The Mystery Phenomenon: Lesson Plans

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ABSTRACT:– In the lesson plans that follow, page references are to a course pack, image references are to a Microsoft® PowerPoint® presentation, and "BugHunt!" to a new version of a freeware program modified by its creator, Dr. Steve Brewer, specifically for this course (http://bcrc.bio.umass.edu/BugHunt/bughunt.1.0.5.sit.hqx). Images associated with the PowerPoint presentations are identified: "[number]". All are available from the author by request.

Class #1

Reflections on Variation/

Microevolution/Mystery Phenomenon Part 1

This class introduces students to evolutionary biology. It begins with a discussion of variation using the "Reflections on Variation" activity (based on B. Bishop and C. Anderson (1986)). Students are then asked to participate in a Views on the Nature of Science (VNOS) survey that will be used as a pre-assessment measure of their understanding of what scientific theories are and how they are evaluated. Upon the completion of the surveys, instructors introduce the “Mystery Phenomenon”, which students are encouraged to recognize is a potential example of microevolutionary change. Students are asked to develop theories that might account for this change as a means of inviting them to explicitly share and discuss misconceptions they and their classmates may have about evolutionary processes. Following this discussion, students watch a movie that reviews the basic argument of Darwin’s *Origin of Species*. Students are encouraged to explicitly reflect on what theories are, how Darwin’s theories of common descent and natural selection in particular were created, and what evidence convinced Darwin and others to support these theories. The class then engages in an activity aimed at providing further insight into natural selection: BugHunt!

Class 1 Objectives

- to introduce students to the topic of evolution in a non-threatening context;
- to draw attention to the large amount of variation that exists in populations and to clarify that while some variation is due to environmental differences, the component due to heredity is what is important from an evolutionary perspective;
- to remind students of the difference between macro- and micro- evolutionary change;
- to introduce students to the "Mystery Phenomenon", help them recognize that it is an example of microevolutionary change, and invite them to develop and begin evaluating theories that might account for it;
- to review the argument Darwin provides in the *Origin of Species* for his Theory of Common Descent and his Theory of Evolution by Natural Selection;
- to begin a discussion of what theories are in science, how they are created, and how they are evaluated; and,
- to use the BugHunt! computer simulation to help students deepen their understanding of natural selection.

Class 1 Materials and Equipment

1) 12 rulers and a protractor

2) 24 VNOS surveys

3) Microsoft PowerPoint file – "Mystery Phenomenon Part 1", LCD projector

4) Videotape "The Origin of Species: An Illustrated Guide" and the VCR playback unit

5) Make sure BugHunt! is on all computers

Class 1 Instructor Background Reading Materials

Read the background evolution readings students will be asked to do for this unit on pp. 263-338 in the course pack. Read also the selection entitled "Critical Barriers to Understanding Natural Selection" on pp. 256-260- students will be required to discuss this reading for a future class, but it will help you appreciate where many of them are coming from with reference to the discussions you will lead during today's class. Read the simulation directions for BugHunt! that appear on pp. 339-341 and become familiar with how to use the simulation.

<u>Set-up prior to class</u>:

1. Equipment

Read the Reflections on Variation activity in the course pack (pp. 252-255) and answer the questions which follow with reference to your own body.

Become familiar with Microsoft PowerPoint and how to use the file to teach.

View the film "Origin of Species" and think through how you will use it as a basis for discussion.

2. On Board:

<u>Agenda for today</u>:

1. Reflections on Variation Activity

2. VNOS survey

3. Mystery Phenomenon Part 1

4. Movie (30 minutes)

5. Discussion

6. BugHunt!

Class #1

Reflections on Variation/

Microevolution/Mystery Phenomenon Part 1

Overview

1. Reflections on Variation Activity (~ 15 min)

Some understanding of basic genetics concepts, such as the presence of variation in populations and the fact that some of this variation is inherited, is necessary to make sense of the evolutionary processes that are the focus of this unit.

Genetics is a topic which has seen a lot of press lately, e.g. the Human Genome Project has been discussed regularly in the news, and the possibility of cloning dinosaurs was depicted in the movie "Jurassic Park". While most students are aware of its potential impact on a wide variety of fields from medicine to agriculture, many have only a superficial awareness of the enormous genetic variation present in human populations. The Reflections on Variation activity meets students where they are by drawing their attention to the fact that people do differ from one another in many subtle ways, and that the variations they will examine have a genetic component.

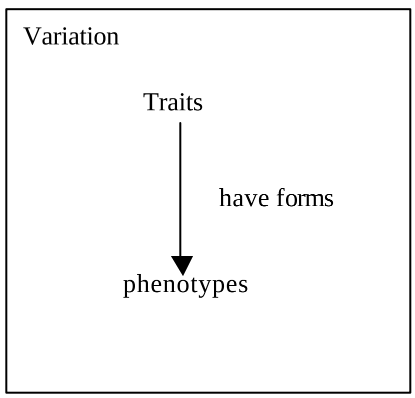
Introduce students to the concept of variation by explaining that we will begin looking at something we may not have noticed has great variety – ourselves. Have students read the introduction to the Reflections on Variation activity in the course pack (pp. 252-255) and then divide them up into research groups of three. Each person should fill in the appropriate answer to the question on the survey as it applies to them personally using the definitions of different forms of the trait provided. In some cases, such as eye color, they may need the assistance of group members. As students fill out the sheets, wander about the room and help anyone having problems interpreting descriptions of different forms of traits. The trait which seems to cause the most difficulty is the Simian Crease.

After all students have a profile sheet for themselves, invite everyone to stand. Pick an individual at random and identify him/her aloud as appearing to be a typical "normal individual". Ask this individual to slowly read aloud his/her answers one at a time to each of the questions. Tell the other students that they may continue to stand only if the answer they put down with reference to their own body agrees with that of the "normal student"; if their answer disagrees with that of the normal student they must sit down.

(Instructors should participate as well using the answers they have already jotted down in preparation for this class.)

Generally, by the time the “normal” student reaches the end of the list no one else is standing. Act puzzled and repeat this a couple of times using other students as the “normal individual” against whom everyone else is compared. After a couple of trials it becomes obvious that no matter who you start with, all of his/her answers will not be shared by any other person in the room.

The point behind this activity is to help students understand that there is no such thing as “normal”. Even confining our attention to a small number of traits and a small group of people, the activity illustrates that we are each unique in the combination of ways we express these traits. Point out this variation can also be found among all living species, including *Brassica rapa*. Generally, this variation can be expressed in the following way.



Traits are coded for by genes. There are multiple forms for the gene associated with any given trait, different versions of the same gene are referred to as alleles. The precise expression of an individual trait is referred to as the **phenotype** (small “p”), and the sum of all of the phenotypes an individual has for all traits is referred to as the **Phenotype** (big “P”). It is on the basis of <u>visible</u> phenotypes (morphology, behavior) that scientists infer the underlying genetics, i.e. the presence and inheritance patterns of the alleles (different forms of genes) that are responsible for how the trait is expressed.

Remind students that while some of the variation we observe may be due to environmental differences and age, much is due to differences in genetics. Indeed, all of the specific examples of variation on the survey they just completed are known to be inherited, i.e. they have a genetic basis.

Students should start to think about variation.

1. No matter what the species, the individuals that comprise that species differ from one another.
2. There is often greater variation within a group than between groups.
3. While some of this variation reflects environmental differences, disease and age (nurture), some is due to heredity (nature).
4. The inherited portion of variation is what is important from the standpoint of evolution.

2. VNOS survey (~20 min)

Invite students to voluntarily participate in a survey that will be used for formative rather than evaluative purposes. A script of precisely how to introduce this survey will be provided to you.

3. Mystery Phenomenon (~10 min slides, 10 min to develop theories)

It is now time to introduce an example of microevolution to students: the phenomenon of industrial melanism using the Microsoft PowerPoint Presentation "170 Mystery Phenomenon Part 1". The point of this discussion is to elicit *without judgment* student views (including alternative and misconceptions) about how this change might have occurred and to provide a basis for a more general discussion of theories that follows. The title "Mystery Phenomenon Part I" appears as the first slide [Slide 1].

As was just pointed out, every population in nature is composed of organisms that differ from one another. A central problem at the turn of the twentieth century was that of accounting for both the origin and the incidence of variation in nature, both within groups and between groups.

