁷ The available evidence indicates that bat predation, predation on caterpillars, and other causes of mortality appear to be generally equal for both color forms; therefore, the selective disadvantage for the color form of the adult peppered moth that is mismatched with the environment is not as strong as we might expect. This is one reason why natural selection for dark or speckled forms of the peppered moth resulted in gradual changes in the proportions of moths with each color form.

⁷ This is an example of phenotypic plasticity (the ability to adapt to different environments within an organism's lifetime). The analysis and discussion activity, "How Animals Adapt to Changes in Their Environments – Examples and Evolution" (<http://serendipstudio.org/exchange/bioactivities/evoadapt>), helps students to understand natural selection for phenotypic plasticity.

Question 10 asks students for peppered moth examples of two important generalizations about natural selection. The phenotype (color form or camouflage) of individual peppered moths influences whether they survive to reproduce. As a result, there have been changes in the proportion of the populations that has the dark color form and corresponding changes in the frequency in the populations of the alleles that influence color form.

You may also want to discuss with your students the multiple processes that can result in changes in allele frequencies in populations, including mutation, gene flow, genetic drift, and natural selection. Of these processes, only natural selection can explain the following observations.

- When similar environmental changes occurred in industrial regions in England and the US, similar trends are observed in the populations of peppered moths in both countries.
- In both England and the US, the trends observed in industrial areas were not observed in peppered moth populations in rural regions away from industrial regions.
- Increased prevalence of darker moths in polluted forests has been observed for over 100 other species of moths (this is called industrial melanism; <https://askabiologist.asu.edu/peppered-moths-game/>).

Sources of Figures in Student Handout

- Figures on Page 1 from <http://www.ucl.ac.uk/~ucbhdjm/courses/b242/OneGene/peppered.html>
- Figures on page 3, adapted from Extended Data Figure 4 in van't Hof et al., 2016, "The industrial melanism mutation in British peppered moths is a transposable element", <https://www.nature.com/articles/nature17951>.
- Figure on page 4, adapted from Grant and Wiseman, 2002, "Recent History of Melanism in American Peppered Moths", <https://www.ncbi.nlm.nih.gov/pubmed/12140267>.

Follow-up Activities

"Resources for Teaching and Learning about Evolution"
(<http://serendipstudio.org/exchange/bioactivities/evolrec>).

These Teacher Notes provide (1) suggestions for teaching evolution to students with religious concerns, (2) a review of major concepts and common misconceptions concerning natural selection, with recommended learning activities, (3) a review of major concepts and common misconceptions about species, descent with modification, and the evidence for evolution, with recommended learning activities, and (4) recommended general resources for teaching about evolution.