ARTICLE

Using David Lack's Observations of Finch Beak Size to Teach Natural Selection & the Nature of Science

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ABSTRACT

One of the key aspects of natural selection is competition, yet the concept of competition is not necessarily emphasized in explanations of natural selection. Because of this, we developed an activity for our class that focuses on competition and provides an example of the effects of competition on natural selection. This hands-on activity models the field study completed by David Lack on Darwin's finches. By using this historical study, we also give students an example of the nature-of-science concept of multiple methods. Although this activity was created for a college introductory biology course, it is appropriate for high school. We also provide an additional objective for upper-level ecology and evolution courses.

Key Words: *Competition; Darwin's finches; David Lack; evolution; multiple methods; natural selection.*

The *Next Generation Science Standards* (NGSS Lead States, 2013a, b) identify natural selection as a disciplinary core idea in biology (HS-LS4.B), yet studies have repeatedly shown that less than 10% of students, even biology majors, begin college with a conceptual understanding of natural selection (e.g., Nehm & Reilly, 2007). Therefore, student comprehension of basic concepts associated with natural selection should be a major objective for college introductory biology courses. In order to meet this objective, Nehm and Reilly (2007) combined active-learning elements, such as working in small groups, having group and class discussions, and nature of science (NOS), in a college introductory biology course. They found that students in this course significantly increased their conceptual understanding of natural selection compared to students taking a lecture-based course. We used these active-learning elements in creating an activity for our class that is intended to promote comprehension of one of the key aspects of natural selection: competition. Since this activity models an influential study done by David Lack on Darwin's finches, we will briefly explain Darwin's finches and Lack's study before discussing the activity.

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○ Darwin's Finches & David Lack's Study

In 1835, before David Lack's famous study on Darwin's finches, Charles Darwin stopped at the Galápagos Islands while surveying the South American coast. These islands are about 500 miles from South America, just below the equator, and are composed of 10 main islands (Darwin, 1897). Darwin suggested that these islands formed from volcanic activity and were never attached to the mainland. He also commented on how the wildlife on the Galápagos Islands was morphologically similar to that on the mainland, yet the habitat was very different. Moreover, he discovered that the finches seemed very similar in beak shape, body structure, and color, yet had a wide range in beak size. Unfortunately, because of time restrictions, Darwin was unable to collect a comprehensive amount of data or specimens. In remembrance of Darwin's foundational work, the finches on the Galápagos Islands are referred to as "Darwin's finches" (Lack, 1947).

Lack (1947) and others traveled to the Galápagos Islands in 1938 to study the characteristics of the finches and infer hypotheses regarding finch distribution between the islands and possible selection forces. During Lack's study, the birds were captured, and beak length and depth, diet, and location were recorded. These measurements were taken from birds on several different islands; on some islands, as many as 200 were captured, creating a very large sample size. Therefore, although one cannot be absolutely certain of their distribution patterns, with the amount of data taken, reliable inferences were made.

Regarding beak depth, Lack made three key observations: (1) there is variation within similar species occupying the same area, (2) there is variation among allopatric populations of the same

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species, and (3) there is a similarity between allopatric populations of different species. Most notably, Lack (1947) observed these patterns in three finch species, *Geospiza fuliginosa* (small ground finch), *G. fortis* (medium ground finch), and *G. magnirostris* (large ground finch). On the island Daphne, *G. fortis* is present without *G. fuliginosa*, and vice versa on the island Crossman; but *G. magnirostris* is not present on either of those islands. All three species are present on the island James.

Moreover, Lack (1947) hypothesized that "all the main differences between the species may be regarded as adaptations to differences in diet" (p. 72). Lack acknowledged that species with the same niche could not coexist, a principle later called the "competitive exclusion principle" (Hardin, 1960). Therefore, he further concluded that when one species first immigrated to an island where another species used the same food resource, the two species gradually created a "subdivision of the food supply and habitats, and then … an increased restriction in ecology and specialization in structure of each form" (Lack, 1947, p. 148). For these conclusions, the main traits that Lack focused on were beak measurements, because beak size limits the types of food they can eat (Snodgrass, 1902). Although differences in traits among the same three species had been noted previously, this was the first time that the cause of variation among these species was explained as interspecific competition that occurred in the past as a result of having a similar niche (i.e., eating similar foods). Lack's work (and that of many others) has subsequently been supported by natural experiments (e.g., Grant & Grant, 2006).

