GALAPAGOS: SITE OF MICROEVOLUTION
A Student Investigation

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Summary

The Galapagos finches provides a context in which students investigate microevolution on a Galapagos island. The scenario provides a simplified version of the data and observations collected on the Galapagos island Daphne Major by Peter and Rosemary Grant. It focuses on the drought of 1977 when the finch population dropped by three-fourths. Students are asked to explain why so many finches died and what enabled the remaining finches to survive.

This investigation is preceded by several lab experiences that build understanding about environmental stress, trait variation, acquired characteristics, generational change and bird beak form and function. My seventh grade students will participate in this study during March 2006. It is our hope and goal that Dr. Nelson Zabala, Professor of Biology at Universidad San Francisco de Quito, will help us find an Ecuadorian class of students of approximately the same age who will do the investigation with us. Considering the threat that intelligent design theory and rote memorization make to effective science teaching and learning, this curricular project can be important. Materials for the experiences are simple. They can be gathered quite easily or sent to the school by our students.

Grade Level

7th - 9th grade/12-15 year old students

Essential Questions

What is an environmental stress? Are they always harmful?

What is a trait and a variation of that trait?

Are variations inherited traits or acquired characteristics?

What is a generation? What can you learn by studying multiple generations?

Why did so many finches die on Daphne Major in 1977?

How were some finches able to survive?

Background Information

Charles Darwin calculated the progeny of elephants that would exist if all elephants survived from a previous set of parents. A consideration of cod fish is more dramatic because the cod parental pair can produce a million eggs in one spawn. The oceans would be overrun with cod if many did not die. Theoretically, in a generation, two cod live to replace their parents and a stable population is maintained. These offspring competed with members of their same species for the same resources. The cod that were faster, smarter, hid more effectively, were bigger or any other number of variations of the same helpful trait were the survivors. This struggle, combined with variation, results in natural selection.

Unfortunately, many students including those in the Francis W. Parker K-12 classrooms, develop misconceptions about evolution by natural selection. Often the example of the contemporary giraffe, whose long neck developed after millions of years, is cited. Longer necks, a favorable adaptation, allowed these giraffes to eat food that was out of reach for the short-necked giraffes. These long necked giraffes were presumably healthier and lived long enough have offspring, many of whom had long necks like their parents. If the environment presented the same challenge or stress, the long necks would prevail. In contrast, some students believe that individual offspring in a new generation is slightly different on a particular feature than a parent's generation. The connection between the trait variation and the environment is not made.

Microevolution that produces gradual changes **within species** should not be confused with macroevolution that produces the radical changes required for the sudden appearance of new species. In a 1972 paper, Steven Jay Gould and Niles Eldredge described punctuated equilibrium as a species remaining unchanged in the fossil record and then abruptly disappearing, to be replaced by something substantially different. Living things persist for millions of years in an *equilibrium* of ecological relationships and then, from time to time, that static equilibrium is *punctuated* by the sudden appearance of a new species. The process of evolution can be explained through a number of theories. There are scientists who believe that macroevolution is merely the result of a series of changes by microevolution.

To effectively study the evolution of life through many generations you need an isolated population, one that will stay put and not mate with other similar populations, combining trait variations. If you observe a change in a trait with this criteria, it can then be directly connected to a change in environmental conditions. Peter and Rosemary Grant, professors in the Department of Ecology and Evolution at Princeton University, went to Daphne Major, a small lonely island even by the standards of the Galapagos. Their work has been documented in the 1994 book, The Beak of the Finch by Jonathan Weiner. It won a Pulitzer Prize and multiple copies have been ordered for my students. With little more than calipers, the Grants measured the lengths of the wingspan, tarsus, beak and more of several varieties of Galapagos Finches. Low-tech tools were appropriate for the reliable results they had to get under unreliable conditions. Back at Princeton, computers stored and analyzed decades of recorded numbers. Other machines read the coded messages on DNA's spiraling scrolls.

