What the Moths Taught Us

This unit will help us to understand the process of adaptation and evolution of a species of moths as an effect of the Industrial Revolution. Students will play a game to gain experience of the concepts central to the unit. Then, they will read a passage about observations made in the 1950s by a biologist about the phenomenon of industrial melanism. Finally, they will think through their experiences in the game, and what they read in the passage, by answering some questions.

This unit combines the following concepts from their curriculum:

a) Predator-prey relationships (class 6th, Chapter - Living Organisms and their Surroundings)
b) Adaptation (class 7th, Chapter - Weather, Climate and Adaptation of Animals to Climate)
c) Effect of Pollution (class 8th, Chapter - Pollution of Air and Water)
d) Biodiversity (class 8th, Chapter - Conservation of Plants and Animals)

It also introduces the students to the concept of evolution which may be new to them.

Learning objectives: This learning unit will enable the students to understand the following concepts:

a) How a predator-prey relationship evolves in an ecosystem.
b) A non-trivial effect of pollution on survival of an insect species.
c) Correlation between evolution and diversity and the significance of diversity

Additionally, it would help them to develop the following skills:

a) The process of data acquisition, conversion of numbers into percentages and analysis of the acquired data.
b) To identify the variables in a scientific problem
c) Understanding the advantages as well as limitations of models to study the real world.

Background of the unit

Evolution and the mechanism of natural selection are two of the most important topics in modern biology. Although evolution is well-accepted within the scientific community, it continues to be debated in society at large. In addition, there are several mechanisms about these themes. This learning unit seeks to help students think about evolution and natural selection in a clearer way, by building up from a simple model of a real case-study.

i. Differentiating population changes from individual changes

Envisioning natural selection as a cause for diversity of living forms and ecosystem may seem challenging. It is also difficult to appreciate how populations of living things gradually undergo change, particularly, when we frequently see that individual offspring tend to be similar to their parents.

ii. Thinking at large scales

Evolution through natural selection permits of such change because it occurs at immense scales of time and number. Species do not change overnight; instead the process takes millions of years. For the same reasons, even though individuals do not change, populations as a whole do. In everyday life, we frequently do not envision things at such scales. However, in order to gain a nuanced understanding of natural selection, it is necessary to learn to take into account large numbers and long times.

iii. Using mathematics

One way to work with large numbers is by using mathematics. Calculating percentages and averages allows us to make quantitative comparisons between different natural populations. Mathematical skills are therefore essential if one is to study evolution.

iv. Thinking through scientific hypotheses

Finally, scientific work revolves around formulating and testing hypotheses. This applies in the case of evolution as well. Our activity also attempts to provide students with some experiences of thinking about scientific hypotheses.

Materials required: Newspaper, black chart paper, scissors, pen and notebook, graph paper, ruler.

Pre-Requisites

Students: The students should have a very basic knowledge of the effects of air pollution (like coal and soot burning) and of predator-prey relationships. They should also be familiar with the concept of percentage.

Teachers: Teachers should be comfortable with the concepts of evolution and natural selection. They should also be comfortable with percentages, and may need some experience in guiding students through thinking about questions on percentages and graphs.

Time required:

Organization for game and actual game, including data collection- 30-40 min

Reading the passage and solving questions- 30 min

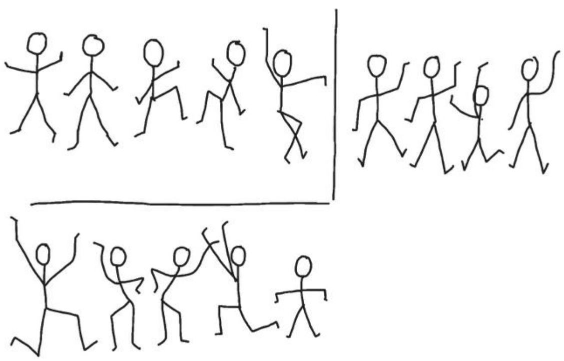
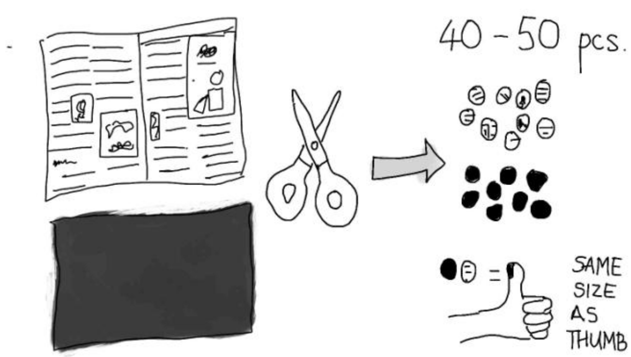
Discussion- 30 min

