Natural Selection: Understanding the Driving Force Behind Evolution

Alan Tso
Furness High School

Overview

Despite being a well-supported scientific theory, evolution is still a controversial topic in today's society. The word theory on its own lends itself to doubt because of its lay meaning. As one of the few scientific topics frequently thrown about in the mainstream media, it is riddled with misconceptions due to poor understanding of the actual process of evolution. Though there are several mechanisms by which evolution can occur, natural selection is perhaps the most influential among them. I want to spend time on illustrating the process of natural selection and how it can change a population. A good understanding of the mechanisms of evolution will help students see why most scientists accept it for a model of how the planet's natural diversity came to be.

This unit is designed for high school students studying biology. It includes activities such as analyzing literature, experiencing different modes of sight through the use of light restricting goggles, and gauging change in a population of pom-pom animals.

Rationale

Evolution can be described as the change in frequency of alleles within a population over time. While this definition is a bit confusing at first, after defining a few words it should be quite clear. Let's start with allele. An allele is a version of a gene. Imagine ice cream. It comes in many different flavors, all of which are considered the same type of food. Next, we should define gene. A gene is a segment of DNA that codes for something within the organism, like hair color or the number of fingers and toes. Thus we see now that should the ratio of alleles in a population change at all over time, evolution has happened. Now that we have that ironed out, we need to consider how evolution happens. We already know that the frequency of alleles needs to change. What matters now is how.

There are five main ways evolution can occur: genetic drift, non-random mating, mutation, gene flow, and natural selection. The first four are not explored in this curriculum unit. Despite that, a brief explanation of each will help contrast them to natural selection.

Genetic drift is essentially change in allele frequency due to random chance. Imagine a small group of twenty chickens consisting of ten white and ten brown individuals. If a fire kills off ten chickens and by sheer coincidence, all ten of them happen to be black, the frequency of the black allele in this population has gone from fifty percent to zero percent. This can have large effects on small populations.

Non-random mating is just that: not random. Should individuals choose mates that display certain characteristics over others, there will be a change in the ratio of alleles. Again evolution has happened.

Mutations are changes in genes that can create new alleles. If a gene is mutated it can create an entirely new allele, which changes the ratio of alleles in the population.

Gene flow is a fancy word for migration. If individuals from a different population flood into an existing population, they can change the ratio of alleles in the population.

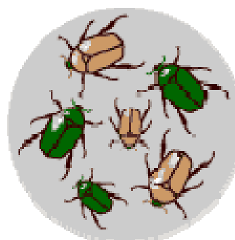
Now, something that needs to be stressed about these first four causes of evolution is that they do not necessarily cause an organism to be better adapted to its environment. Often times it is quite the opposite. Natural selection is the only method by which a population of organisms can become better adapted to an environment over time. It is also the main method by which one species splits into two different species. Natural selection is the method of evolution that this curriculum unit will be focusing on. More information on the five modes of evolution can be found in the TED ED lesson “Five Fingers of Evolution” (http://ed.ted.com/lessons/five-fingers-of-evolution).

Now that we know that natural selection is the only way populations of organisms can accrue adaptations to their environment we need to define it. Natural selection is an unguided process by which alleles that confer traits that increase fitness become more abundant in a population over time. That brings us to the word fitness. Fitness is how well an organism survives and reproduces. So, organisms in a population that have alleles allowing them in some way to stay alive longer and reproduce more have a greater chance of passing these advantageous alleles to their children.

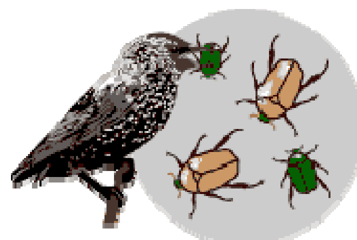
In order for natural selection to occur, three things are necessary. First, there must be variation within a population. What that means is that the members of the population cannot be genetically identical. Second, there must be a difference in the survivability of individuals with different alleles. Basically, some organisms in the population will have alleles that will help them survive and reproduce. Imagine a population of black and brown mice that live on brown soil. The brown mice will be better able to hide from predators while the black mice will be eaten more often. The brown mice will reproduce more than the black ones. This will cause subsequent generations of this population to have more and more brown mice because, on average, they are better able to survive and reproduce. The last requirement of natural selection is perhaps a bit of common sense. In order for a trait to appear in an organism's descendants, it must be inherited genetically. In summary, a population needs variation, differential survival and reproduction, and the traits that cause this differential survival and reproduction must be heritable.

