HOW TO DO IT

Hands-On Laboratory Simulation of Evolution: An Investigation of Mutation, Natural Selection, & Speciation

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Abstract

Evolutionary theory is the foundation of the biological sciences, yet conveying it to General Biology students often presents a challenge, especially at larger institutions where student numbers in foundation courses can exceed several hundred per lecture section. We present a pedagogically sound exercise that utilizes a series of simple and inexpensive simulations to convey the concept of evolution through mutation and natural selection. Questions after each simulation expand student comprehension; a class discussion encourages advanced thinking on mutation and speciation. A final paper requires students to synthesize their learning by summarizing selected papers on these topics. A grading rubric for the papers is included.

Key Words: *Adaptation; genetic pool; genotype; phenotype; mutation; binomial nomenclature; speciation.*

Nearly 40 years ago, Theodosius Dobzhansky (1973), a prominent geneticist, stated that "Nothing in biology makes sense except in the light of evolution." This statement gave distinction to evolution as the only acceptable, biologically sound explanation for the biodiversity and unity of life on Earth. Over the ensuing decades, results from research studies have added a plethora of evidence that supports evolution as the definitive biological model. Some resistance to the presentation of evolutionary theory in the classroom remains, but scientists and educators recognize that an understanding of the processes by which populations change over time provides the foundation for scientific studies (Wilson et al., 2009; King & Cabeza de Baca, 2011; Stansfield, 2012). Recently, the National Science Teachers Association (NSTA) published its official position on the study of evolution, describing the theory as the "major unifying concept in science" and stating that it "should be emphasized in the K–12 science education frameworks and curricula" (NSTA, 2013).

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Understanding how populations evolve over time eventually leads to the question "How different do populations have to become before they are recognized as different species?" Most scientists recognize a species as a natural taxon, or a group of organisms with a well-defined and most recent shared evolutionary history. A "biological species" represents a population that has evolved sufficiently that its members can no longer interbreed and produce fertile offspring (reproductive isolation). Other species definitions include "phylogenetic species," groups that are recognized only if their shared evolutionary history is well described. Regardless of the species definition used, biologists generally agree that speciation, or the process of forming new and distinct species in the course of evolution, requires a significant divergence in genetic composition among the populations considered.

Our objective was to design a cost-effective lab-exercise simulation that simply, yet elegantly, investigates evolutionary mechanisms and their effect on speciation. Because of our direct yet entertaining approach, students easily grasp the basic principles presented. In addition, and equally important, our exercise is designed for and easily implemented in a 2-hour lab session.

During this exercise, students discover (assemble) and then allow mutation and selection to act on "creatures" from another planet. The students' spaceship leaves the planet for an extended period and returns several millennia later to reexamine the creatures. During the time the spaceship is absent, mutation and natural selection have occurred; many of the creatures have changed considerably since they were first "described." Students must decide if the ongoing mutation and natural selection have resulted in speciation or not.

Prior to this exercise, students must have been exposed to introductory topics covering evolution and speciation. They should have developed an understanding of the following terms and concepts: adaptation, artificial and natural selection, classification, evolution, fitness, gene pool, genome, genotype, mutation, phenotype, reproductive isolation and success, speciation, and species concepts. This activity uses simulations at both the high school and undergraduate levels to illustrate the evolutionary processes acting on populations. Using these manipulations, students gain knowledge in

- characterizing species on the basis of their phenotypes,
- linking mutations with their phenotypic effects,

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Figure 1. A bag of creature "parts." Each group receives two bags: the first is used to assemble the original creature, and the second is used in a later manipulation.

Table 1. Example of the first table that students produce during the laboratory exercises. Students record data in several tables throughout the activity, each of which is a variation of the table shown.

Table A.	Description of Character	Sum of Rolled Dice
Example:	*Six legs*	
1.	______	2
2.	______	3
3.	______	4
4.	______	5
5.	______	6
6.	______	7
7.	______	8
8.	______	9
9.	______	10
10.	______	11
11.	______	12

- correlating evolutionary processes of mutation and selection, and
- recognizing the effects of geographic isolation on speciation

○ Protocol: Activity 1

Working in groups of four, students become intergalactic visitors that have discovered a new organism on a previously unexplored planet. As the first visitors, they are assigned the task of observing and recording the phenotype of this new species collected from the planet's surface. Instructors provide each group of students with two identical bags of creature "parts" (foam balls of various sizes, pipe cleaners, and other creative "body parts"; Figure 1) in addition to a coin and four dice. Students assemble their space creature using the parts from one of the bags. Each group should not use all the parts; extra pieces are kept for later manipulations.

