INQUIRY & INVESTIGATION

A Sweet Dive into the Gene Pool: An Ease Look at p & q

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Abstract

Teachers are being challenged to engage students in ways that will elevate student interest and understanding of concepts in science and encourage students to gather evidence to support what we know about science. It is critical for teachers to have budget-friendly, supporting activities that are aligned with current educational standards, that are easy to present, and that incorporate a variety of skills important to the study of science. This simulation activity is an inexpensive exercise that challenges students to hypothesize the evolutionary outcome of genotype selection in a population and then gather and analyze a set of unique data. Connections to recent evolutionary changes in familiar organisms ground the activity for students, helping them grasp the importance of such investigative work.

Key Words: *Evolution; gene pool; Hardy-Weinberg equilibrium; allele frequency; educational standards.*

To a population geneticist, the word "evolution" indicates changes in a gene pool over time. In the natural world, evolution is ongoing in all populations in one way or another. Slowly or quickly, change is inevitable.

In 1908, Godfrey Hardy and Wilhelm Weinberg described for us the concept that an infinitely large population will not evolve over time in the absence of evolutionary forces that affect gene-pool frequencies (O'Neil, 2012). Evolutionary factors may include events such as mutation, natural selection, gene flow, genetic drift, and mating patterns. The concept describing a lack of change is known as Hardy-Weinberg equilibrium and is not consistently seen in real populations but can be used to understand the impact of evolutionary factors on real populations.

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At a time when evidence-based concepts of evolution are being challenged and teaching evolution in a meaningful way requires creativity, the development of varied, flexible activities for students at all levels is critical to science education. When time and resources are limited, simulations of evolutionary events have long been effective choices (Thomerson, 1971; Maret & Rissing, 1998; WGBH Educational Foundation, 2001; Chinnici et al., 2005; Lapiana, 2009; Learning ACE, 2014). Here, we present an updated version of an inexpensive exercise for students to examine changes in two values described by Hardy and Weinberg: p and q. The value p represents the frequency of the dominant allele, and the value q represents the frequency of the recessive allele in a dimorphic allele pool. Changes in these simple values represent the evolutionary process at work for a single gene (Nature Education, 2013).

○ Materials & Preparation

For a class of 18, with students working in pairs:

- 9 brown paper lunch bags
- 2 medium bags of regular M&M (or other similar) chocolate candies
- 3 medium bags of an alternative color palate (such as pastel) M&M chocolate candies
- 18 disposable 8-ounce or 12-ounce plastic cups
- 9 two-foot pieces of spill paper or paper towels
- 2 large bowls for holding the 2 types of candies (or other)
- 9 calculators
- 9 permanent markers

Each student station should include a sheet of spill paper or paper towels, 2 plastic cups, a lunch bag, a marker, a calculator, 50 regular-colored M&Ms, and 50 alternative-colored M&Ms. The remaining M&Ms should be poured separately into the bowls and kept for student use at the front of the room.

Where there are regulations on food in the classroom or concerns about allergen exposure, easy substitutions are possible; using two

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varieties of similarly sized dried beans, such as black beans and navy beans, is one alternative.

There are many times of the year when holiday varieties of various candies are readily available. We usually do this activity in the spring and use regular and pastel Easter M&Ms. With a small class, another option is to sort the candy, pulling out just two different colors to use for the activity. If alternative colored candies are not available, different types of candies can be paired, as long as they are similar in size and shape, such as M&Ms and Skittles.

○ Setting the Scene

As most educators would agree, it is always a good idea to select examples for discussion that students can relate to, ensuring student engagement from the start. With innumerable populations to choose from, any number of organisms could be exemplified in this activity. We typically begin with a discussion about a group of majestic animals, bighorn sheep (*Ovis canadensis*), which most students have seen either in a zoo or in the wild if they have traveled to one of the western national parks or in parts of western Canada. These sheep have a natural range spanning from western Canada southward all the way to New Mexico (National Geographic, 2013). The characteristic horns on these herbivores can grow quite large, reaching a weight of 30 pounds or more (National Geographic, 2013). The horns are used in clashes for dominance among rams. Researchers have observed interesting changes in horn size in these mammals during as little as 30 years and have suggested evolutionary factors at work.