For a more detailed example, please refer to the text and figure below.

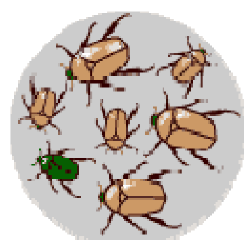
1. **There is variation in traits.**
   For example, some beetles are green and some are brown.



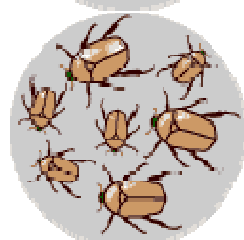
2. **There is differential reproduction.**
   Since the environment can't support unlimited population growth, not all individuals get to reproduce to their full potential. In this example, green beetles tend to get eaten by birds and survive to reproduce less often than brown beetles do.



3. **There is heredity.**
   The surviving brown beetles have brown baby beetles because this trait has a genetic basis.



4. **End result:**
   The more advantageous trait, brown coloration, which allows the beetle to have more offspring, becomes more common in the population. If this process continues, eventually, all individuals in the population will be brown.



< http://evolution.berkeley.edu/evolibrary/article/evo_25>

The difficulty of understanding natural selection often stems from an inability to think of a single organism as part of a population. One thinks of a dog, or maybe their dog, but usually not of a member of a larger group of organisms collectively labeled *Canis lupus familiaris.* It would seem that the first step in communicating natural selection effectively is to stress the notion of organisms belonging to populations. After all, evolution affects populations, not individuals.

The second challenge is to unteach the misconception that survival of the fittest means survival of the fastest, strongest, or largest organisms. While these are adaptations that help some organisms survive, every environment presents challenges to life. In some environments, being quick footed may well be an advantage, but in others a slow stride may be the key to success. Either way, advantageous traits, even ones that do not readily present themselves as such, will often spread though a population over generations.

Lastly, there is the misconception that complex structures like the eye could not possibly develop gradually because the eye is irreducibly complex. The term irreducibly complex refers to an argument that half of an eye, or a transitional eye, is of no use to an organism, while a fully developed eye is. I hope to show that among the animals alive today, there is remarkable variation in the function and complexity of eyes, and that this variation is evidence that transitional forms of the eye with varying capabilities were useful to the organism utilizing them.

Objectives

- Students will be able to define natural selection and identify the three factors needed for it to occur.
- Students will be able to analyze trends in generations of fictitious organisms by modeling natural selection in their environment.
- Students will be able to explain how the outcome of natural selection depends on which characteristics are adaptive in a given environment
- Students will be able to analyze readings in an article and draw comparisons to prior knowledge.
- Students will be able to evaluate the function of several types of eyes using models.
- Students will be able to synthesize as a group a visual and written explanation for the evolution of the eye.
- Students will be able to present written ideas verbally to a group of their peers.
- Students will be able to analyze scientific evidence to draw new conclusions.

Strategies

As students explore what natural selection is, I would want to give them a wide range of activities to model the process. I will try to give students several sensory and hands on activities to help students understand a difficult conceptual process.

I would emphasize that students work in groups and assist each other with writing and reading tasks. These would likely be guided in part by me to help students understand portions of the readings that might be above their reading level.

Animations and illustrations of data would be ideal ways to help students understand how some of these new discoveries come about.

It would be essential to practice presentation and speaking skills in order to articulate points for the culminating assignment.

Classroom Activities

This unit will reinforce how natural selection works and how much a population can change. I hope to explain how natural selection can actually give rise to structures in living things that are often thought of to be irreducibly complex.

Lesson 1:

Objective: Students will be able to define natural selection and identify the three factors needed for it to occur. Students will be presented with several examples of camouflage. They will differentiate which camouflage is most advantageous for the environment.