We will be discussing variation in the context of evolutionary change. One key distinction for us throughout this unit will be the distinction between *macro-evolution* and *micro-evolution*. Can anyone explain to us the difference between evolution, macro- and micro- evolution? [2] **Evolution** in general refers to changes in species over time. **Macro-evolution** refers to large scale irreversible changes that are thought to take place over large spans of time (e.g. thousands of generations and millions of years), such as speciation (the origin of new species) and extinction (the loss of species). These changes occur in the biological hierarchy at the level of species and larger taxonomic groups. **Micro-evolution**, in contrast, refers to reversible evolutionary changes that occur in relatively shorter periods of time (e.g. tens of generations, over hundreds or thousands of years), such as changes in the composition of a population over time. Thus whereas macroevolution is evolutionary change at the level of species and larger taxonomic groups; microevolution occurs at the level of populations. Because species are composed of populations a central question we will want to consider as we go through this unit is what, if anything, is the relation between micro- and macro- evolution.

I now want to introduce you to our Mystery Phenomenon and I'd like you to consider whether it is or is not an example of microevolutionary change. [3] Here is a photograph of the typical form of a moth known as *Biston betularia*. It is a very common moth throughout Continental Europe and a member of a night flying order of the Lepidoptera known as the Heterocera. It's pale appearance actually represents a very complex pattern, and as you can see [4], when it rests on the surface of lichen covered tree trunks in rural areas during the day it is very difficult to detect.

Let me now introduce our mystery about this moth. [5] The moth was first characterized in 1766 by the British naturalist, Moses Harris. [6] Up until the early nineteenth century, this moth was believed to have one pale form, known as **f. *typica***. [7] In 1848 a different dark colored form was discovered by an amateur lepidopterist, which was named *carbonaria*. [8] Here's a photograph of this form. [9] Moth collectors, like stamp and coin collectors today, were very excited by this finding and continued to look for more specimens. Interestingly, over time they discovered more and more examples of it [10-19]. This is when biologists started to get interested in it, because people noticed that only a hundred years time not only was this dark form being found in an increasing larger area, but whole populations were shifting from being composed primarily of the light form to primarily of the dark form. [20] Here's an image of a frequency map of the two forms of the moth. The circles are pie graphs that represent the relative frequencies of the pale and dark forms. When the circle is completely white, it means the entire population is composed of the pale form; when it is half white, only half of the population in that locality is white, the rest are dark. Does any one notice a pattern? (*The rise in frequency seems to be limited to a particular part of the country*).

Scientists were fascinated not only by the fact that the dark form was becoming more common, but also that this increase only seemed to be occurring in certain areas throughout Britain and also Continental Europe. What do they have in common? Does anyone recall the major change that was taking place in the British Isles and Continental Europe from about 1820 onwards? (*The Industrial Revolution*.) [21] For the most part the areas where the dark form is becoming more common are all downwind of industrial sites. Unlike the pale lichen covered trees in rural areas, the forests in these areas are blanketed with soot that kills off the lichen cover. [22] Here you see a depiction of what happened to the countryside outside of Manchester. So there appears to be a correlation between air pollution and an increase in the frequency of these dark moths. Moreover, naturalists noticed a similar change was occurring in at least fifty other species.

Now let me briefly share with you the results of some initial studies of the genetics of the particular moth we have been discussing, *Biston betularia*. Breeding experiments conducted in the early 1940s established that there was only one gene responsible for the dark coloration, and moreover, that it not only made moths darker but they also appeared to be "hardier" or physiologically stronger than the pale form.

[23] Let's go back to our original question. In view of what I've told you so far, does this appear to be an example of micro or macro-evolutionary change? *Because this is a population level change and has a genetic basis, it appears that it might be an example of micro-evolution.*

Our mystery phenomenon, is the question of why industrialization per se would cause this change. [24] What I'd like you to do now is split up into groups and develop a theory about why you think this change is occurring. Pass out Handout 1.

> **Many moth species have both pale and dark forms. In a number of moth populations in areas of high pollution downwind of industrial sites the dark form has become more common. Develop a theory that might account for this change.**

Split up students into groups of four and ask them to develop a theory that might account for the mystery phenomenon, i.e. why dark moths are becoming more common downwind of industrial areas. Encourage them to be creative. Have them share their ideas with the rest of the class, and invite students to raise questions and comment on one another's ideas. *Do not edit or correct their responses, instead invite* *other students to reflect and comment on the opinions being expressed.* Develop their answers in the form of a table (below) to ease comparisons.

Past experiences with students in this course suggest that in all likelihood you will get examples of each of the three types of theory identified below. If students don't immediately volunteer all three, remember that *wait time on your part is crucial*. Ask students if there is some other way to account for this change and give them a chance to think.

1. Physiological Adaptation to Changed Circumstances. Some may suggest that moths became darker because "they needed to" which is an example of a Lamarckian perspective, i.e. a change in the environment leads directly to an adaptive change in form. [Note this mistakenly focuses on individual organisms, rather than interpreting micro-evolutionary change as a population-level phenomenon.]

Ask students to elaborate on what they mean: *the environment became dark due to the pollutants and in order to escape predators, the moths has became darker to hide from them.* Ask students to clarify why they think this might be a plausible explanation, i.e. What reasons do you have for believing variations arise in this way?. Don't let them off the hook by simply saying it makes sense to them. *Some might draw attention to the fact that there are certain organisms, such as chameleons and mosquito fish, that are able to change their skin coloration against different backgrounds. Others might point out that we know that when people work out, their bodies respond to this demand by becoming more muscular, or when people sit in the sun for long periods of time, they become more tanned.* Ask students to consider whether they think exposure to pollution is similar to exposure to sun. What evidence do they have that leads them to believe this is what is happening?

2. Mutation. Others may suggest that it is due to mutation. By this, they won't mean that the mutation existed and was selected for (as with the explanation in terms of natural selection below). They will mean that ingestion or exposure to a contaminant in the environment caused the organism to mutate. [Note: Like the physiological adaptation theory above, this perspective mistakenly focuses on individual organisms, rather than interpreting micro-evolutionary change as a population-level phenomenon.]

Ask students to elaborate on what they mean: *pollutants caused a mutation in each moth that was exposed to it.* Ask students to clarify why they think this is a plausible explanation, i.e. What reasons do you have for believing variations arise in this way? *Some might point out that when people are vaccinated* *against the flu, they become resistant.* Some might indicate they have heard that mutations cause variation. Ask students to consider whether exposure to industrial pollutants would lead to an increase in mutation. What evidence do they have that leads them to believe this is what is happening?

3. Natural selection. Others may correctly recognize that this is a phenomenon that can be explained in terms of natural selection. If so, they will point out that some moths in these populations happened to be dark at the start of the industrial revolution, and that the reason why some populations are now composed primarily of individuals that are dark is because of differential survival and reproduction. Some may ascribe this to differences in color: dark moths are better able to escape capture from bird predators than pale moths in those environments. As such, they were more likely to have offspring than those that were pale and over time, their descendants have become an ever larger proportion of the population. Others may account for this in terms of the physiological difference mentioned above in connection with the genetics of the dark coloration in this moth discussed above. Others may see that it could be a combination of these two factors.

Ask students to elaborate on what they mean: *being dark is an advantage in a polluted soot-darkened environment against bird predation.* Ask students to clarify why they think this is a plausible explanation, i.e. What reasons do you have for believing variations arise in this way? *Some may draw attention to the results of artificial breeding experiments.* Ask students to consider whether a general darkening of the environment due to the accumulation of soot would lead to the dark form becoming more common. What evidence do they have that leads them to believe this is what is happening?

Point out we will discuss Darwin's theory of natural selection further in connection with a movie we will see momentarily.

Theory	Possible evolutionary mechanism	Applied to the mystery phenomenon
Physiological Adaptation to Changed Circumstances	Organisms can adapt to their environment. When the environment changes, organisms adapt to these changes. These changes can be passed to their offspring. Populations change over time because the individual organisms composing them are adapting to their environment.	Moths were not originally dark. When their environment was darkened by air pollution, they needed to become dark. The population has become darker because color changes on the part of individual organisms has led to each generation becoming more and more dark.

Mutation	Much of the variation we observe is inherited in the form of genes. Genes are altered by mutation Changes in the environment can increase the rate of mutation. Populations change over time because contaminants in the environment have led to the same mutation in all of the organisms composing the population.	Moths were not originally dark. Pollutants caused a mutation that makes moths dark. Populations change over time because the rate of this mutation has increased.
Natural selection	There is variation in natural populations, some of which is correlated with survival and reproduction. Since some of these variations are inherited, and there is a limit to how many organisms can survive in a given environment. Populations will change over time because descendants of organisms with favored variations are over represented in the next generation.	Some moths were originally dark in the population because of genes they happened to possess. With the advent of the first wide scale pollution associated with the industrial revolution, these moths now survived at the expense of other moths in the population. Over time, the descendants of dark moths will become more common.