Having morphological differences between sympatric populations of similar species yet overlap in characteristics when the similar species are allopatric is termed "character displacement." Furthermore, biologists infer that character displacement is likely due to interspecific competition that occurred in the past. This hypothesis is now referred to as "ghost of competition past." Although Lack (1947) did not use these terms specifically, he did provide a great deal of evidence for them during his field observational studies on Darwin's finches. Please see Pfennig and Pfennig (2010) for a review of character displacement.

○ Laboratory Investigation

Student Profile

We created this activity for our college-level introductory biology course, but it may also be appropriate for high school biology students. We also suggest modifications for advanced evolution or ecology courses at the end of the article.

Learning Objectives

This activity meets the *Next Generation Science Standards* (NGSS Lead States, 2013a, b), and there are several Cross-cutting Concepts and Science and Engineering Practices that are met via this activity (see Table 1). Moreover, because one of the four main factors of natural selection is "competition for limited resources" (HS-LS4-2, p. 91), one of the objectives is for students to be able to explain the importance of competition by using a historical example. In order to meet this objective, we assumed that students should already have a basic understanding of evolution, natural selection, and ecology. Therefore, in our introductory biology course, students completed this activity toward the end of the evolution unit, which was after the ecology unit.

The other main objective, an NOS concept included in the *Next Generation Science Standards*, is for students to be able to identify that "scientific investigations use a variety of methods" (NGSS Lead States, 2013: Appendix H, p. 4). For instance, science can be explored in the field, not just in a laboratory, and science can occur via observations.

Table 1. An explanation of how Cross-Cutting Concepts and Science and Engineering Practices in the *Next Generation Science Standards* are met by this activity.

Cross-Cutting Concept	Activity Component
Patterns: Observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them.	After collecting data and creating histograms, students identify patterns. Later, students provide possible explanations for these patterns.
Cause and effect: Mechanism and explanation. Events have causes, sometimes simple, sometimes multifaceted. A major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across given contexts and used to predict and explain events in new contexts.	After identifying the patterns in the data (i.e., the "event"), students hypothesize possible causes of these patterns. A class discussion also occurs, which closes with the current scientific explanation for the cause of the observed patterns.
Science & Engineering Practices	**Activity Component**
Analyzing and interpreting data	After students collect data, they analyze the data by looking for patterns.
Constructing explanations	After students have examined the patterns, they need to identify possible explanations for why the patterns are occurring.
Engaging in argument from evidence	After students have formulated their explanations, they must use their evidence (i.e., the patterns from the data) to justify their explanation to their group and to the class.

Experiments are not always necessary and are sometimes even impractical. To illustrate these points, we chose to model a historical example. Before making comparisons between experiments and other methods of science, we advise that students learn what a true experiment entails (e.g., having a control and an experimental variable) in a previous lesson, as we have found that some students interchange the terms "science" and "experiment."

Materials

- Finch packets (described below)
- Instructions on measuring beak depth (Figure 1)
- Calipers or rulers
- Worksheet (Figure 2)
- Optional: bird netting (or garden netting)

Preparation

We created this activity so that our students can experience collecting data on bird specimens that consist of laminated, colored photographs. Only two finch species are used in the activity: *G. fuliginosa* and *G. fortis*. Pictures of these finches can be found by doing a simple online image search. We varied the sizes of the photographs slightly in order to better visualize the variation in beak depth between individuals, as well as the size variations between populations (for examples of beak depth measurements, see Table 2). *Geospiza fuliginosa* has a larger average beak depth on Crossman than on James, and *G. fortis* has a larger average beak depth on James than on Daphne. We used 12 birds of one species on each island (James had 24 birds total, because both species are on that island). Once the finch images were completed, we separated them by island to make "finch packets" for the students. To make the activity more realistic, we recommend actually setting up bird netting in the classroom and hanging the bird photographs from the netting by paperclips. All in all, although finding, modifying, printing, laminating, and cutting out the photographs can be time consuming, the laminated photographs can be repeatedly used.