Activities:

- Students will have a short lecture on natural selection describing the conditions needed for natural selection to occur (variation, differential survival, heritable traits)
- Students will play the Charles Darwin Game on the Discovery Channel (http://science.discovery.com/games-and-interactives/charles-darwin-game.htm) "Who Wants to Live 1,000,000 Years?" to show students how the environment shapes the organism

Lesson Notes:

The lecture should teach students the vocabulary and the conceptual content from the Rational. Students should be able to define words like variation, gene, allele, heritable, and differential survival. When conducting the Charles Darwin Game, consider the resources available to your classroom. Should the class have a set of laptops, it might be preferable to allow students to play the game a few times before going over it as a class. I prefer to put the game up on the smart board and ask a student volunteer to punch in the students' requests for variations. The game is a simulation of a species attempting to avoid extinction for at least one million years. You or your student will be able to pick three different versions of the imaginary animal. These represent the variation in the population. As you start the game you will see your population of animals changing. This is meant to show evolution is at work even when there is no apparent need for it. Students will be presented with environmental and predatory challenges. Luckily, if students don't think their animals are up for the task they can use a mutation to add extra variation to their herd. At each juncture you should be prepared to question the choices of the students, asking them how such a variation might help or hinder their organism in a particular situation. The game can sometime throw curveballs, killing off all the animals before they exist for the game's simulated one hundred million years. Be prepared to discuss this outcome often as the first few games usually result in a game over.

Lesson 2:

Objective: Students will be able to analyze trends in generations of fictitious organisms by modeling natural selection in their environment. This activity is based on Evolution by Natural Selection, available at http://serendip.brynmawr.edu/sci_edu/waldron/#evolution.

Activities:

- Students will perform a lab simulating natural selection on a fabric environment with different colored pom-poms being hunted by plastic utensil predators.
- For homework students will read a portion of the Grant's research on break size.

Lesson Notes:

The pom-pom lab setup is more or less like setting a table. You'll need to purchase a tablecloth sized piece of synthetic fur fabric. This will serve as the environment. You will also need some small pom-poms in at least two different colors: one that blends in well with the color of the fur and one that does not. Buy enough so that each setup has at least 100 pom-poms. Next you will need disposable cups, spoons, and forks. Set up 6 cups around the table. Put a spoon in three of them and a fork in three of them.

You will explain to the six students participating in the demonstration that they are predators in the fur environment and that the utensil is their mouth and the cup is their stomach. Clearly state that stomachs cannot be tilted, lest the predator vomit and lose all of his or her food. Tell the students to look at the other predators and make an observation. Lead them to the fact that the different utensils represent variation among these predators. Place fifty of each color pom-pom on the fur. Show the class and the volunteers the pom-poms and inform them that these will represent the prey. Once again ask the class to make an observation about the pom-poms and lead them to the idea that the difference in color is a variation in the pom-pom prey. Now you should ask students to make a prediction as to which variations, if any, in both groups of organisms, do they think will confer an advantage.

After students have discussed or written down their hypotheses, have the predators close their eyes and mix up the pom-poms on the table. After they have been mixed, have the predators open their eyes and then give them ten seconds to "eat" as many pom-poms as possible. Once time has expired, have students count the pom-poms they have "eaten" and tally how many of each color was eaten. Use this to know how many pom-poms are left. Let students know that each pom-pom that survives reproduces. Place a new pom-pom on the fur for each one left. Explain to students that the three predators that got the least amount of food starve to death. Ask these students to sit down. Announce that the surviving predators each reproduce and that these offspring have the same utensil mouth as their parent.

At this point it is important to ask students if their predictions were correct. Ask them if either of the variations gives an advantage to the simulated organisms. Also, ask them if the traits of the parents are heritable. They should be able to tell you that if the offspring are born with traits that the parents had, then the traits are heritable. You can take this opportunity to have some students begin drawing a table comparing the ratio of the two colors in the pom-pom population as well as the ratio of spoon mouthed predators to fork mouthed predators as generations go by. I usually continue this game until the predators or the pom-poms populations become homogenous. Once this happens students should be asked if the population could evolve by natural selection anymore. Students should arrive at the conclusion that once variation has disappeared from a population they are no longer able to change by natural selection. If you have taught the other four modes of evolution already, you may wish to review how mutation and gene flow could allow natural selection to begin again.

In the lab you can use two different colors of fabric. I found that using one generally gets the point across. If you do choose to do two different colors of fabric, you'll simply need to set two tables. This will show how if the environment changes, a once detrimental trait might now help an organism survive and reproduce. The way I planned this activity is as a demonstration in front of the rest of the class. Should you find yourself wanting all students participating at the same time, you'll need duplicates of all the setups.