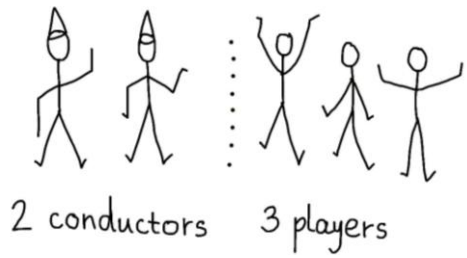
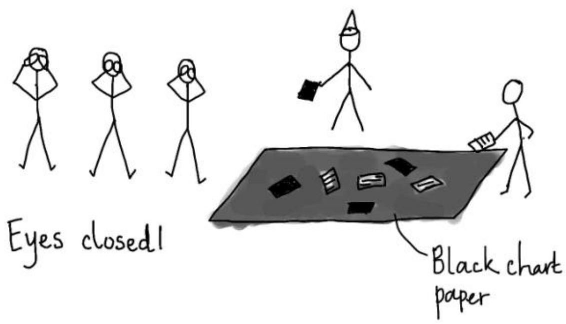
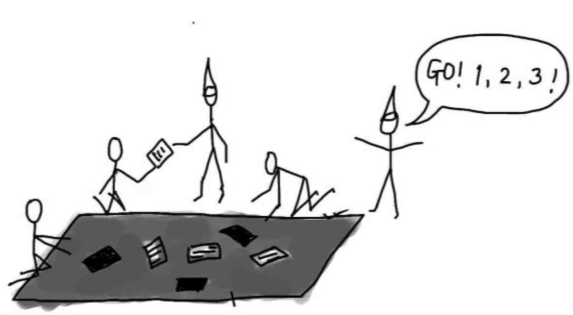
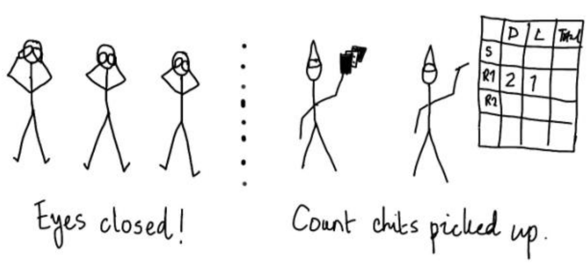
Novelty of the unit: The concept of evolution and natural selection is explained in textbooks, but rarely *experienced* by students. The game, accompanying passage and questions allow the students to gain an experience and then draw upon it to understand this concept. The game will help the students understand the experiment by H.B.D. Kettlewell on evolution of dark moths in forests of England. The questions which follow the passage would enable the students to think critically, perform mathematical calculations and answer open-ended questions.

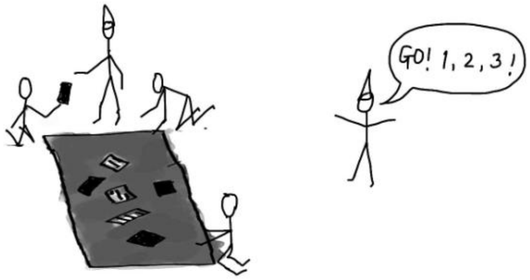
Variations in response of students from various backgrounds: If the students understood the effect of industrial revolution on evolution of dark moths, there would not be much variation in the responses of students to most of the questions. They may come up with ‘other’ factors of moths getting killed or may offer variation in their reasoning to the open-ended question.

Learning unit description

The unit begins with the students playing the game of moths and birds. The teacher may need to demonstrate how the game is to be conducted, before splitting the class into groups. The students should represent their results as is shown in the appendix (Students' document)

	Divide the class into groups of 5 people. Groups of 4 will also work, but 5 are preferred.
	Each group is given some newspapers, black chart paper, and some scissors. Each group cuts approximately 40 – 50 chits from old newspapers and black chart paper. 1. Chits cut from the newspapers should be covered with black-and-white text from printed sections of the newspaper. Avoid having any colors other than black and white. 2. Try to keep all the chits of about the same size as your thumbnail.