My students will have access to some of this data through software developed for the

Biology Guided Inquiry Leaning Environments (BguILE) directed by Brian J. Reiser, School of Education and Social Policy at Northwestern University. The computer environment provides tools that enable students to gather data and facilities to help students interpret data and consolidate their explanations. Students may take quantitative measurements of environmental factors (e.g., amount of rainfall) and the distribution of various structural characteristics of the birds (e.g., feather coloration, weight, beak length). Students construct questions to retrieve data. These questions reflect the type of questions biologists can ask of their data when they investigate natural selection events.

This investigation will be enriched with slides that I had taken while visiting the Galapagos Islands on the Fulbright trip. Our Ecuadorian "sister school" would need computers with Internet access. We are investigating an alternative: making the data available on paper and sending these charts and tables to the school.

Standards

Science teaching standards in the United States vary from state to state. Illinois state standards were revised in 2002 to add a detailed description of evolutionary principles that elementary and high school students should learn. This revision does not state that evolution is a unifying theory in biology. Critics refer to this as a critical omission.

In anticipation of the latest debate over evolution and intelligent design in Kansas and Pennsylvania, the Chicago Public Schools issued a new policy in October 2005 mandating that evolution remain part of the district's science curriculum. The policy statement said: "No CPS teacher should be pressured into promoting nonscientific views."

In a survey of teachers released in March 2005, the National Science Teachers Association found that 30 percent of the respondents had felt pressure to omit evolution, usually from parents or students.

Opposition has come and continues to come from people whose interpretation of religious writings conflict with the story of evolution. Schools need not avoid the issue altogether. Perhaps science courses can acknowledge the disagreement and concentrate on frankly presenting the scientific view. Even if students eventually choose not to believe the scientific explanation, they should be well informed about what it is.

Francis W. Parker is a private, independent school. The science department uses the guidelines recommended by the American Association for the Advancement of Science in their Project 2016/Benchmarks publication.

By the end of seventh grade, students in my class should know that:

Small differences between parents and offspring can accumulate (through selective breeding) in successive generations so that descendants are very different from their ancestors.

Individual organisms with certain traits are more like than others to survive and have offspring. Changes in environmental conditions can affect the survival of individual organisms and entire species.

Many thousands of layers of sedimentary rock provide evidence for the long history of the earth and the long history of changing life forms whose remains are found in the rocks. More recently deposited rock layers are more likely to contain fossils resembling existing species.

New heritable characteristics can result from new combinations of existing genes or from mutations of genes in reproductive cells. Changes in other cells of an organism cannot be passed on to the next generation.

Natural selection leads to organisms that are well suited for survival in particular environments. Change alone can result in the persistence of some heritable characteristics having no survival or reproductive advantage or disadvantage for the organism. When an environment changes, the survival value of some inherited characteristics may change.

Life on earth is thought to have begun as simple, one-celled organisms about 4 billion years ago. During the first 2 billion years, only single-cell microorganisms existed, but once cells with nuclei developed about a billion years ago, increasingly complex multicellular organisms evolved.

Evolution builds on what already exists, so the more variety there is, the more there can be in the future. Evolution does not necessitate long-term progress in some direction. Evolutionary changes appear to be like the growth of a bush: Some branches survive from the beginning with little or no change, many die out altogether, and others repeatedly, sometimes giving rise to more complex organisms.

These are challenging and difficult concepts. Understanding does not occur during a single unit, course or grade level year. Grant Wiggins and Jay McTighe have developed a multifaceted view of understanding along with guidelines that assess levels and degree. Their book *Understanding by Design* (1998. Alexandria, Virginia: Association for Supervision and Curriculum Development) describe six facets.

When we truly understand we:

Can explain: provide thorough, supported, and justifiable accounts of phenomena, facts and data.

Can interpret: tell meaningful stories; offer apt translations; provide a revealing historical or personal dimension to ideas and events; make it personal or accessible through images, anecdotes, analogies and models.

Can apply: effectively use and adapt what we know in diverse contexts.