<u>Lesson 3:</u>

Objective: Students will be able to analyze readings in an article and draw comparisons to prior knowledge.

Activities:

- Students will review the simulation and the principles of natural selection observed within.
- Students will work in groups to read portions and analyze parts of the Grant's research on the beak size of finches. This reading can be found in the Zimmerman source
- For homework, students will prepare a summary of key points in their reading.

Lesson Notes:

Students should review the activity from the day before. It often runs long and it is helpful to summarize for any student that was absent or having trouble following the discussion. Remember to emphasize that natural selection requires variation, differential survival and reproduction, and heritable traits.

Students should break up into groups of four or five to read and discuss the article as a group. This can be augmented by a worksheet or questions on the board. Students should, with the help of the article be able to decipher all the graphs in the passage on the Grants' work. Each group should describe in their own words the meaning of each graph. Additionally it is important for each group to answer the question of why these studies were important and what do they show. With some guidance you should be able to lead them to the conclusion that, while the fossil record shows natural selection to be a slow unidirectional push, the Grants' work shows natural selection to be highly responsive, dynamic, and able to take effect in a matter of generations. The homework is designed to reinforce the lesson and to improve upon the students' ability to summarize. Where they will likely have a page or so of notes, I would want them to condense their findings down to a short paragraph.

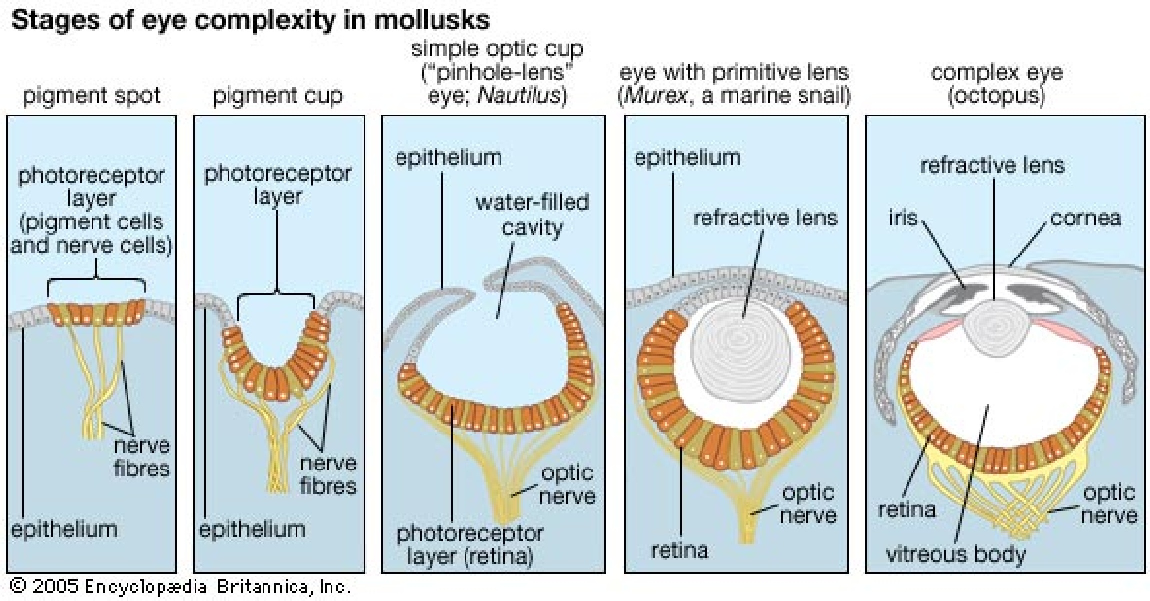
Lesson 4:

Objective: Students will be able to evaluate the function of several types of eyes using models. Students will be able to propose a likely scenario for the evolution of the eye.