4. Movie (~30 min)

At least one of the groups will presumably attempt to explain the phenomenon with reference to natural selection. If not, you might want to mention at this point that you will now share a brief movie that provides a well known account for how changes like this might be explained. Tell students that the movie provides a brief overview of the main argument of Darwin's Origin of Species (*The Origin of Species: An Illustrated Guide*). Watch the film together and then invite students to briefly share their comments and questions.

5. Discussion

Point out to students that the *Origin of Species* film mentions two distinct theories, (1) Darwin's Theory of Common Descent and (2) Darwin's Theory of Natural Selection.

Darwin's theory of common descent is essentially a factual claim that all of the diversity of life as we know it has descended with modification from a single common ancestor. Point out that it was well accepted by virtually everyone we would now identify as biologists within the first ten years of the publication of the *Origin of Species*.

Ask students to identify what evidence the film identifies led Darwin to believe that all organisms had descended from a single common ancestor:

(1) *Biogeographic evidence* - within both the fossil record and among living populations species of the same type tend to resemble their neighbors;

(2) *The fossil record* - there is a clear progression in the fossil record among organisms that has a definite ordering from simpler to more complex organisms. There are also transitional organisms - e.g. Archaeopteryx;

(3) *Embryological evidence* - similar species share common stages of development. This makes sense on the presumption they share a common ancestry, evolutionary changes in morphology are the result of changes in development; and,

(4) *Anatomical evidence* - there are patterns among the structures of organisms that make sense on the presumption they share a common ancestor, e.g. homologies, vestigial organs.

Things to draw students attention to about Darwin's theory of common descent. (1) It accounts for patterns in the Biogeographic distribution of organisms, similarities in the embryological development of organisms representing different taxa, similarities and differences between the comparative anatomy of different organisms, and patterns in the fossil record. (2) It raised new questions for biologists and provided a basis for a series of new lines of research aimed at understanding how different groups are related to one another in several different subfields of biology, including comparative anatomy and embryology. (3) It predicted there are transitional forms between groups that otherwise may look quite distinct. Darwin's theory of common descent is an account of the history of life on this planet. In the absence of a time machine, we cannot directly test the veracity of several claims that follow from this theory. But we can trace out implications of these conjectures that themselves can be tested.

The second, more controversial part of Darwin's theory, is what he identified as the most important mechanism of evolution, namely his **theory of natural selection**:

(1) Since organisms vary from one another in ways that affect their ability to survive and reproduce; and

(2) These variations are heritable (i.e. offspring resemble their parents); and

(3) There is a competition in nature for resources, owing to the fact that organisms reproduce far in excess of those that can possibly survive,

(4) It follows those organisms with favorable variations (i.e. variations that enhance their ability to survive and reproduce) will be more likely to survive, and over time, favorable variations will tend to be preserved while injurious variations will tend to be destroyed.

Point out that Darwin conceived of natural selection as the chief mechanism of evolution. It provides explanations for why species are adapted to their environment, why they go extinct, and why species multiply.

Darwin's evidence for his theory of natural selection takes two different forms. First, he was able to marshal an enormous amount of evidence documenting the three conditions identified above as being necessary for evolution by natural selection to occur. For any given species, there is an enormous amount of variation within a population for many traits that are correlated with their abilities to survive and reproduce. Much of this variation is heritable. And since, as we know from our ecology unit, organisms generally reproduce in excess of the amount of resources available to support all offspring, it follows the offspring must compete for scare resources. Those who have traits that favor their ability to survive and reproduce will be at an advantage- and as such, they will be more likely to have offspring than those who do not.

The time frames posited by Darwin's theory were beyond what is possible for man to observe. But Darwin had a second line of evidence that established this mechanism could result in significant change - namely the evidence of plant and animal breeders, who "picked" or selected breeding stock with regard to various criteria. Darwin drew special attention to the work of pigeon fanciers, who in a relatively short time period had been able to effect incredible changes in varieties of domestic pigeons. Some of Darwin's critics disputed this evidence by claiming that it only shows how varieties can develop *within* species, not how a new species can arise. Part of the force of their criticism has to do with the fact that there were well known limits to how far a fancier could push a given trait. Darwin's reply was that these limits were an artifact of the short period of time breeders worked with these organisms. He claimed that over geological periods of time, new variants would continue to occasionally arise, and that the net effect of the accumulation of slight changes would result in species level change.

Things to draw students attention to about Darwin's theory of theory of natural selection. (1) This theory explains how populations change over time, the origin of adaptations, and the process of speciation. (2) The theory provides a basis for explaining and predicting what will happen to populations over time when environmental conditions change. (3) Developments in the related field of genetics during the turn of the twentieth century led many to speculate that this theory was inadequate as an account of the origin of species. Recognition of the importance of population thinking during the Evolutionary Synthesis of the early 1940s led researchers to recognize that the rediscovery of Mendel's work did not undermine the possibility of explaining the origin of species with reference to natural selection.

6. BugHunt!

Directions for the simulation are located in the course pack on pp. 339-341 and in the simulation. Caution students that there are occasional computer glitches associated with this program: (1) After finishing the "unpolluted" wood simulation they will need to select "Cleanup" before running the second "polluted" wood simulation.

The BugHunt Directions are fairly self explanatory. Encourage students to do 8 cycles of each simulation, and answer each of the questions in their course packs. As you go around the room, invite students to share what they are finding, and ask them individually when they notice that a new variant has arisen whether they think it arose because the bug needed to be that color or not.

One way to motivate BugHunt! is to draw attention to how the simulation allows us to understand how someone might make sense of the mystery phenomenon with reference to natural selection. People who seriously considered this as a possible explanation, thought birds might play a selective role. The simulation invites students to act out the role of a predatory bird and thereby observe in a short period of class time what the cumulative effect of many birds might be on this population. Discuss their results as a group, by asking students to share their answers to each of the questions.

Things to emphasize with regards to BugHunt!: the origin of the variation (mutation) is independent of what the organism needs. If it is beneficial, it will be selected for, if it isn't, it will be selected against. In a different environment, something that was beneficial may no longer be. What is changing over time is not individual organisms, but the composition of the population. It is the population that is adapting, not the individual. Those who have the favorable variation have offspring, those that don't are more likely to be preyed upon. Changes are not necessarily incremental.

Final Notes for Instructors

Things to keep in mind as you teach this class:

Evolution and Religion

Most of the students who take this class come from religious backgrounds and are inclined to interpret any discussion of evolutionary theory as an overt attack on their religion. In particular, you must avoid the suggestion that a religious account represents a misconception or is otherwise mediocre to a scientific account. One way to handle this is to point out that religious and scientific explanations do not have to be interpreted as conflicting with one another - whereas a religious explanation provides an account for the diversity of life as we know it from an ultimate standpoint (i.e. *why* God created the universe in the manner He did), a scientific explanation can be interpreted as an attempt to explain *how* God created it (by special acts of creation or a consequence of laws he laid down in the beginning).

From time to time in teaching this class we have pointed out to students that religious texts should not be interpreted as scientific texts and vice versa.. Many students are not persuaded by this line of reasoning - from their perspective there is only one truth, and if the bible and science disagree, so much for science. For the most part, even the most religious individuals who take this course countenance what evolutionary biologists describe as microevolutionary change- changes in the genetic composition of populations over short periods of time. The possibility that these processes could, over huge time periods lead to changes at the level of the species is something they dispute. Like other topics in this course (e.g. the silver box activity, studying inheritance patterns at the phenotypic level in the absence of following the fates of individual genes at the molecular level) you should feel free to point out that scientists are often able to reach conclusions about natural phenomena in the absence of direct evidence. The mere fact we do not have a time machine that would allow us to go back in time to observe the origin of a new species in no way shape or form makes the claim species evolved mere speculation. We have lots and lots of circumstantial evidence. In this way, experiments in historical sciences like evolutionary biology, earth science and cosmology require scientists to act in a manner similar to detectives at a crime scene who use the available remaining evidence to make inferences about what happened. The fact that we are not certain in the logician's sense about such matters does not preclude us from having a great deal of confidence. You might point out that even in the ahistorical sciences, e.g. physics, we often make claims about the motions of bodies we have not observed (because they are too far away or the events in question happened in the past).

You may wish to also direct students' attention to the importance of understanding evolution for their future careers as teachers of elementary and middle school. Point out that state standards such as the MEGOSE require instructors to teach evolution. At the very least they must be proficient in being able to communicate how a biologist reasons about evolution, regardless of whatever private reservations they have about the topic.

If all else fails, point out that just as it is ignorance on the part of an evolutionary biologist to reject a theistic account without understanding it, so too, it is ignorance to discount evolutionary theory without understanding it.