In 2003, Coltman and colleagues reported on the negative impact of hunting large-horned rams on the average horn size in a population of bighorn sheep on Ram Mountain in Western Canada (Coltman et al., 2003). In the period 1971–2002, the researchers determined that horn size decreased by 25%; they concluded that restricting hunting to only the larger herd members, a practice that began in 1996, while protecting younger rams not yet of breeding age, may have actually selected against rams with genes for early growth of large horns. More recently, Festa-Bianchet et al. (2014) suggested a decline in horn growth rate in response to trophy-hunting practices. By contrast, Hedrick (2011) examined horn size in desert bighorn sheep in Arizona and reported a decline in horn size, but he concluded that a combination of poor environmental conditions – including drought, inbreeding, and hunting – contributed to the decline. While evolution is often looked at in the long term, these studies of sheep exemplify the visibility of real evolutionary changes over relatively short time frames. Coltman et al. (2003) also suggested that horn-size decline in a population may be a sign of more significant evolutionary events, given that horn size is likely tied to other, less easily observable features in the sheep (also see Whitfield, 2003). Descriptions of such real-life cases of observable population changes pique the interest of students, readying them for further work.

○ The Activity

The activity we describe allows students to see how an evolutionary factor can directly contribute to observable changes in the allele frequencies in a population of limited size in just a few generations. Hunting, or other human-centered activity, may target very specific phenotypes and may lead to very specific changes in a population, as individuals harboring "desirable alleles" are removed. Students can predict how changes in allele frequency will affect the future phenotypic and genotypic composition of a population.

For this activity, alleles are represented by individual candy pieces. We have the students look at one gene with a dimorphic allele pool. To begin, a notation system must be established for the alleles represented in the activity; we generally designate the dominant allele "B" (represented in the activity with a brightly colored regular M&M) and the recessive allele "b" (represented with a pastel-colored M&M). In this exercise, we always keep the population size at 50, so the gene-pool size is 100. We set the initial gene-pool allele distribution at $p = 0.5$ and $q = 0.5$, but, like the population size, these numbers can be set at any appropriate values at the discretion of the instructor.

In pairs or small groups, students use the p and q values for the generation they are working on to determine how many of each candy type must go in the bag (e.g., with $p = 0.5$ and $q = 0.5$ and a gene-pool size of 100, 50 of each candy type should be placed in the bag). After shaking briefly to mix, students reach into the bag and pull out candy pieces, two at a time, to represent the results of mating and the various combinations of parental allele pairs that would occur during fertilization. Each pair represents a diploid offspring of a particular genotype. Students arrange the pairs in groupings: BB, two bright candies pulled out together and therefore a homozygous dominant offspring; bb, two pastel candies pulled out together and therefore a homozygous recessive offspring; Bb, a mixed pair, and therefore a heterozygous offspring. Candy pieces from the three different genotypes are arranged separately, as shown in Figure 1. Once the students have pulled out all 100 candy pieces in pairs, they tally up how many homozygous dominant pairs, how many homozygous recessive pairs, and how many heterozygotes are represented in their population (Figure 1A). The students record their data in Table 1, and we ask the students to hypothesize what will happen to the allele frequencies in the gene pool over time when natural selection acts on a particular genotype in the population.