Procedure Overview

- Introduction (~5 minutes)
- Collecting data (~10 minutes)
- Creating histograms (~10 minutes)
- Answering worksheet questions (~20 minutes)
- Class discussion and activity wrap-up (~25 minutes)

Procedure

Our introductory discussion follows this outline:

- Review the location and importance of the Galápagos Islands.
- Review Darwin's observations on the voyage and that several scientists have since studied "Darwin's finches."
- Describe Lack's field study, how he collected finch specimens and made measurements, including beak depth, but do not reveal his results.
- Explain the purpose of the activity: to model Lack's field study.
- Define "beak depth" (but describe how to measure it only after students have received materials).
- Name the finch species and the islands on which they are found.

Table 2. Example measurements of beak depth (mm) for *Geospiza fortis* and *G. fuliginosa* from the three islands, Crossman, Daphne, and James. A sample size of 12 was used for each island–species combination.

Island	***G. fuliginosa*, Small Ground Finch**	***G. fortis*, Medium Ground Finch**
Crossman	13.1	
	13.4	
	13.5	
	13.6	
	14.0	
	14.0	
	14.5	
	14.6	
	14.8	
	15.2	
	15.3	
	15.8	
Daphne		12.3
		12.8
		13.5
		13.6
		13.7
		13.9
		13.9
		13.9
		14.3
		14.4
		14.5
		14.7
James	11.2	14.7
	11.5	15.5
	11.6	15.8
	11.7	15.8
	12.1	15.8
	12.5	16.7
	12.5	16.7
	12.8	17.1
	13.4	17.4
	13.4	18.0
	13.6	18.3
	13.7	18.7

Next we divide the class into three "islands," with twice as many students assigned to James because both species are on that island. We pass out (1) finch packets (see Preparation), (2) beak depth measurement instructions (Figure 1), (3) calipers (possible alternative: rulers), and (4) the student handout (Figure 2). We explain how to use the calipers to measure beak depth and remind students to fill in the correct cell of the data table, since everyone is gathering data for a different island. After the explanation, students take turns measuring and recording beak depth in Part A of the handout until all birds are measured. While students are working on this activity, we walk from group to group to make sure that beak depth is being measured accurately. After initial assistance, our students are able to measure beak depth with ease.

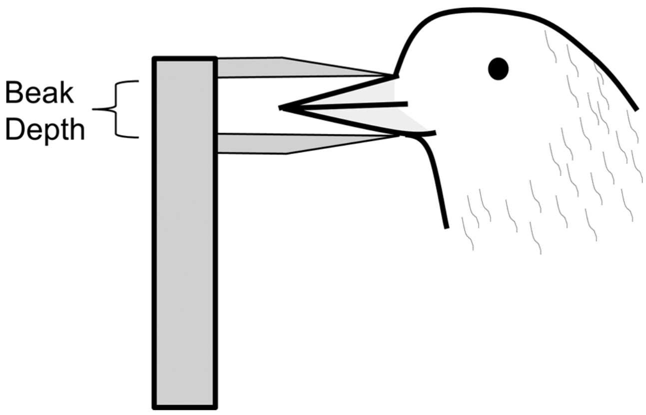

Figure 1. Calipers are extended to fit around the beak to measure beak depth.

After measuring all birds, students write their data on the board so that all have the data from the three islands. After recording all the data, the students create histograms (Figure 3). (Because histograms had not been used previously in the course, we had to explain how a histogram differed from a bar chart and how to create histograms, as many students were initially confused.)

Once the students finish the histograms, they answer the questions in the handout. Before any class discussion takes place, we have students answer all questions from both Part B, which covers biological content, and Part C, which covers the NOS concept. (Few students asked us any questions.) After the students are done answering questions, there is a class discussion.

Name: ___________________________________
Date: ___________________

Part A

1. Record all class data; distinguish between islands and finch species.
2. Using the data from Part A, create histograms for each population. For the beak depth (x axis), use the 0.5-mm intervals; all four graphs have the same range so that easy comparisons can be made. Estimate the mean on each graph.