Discussing the Nature of Science

The approach taken here and in the next two classes has two emphases. (1) For students to appreciate various aspects of the nature of science, their attention must explicitly be drawn to questions about the nature of science both with reference to particular examples (e.g. Why do you think this is a theory?) and in general (e.g. What is a theory?). And (2) for meaningful change to occur, the conclusions must be ones students draw for themselves, rather than having an instructor tell them what to memorize for the test. The latter is essential from the standpoint of the research we are doing in connection with this unit: we cannot claim to have demonstrated the efficacy of this unit in helping students reach a more sophisticated understanding about the nature of science if along the way their instructor tells them what to think. *In that circumstance, we have no way in principle of distinguishing between conclusions students reach themselves on the basis of this approach and what reflects rote memorization.*

As such, the instructor walks a tight rope which is potentially frustrating to students. On the one hand you must raise very general issues about the nature of science, such as what are theories and how are theories evaluated. And on the other hand, you must refrain from providing students answers to these questions. Our ultimate goal is not merely having students acquiesce to a particular perspective. What is important from the standpoint of scientific literacy is that the perspective they develop is one that is the result of critical reflection.

We certainly have an agenda, as noted in the asides in the lesson plan above and in the next two classes, about what students should think about these issues. Indeed, we can hardly claim to be in a position to help students reach a more sophisticated understanding if we the instructors to do not have such an understanding ourselves. But the perspective we take is that in possession of the relevant information and questions to consider, students by their own reflection and critical thinking will reach the desired insights.

Thus, while the questions about the nature of science are explicit, the agenda we have for what students should think about these issues is implicit. It takes the form of examples for which these features are drawn attention to and carefully thought out questions aimed at guiding students' thinking along the desired lines. Sometimes the best way to help a student see the limits of his or her perspective is simply to invite other students to express their thoughts on what the student has just said, rather than correcting him or her. On other occasions, it is helpful to have a repertoire of questions at your fingertips that you can use to follow up a student comment that lead him or her to recognize the limits of their perspective.

Class #2

Mystery Phenomenon Part 2

This class continues an activity aimed at helping students develop insights into how evolutionary biologists study micro-evolutionary phenomena, while drawing their attention to several nature of science issues. After briefly reminding students of what the "Mystery Phenomenon" is, the instructor asks students to volunteer once more each of the three theories they have offered that might account for it. The instructor now validates each of these theories students have come up with, by drawing attention to the fact that each of them was indeed proposed by a scientist during the twentieth century. The instructor shares some of the reasons that historically led these scientists to propose their explanations.

Students are then encouraged to consider the strengths and weaknesses of these proposed explanations. They are asked to develop predictions and think through how if they were the scientist who proposed the theory how he might have designed an investigation that would allow him to test the veracity of his predictions. The sorts of investigations students will suggest are entirely predictable (with some advice, comments and questions). The instructor then presents them with the historical results of investigations the scientists actually conducted (similar to those students have come up with on their own) and invites them to interpret these results and those of the other investigators. Students are asked to consider both what adherents and detractors of a particular theory might say about results offered in favor of it. In each case, students discover that the results are ambiguous - they neither clearly support the theory in question, nor do they necessarily refute it.

Students are asked to consider what experiments in general and how advocates of the theories they just discussed might defend their theory in view of discrepancies with the predictions of the model and/or interpretive problems with the investigations. The class concludes with a viewing of a film by H.B.D. Kettlewell, "Evolution in Progress", which serves to provide a temporary sense of closure and the basis of a more sophisticated discussion of the phenomenon, research on it, and how it (and scientific results more generally) should be depicted to introductory students.

Day 2 Objectives

- to help students learn how biologists reason about microevolutionary phenomena with reference to several different possible mechanisms.
- to encourage students to evaluate proposed theories for the "Mystery Phenomenon" with reference to their internal coherence, predictions that appear to follow from them;
- to provide students with opportunities to interpret the results of investigations conducted by historical actors that closely resemble the sorts of investigations they have proposed as tests of their theories;
- to help students recognize that the interpretation of results in science is sometimes ambiguous, in part because the interpretation of evidence depends upon one's theoretical perspective. Recognition of this fact does not preclude consensus in science; and,
- to help students reflect on broader nature of science issues concerning what experiments are and how theories are evaluated and tested.

Day 2 Materials and Equipment

1. Movie: "Evolution in Progress"
2. Microsoft PowerPoint file – "Mystery Phenomenon Part 2", LCD projector

Day 2 Instructor Background Reading Materials (all in course pack)

Read the background evolution readings students will be asked to do for this unit on pp. 263-338 and the selection entitled "Critical Barriers to Understanding Natural Selection" on pp. 256-260.

Set-up prior to class:

1. Equipment

VCR playback unit

2. On Board:

Agenda for today:

1. Mystery Phenomenon Part 2

- summary of last time

- discussion

Class #2

Mystery Phenomenon Part 2

Overview

1. Mystery phenomenon (con't) (~20 min)

To motivate today's discussion (and also because some students may have missed the last class), it is important to begin by briefly reminding students once more about what the mystery phenomenon is and also the tentative theories they have proposed that might account for it.

Begin [1] by mentioning that the balance of today will be devoted to a continuation of our discussion about the mystery phenomenon and how we might account for it. [2] Remind them that the mystery phenomenon concerns a moth species (*Biston betularia*) that until early in the nineteenth century was thought to only have one form, f. typical. In 1848 a dark form of this moth was discovered outside of Manchester [3], and that by 1950 the dark form had not only spread to other areas [4], but was also becoming extremely common in some of these areas -as much as 90% in the space of only a hundred years as indicated in pie graphs of frequencies [5]- which is an extremely rapid change from the standpoint of evolution. Remind them that we discovered that there seems to be a correlation between areas where the dark form has become more common and pollution centers [6].

Point out that if you visited unpolluted areas, trees in these areas have a pale appearance owing to the presence of lichens that cover them [7], whereas in polluted areas this lichen cover has been completely killed off by the pollution and the trees are darkened by soot [8]. Draw their attention to how some of us suggested that the change might have to do with the obvious color difference between the two moths [9], and in particular how difficult it is to locate the pale moth in rural forests [10] and the dark form in polluted areas [11]. Document this with photographs in these two settings [12, 13] and invite students to see if they can spot both moths in each photograph. Point out also that some of us suggested that the alleged physiological differences between the two forms of the moth might also play a role - perhaps the dark form is more resistant to toxins in the pollutants. So the mystery phenomenon is accounting for why the dark form is becoming more common in the polluted forests. [14]

With this summary in place, tell students that we will explore the tentative answers they suggested in more depth, and in particular, three different theories that might account for this change. Ask students to remind the class what these three theories were: (*1). Physiological Adaptation to Changed Circumstances*, (2) *Natural Selection* and (3) *Mutation*. [15]

Point out that each of these three theories was once seriously considered by scientists, and that you will now briefly review these from the perspectives of the scientists who proposed them: (*1). Lamarck's Theory of Acquired Inheritance*, (2) *Darwin's Theory of Natural Selection* and (3) *De Vries' Mutation Theory*. [16] We will discuss both the theory in general and consider how subsequent workers proposed it applies to the "Mystery Phenomenon". [These are summarized in the table below.]

<u>1. Lamarck's Theory of Acquired Inheritance</u>. Share the basic tenets of Lamarck's theory using the intuitive example of how giraffe's necks got longer [17]. Emphasize that no one doubts that bodies can adapt within limits to their surroundings (e.g. plants grow towards sources of light, people tan on the beach, people who work out in the rec. center regularly can get more muscular). What is controversial about this theory is whether these sorts of changes that take place in the life time of an organism can be passed on to its offspring. [18] Point out that a scientist (Nicholas Cooke) suggested just like them that perhaps the dark form was becoming more common due to a physiological adaptation on the part of individual organisms to their environment- and in the case of the peppered moth, a general darkening caused by pollution and increased humidity has led the moths to adapt to their environment by becoming darker in order to hide from birds.

2. Darwin's Theory of Natural Selection. Share the basic tenets of Darwin's theory using the intuitive example of antelope becoming quicker as a result of predation by cheetahs against slow antelope [19]. Emphasize the contrasting claims made by Lamarck and Darwin - whereas Lamarck claimed these changes take place within the life of an organism, Darwin argued that populations have variation to start with and that the change that occurs is at the population level - in terms of shifting frequencies of the various forms and not changes at the individual level. [20] Point out that a amateur lepidopterist (James Tutt) suggested just like them that perhaps the dark form was becoming more common due to the selective advantage of being dark in polluted environments. [21] Draw attention to how the ecological geneticist E.B. Ford built off of Tutt's theory by combining his insights about the physiological advantage of the dark form by suggesting that the spread was due to the physiological difference and the limit to the spread was imposed by the obvious handicap of being dark colored in an unpolluted environment.