Have perspective: see and hear points of view through critical eyes and ears; see the big picture.

Can empathize: find value in what others might find odd, alien, or implausible; perceive sensitively on the basis of prior direct experience.

Have self-knowledge: perceive the personal style, prejudices, projections, and habits of mind that both shape and impede our own understanding; we are aware of what we do not understand and why understanding is so hard.

Sequence/Strategies

Lesson One: Environmental Stress

Environmental stress is a biological or physical factor that puts a strain on populations of organisms and their essential habitat in an environment. There is a strain on the population because the living conditions could be affected: food resources can be limited, soil nutrients might change, etc. Students may define the word "stress" as it pertains in their own lives. This misconception must be avoided.

A biological factor, the lamprey eel, put a strain on native fish living in the Great Lakes, local to Chicago and the Parker School. A physical factor that put a strain on wildlife in the state of Washington was the Mount St. Helen's eruption. Both of these events occurred decades ago and there is data on the damage that has taken place.

For example, the Washington State Department of Game estimated that nearly 7,000 big game animals (deer, elk and bear) died in the area most affected by the eruption that took place over two days in 1980. Birds and most small mammals died as well. But, many small animals, chiefly burrowing rodents, frogs, salamanders and crayfish, managed to survive because they were below ground level or below the surface of the water when the disaster struck. Several lakes that were still frozen over went virtually untouched. Animals and plants found their way through the thick ash to the surface. The presence of life enticed deer and elk to return. As they walked, they stirred up even more ash, freeing seeds and shoots still buried.

From both of these accounts, students should be able to answer the following questions:

Can you identify the environmental stress(es)?

Using a chart, can you identify the plants and animals that have been impacted by the stress?

Column 1: Name of plant or animal
Column 2: How was it hurt by the incident?
Column 3: How was it helped by the incident?

Then using a graph and data from a resource, present a visual representation of a population of plants or animals over time: before the event, immediately after, a year after the incident, and then after longer periods of time.

Can you define a generation of a plant or animal?

The learning process above can be applied to any event. It may be far more interesting to use recent disasters even though all of the data has not been collected. For example, Hurricane Katrina in the United States and volcanic eruptions in the Galapagos can be researched.

The U.S. Department of the Interior, the U.S. Fish and Wildlife Service, the National Park Service and the Bureau of Land Management are currently studying the effects of Katrina on several species. Along the coastline of Alabama, 50 sea turtle nests have been destroyed and 10 nests have been lost in the Bon Secour National Wildlife Refuge. The endangered red-cockaded woodpecker have been affected because so many trees went down in the Noxobee National Wildlife Refuge. Many Mississippi sandhill cranes were lost. And a "toxic soup" consisting of oil spills, sewage, household paints and solvents, fertilizers, pesticides and industrial metals such as copper, zinc and cadmium. John Pardue, Director of Louisiana's Water Resources Research Institute states that the danger from standing water was not serious and is now predominantly gone. However, the sediments will find their way back to Lake Pontchartrain's substrate. Tissue samples must be taken from shrimp, blue crabs and bottom-feeding fish so that future damage can be assessed.

The Galapagos were built by volcanism. There have been 60 recorded volcanic eruptions in the past 60 years (physical factors). Humans have also introduced dogs and pigs that prey on the eggs, hatchlings and the young of Galapagos giant tortoises (biological factors). On October 7, 1998 the Cerro Azul volcano on Isabel Island blew, endangering the tortoises that were in the path of the lava. Twenty adult tortoises were airlifted by helicopter and taken to the Charles Darwin Research Center. These tortoises have been able to produce from 200-500 eggs. When 5 years old, these hatchlings will be large enough to resist feral animal attacks and can be returned to Isabel. It is predicted that 60% will live until age 15. On May 13, 2005 the Fernadina volcano, on an island with the same name, erupted. This is a younger island and has no introduced species. The heat from the lava entering the sea killed fish. The seabirds then dived into the water to eat the fish and were scalded. And, recently, on October 22, the Sierra Negra volcano erupted. The tortoises were not affected and we await news about the health of other populations.