Part B

1. Why is it important to study beak size? Why do some birds in nature have different beak sizes than others? (Hint: What are beaks used for?)
2. Compare the histograms from Part B. Are there any patterns of variation?
   a. Between different species?
   b. Between different populations of the same species (note that in this study a population consists of individuals of the same species on the same island)?
3. Why are these patterns occurring? Develop at least two possible biological hypotheses for these patterns. Make sure to include the evidence that supports each hypothesis.

Part C

1. Throughout this course, we have described various aspects of science. Does all science require experiments? Describe an example, apart from the current activity, in your explanation.
2. Does science ever occur outside of the laboratory (a laboratory being a controlled environment)? Describe an example, apart from the current activity, in your explanation.
3. Was the study that we did today an experiment?
4. Did the original study occur in a laboratory?
5. Could this study have been completed via an experiment? Explain.
6. Was this study science?
7. Do all studies done in the present time involve experiments? Do they occur only in the laboratory? Provide an example.
8. Is there one type of methodology that all scientists follow?

Figure 2. Student handout. Table 1 illustrates the data table provided for Part A (1), and Figure 3 illustrates the charts provided for Part A (2).

We discuss Part C first, and the handout serves as a general outline of the discussion. During this discussion, our students were quick to identify that there is no single scientific method. Moreover, they rapidly acknowledged that investigations can occur outside of the laboratory and do not have to involve experiments. They explained that the method employed depends instead on the research question. However, the "myth of the scientific method" had been briefly introduced at the beginning of the course, when several other NOS tenants were defined (the activity took place several weeks later). Because of this, it was unclear whether students had already accepted that there was not a single scientific method. Without the prior experience, they may or may not have been so quick to disagree with the scientific method.

After wrapping up the discussion on Part C, we move to Part B, addressing each question one at a time. First, students discuss why it is important to study beak depth. With the hint provided in the worksheet (What are beaks used for?), our students were able to discuss how the beaks determine what the birds can eat. To ensure that they saw the patterns in the data, we asked them to describe patterns between different species and different populations of the same species. Then we asked them to hypothesize explanations for the patterns observed. Most of our students concluded that the differences found among populations living on the same island were due to competing for limited food resources, but they needed further direction in identifying how the competition influenced the evolution of these