3. De Vries' Mutation Theory. Share the basic tenets of DeVries mutation theory using results of his famous experiment on the evening primrose [22]. Emphasize that De Vries disputed that species level differences could occur with reference to the accumulation of slight changes as Darwin proposed, but instead were the result of dramatic changes due to mutation. [23] Point out that the scientist J. W. Heslop-Harrison just like some of them believed this might account for the increase in the dark form, and that he was convinced that lead salts in the soot might have mutagenic properties.

Summarize these three theories by visually contrasting how each depicts the mystery phenomenon:

1. Cooke's Theory [24]. Emphasize that Cooke's theory suggests the change was gradual, and indirectly caused by pollution. On Cooke's theory, the darkening of the environment caused each individual moth in the polluted environment to adapt and these changes have been inherited by their offspring.

2. Tutt and Ford's Theory [25]. Tutt and Ford's theory also suggests the change was gradual and an indirect result of the pollution. However, they contended the dark form arose as a result of mutation *completely by chance* not because of either the direct or indirect effect of pollutants in the environment. On their view, the dark form has *always* been present at a low frequency in the population as a result of recurrent mutations. The pollution did not cause the mutation to occur, it simply changed the environment in a way that now

favors the survival of the dark form relative to the pale form and as a consequence, its numbers are rising. On this view, it is not the individual that is changing– it is the composition of the population over time.

3. Heslop-Harrison’s Theory [26]. Heslop-Harrison's theory suggests the change was very dramatic. Iron salts in the pollution *directly* caused individual moths to mutate and this mutation has been passed down to their offspring.

Theory	Possible evolutionary mechanism	Applied to the mystery phenomenon
Lamarck's Theory of Acquired Inheritance	Organisms can adapt to their environment. When the environment changes, organisms adapt to these changes. These changes can be passed to their offspring. Populations change over time because the individual organisms composing them are adapting to their environment.	**Cooke's theory:** Moths were not originally dark. When their environment was darkened by air pollution, they needed to become dark. The population has become darker because color changes on the part of individual organisms has led to each generation becoming more and more dark.
Darwin's Theory of Natural selection	There is variation in natural populations, some of which is correlated with survival and reproduction. Since some of these variations are inherited, and there is a limit to how many organisms can survive in a given environment. Populations will change over time because descendants of organisms with favored variations are over represented in the next generation.	**Ford's theory:** Some moths were originally dark in the population because of genes they happened to possess. With the advent of the first widescale pollution associated with the industrial revolution, these moths now survived at the expense of other moths in the population. Over time, the descendants of dark moths will become more common.
DeVries Mutationist theory	Much of the variation we observe is inherited in the form of genes. Genes are altered by mutation Changes in the environment can increase the rate of mutation. Populations change over time because contaminants in the environment have led to the same mutation in all of the organisms composing the population.	**Heslop Harrison's theory:** Moths were not originally dark. Pollutants caused a mutation that makes moths dark. Populations change over time because the rate of this mutation has increased.

With these examples in mind, it is time to pose a more general question: *What is a theory?*[27]

Background information for the instructor:

Scientific theories are well-established, highly substantiated, internally consistent systems of explanations. (1) Theories serve to explain relatively huge sets of seemingly unrelated observations in more than one field of investigation. (2) Theories also play a major role generating research problems and guiding future investigations. (3) Since theories often refer to entities that are not themselves directly observable (e.g. atoms), they are tested indirectly with reference to predictions based upon the theory, claims about the test conditions, and other claims furnished by yet other theories. Theories are also evaluated with reference to whether they are internally coherent and whether they are consistent with other theories in the same or related domains. In view of these considerations, scientists recognize that theories are tentative, i.e. that they change over time as the result of new evidence (observations or experiments, perhaps as a result of new technologies), changes in how previously collected data is interpreted, and theoretical developments in related fields. As noted in the previous lesson plan above, both of Darwin's theories exemplify these features.

In order to assess the value of this pedagogy on influencing student understandings of what theories are, as well as provide them with a basis for understanding how theories are developed and evaluated, it is important that the instructor refrain from telling students what theories are, etc. The insights students reach about what theories are, how they are created and how they are evaluated should arise from their <u>own</u> deliberations.

Student responses to this question range from a very naïve understanding to ones that may be considered closer to the goal conception held by scientists. Young children often equate a theory with simply a restatement of a problem. For example, when asked for a theory about why heating a hot air balloon makes it rise, some children merely restate that the reason is that hot air causes it to do so.

Another naïve interpretation of a theory, consistent with the colloquial use of the term, equates it with the term "hypothesis" or "educated guess". This is often paired with the belief that a theory is something that can be directly tested empirically, and moreover that there is no other basis upon which theories can or should be evaluated. This conception of theories is often associated with a related belief that theories are unchanging; which contrasts with the goal conception of theories held by scientists that holds they are constantly subject to change and refinement.

Some students may recognize that theories provide a basis for explaining phenomena in their domain, and that the greater the number and diversity of phenomena the theory can account for, the more robust the theory. Even here, students may simply equate a theoretical exp lanation with providing a causal explanation, rather than recognizing that this causal explanation must itself be accounted for with reference to still more general principles. To return to the example, "a hot air balloon arises because the air has been heated, which causes the balloon to rise" is not an adequate theoretical explanation. The relative low density of hot air compared to the surrounding air of the balloon (which is itself explained in terms of thermodynamics) is what accounts for why the balloon rises. Students may also be under the impression that theories develop into laws rather than recognizing that laws are empirical regularities and not explanatory frameworks.

Given the foregoing, instructors should begin the process by inviting students to consider, *"What is a theory?"* Answers to this question may go in several directions. Some questions to facilitate the discussion are:

What features of Darwin's theory of common descent and his theory of natural selection suggest to you that they are indeed theories?

In Class 1 above these features are spelled out in detail for the <u>instructor's</u> benefit. Do not share these with students - invite them to come up with answers on their own.

Can you give me other examples of theories?

If students are unable to provide one, you might consider sharing Newton's theory of gravitational attraction. According to this theory, all objects with mass exert a force of attraction upon one another, a force that is inversely proportional to distance. (1) This theory accounts for a wide diversity of phenomena, from why apples fall to why the planets orbit the sun. (2) It suggested new lines of investigation, e.g. determining what the gravitational constant of attraction is and suggested a mechanism by which still other phenomena (e.g. the tides) might be explained. (3) The predictions of this theory can lead to startling new observations - for instance the discovery of existence of Neptune was first suggested by problems accounting for the orbit of Uranus. The failure of the theory to account for the perihelion of Mercury is conversely considered one reason for why it was ultimately abandoned in favor of Einstein's theory of gravity.

Still another is Cell Theory developed by Theodor Schwann. It claims all life is composed of cells. (1) It implies the properties of all complex living organisms can and should be ultimately accounted for with reference to the activities and products of cells that compose them, and moreover that cells come from preexisting cells. (2) This suggested new lines of inquiry concerning the composition of cells, as well as suggesting an alternative theory of embryology (epigenesis) to the prevailing theory (preformation). (3) It led to the prediction that all cells of the body are totipotent or contain all of the hereditary information.

Still another is Winger's Theory of Continental Drift. According to this theory, the continents are not stationary, but move over geological time on large plates. (1) It provides an explanation of biogeographic patterns as well as an explanation for the formation of mountains and earthquakes. (2) It opens up new lines of inquiry, particularly with reference to the history of the earth and how it might have evolved. (3) It leads to specific predictions e.g. about the movement of magnetic poles.

What makes these examples theories?

If students persist in suggesting they are just a guesses, point out that scientists use the term in a different way than we do in ordinary conversation. Invite them to consider whether any guess constitutes a "theory" *as the term is used in science* or whether it might be something more.

What do scientists use theories for?

Students should recognize that theories provide a basis for explaining and predicting. *Again, don't tell them this - provide students with sufficient wait time to come up with this on their own.*

Is a theory the same thing as a prediction?

If students suggest they believe this is the case, invite them to consider whether there are examples of something that is predictive, yet not explanatory. One stock example is a barometer. A barometer can be used to predict that a storm will occur, but it does not explain why the storm occurs. (A barometer reading falls because a low pressure system moves into the area; the latter is often the precipitating cause of a storm.)

Where do theories come from?

With a few examples in mind, students at this point should be able to share ideas about where theories come from. You might want to remind them that Darwin developed his theory of natural selection to account for the origin of adaptations in nature with reference to how animal and plant breeders are able to affect change among domestic populations. Darwin saw how consciously selecting organisms with favored forms of traits for breeding purposes had led to long term changes in pigeons and other organisms. The puzzle for him was identifying something in nature that might have a similar affect on wild populations. Darwin reached his great insight with reference to reading Malthus' book on populations, in which his prepared mind was drawn to the fact that organisms often reproduce far in excess of those that can possibly survive. Darwin recognized that because of this, a competition would naturally occur in natural populations and moreover that those with advantageous versions of traits would be at an advantage when it came to surviving and reproducing. Thus in the absence of conscious selection, the population over time would adapt to its environment.