Activities:

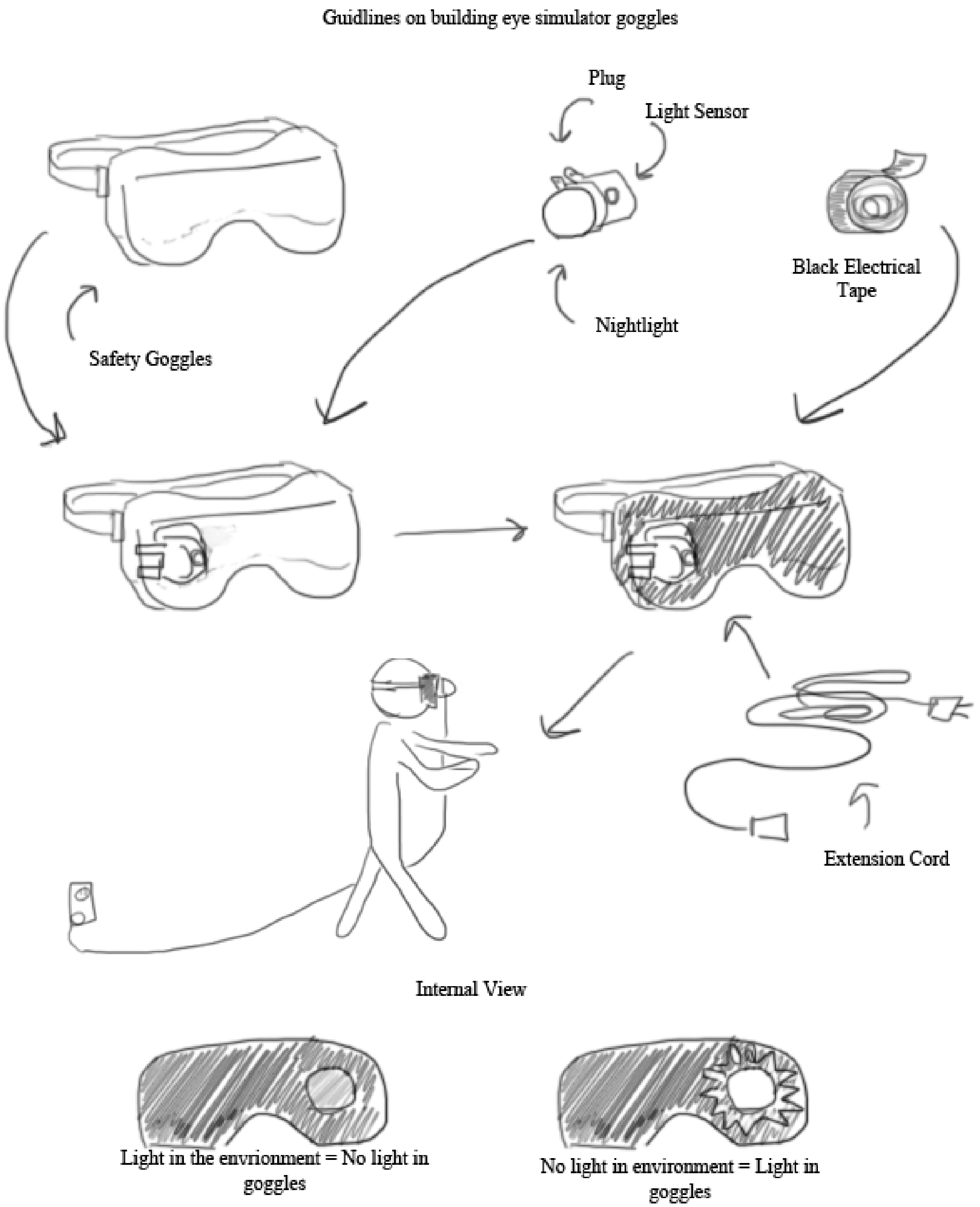
- Students will use models of each eye and write their observations on how each eye functions and what kind of organism might use each.
- Students will consider which organisms from a group provided to them would use each of the eyes.
- For homework students would draft a prediction on how the eye evolved.

Lesson Notes:



In order to do this activity, you will need to invest some time and money to make wearable models of each kind of eye. This will take some effort, but I do believe it is well worth it. You will create models of five different eyes: A photoreceptive patch, a simple concave dish, a pinhole lens, a simple lens, and a lens that is able to focus. These "eyes" will help students understand the benefits and drawbacks of certain types of eyes. It should also give them a plausible explanation of how complex eyes arose out of simpler eyes.