In the next step, students simulate natural selection on this generation; selection will produce a new gene pool that will ultimately determine the genetics for subsequent generations. We describe a scenario in which only 60% of the homozygous dominant individuals survive to reproduce, 80% of the heterozygotes survive, and all the homozygous recessive individuals survive to reproduce in each generation. Using the candy pairs that have been generated, 40% of the BB pairs are removed (i.e., 60% survive) and 20% of the heterozygotes are removed (i.e., 80% survive) (Figure 1B). The students then calculate the new allele frequencies (p and q values) for this generation and add these values to Table 1. Subsequently, the students determine how many of each color of candy would represent these new p and q values for a constant gene-pool size of 100. Once the new p and q are determined, the appropriate candies are counted out and placed in the paper bag a second time. The bag is shaken and the candies are again taken out of the bag in pairs, tallying BB, bb, and Bb offspring pairs as before. The "mating" and "selection" process is repeated for five or more generations. Students soon see that allele frequencies can change noticeably in just a few generations when selection acts on a particular genotype. Furthermore, as allele frequencies change, genotype frequencies and the phenotypic "appearance" of the population change as well. Harkening back to the bighorn sheep, males with large horns will give way to a population in which moderate horn size is more common. The p and q values can be plotted to illustrate the changes in allele frequencies over multiple generations.

○ Discussion, Standards, & Final Comments

From stem cells to genomes to nanotechnology and climate change, the world is constantly changing, and science is constantly changing the world. Our students, young and old, must learn to understand and appreciate current science, including what we know, what we are now learning, and how we are going to decipher what we do not yet know. Scientific and academic organizations have recently collaborated to produce the *Next Generation Science Standards* (NGSS Lead States, 2013), which cover far-ranging topics aimed at K–12 students (Pratt, 2012). The need for such educational standards is apparent; one recent report suggests that more than two-thirds of high school graduates fail to meet readiness standards in science (ACT, Inc., 2012). The intent of the *Next Generation Science Standards* is clear; such educational standards will not only lead U.S. students into the forefront of a global workforce but will also allow them to grow into scientifically and technologically literate members of society, able to make well-informed, intelligent decisions for themselves and their families.

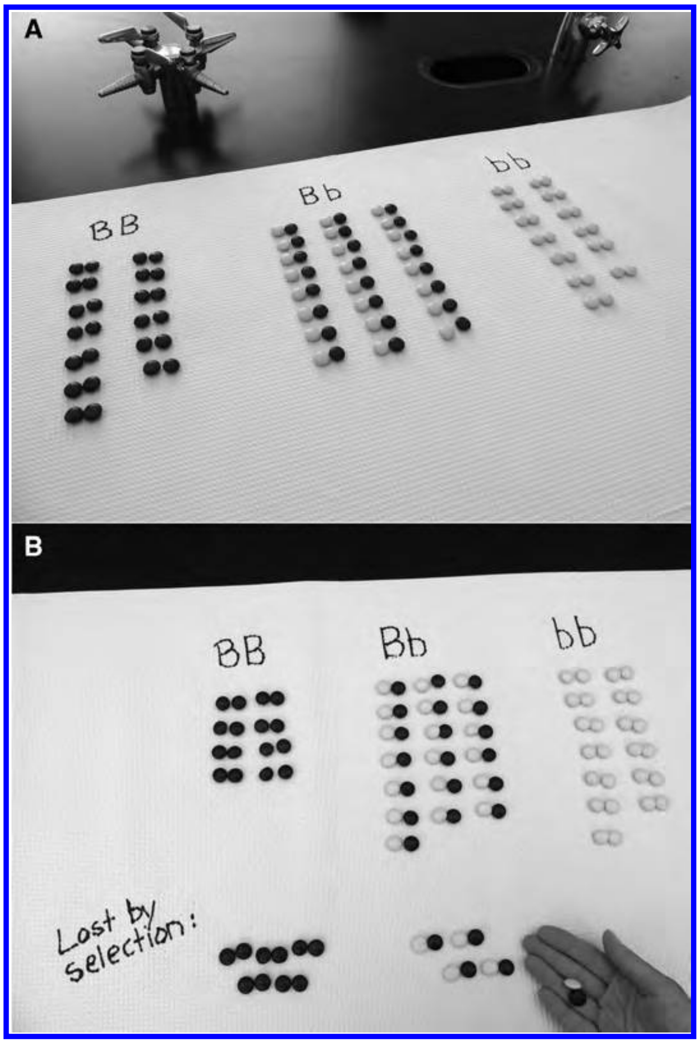

Figure 1. The results of initial offspring collection (A) and removal of offspring lost by selection (B). Photos by authors.