Students can use the Internet to research their choice of stress sites and report their findings to the class.

Lesson Two: Trait Variation

In this lesson students will observe the traits of a pinto bean including color, weight, length and width. This lesson then focuses on the distribution of the length of a population of pinto beans. They will measure the trait and construct histograms of the data they collect. In the course of the activity they will analyze the histograms and discuss the variation they find in the trait. Students will then investigate how two drastic changes in the environment can become selective stress when there is variation in the distribution of an advantageous trait within the population. The two drastic changes will be drought and an increase in predators, animals that eat pinto beans. In addition to investigating the effect on the current generation, they will predict the effect on future generations.

Materials

Bags of pinto beans (each team of two students will get 100)
Metric rulers (length will be measured in millimeters)
Beaker of beans that have been soaked in water for at least 24 hours
Magnifying lenses (10x or 15x)

A transparency or chalkboard drawing of the parts of a bean: seed coat, embryonic plant and cotyledons

Introduction

After placing a handful of beans in front of each pair of students, ask about the characteristics that they observe in their beans. Of course, the pinto spots will be mentioned and then ask if all of the patterns are the same on all the beans. The differences they observe are called variation.

Pass out the metric rulers and ask the students to identify and describe a centimeter and a millimeter. Millimeters will be used as the unit of measurement for this activity and ask them to use the middle of the ruler instead of the ends because they may be worn down. Stress the importance of accuracy when measuring. It is best to switch the role of measurer and recorder after every 10 beans so that fatigue does not affect their results. A more accurate measurement is obtained if their head and eyes are directly above the bean looking down. If they look from the side, the bean may look larger as a result of parallax.

Find the longest bean in the room. When you find that bean, add a few millimeters and that will be the first number on a table each pair of students will make on a piece of paper. Then, find the shortest bean cautioning students to measure only whole beans and not damaged ones. After finding that bean, subtract a few millimeters and that will be the last number on your chart.

Activity

During the rest of the class period students will measure the length of 100 beans randomly chosen; they should not seek out certain sizes. They will use tally marks on their chart/list to record the number of beans of each size.

After all the groups have completed their measurements, have each group share the range of their data. You will need to record these on the chalkboard or the overhead. Then you will want to determine the range of data for the class. Ask your students what the smallest measurement of length was in the class and this will be the lowest number in the class range. Then ask for the highest number that will be the highest number in the class range.

Explain that they are going to construct a graph of the data from the class. Depending on your students' understanding of graphing, you may need to expand this section of the lesson. You may work with graph paper or use spreadsheet and graphing programs found in AppleWorks or Excel.

The students will be creating a histogram with only 5 bars on it and each bar will represent a size category of lengths. They will need to decide how they will combine bean lengths in 5 size groups. This type of graph is called a frequency distribution graph because it shows how many individuals are in each range or how frequently they occurred. All groups should use the same intervals. Work through the numbering of the y-axis as students often have difficulty in deciding how to number this axis.

While each student is making their graph, ask them to examine the soaked beans that are available. They should sketch both halves of the bean and the seed coat which is now soft and barely attached. On one half they will see an embryonic plant with tiny leaves and the first root. Ask them to speculate on the purpose of the two large halves. Why do we eat beans? Why do animals? Are they good food for the embryonic plant? At what time in the plant's development is there a dependence on this food?

Students should be reminded that plants make their own food through photosynthesis requiring sunlight. While a seed is under the ground, development depends on the stored food in the cotyledon. What lengths of bean have more stored food?

The seed coat is so hard that the embryonic plant cannot push through it until it is softened by water. What lengths of beans had the thicker, more substantial seed coats? These beans would need more water.

Tell the students that a drought has wiped out a portion of the pinto bean population. All of the longest beans with the thickest seed coats could have been wiped out. This is an arbitrary choice on your part. Explain that you don't have data for this, but that this is a representation of what might have happened. Students should realize that **some** short beans would not germinate and that not **all** long beans would survive to be plants.