I recommend using safety goggles as the base of all the eyes as they cover the entire field of vision for a person. A patch of photoreceptors is one of the simplest forms of the eye. This allows an organism to determine if light is present or not. It does not allow for detection of the direction of light. To simulate this, we will use a photoreceptor in the form of a nightlight. Attach the light producing side of a night light to the front of the goggles with electrical tape. You will need a long extension cord to allow the student wearing the photoreceptor eye free motion. If possible buy nightlights that can swivel as this allows you to position the light detecting portion closer to the front of the wearer. Once the nightlight is attached cover all clear portions of the goggles with electrical tape. Test it to see if you can see light through the tape and add more tape as necessary. Upon putting them on the wearer should not be able to see anything with their own eyes. Instead the wearer should see nothing in the presence of light and a light in the absence of light. Please explain this to the students so they understand what each stimulus indicates. Place a few lights around the room and see if they can locate them. Please remind students not to run and to clear any obstructions in their way. Discuss what light and shadow mean for living things. Have students split up in groups and ask them what kind of animal might benefit from an eye like this. Also propose the question of what advantage this might offer over having no eyes at all. Here is a diagram of how to construct a pair of these goggles. They cover how to make the simple photoreceptor patch.



The next eye model to be made is the simple concave dish. A dish eye is simply a patch of photoreceptors that have been placed in a shallow bowl-like groove rather than simply on the surface of an animal. This will allow an organism to determine what direction light is coming from since light rays coming from an angle will not stimulate photoreceptors on side closest to the light due to the curvature of the eye. To make this model take another pair of goggles and cover all clear surfaces except for a quarter sized circle in front of one of the eyes. Instead of tape place frosted plastic or frosted glass over the opening. This will keep the wearer from using their eyes for anything but perceiving light and darkness. This will allow the wearer to determine what direction light is coming from in addition to light and dark. Each group should consider the same questions they answered for the first eye.

The next eye model will be that of a pinhole lens. A pinhole lens is simply a dish eye that has receded so far into the surface of the organism that rather than looking like a wide mouthed bowl, it appears to be a dome like structure with a small hole in the top. This actually causes light to be focused into an image due to the small opening only allowing some rays of light into the eye. To make this eye, cover a pair of goggles with black electrical tape, leaving a small space uncovered over one of the eyes. Then, poke a small hole with a push pin into a piece of tape large enough to cover the space. Additionally you may want to purchase a simple lens to be placed behind the pinhole to reduce the ability of the wearer to use his or her eyes to focus as much. What the wearer should experience is a fairly clear image that is dim and has an extremely small field of vision. Students should consider previous questions for this eye.

The next eye model will be the simple lens. The simple lens cannot focus, but unlike the pinhole lens, it uses a sack filled with refractive proteins to bend light rays rather than a pinhole. This allows more light in thus giving the user a wider and brighter picture. To make these, cover a pair of goggles with black electrical tape, leaving a quarter sized opening. Attach a simple lens over the opening. This should allow the wearer to see clear images when at a certain distance from objects but he or she will not be able to focus as well on distant and close objects. Students should consider previous questions for this eye.

The last model of the eye is very easy to construct. Simply tell the student to put on a pair of normal safety goggles. Let them know that their eyes are complex eyes that contain a lens and can focus on near or distant images. Students should consider previous questions for this eye.

<u>Lesson 5:</u>

Objectives: Students will be able to synthesize as a group a visual and written explanation for the evolution of the eye.

Activities:

- Students break up into groups and create a poster that shows a progression from a simple eye to a complex eye. These posters should draw on the vocabulary taught to them, including terms like fitness, adaptation, and natural selection.
- For homework they will prepare for a presentation of their poster.

<u>Lesson Notes:</u>

Students should use their observations from the day before to attempt to create a proposed progression from the simple photoreceptor patch to the complex eye. They should be pushed to use both graphic and written methods to convey the benefits and uses for each type of eye. You may want to ask students to explain why all of the eyes simulated are still around today if some are less complex than others. Students should also be able to explain this progression using the vocabulary used in the natural selection lecture. For example, when moving from a flat patch of photoreceptors to a concave dish, the advantage would be that the organism would be more aware of the directionality of the light and that would help it avoid predators or navigate around light sources. This might prove useful for survival.

<u>Lesson 6:</u>

Objectives: Students will be able to present written ideas verbally to a group of their peers

Activities:
- Students will present their findings to the class
- For homework they will write a reflection on why they have eyes that are complex rather than simple.

<u>Lesson Notes:</u>

Encourage group members to be active in the presentation and to present with a loud and clear voice.