Once their creature is complete, each group compiles a list of characters that define the creature's phenotype. Using a table similar to that shown (Table 1), they describe the organism (e.g., body shape and size, appendage color, and number) using 11 unique characters.

Binomial nomenclature provides an organism with a scientific name composed of two designations. The first term, or genus, represents a taxonomic level that clusters several species together. The second name (specific epithet) refers to the distinct species within a genus. The generic name begins with a capital (e.g., *Rosa* or Rosa) and the specific epithet with a lowercase letter (e.g., *woodsii* or woodsii). The specific epithet is always combined with the genus name and represents the complete scientific binomial (e.g., *Rosa woodsii* or Rosa woodsii). An example of a classification scheme (domain to species) is shown in Figure 2. Each group of students should name their creature using correct binomial nomenclature. In addition, they should provide a description of the environment in which it lives.

After all groups have formed and named their creatures, instructors inform the students that their spaceship is leaving the planet and will not return for many years. Group members enter a deep sleep and do not experience the elapsed time. Many creature generations occur during the ship's absence and they undergo multiple mutation and natural selection events. To simulate these events using two dice, each group rolls a sum that determines which creature character has been modified by mutation. Groups determine the types of character modifications (e.g., blue appendages become green) and make these changes using extra body parts from the first bag. For each mutation, a member of the group flips a coin to determine the selective response to each modification. If the coin flip reveals "heads," natural selection favors the mutated character. Alternatively, if "tails" appears, the modified character is selected against. For character modifications *not* favored by selection, students should return the character to its original form (Figure 3). Students repeat this process for 10 generations, with some characters, potentially, undergoing modification more than once. Track the modifications in a table similar to that shown in Table 2, but with 10 lines, one for each generation. Figure 4 illustrates changes that occurred in two of the creatures after mutation and natural selection.

After students complete a round of mutation and selection, they must decide whether the creature now formed represents a new species or the same one with which they began. Their decisions are primarily based on morphological characteristics, but the instructor should task the students to consider the environments in which mutation and evolution occurred, as well as the degree of change. If students determine they have a new species, groups must record a