Students will return to their original tables and, with pencil, cross out the portion of the bean population that will be wiped out by the drought. What is the total number of beans that remain and what is the range. Students will graph the results. In order not to take too much time you can work through this process as a whole group.

Another environmental stress factor can be introduced such as a wind storm that covers the beans with more soil or sand. Larger beans will be differentially favored because their stored food will help them grow up to the surface of the ground and to the sunlight they need for photosynthesis. Repeat the work you need to do with the crossing off of short beans from the original data tables and the making of a class graph. You can decide if this final repetition is necessary.

Lesson Three: Inherited Traits/Multiple Generations

In the pinto bean activity students saw only one generation of change. They will now be asked to consider what happens to a population after many generations.

Introduction

Students will be observing a population change over multiple generations. Discuss the concept of generations. Use the following questions as a guide:

What does the term generation mean?
Are you part of a generation?
Are you aware of the names given generations, i.e., Baby Boomers?
Who else is in a generation?
About how many years are in between your generation and the previous generation?

Explain to the students that they will be looking at a population of insects in this simulation. The following questions help the students think about how a population might change over several generations:

If we wanted to observe an insect population in nature through five generations, do you think the fifth generation would be identical to the first generation?
Why or why not?
What types of environmental stresses do you think insects might be exposed to that might cause a change in these populations?

Materials

Wooden toothpicks dyed with food coloring in four different colors.
Generation chart or table that lists the four colors and has 5 columns of the numbers in each of 5 generations. All populations will start with the same number of a color, 100 for example.

You will decide the colors based on the floor or ground that you use, whether it is the classroom floor with furniture moved aside or an outdoor space on your school's grounds.

Two of the colors should be a good match and two should stand out more easily. For example, when we go outside, I use green and black toothpicks to match a patchy lawn. The red and yellow toothpicks are more easily seen.

Activity

Students will surround the perimeter of a space where you have distributed equal numbers of each of the four colors. Explain to the students that they are birds that eat insects and the toothpicks are those insects. Ask them to name the trait that will be most advantageous to the insects that are not "eaten." Ask them to predict what will happen to each of the four traits in five generations.

Students will have 15 seconds to collect as many insects as they can find. They should pick randomly and not be selective, thus modeling a hungry bird. At the end of this time, they will count how many beans they have collected. Then they will subtract that number to determine how many of each color remains. They will need their generation table to record the results.

Once the values have been recorded, have the students double the numbers that remain and add that number of each color to the environment. For example if 72 green insects remain, add 144 more green toothpicks to the environment. Continue this process for the next 4 generations.

Ask:

Were there any patterns in how the population changed?
How can you support your claim?

Use the answers to these questions to have a discussion that supports the claim that variation is important in a population. If all the individuals in a population looked the same, then those same traits would get passed on to the next generation and the next generation. If a biological or physical stress occurred, the population might not survive. Variation within a population ensures the survival of some individuals when natural disasters or biological invasions stress the population.

Conclude by reminding students that the population changes they saw are the result of parents passing on their trait to their offspring. You dyed the toothpicks. However, the color an insect is most likely going to be the same color as its parents. This is a fine opportunity to bring up an acquired characteristic. Humans dye their hair. You may have two parents who are brunettes who have dyed their hair blonde. Their child will most likely be a brunette and not a blonde. The blonde hair was acquired during the parents' lifetime and not expressed in their genes. Other examples can be given: weight lifters do not have muscular children and giraffes who stretch their necks will not have offspring with longer necks. In the latter example, there are some giraffes that may have the variability of a longer neck. If environmental conditions favor long necks to survive, these long-necked animals will survive in order to have long-necked children in their genetic image.

Lesson Four: Birds' Beaks as Tools

Beaks are to birds what hands are to us. They are the birds' chief tools for handling, managing, and manipulating the things of this world. And the shape of the bird's beak sets tight limits on what it can eat.