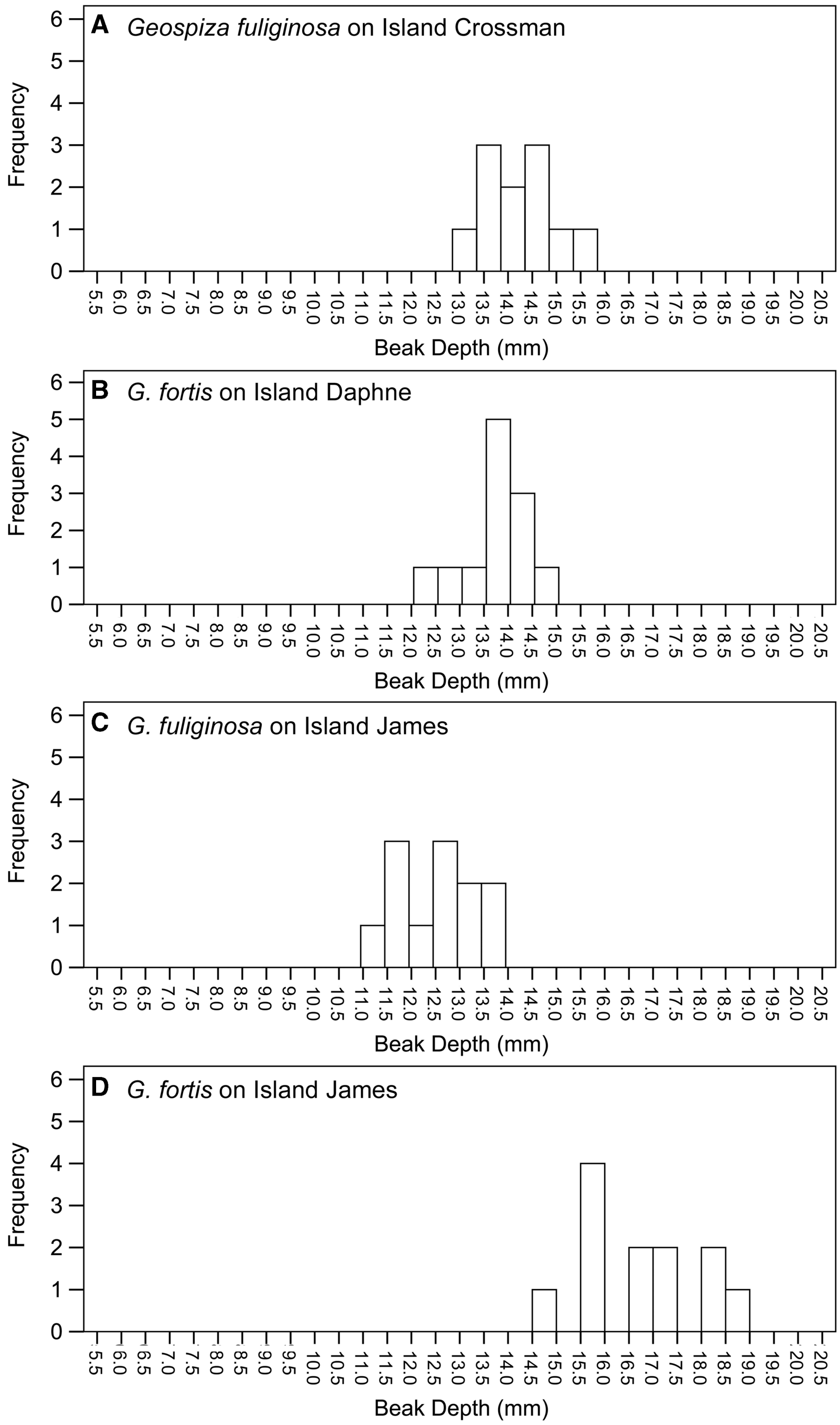

Figure 3. Histograms of beak depth using data from Table 1 for (A) *Geospiza fuliginosa* on Island Crossman, (B) *G. fortis* on Island Daphne, (C) *G. fuliginosa* on Island James, and (D) *G. fortis* on Island James.

populations. The discussion commenced with how Lack's study, which the students modeled, provided evidence for the importance of competition to natural selection.

○ Summative Assessment

Both the biological concepts and the NOS concept were covered in the summative assessment, in order to stress the importance of both objectives. Summative assessment can include both general definitions and application to the historical episode. If students are allowed to practice, novel examples can also be provided to students to let them predict what could happen in certain situations. For example, Anderson et al. (2002) provided a tested conceptual inventory of multiple-choice questions on natural selection that utilizes three case studies, including Darwin's finches.

○ Activity Modifications

The following are possible modifications of the activity, most of which will increase the level of inquiry.

- Students write a web-based research report on both finch species before starting the activity. The report may cover (1) morphology, (2) life history, and (3) biogeography. Possible resources:
  - http://bioquest.org/birdd/
  - http://eol.org/pages/36192/details
- Before beginning the activity, discuss the importance of measuring beak depth. This leads into a discussion about possible hypotheses to test.
- Continue the activity by instructing students to create an experiment that could provide additional evidence for Lack's conclusions. The students' designs can then be compared to Lack's methods.
- After completing the activity, students select an article that provides evidence for character displacement (either on their own or predetermined by the instructor) and summarize, critique, and compare the article to Lack's study.
- For Advanced Ecology or Evolution Courses: During the discussion, introduce the competitive exclusion principle, character displacement, and ghost of competition past (as described above in Darwin's Finches & David Lack's Study).

○ Conclusion

All in all, we believe that this activity is an excellent addition to a biology course. Our students were able to complete the activity with little confusion and comprehend the information, especially the NOS concept. The activity gives students a chance to collect data, while giving instructors the ease of relying on materials that can be used repeatedly. Moreover, because of the nature of the activity and the explicit questions, students learn more about the possible ways that science can be explored.

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