Ask students to once more return to the theories they created to account for why some moth populations are darker. [28] *We now have several different theories that might explain why some moth populations have become darker. Are they all equally valid?*

If students suggest yes or refuse to comment, you might consider inviting them to consider whether allegiance to a scientific theory is like a preference for a particular flavor of ice cream. *Are these theories all equally probable, or are there ways to distinguish among them?*

If students still have trouble starting to answer this question, instructors should invite students to consider sharing what they consider to be the strengths and weaknesses of each theory on the board, by elaborating on the previous table with two additional columns for strengths and weaknesses. Students by this point should recognize that theories can be evaluated with reference to initial plausibility and coherence, how consistent they are with other better supported theories, their explanatory and predictive power, and also their fruitfulness (do they suggest other lines of research?).

Ask: *If you wanted to determine whether any of these three theories was indeed an accurate account for the mystery phenomenon, how would you do it?* Extend the table by introducing two additional columns [assumptions made by the theory, predictions of the theory] and place student answers in the cells of the table as appropriate. Don't label these two columns until students have finished offering suggestions.

Examples:

Applied to the mystery phenomenon	Assumptions of the theory	Predictions of the theory
Cooke's theory: Moths were not originally dark. When their environment was darkened by air pollution, they needed to become dark. The population has become darker because color changes on the part of individual organisms has led to each generation becoming more and more dark.	The moths can indeed change their color in response to a change in their environment. Are physiological changes that occur in the life of an organism inherited by its offspring?	Whenever moths are put in circumstances in which the environment is dark, we should be able to detect a change in either their color or that of their offspring in response to this new environment. This should happen in any dark environment, not just polluted ones. If we raise moths in darkened settings over a series of generations, one would expect the proportion of dark individuals would increase.
Ford's theory: Some moths were originally dark in the population because of genes they happened to possess. With the advent of the first widescale pollution associated with the industrial revolution, these moths now survived at the expense of other moths in the population because they were better able to avoid predators. Over time, the descendants of dark moths will become more common.	There is a genetic basis for dark coloration. There is a selective advantage associated with the gene causing the dark form in the environments they live in. Birds prey upon the moths. Moths spend the day on tree trunks in plain sight	Breeding experiments should provide light on how it is inherited. If we put moths of both types into a darkened environment, it should be possible to measure whether the dark form is better able to survive and reproduce than the pale form. It should be possible to observe whether dark moths are "hardier" than pale moths. It should be possible to observe birds prey upon the moths, and also differential predation if they indeed attend to the color difference.
Heslop Harrison's theory: Moths were not originally dark. Pollutants caused a mutation that makes moths dark. Populations change over time because the rate of this mutation has increased.	Why would just any mutation have an advantageous effect? Why is the gene responsible for color particularly vulnerable to pollutants in the soot?	If we feed moths polluted vegetation, the frequency of the dark form should increase (either in the parents or their offspring) because ingestion of the pollutants has caused the rate of mutation to the dark form to increase.

Point out that some of their suggestions have to do with determining whether the assumptions of the theory are true or whether it is internally consistent. These contrast with suggestions of a second type, namely predictions of the theory. Label the two new columns at the top as indicated. Pointing this out may lead students to make still other suggestions. *The first is probably the hardest- instructors should feel free to* *make the suggestions noted above for students if the students are unable to come up with these on their own.*

Design of Investigations

Let's now put ourselves in the position of scientists working with these three theories. What I'd like you to do now is split up into groups and develop an investigation for each of these theories that would provide us with evidence either in favor or against that theory. Pass out Handout 2.

> **We now have three theories that might account for the mystery phenomenon. For each theory design an investigation that might allow you to determine whether one of the assumptions <u>or</u> one of the predictions of that theory is true.**
> **1. Cooke's Theory: Industrial Melanism is the Result of Physiological Adaptation to Changed Circumstances.**
> **2. Ford's Theory: Industrial Melanism is Due to Natural Selection (Physiological Advantage, Protective Camouflage)**
> **3. Heslop-Harrison's Theory: Industrial Melanism is Due to Mutation.**

Note to instructors: The advantage of having students work on all three theories at once is that they may find one of the theories easier to design an experiment for than the others. The experience of writing up what they perceive to be the easiest first, may help them with what they perceive to be more challenging.

Split up students into groups of four and ask them to design investigations that would allow them to test each of the theories. Encourage them to be creative. Walk around the room and help students to stay on task. After all of the groups are finished, have them share their ideas with the rest of the class, and invite students to raise questions and comment on one another's ideas. *Do not edit or correct their responses, instead invite other students to reflect and comment on the ideas being expressed.*

For each theory, use questions to guide students into thinking about the phenomenon as scientists historically did as follows:

<u>1. Cooke's theory</u>

Historically scientists did not take Cooke's theory seriously, as it was developed right around the time that August Weissman's experiment (described below) was widely regarded as disproving the possibility of the inheritance of acquired characteristics. This being said, our goal is that of helping students recognize the limits of this theory without having it dismissed out of hand. We anticipate students will go in one of three directions in the design of their experiments:

> A. Students will suggest we raise moths in a darkened environment and see whether they or their descendants get darker.

B. Students will suggest we survey the entire moth population to see whether the dark form is becoming darker in other settings.

C. Students may suggest we test the mechanism posited by this theory by introducing a change to the body of an organism and seeing whether it is inherited by the offspring.

If students don't suggest one of these lines of inquiry, instructors should raise it as a possibility.

Pass out the handout entitled "Handout 3: Cooke Results" [*The answers provided below to open ended questions regarding how scientists would interpret results are provided for the benefit of instructors only*.].

Ask students to consider how Cooke, Ford and Heslop-Harrison would interpret them.

Historically, scientists tested Cooke's theory in three ways, some or all of which are similar to what you suggested.

A. Geneticists raised moths in darkened environments and tried to detect whether the moths or their descendants were getting darker.

"I took a group of twenty pale moths and placed them in a wooden container the insides of which were painted black. None of the twenty moths appeared to get darker, nor were any of their offspring darker."

B. Naturalists surveyed the whole of Britain to see whether dark forms of moths were becoming more common in areas <u>not</u> downwind of industrial areas.

They found that there are some populations with high frequencies of dark moths in rural environments, especially near the East Coast of Britain where high humidity tends to darken the environment.

C. Physiologists were curious whether it is even possible acquired characteristics to be inherited.

August Weissman conducted an experiment using rats to see whether Lamarckian inheritance was possible at all. Weissman was convinced that the body consists of two types of cell lineages, cells that give rise to the body (soma) and cells that give rise to gametes that combine to form the next generation (germ plasm). He reasoned that if physiological changes in the body parts were inherited, it should be possible to demonstrate this by introducing the same change and measuring what effect if any it had on descendants. His experiment involved rats. He cut off the tails of dozens of rats and allowed them to breed with one another over several generations, but was unable to detect any progressive shortening in the tails of descendants.

If you were Cooke, what how would you interpret these results?

Students should recognize results A and C count against the theory, but that Cooke might be able to account for these discrepant results. In A, the small number of moths used might be below our ability to detect the change; C is an introduced change that is not quite the same as what Cooke had in mind.

If you were Ford or Heslop Harrison, how would you interpret these results?

Ford and Heslop Harrison would agree that A and C count against Cooke's theory. Ford would argue that results B are consistent with his theory, albeit the darkening of the environment is caused by another factor. In the absence of pollution, Heslop Harrison's theory cannot account for B.

2. Ford's Theory

Genetics

During the previous class, students were told that breeding experiments suggested that a gene was not only responsible for dark coloration, but might have a beneficial effect on the physiology of the moths as well. To establish that color has a genetic basis, Ford and others raised large batches of the moths and saw that the results of crossing the moths conformed to ratios that accord with the presumption it is inherited as a simple Mendelian dominant. Point out that when pale moths are crossed with one another, they only have pale offspring (bb x bb -> 4bb). When dark moths are crossed with pale moths, they sometimes have the predicted ratio of half dark to half pale (Bb x bb -> 2Bb + 2 bb) and sometimes all dark. (BB x bb -> 4Bb). Follow up crosses confirm this explanation- e.g. offspring dark moths from the second and third crosses when paired with one another (Bb) have both dark and pale offspring in a predicted 3:1 phenotypic ratio (Bb x Bb -> BB: 2Bb: 1 bb).

One possible way to test the second prediction is simply creating 2 colonies of equal numbers of dark and pale moths in a rural and a polluted setting to see what happens over time. Ford did just this, but found his results extremely difficult to interpret.