<u>Introduction</u>

There is a wonderful passage on the variety of birds beaks in general, and the beak variation among Galapagos finches specifically, in *The Beak of the Finch* by Jonathan Weiner that begins on page 50. I am ordering multiple copies of this book for my students. However, I cannot find a Spanish translation even though it was a winner of the Pulitzer Prize. If we have an Ecuadorian sister classroom, I will seek the publisher's permission to have brief passages translated and sent to the Ecuadorian students.

<u>Materials</u>

Even numbers of the following 4 tools so that all students will have one tool:

Tongs
Tweezers
Spatulas
Aquarium nets (small)

Beans (use the pinto beans)
Marbles
Toothpicks
Floating wiffle balls

<u>Activity</u>

Explain to the students that they will be foraging as birds with beaks that they will be given after these directions. They will be eating a variety of four foods: 3 on the ground and the wiffle balls that will be floating in sinks or buckets of water. They will have a cup that will serve as their stomach to hold their collected food. They may not "eat" with their stomach; they are not starfish.

Scatter the beans and when finished, ask the students to forage until most of them have been collected. Students should be discouraged from competing for morsels. Birds that find their beak a more useful tool should do better, without being obstructed or distracted by fighting. When the students stop, ask them to count the number of food items and return them to you.

One at a time, repeat this process with the marbles and toothpicks on the ground. The wiffle balls will favor the use of aquarium nets if they are used in the buckets with four students/tools around each pail of water.

Make a chart on a transparency or on the blackboard where students will make a running total of all food items collected by each tool. Students can be asked:

Are there tools that are fairly good at picking up several items? (Tweezers)
Are there tools that are much better than the others at picking up one item? (Nets)

Upon examination, they will find that certain tools allow students to forage for certain foods more effectively. Some tools are good at picking up (eating) several foods and some tools are very good at picking up one food. The former would be metaphors for generalized beaks and the latter, specialized beaks.

Lesson Five: Formulating a Claim: Why did three-fourths of the finches die in 1977? How did some finches survive?

This last lesson is adapted from Northwestern University's BguILE program directed by Brian J. Reiser, who was my professor in a course I took in 1995 when I was getting an advanced degree. *The Galapagos Finches* can be accessed at no charge from the Internet. It can be used for educational purposes only and BguILE is funded by a grant from the James S. McDonnell Foundation. Dr. Reiser knows that I am referencing it in this curriculum project.

The Galapagos Finches is designed to help students develop a sound conception of evolution by natural selection, in addition to developing inquiry skills and a general understanding of scientific argumentation. The scenario emphasizes constructing explanations that include identifying pressures, variability and successful traits in their claims and conclusions.

In the software, students investigate microevolution in a simulation of a Galapagos island system, based on a twenty year study of finches on the island of Daphne Major conducted by Peter and Rosemary Grant. Students are asked to explain why some of the finches are surviving while others are dying during a 1977 drought. They are also asked to make predictions about future generations. The computer environment provides tools that enable students to gather data, and facilities to help students interpret data and consolidate their explanations. Students may take quantitative measurements of environmental characteristics of the birds (e.g., weight, beak, length). Students can also examine field notes collected about plants, animals and the environment of the island. The field notes provide students with important behavioral information. My class will read most of the account in *The Beak of the Finch* by Jonathan Weiner.

This program makes explicit and continually reinforces strategies for reasoning about biological data, such as looking for structural and behavioral differences. This is achieved by having data requests made through a question-based interface where students construct questions to retrieve data. These questions reflect the type of question field biologists ask of their data when they investigate natural selection events.

A sample question is "Are there changes between time periods in the variation of structural traits?" A graph will appear in response to this question that will provide the student with follow-up observations.