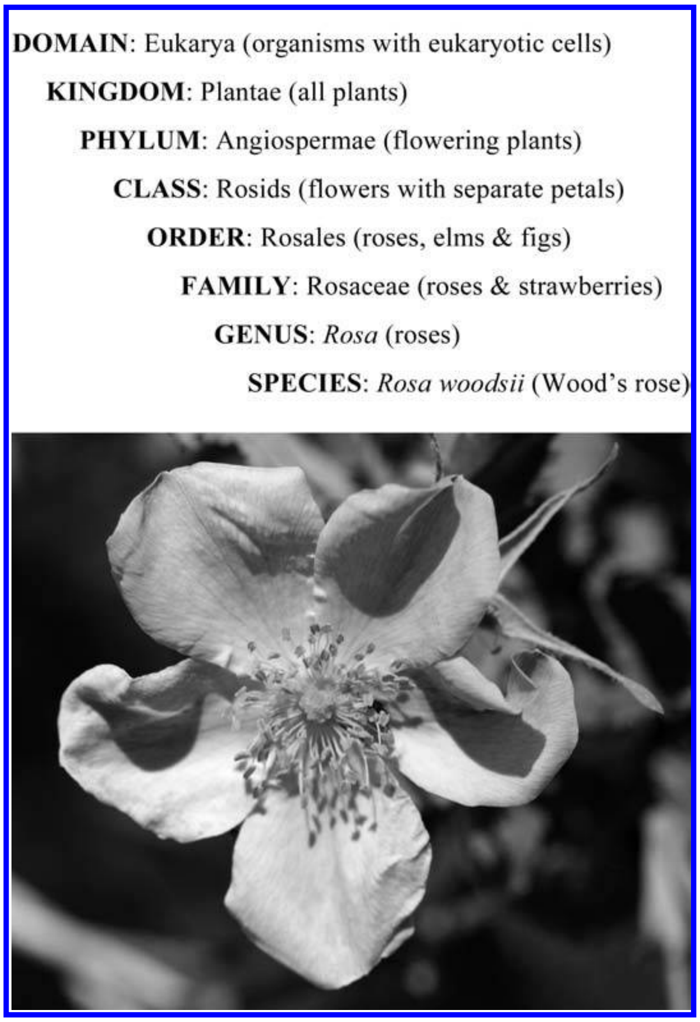

Figure 2. Classification of a wild rose from most (domain) to least (species) inclusive.

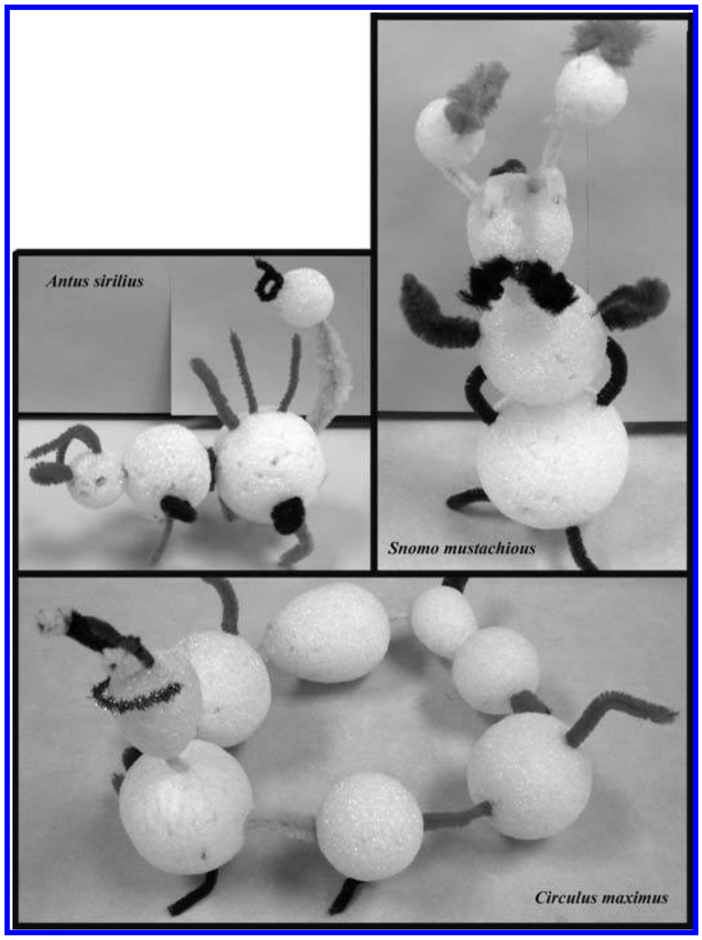

Figure 3. Creatures originally assembled using the provided supplies.

Figure 4. Creatures that resulted after mutation and natural selection occurred. Left: *Snomo mustachious*. Right: *Antus sirilius*.

new scientific name and the environment in which the new species resides.

○ Protocol: Activity 2

Using the second bag of creature parts, each group of students should make a *copy* of the creature they produced after mutation and selection. Again, students are instructed that their spaceship leaves for another extended period and does not return for many creature generations. During its absence, a major geologic shift has occurred on the planet and the original creature populations have been split into isolated populations. Each student group of four simulates the geologic shift by splitting into two groups of two students, each of which has one copy of the creature. Smaller groups now repeat the processes of mutation and selection with their respective creature and track character changes and selective responses in another table (Figure 5). Back in their groups of four, students should discuss the two activities. The questions in Table 3 are suggested, but the instructor may guide students as they explore their interpretations in other directions.