	In each group, 3 students play the game, while 2 conduct it.
	1. The players initially sit with their eyes closed or blindfolded. 2. The conductors will set up the game board. They distribute dark (D) and light (L) chits across the game board. 3. In total, about 40 – 50 chits should be placed on the board. The number of dark and light chits should be approximately the same. 4. While distributing the chits, ensure that they are evenly distributed on the board and do not overlap each other.
	1. The 3 players come to the board with eyes still closed. 2. One of the conductors shouts "go", and starts counting to 3. 3. The players open their eyes, and pick up any one chit from the board within the time count. 4. At the count of 3, they close their eyes again.
	The conductors take the chits picked up by the players, and count how many of each type were picked up. They enter this information into a data collection sheet like that shown in Appendix 1.

	The conductors **rotate** the board, and **shuffle** the chits on the board.
	The game is played a total of 7 times. Thus, three players should have picked up total 21 chits (7 each) by the end of the round. Keep track of the number of chits picked up and left behind during each round!

Extensions to the Learning Unit

While designing these learning units, we have generated numerous ideas. Some of these have been excluded from the main section, mainly because exploring them fully may require more time and interest on the part of students and teachers.

Our sincere hope, however, is that the existing learning unit stimulates both teachers and students to be curious about the topic of industrial melanism and adaptation. We do not wish that such curiosity remains unsatisfied. As such, we include here additional information and activities which can help teachers and students curious to extend their learning from this learning unit.

Extension I

Last part of the story: Kettlewell's Control Experiments

When we left off our story, Kettlewell's fellow biologists were not convinced by his findings. He had to conduct a new set of experiments to satisfy them. He wanted to show that it was the difference in color between the polluted trees and the moth wings that allowed fewer white moths to survive, and led to the increase in population of the black moths. Some months later, Kettlewell conducted the same mark-release-recapture experiments, but this time in an unpolluted forest near Dorset. The following table represents the number of moths recaptured:

	Unpolluted Forest(Dorset)
Light Wings	62/496
Dark Wings	34/488

With the combination of this data and his previous data from the polluted forests, Kettlewell was more successful in convincing his fellow biologists that color differences between the moth wings and their background had led to a change in the proportion of the dark-winged moths.

Questions:

1. Let’s play with some numbers again:
    a. What percentage of light-winged moths were recaptured?

    b. What percentage of dark-winged moths were recaptured?

    c. Which type of moth was more likely to be recaptured – light-winged or dark-winged?

    d. Were the percentages calculated here similar to the percentages calculated in Kettlewell's previous experiment?

2. Play another game that is similar to Kettlewell’s second round of experiments.

    a. Do the results from your game match those obtained by Kettlewell?

b. Do they match those obtained in your previous game?

3. Do you think the other biologists would now be convinced by Kettlewell's explanation? Discuss among yourselves

Extension II

Language

1. A physical property that helps organisms survive is called a **favourable adaptation**.
   a. Could we describe the black wing colouration as a favourable adaptation? What about the white wing colouration?

   b. In everyday language, we make statements like

      "The boy adapted to the hot sun by putting on a hat." OR
      "The girl adapted to being trapped in the jungle by learning to forage for fruits and roots."

In what ways is "adaptation" in these examples different from adaptation as seen in the case of moths in Britain?

Changing conditions

1. Try games with the following conditions, and see what happens.

    a. Play the game using larger chits, of size 3 cm x 5 cm.
    b. Play the game with two types of predators. Normal predators are like the ones we played with, and grab a chit as soon as possible. In addition, special predators only try to grab a particular colour of chit, regardless of the background.
    c. Play the game with many more chits (about 200).
    d. Play the game with much fewer chits (about 10).
    e. Play the game sitting further away from the game board.
    f. Play the game with your eyes closed the whole time. Use a different sense to detect and pick up the chits.

How do the results that you have obtained in these games differ from the original results that you obtained?

What do the changes that you have made in these games represent in the real world?

Differentiating models and the real-world

1. Imagine that Kettlewell called his fellow biologists over and had them play the same game that you did. Would it have convinced them that his hypothesis was correct? Why?

    a. In what ways is the game different from the real world?

b. In what ways is the game you played similar to the real world?

c. In the extension titled “Changing conditions”, we played many more games. However, we know that the games would probably not convince scientists. If so, what do you think is the benefit of playing such games?

d. In the dictionary, search for the meaning of the word “simulation”. Do you think this game is a simulation? Why?

Extension III

The story of the melanic moths is long and convoluted. Here, we have tried to put together some of it. We also attach links to papers where you can read more about melanic moths.

Collecting Complementary Evidence

Kettlewell collected multiple types of evidence in support of his hypothesis. While his mark-release-recapture experiments served as the primary quantitative data supporting his claim, he also collaborated with the ethologist Niko Tinbergen to capture photographs and videos of birds feeding. Tinbergen used hidden cameras to capture videos of moths on tree-bark. He noted that in polluted forests, 43 of 58 moths that were eaten by birds were light-winged. On the other hand, in unpolluted forests, 164 out of 190 moths eaten by birds were dark-winged.