The Investigation Journal

This piece of the software package allows students to construct an explanation by typing in free text. There is a journal template that consists of the theoretical building blocks of an evolutionary explanation: environmental pressure, organism affected by pressure, variation of traits in the organism, and selective advantage of a variation. The investigation journal enables and encourages students to directly support the claims they make in their explanations with evidence collected in the investigation environment.

Classroom Discussion

The current scientific explanation is that the finches are dying as a result of lack of food caused by a drought. Normally, the birds' diet consists of small, soft seeds, but due to a prolonged drought those seeds are not readily available, and the seeds that are more available are the large, hard, thorny seeds. Finches that have a slightly deeper beak are able to eat the available, larger seeds, and thus are better able to survive the drought. However, students have the opportunity to consider and pursue a range of valid hypotheses. For example, some students conjecture that the finches are dying due to an increase in predation, and they observe owl data in order to investigate this idea. Other students relate the finches' demise to lack of food resources and speculate that leg size is the selected trait. They can compare graphs of the variation in leg size of live and dead finches and see if there are marked differences in the trends between two populations, and examine field notes to see whether leg size affects the foraging ability of the finches. Students should be free to debate which hypothesis is best supported by good data. **It is important to focus on hypotheses that are well supported by data rather than on matching an answer with the Grants' conclusion.**

The computer activities are combined with whole class discussions where students describe their current questions, hypotheses and investigation plans. One of the main goals of these discussions is to help students reflect and generalize from the specific case they are investigating to the principles of natural selection.

A Final Statement

This curriculum will benefit my science students immensely. However, the learning experience would be more rich and meaningful if we can work in tandem with a class of students in Ecuador. Spanish is the exclusive foreign language course in our Middle School. My students are second year Spanish students and, because Parker is a K-12 grade school, I have access to high school students who can help with translation. It would be quite simple to do only the first four lessons and we will provide the equipment including photocopied handouts and graph paper, as one example. While it is best to have a computer to access the Internet-available software program, the process does ask students to print out data tables that are included in their investigation journals as evidence. Perhaps we can mail our sister school multiple copies of the data tables with Dr. Reiser's permission.

Additional Resources

Video: What Darwin Never Saw produced by Bill Kurtis Productions
This film can introduce students to the Galapagos Islands, to the history of Charles Darwin before taking the viewer to Daphne Major and the Grants. It is best to stop at 36:58, just after the Grants find that 50% of the finches have died. Otherwise, the students will realize the answer to their investigation.

Photos: I can provide teachers with selected photos I took on the Galapagos Islands that include a large number of well-known species. While I may have pictures of at least five species of the thirteen known species of Galapagos finches, I do not trust my ability to identify them or my sources at the time of identification. I have chosen not to send the photo file with this written project because of the difficulty it creates when downloading.

Books: There are massive numbers of books and articles on evolutionary biology that a teacher can read as background for this study. In addition to *The Beak of the Finch*, I recommend a few others:

Darwin, Charles. 1964 (1859). *On the Origin of the Species.* Ed. Ernst Mayr. Facsimile of 1st ed. Cambridge, Mass.: Harvard University Press.

Dawkins, Richard. 1985. *The Blind Watchmaker.* New York: W.W. Norton

Gould, Stephen Jay. 1983. *Hen's Teeth and Horses' Toes*. New York: W. W. Norton.

Grant, B. Rosemary, and Peter R. Grant. 1989. "Natural Selection in a Population of Darwin's Finches." *American Naturalist* 133: 377-93.

Grant, Peter R. And B. Rosemary Grant. 1992. "Global Warming and the Galapagos," *Noticias de Galapagos* 51: 14-16.

Miller, Kenneth R. 1999. *Finding Darwin's God*. New York: HarperCollins.

Wilson, E.O., ed. 1992. *The Diversity of Life.* Cambridge, Mass.: Belknap Press of Harvard University Press.

And finally when I retire, I will purchase, read and reference the entire works of Darwin:

Darwin, Charles R. 1987-89. *The Works of Charles Darwin.* 29 vols. Eds. Paul H. Barrett and R. B. Freeman. New York: New York University Press.