Annotated Bibliography/Resources

Teacher Bibliography

"Avoid Common Teaching Pitfalls." Understanding Evolution. Berkeley University, N.d. Web. 26 Feb. 2013. <http://evolution.berkeley.edu/evolibrary/teach/912pitfalls.php>

This site provides great insight into common areas and topics that students find hard to grasp. The main site is also extremely helpful for brushing up on some of the basics of evolution. The information is straightforward and quite comprehensive.

Lesnick, Alice, Ann Dixon, Anne Dalke, Ingrid Waldron, Jennifer Spohrer, Jody Cohen, Julia Lewis, Laura Cyckowski, Olivia Castellano, and Riki Gifford-Ferguson. Evolution by Natural Selection. N.p., 1994. Web. 24 June 2013. <http://serendip.brynmawr.edu/exchange/waldron/naturalselection/>.

This site provides a wide variety of activities and articles including more on the development of the eye by natural selection and the pom-pom simulation.

Hewlett, James A. "Trouble in Paradise." National Center for Case Study Teaching in Science. N.p., 4 Dec. 2000. 27 Feb. 2013. <http://sciencecases.lib.buffalo.edu/cs/collection/detail.asp?case_id=312&id=312>.

This site gives a case study in which students can attempt to explain changes in a population.

Johnson, George B. Holt Biology. Austin: Holt, Rinehart and Winston, 2004. Print.

This textbook gives a basic overview of the process of natural selection and is useful for teachers and students alike.

Zimmer, Carl, and Douglas John Emlen. "Chapter Eight Natural Selection: Empirical Studies in the Wild." Evolution: Making Sense of Life. Greenwood Village, CO: Roberts and, 2012. 219-53. Http://ncse.com. Web. 27 Feb. 2013. <http://ncse.com/files/pub/evolution/excerpt--evolution--fb.pdf>

This website has empirical data and excerpts from the Grant’s finch research. Students can practice analyzing graphs and interpreting raw data in the context of evolution.

Student Bibliography

Andersen, Paul, and Alan Foreman. "Five Fingers of Evolution." Ted Ed. TED, 7 May 2012. Web. 24 June 2013. <http://ed.ted.com/lessons/five-fingers-of-evolution>.

This video teaches the various ways evolution can happen. It also helps to understand how natural selection itself works.

Anderson, Dianne, and Kathleen Fisher. "Concept Cartoons About Evolution." *Concept Cartoons*. N.p., n.d. Web. 28 Feb. 2013. <http://www.biologylessons.sdsu.edu/cartoons/concepts.html>.

These cartoons depict several misconceptions. These are good for getting students to argue a little about the right answer. They also reveal what preconceived notions students have about the topic of evolution.

"Evolution:Survival." *PBS*. PBS, n.d. Web. 26 Feb. 2013. <http://www.pbs.org/wgbh/evolution/survival/clock/index.html>.

This site shows how quickly mutations can accumulate within a population of bacteria.

"Charles Darwin Game." *Sci.* Sci. Web. 2 Apr. 2013. <http://science.discovery.com/games-and-interactives/charles-darwin-game.htm>.

This site is a fun way to see how variations help a species to survive. Students will select variations in a group of imaginary animals and see how their population tolerates changes in the environment. Many instances for teachers to point out how adaptations previously helping an organism to survive can become harmful should the environment change.

Johnson, George B. Holt Biology. Austin: Holt, Rinehart and Winston, 2004. Print.

This textbook gives a basic overview of the process of natural selection and is useful for teachers and students alike.

Classroom Materials

Print outs of articles about micro evolution, pom-poms, fur fabric, plastic forks and spoons, disposable cups, safety goggles, nightlights, electrical tape, paper, extension cords, lenses, frosted plastic or glass, computer, internet connection

Appendix/Standards

State Standards

BIO.B.3.1.1: Explain how natural selection can impact allele frequencies of a population.

BIO.B.3.1.3: Explain how genetic mutations may result in genotypic and phenotypic variations within a population.

BIO.B.3.2.1: Interpret evidence supporting the theory of evolution (i.e., fossil, anatomical, physiological, embryological, biochemical, and universal genetic code).

BIO.3.1.A:

- Formulate and revise explanations and models using logic and evidence.
- Communicate and defend a scientific argument.
- Interpret the results of experimental research to predict new information, propose investigable questions, or advance a solution.