Kettlewell needed this data simply because some scientists doubted that birds ate moths during the daytime. Now, Kettlewell was able to show that birds did indeed feed on moths, and that their feeding followed the pattern he had predicted using his mark-release-recapture experiments.

Kettlewell's complete experiments are well-described in two resources, which are available online.

1. H. B. D. Kettlewell and the Peppered Moths, by Joel B. Hagen.
   URL: http://shipseducation.net/db/kettlewell.pdf

2. Industrial Melanism in the Peppered Moth, Biston betularia: An Excellent Teaching Example of Darwinian Evolution in Action, by Michael E. N. Majerus.
   URL: https://link.springer.com/article/10.1007/s12052-008-0107-y

Independent Supporting Studies

After Kettlewell's work, a number of other studies on the peppered moth verified his conclusions. For example, in 1972, a study of moths at seven sites across Britain, going from more industrialised to less industrialised areas, was published. In this study, the authors found that the survival of the dark-winged moth gradually decreased as one went from more polluted areas to less polluted areas.

The population of the dark-winged moth had increased following industrialisation. In the 1950s, anti-pollution laws started to be passed. By the 1990s, scientists were able to see how the proportion of dark-winged moths at industrial sites had changed. For example, in the industrial city of Liverpool, it was found that the proportion of dark-winged moths decreased from 90% in 1970, to less than 20% in 1995.

Such studies provided further support for Kettlewell's results.

Studies supporting Kettlewell's work are described in:

Industrial Melanism in the Peppered Moth, Biston betularia: An Excellent Teaching Example of Darwinian Evolution in Action, by Michael E. N. Majerus.
URL: https://link.springer.com/article/10.1007/s12052-008-0107-y

Criticisms

Many researchers also continued to criticise Kettlewell's work.

For example, people argued that Kettlewell had released moths onto tree-trunks, but that in natural conditions, moths rested on horizontal branches. Maybe the location where the moths rested could affect how easily they could be seen by birds?

Similarly, others pointed out that Kettlewell had released moths during the daytime. Because moths don't like to fly around during the day, they just attach to the first place that they see. This place might be in the open. But if the moths had been released at night, then they could have come to rest at a different place. Maybe if the resting places had been different, the survival of the light- and dark-winged moths would also have been different?

Some others suggested that although dark-winged moths may have survived because of camouflage, they may also have advantages which did not depend on their visibility. One of the arguments made was as follows: (1) Dark-winged moths were more likely to be preyed upon in non-polluted areas. (2) So, they should eventually become extinct in these areas, and only be found in polluted areas (Remember the predictions from graphs in your first experiment). (3) However, dark-winged moths are still found in unpolluted areas, although in a smaller number. (4) Therefore, dark-winged moths must have some kind of advantage which lets them survive despite being preyed on more.

All in all, while Kettlewell's experiments were satisfactory, they continued to be scrutinised and checked for many years after.

Some criticisms of Kettlewell's work are provided in the following two works:

1. Decline of melanism in two British moths: spatial, temporal and inter-specific variation, by LM Cook and JRG Turner.
   URL: https://www.nature.com/hdy/journal/v101/n6/full/hdy2008105a.html

2. Industrial Melanism in the Peppered Moth, Biston betularia: An Excellent Teaching Example of Darwinian Evolution in Action, by Michael E. N. Majerus.
   URL: https://link.springer.com/article/10.1007/s12052-008-0107-y

The work of Michael Majerus

We have described the criticisms and supporting evidence here to show you that the story of the peppered moth did not end with Kettlewell at all. On the contrary, scientists continued to argue with each other about the reasons why dark-winged moths were more commonly found in industrial areas, and light-winged moths were more commonly found in non-polluted areas.

A British biologist called Michael Majerus attempted to respond to all the criticisms by conducting a wide-ranging study. Majerus released 4864 moths in his study, over a period of 6 years, to determine whether any other factor (apart from predators) had a significant effect on the moth population. Unfortunately, Majerus died before he could publish his results. His data was compiled and analyzed by Cook, Grant, Saccheri and Mallet in an extremely short and readable paper. We do not describe the results here, and instead encourage you to read it.

Selective bird predation on the peppered moth: the last experiment of Michael Majerus by LM Cook, BS Grant, IJ Saccheri, and J Mallet.
URL: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3391436/