After students complete their questions, we suggest the instructor begin a class discussion that focuses on how mutations arise. Begin by asking if students think mutations randomly occur or if some DNA regions are more likely to mutate than others. The laboratory exercise the students just completed is based on the *selectionist theory* of mutation (Gillespie, 1991). This theory states that advantageous mutations are common and their effect on a population's gene pool cannot be ignored. By contrast, the *neutral theory* (Kimura, 1983) suggests that advantageous mutations are very rare and most mutations are selectively neutral (i.e., have no effect on individual fitness or the population's genetic pool). Ask each group to modify the exercises

Table 2. Example of a table that records character changes after mutation and natural selection.

Generation (Dice Roll)	Character Changed (from Table A)	Description of Character	Selected For	Selected Against
Example:	*1*	*Eight Legs*	☑	☐
1			☐	☐
2			☐	☐
3			☐	☐
4			☐	☐
5			☐	☐
6			☐	☐
7			☐	☐
8			☐	☐
9			☐	☐
10			☐	☐

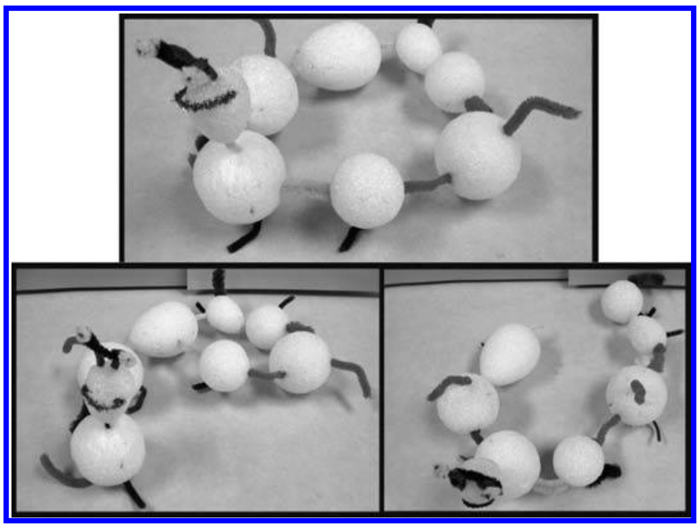

Figure 5. Modified *Circulus maximus* (bottom left and right) after geographic isolation followed by mutation and natural selection. Students determined that speciation had not occurred, but that modified creatures were morphological races of their creature prior to isolation (top).

they just completed and redesign these to consider neutral mutations. Students then present their modifications to the entire class to receive feedback. Alternatively, divide the class into two teams that present and discuss both theories. Students should specifically discuss whether the information on the contrasting theories of mutation changes their opinion(s) concerning the randomness of mutations.

Table 3. Suggested questions that allow students to explore the activities.

1. If the creature populations remain separated, do you think the isolated populations will become more similar or more distinct over time? Explain your reasoning.
2. What process is driving your observations of the isolated populations?
3. Discuss why some character modifications might be selected against and others favored.
4. Many students have the misconception that natural selection leads to the mutations that are observed. Explain, using your activities, why that is not the case.
5. Does natural selection have a "goal" or objective? Explain your reasoning.

○ Extension: Exploring the Literature

Background: Early widespread use of antibiotics produced bacteria populations that are selectively resistant to many antibiotics. Pharmaceutical companies continually work to develop new drugs that kill the increasingly more common resistant bacteria populations. *Antibiotic resistance* is an example of how a selective response can result in substantive phenotypic changes in a population's genetic pool.

Task: Students should explore the current, peer-reviewed literature and determine whether the DNA mutations responsible for antibiotic resistance in bacteria are known. After reading three publications, students write a one-page summary of the studies. In the paper, publications should be correctly cited in a reference section, and the front page of each publication is attached to the final paper.

○ Online Supplementary Materials

Instructors may find the Grading Rubric useful in their assessment of student papers. In addition, the entire laboratory exercise, written for the student, is available. We also have a separate document that provides extensive introductory material, including the terms used in the activity as well as the basic concepts of evolutionary theory. We've included a homework assignment that accompanies this introductory material. If students read the introductory material and complete the assignment beforehand, or the concepts are covered in another context prior to the laboratory exercise, it is anticipated that they will have a better understanding of the concepts presented in this lab exercise. Readers that desire online supplementary materials are encouraged to contact the primary author (hildebrandterri@gmail.com), and the requested files will be forwarded to the instructor.

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