If students decide to pursue the third prediction that the gene confers a physiological advantage, one predictable sort of investigation they might suggest is that of breeding pale and dark moths to compare their relative survival rates. One key point to draw students attention to is the importance of spelling out precisely what one means by "physiological advantage". Ford's contemporaries shared a gut intuition that the dark form was hardier, but did not share common criteria for how it should be measured. Indeed, even when they adopted specific measures, they were unable to document that there was indeed a difference.

Students will probably latch on to the fourth prediction as the one they want to test. Kettlewell initially tested whether birds even attend to the difference by constructing a cage in an aviary and presenting a pair of captive Great Tits with moths of both types on lichen covered and soot darkened backgrounds. Share a narrative of these results with students. (Handout 4 Kettlewell Results)

Historically, H.B.D. Kettlewell tested Ford's theory in a manner similar to what you suggested using a pair of captive Great Tits.

A. Kettlewell wanted to find out whether a pair of captive birds ate stationary peppered moths, and if so, whether they had the same difficulty finding moths that humans do. He conducted these experiments using two nesting Great Tits (*Parus major*) in a large cage in an aviary at the Research Station, Madingley, Cambridge. The cage was 18 yards by 6 yards and 7 feet high, composed of wire netting and supports of dark larch and spruce trunks with bark. This provided 13 resting sites for moths, to which Kettlewell added 20 other resting sites making a total of 33, 15 light and 18 dark. The two birds were driven to one end of the cage and screened off from the rest by a large sheet. Kettlewell then released 10 moths (5 pale typical and 5 dark carbonaria) onto several resting sites and scored them as being on either their correct or incorrect backgrounds. The birds ignored the moths during the first hour, and during the second consumed all the conspicuous and two of the inconspicuous moths. A second run the following day on 18 betularia (6 of each form) on both correct and incorrect backgrounds, resulted in all but two inconspicuous moths being consumed in the first half hour. This led Kettlewell to consider the birds were becoming specialists on the moth, and he noted that in subsequent runs he noticed that immediately after they were released they would start to actively search each tree trunk. To get around this problem, Kettlewell decided to try to broaden their feeding interests by introducing a number of other local insects. This alteration "proved successful", and in experiment A/16 (9 carbonaria 8 typical) he was able to document that all 8 conspicuous moths were taken after two periods of 20 minutes, but only 4 "inconspicuous" moths. Subsequent trials had similar results.

Phenotype	On pale lichened bark	On soot darkened bark	At commencement	After 20 minutes	After 40 minutes	After 1 1/2 hour
Carbonaria	4	-	4	3	0	0
Carbonaria	-	4	4	3	1	0
Typical	4	-	4	4	3	0
Typical	-	4	4	2	0	0
Total left			16	12	4	0

[Simplified version of table A/16 appearing in Kettlewell's original paper]

Kettlewell, H. B. D. (1955) "Selection Experiments on Industrial Melanism in the Lepidoptera." ***Heredity 9*** **(Part 3 Dec): 323-342.**

B. [T]o demonstrate that the effect of natural selection is quite negligible as a factor in progressive melanism, I carefully studied the case of Polia chi, which in the Team Valley produces about 50% each of the typical and of the melanic forms grouped under the name olivacea, and near Middlesbrough about 10% of dark and 90% of pale forms. For several years and on every day during their season–rain or fine–either my wife or my brother carefully noted the positions of the insects resting on three walls: (1) old and dark in parts, proceeding from Birtley to Newcastle; (2) old light yellow sandstone, proceeding to Burnmoor; (3) mixed new greyer sandstone and old reddish ones leading to Chester-le-Street. On these three walls I have seen up to three hundred examples daily, so that the present test is not confined to a few insects; in the evening full particulars would be given to me and sometimes alone and sometimes accompanied with my brother I would go over the ground and investigate the fate of insects observed earlier in the day. Never was there any diminution of numbers in which more olivacea vanished than type chi; as a matter of fact we used to consider it a marvellous thing if a single one had disappeared."

Harrison, J. W. H.: 1920a, 'Genetical Studies in the Moths of the Geometrid Genus *Oporabia* (*Oporinia*) with a Special Consideration of Melanism in the Lepidoptera', ***Journal of Genetics*** **9, 195-280.**

If you were Ford, how would you interpret these results?

Ford, of course, thought that (A) provided support for his theory- but even he had some reservations about the artificiality of the experiment. Ford disputed (B), drawing attention to two different problems with this investigation: (1) it is anecdotal and (2) it relies on a type of moth that is not an industrial melanic. Kettlewell, Ford's associate, also pointed out that the magnitude of the selective difference might escape human attention in the short run, but in point of fact lead to dramatic changes.

If you were Cooke or Heslop Harrison, how would you interpret these results?

Heslop Harrison and his contemporaries had numerous problems with this part of Kettlewell's experiments (A). The aviary cage experiment relied on the same two captive birds for all runs of the experiment, which strongly suggests they might be conditioned to eat moths as a result of their participation in the experiment. One might also question Kettlewell's decision to tinker with the experiment by introducing other insects until he got what he wanted in the way of results.

This is a perfect opportunity for instructors to discuss the problem of experimental artifact in science.

Heslop Harrison took B as evidence that natural selection does not play a role in explaining the frequency of the melanic form.

3. **<u>Heslop Harrison's Theory</u>**

Students will predictably suggest that we feed moths leaves covered with soot to see whether their descendants become darker.

Pass out the handout entitled "Handout 5: Heslop Harrison Results". Ask students to consider how Cooke, Ford and Heslop-Harrison would interpret them.

Historically, Heslop Harrison tested his theory in a manner similar to what you suggested.

A. "With *Selenia bilunaria*, Esp.
In this series we began with a small batch of eggs laid by a wild Abbot's Wood (Sussex) female captured in July, 1921. The larvae from these hatched in August, and as we contemplated critical work in several directions, particular care was taken with their food, this being procured in [an] oak wood… Nearly 70 pupae were obtained and 59 imagines (26 VV and 33 MM) emerged in 1922… Two moths chosen at random from these were mated… and the larvae obtained were fed from the same pure hawthorn… these produced moths in June and July. This brood… consist[ed] of 24 VV and 33 MM. Pairings were made, and two small batches, each of about 60 ova, from different females, were sent to Hexham to be reared there. One of these batches was divided, one half being destined to serve as a control, while the larvae from the other half were reared on food (hawthorn) to which lead nitrate had been added… The hawthorn on which [both] groups were fed was cut from a particular tree, known from direct analyses to contain an unusually small amount of manganese.

[Re. the lead experiments] Concerning the controls, it is only necessary to say that three successive inbred generations were fed on untreated food, and… contained nothing but typical [pale] insects… But the summer broods of 1923, inbred from spring broods of that year, and continued on a diet containing lead, showed a marked difference… a type [pale] female was paired with a type [pale] male and the resulting larvae raised on hawthorn with lead nitrate in it. As a result, a batch of moths was obtained, including 7 VV and 12 MM, two females and one male being melanic… [Table 1]"

Heslop Harrison, (1925-6) "The Induction of Melanism in the Lepidoptera and its Subsequent Inheritance", Proceedings of the Royal Society of London Series B. v. 99 p. 245-46.

Family	Treatment	Females		Males	
		Types	Melanics	Types	Melanics
23 AL	Lead	15	-	11	1
23 BL	Lead	11	-	18	2
23 LL	Lead	6	2	11	1

Table I - Showing Selenia bilunaria families in which induced melanism appeared

B. Heslop Harrison demonstrated similar results on several other species of lepidoptera, including *Selenia tetralunaria* Hufn and *Ectropis bistortata* Goeze.

C. When Hughes (1932) and Thomsen and Lemche (1933) independently attempted to reproduce these results using larger numbers of individuals, they were unable to do so. If you were Heslop Harrison, how would you interpret these results?

Heslop Harrison thought these results indicated in A and B confirmed his theory. He disputed the technique used by the investigators in C. If the technique Heslop-Harrison used required a great deal of skill, then the discrepancy might simply reflect their inability to perform the experiments correctly. Or, alternatively, their inability to see the results Heslop Harrison found might reflect a bias on their part against what might be a perfectly acceptable theory.

If you were Cooke or Ford, how would you interpret these results?

Ford pointed out that in a recessive melanic species, the dark form might be hidden in heterozygous parents. [Notice that in the experiment in question, a melanic male is present in the first generation]. He also drew attention to the extremely high rate of mutation that Heslop Harrison was claiming to have observed, 8 % versus the highest amount then known, which was .002%

Historically this discrepancy was resolved among the scientific community in favor of Heslop-Harrison's critics. It was alleged Heslop-Harrison was biased in the interpretation of his results because he was a fan of the mutationist theory and also that he may have committed fraud. (A claim that was alleged with regard to his other research as well.) Because the discrepancies critics found with Heslop-Harrison's findings were discovered independently and also because of ongoing reservations scientists had about the magnitude of rate of mutation Heslop-Harrison claimed to observe, the scientific community has tended to discount his initial claims.

Movie

Point out to students that H.B.D. Kettlewell [28] attempted to experimentally determine whether birds in fact prey upon the moths in nature. Point out that his research involved releasing marked moths of both types in a polluted and an unpolluted setting. [29] He then attempted to recapture as many as possible, the presumption being that differences in recapture rate would reflect differences in their ability to avoid predators during the time between release and recapture. The recapture techniques he used involved both a mercury vapour light trap and assembling traps. Point out also that he attempted to film bird predation as well. [30] Show the movie to students and answer any questions they might have. Tell them we will discuss Kettlewell's work further during the next class when they will hear the rest of the story.

Class #3

Mystery Phenomenon Part 3/

Introduction to Macroevolution

This class concludes an activity aimed at helping students develop insights into how evolutionary biologists study micro-evolutionary phenomena, while drawing their attention to several nature of science issues. During the second class, students considered three different theories that might account for the phenomenon of industrial melanism, and reached a tentative conclusion that Ford's theory in terms of natural selection is the correct answer. In this class, they will explore some of the subtleties of the experiments that Kettlewell used to establish one major claim of Ford's theory, not to disabuse them of the idea that this is indeed an example of natural selection, but rather to acquaint them with some of the subtleties of the conduct of experiments and interpretation of experimental results.

Class 3 Objectives

1. Discuss the conduct of experimental investigations and how results are interpreted in science.
2. Draw broader conclusions about how science is and should be depicted in textbooks.

Class 3 Materials and Equipment

3. PowerPoint presentation - industrial melanism images

Day 3 Instructor Background Reading Materials

Read the background evolution readings students will be asked to do for this unit on pp. 263-338, especially pp. 325-338 which discuss how phylogenies are constructed and evaluated.

Set-up prior to class:

1. Equipment: LCD projector

2. On Board:

Agenda for today:

1. Mystery Phenomenon III

Class #3

Mystery Phenomenon Part 3

Overview

1. Mystery phenomenon (con't) (~20 min)

To motivate today's discussion (and also because some students may have missed one or more of the previous classes), it is important to begin by briefly reminding students once more about what the mystery phenomenon is and also the tentative explanations they have proposed. Begin [1] by mentioning that the balance of today will be devoted to concluding our discussion about the mystery phenomenon and how evolutionary biologists study phenomena like this. [2] Remind them that the mystery phenomenon concerns a moth species (*Biston betularia*) that has two forms, a pale and a dark form. Point out that until early in the nineteenth century the moth was only known by the pale form, but that in the space of just 100 years the dark form went from being a curious rarity to the most common form in certain areas. [3] Remind them that these areas all seem to be downwind of industrial sites, and that what we have been trying to do is figure out why industrialization has caused this rapid change. [4]

Ask students to remind their peers of the three possible explanations we have been considering (last class). Invite students to share the evidence that originally led these scientists to propose these theories, and also what evidence we have that appears to be telling against them. Begin with Cooke's and Heslop Harrison's theories, as these appear to have been dismissed during our last class. Invite students to share Tutt and Ford's theory, using images of the moths in the two settings [5, 6, 7].

Remind them that Kettlewell was interested in documenting the second part of Ford's theory, namely that bird's have the same difficulty finding moths as humans do in the rural and polluted settings. [8] Point out that he did this by a combination of two experiments. The first involved experimental releases of marked moths in unpolluted and polluted settings. [9] Kettlewell released marked moths of both types in a polluted and an unpolluted setting and then attempted to recapture them to see whether he could document that the favored form was more likely to be recaptured. The presumption of the study was that differences in recapture rate reflect differences in their ability to avoid predators. Share these results with students. [10. 11]. Point out that the magnitude of the selection coefficient Kettlewell observed (30%) led him to modify Ford's original theory. Whereas Ford suggested that the spread was due to a combination of two selective forces working in tandem, Kettlewell openly suggested that perhaps the advantage due to color alone might be responsible for the spread. (This illustrates one way that theories are modified over time.) The second involved attempting to film birds preying on the moths [12]. Ask students what they predict has happened as the result of Clear Air legislation in the U.K. (the frequency of the dark form will decline) and point out that several studies since suggest the melanic form is becoming rare once more.

Ask: *What are experiments?*[13]

An experiment, as opposed to an observation, is a systematic study of the response of a system to some perturbation. Heslop Harrison (and Kettlewell) conducted experiments that involved feeding moth larvae polluted leaves to assess whether this would lead to change in their wing color. Another example was Kettlewell's mark release recapture experiments. He introduced large numbers of moths of both types into a field setting to assess what the reaction of the birds would be (or placed the moths in a setting where predation occurs to see whether there was a differential effect upon the moths depending upon their color). Yet another example is Weismann's test of the Lamarckian theory - i.e. cutting off the tails of rats to see whether indeed their offspring have shorter tails.

Are experiments necessary for progress in science?[14]

No. As noted during the last class, theories may be created in the absence of experiments on the basis of observations and reasonable conjectures. Kettlewell learned a great deal about the phenomenon of industrial melanism from careful observations of bird behavior, surveys of moths throughout the British

Isles and studies of the life history of the moths. Experiments are only as good as the underlying assumptions upon which they rest, many of which are rooted in natural history.

Distribute the handout entitled "Industrial Melanism". Point out that it is an example of a textbook account of the mystery phenomenon that you have chosen primarily for its brevity. Have students read the account. Ask: *Have Kettlewell's experiments convinced you that Tutt and Ford's theory is true?*[15] Most students at this point will predictably indicate that they believe Kettlewell has indeed established that Ford's theory is indeed the correct explanation of the phenomenon.

At this point, reveal to students that you will now share some of the details of the rest of the story. Draw students attention to the fact that on the back of the handout they have been given is a set of seven claims made by this example of a standard account. [16] For each of these claims you will now share some additional details that call into question the adequacy of this standard account. [17]

1. The peppered moth doesn't have two forms [18], it has three [19], one of which (f. insularia) is a complex of forms that range in appearance between the pale and dark forms [20].

2. The standard account suggests the moths spend most of the day motionless on the surfaces of tree trunks in plain sight [21]. In point of fact, the actual resting place of the moths during the day is not entirely understood - indeed there is some evidence to suggest it rests higher up in the canopy of trees in the shade [22].

3. The standard account suggests birds are predators of the moths. [23] But the level of predation Kettlewell observed may reflect the high density of moths used during his experiment. In other words, it is possible that birds that normally don't eat moths at all might become conditioned to eat moths when they are present at high enough levels. [24]

4. The standard account suggests that air pollution from the industrial revolution led to a darkening of forests downwind of industrial sites, and in particular that melanic forms have arisen only for this reason. [25] But dark forms have evolved for other reasons and were present prior to the advent of the industrial revolution. [26]

5. The standard account suggests that the melanic form of the peppered moth has only increased in polluted areas [27], but high levels have been reported in some rural areas as well. [28]

6. The standard account [29] does not acknowledge the existence of other theories that might account for the spread of industrial melanics, and misleadingly suggests Kettlewell worked with Tutt's theory all along. [30]

7. The standard account suggests scientists are in universal agreement that Kettlewell's work established the adequacy of Ford's theory [31]. But this neglects controversies surrounding the phenomenon.[32]

In all [33], there seem to be so many problems with the standard account that some have actually suggested it be removed from textbooks.

Point out that these problems don't completely undermine the example [34], most scientists who work on the phenomenon still believe that natural selection due to bird predation is the most important factor. The phenomenon is simply a great deal more complicated than textbooks would have us believe.

Ask: *What do you think science teachers should do in light of these developments?* [35] Invite students to consider whether they think introductory textbooks should share all of the ongoing subtleties of examples like this or be confined only to those examples that are well understood.

Summarize this discussion by pointing out that we are faced with a fundamental tension, namely how to introduce science in a fashion that is assessable to children without completely misleading them about the nature of science. [36] Remind them that the textbook account, while misleading, has a lot of advantages that recommend it as a good introduction to the concept of natural selection. [37-40] Point out that it is a false dilemma to believe once must either choose between using simple examples students can understand and misleading them about the complexities of science [41]. Remind them how we were able, by using the history of research on this phenomenon to discuss how patterns in nature are discovered, models are developed and evaluated and also some of the complexities of scientific practice [42].

References

Bishop, B. and Anderson, C.: 1986, *"Evolution by Natural Selection: A Teaching Module"* Occasional Paper No. 91. Michigan State University, The Institute for Research on Teaching, East Lansing, MI.