While there are a variety of areas within biology that are able to generate interesting classroom discussions, few have generated as much national political discussion as the study of evolution. Although there is no debate in the scientific community on the validity of evolutionary theory, there is widespread debate throughout our hometown communities. The National Science Teachers Association (NSTA) reports that many teachers hesitate to spend much time in the classroom on evolution, for fear of conflicts with parents or school officials who do not believe in evolution (NSTA, 2013). A number of court decisions have clearly ruled against proposals to give non-science-based ideas, with familiar names such as "creationism" or "intelligent design," classroom time, yet a variety of factions continue to push for equal coverage (Beil, 2008; NSTA, 2013).

With abundant, well-supported evidence that evolution has occurred and continues to occur, it is crucial to give a discussion of evolutionary events the importance it deserves and to show our students examples of the effects of evolution that are easy for them to understand. While the nature and principles of evolution are abstract and often challenging for students, evolution is happening all the time in the world around us. This activity allows students to make predictions about the principles of evolution and then run a simulation to provide the necessary evidence to comprehend how evolution can occur in a population over a short period. In just a few generations, the frequencies of two alleles in a population are shown to change dramatically, with the recessive allele becoming predominant. Students are encouraged to consider the future of a population in which a higher frequency of the recessive allele may lead to an

Table 1. Genotype and allele frequencies before and after selection.

Generation	Initial Values						Final Values				
	p	q	BB pairs	Bb pairs	bb pairs		BB pairs	Bb pairs	bb pairs	p	q
1	0.5 (given)	0.5 (given)	13	24	13	⇒	8	19	13	0.44*	0.56*
2	0.44*	0.56*				⇒					
3						⇒					
4						⇒					
5						⇒					

Notes: For each generation, there is an initial population distribution set for the three genotypes (which will have an associated pair of p and q values) and a final population distribution set after natural-selection factors (e.g., hunting or other) have acted on the population. After the final values are available, students calculate and record new p and q values (*), which become the p and q values for the next generation of the population. The data shown are examples of possible student data.

Table 2. A sampling of questions (with possible answers) posed to our students at the conclusion of the lab activity.

Question	Describe the natural-selection pressures on each genotype in the population.
Answer	*Here, natural selection has the greatest impact on homozygous dominant individuals, of which only 60% survive each generation. Heterozygotes are also negatively affected, but to a lesser degree (i.e., heterozygotes here show an alternative phenotype from the homozygous dominant individuals).*
Question	What happened to the number of recessive alleles from generation to generation? What do these results suggest about how the recessive allele frequency will change over time if selective pressures remain as they are presented here?
Answer	*The frequency of the recessive allele increased each generation. If selective pressure continues to negatively affect genotypes containing the dominant allele, the frequency of the recessive allele will continue to increase over time.*
Question	Do your results support or reject your hypothesis? Justify your answer.
Answer	*[Answers here will vary depending on the hypothesis.]*
Question	What does the Hardy-Weinberg premise say about factors such as mutation, genetic drift, or gene flow in a population?
Answer	*An ideal population in Hardy-Weinberg equilibrium will not experience mutation, genetic drift events, or gene flow in its members.*
Question	The current activity examines the effects of natural selection on a population, but how would other factors, such as genetic drift, affect the allele frequencies in the population?
Answer	*Genetic drift, an event that removes individuals by chance from a population, may change the allele frequencies of B and b in a manner dependent on the genotypes of the individuals involved in the chance event. [Note: For more advanced discussions of evolutionary forces, events such as genetic drift, gene flow, or mutation could each be incorporated as variations of the current activity. As an example, to demonstrate a form of genetic drift called "bottlenecking," at a point when 100% of the alleles/candies are in the bag, 90% are removed prior to the "mating" activity and a new p and q calculated for the remaining 10% of the alleles. These post-bottlenecking p and q values, which may represent a very different gene pool, are used to conduct the experiment, and the results are compared with data in the absence of the bottlenecking event. A follow-up question about the effect of genetic drift on evolution and diversity generates critical discussion.]*
Question	Give a definition of evolution and discuss why your data represent or do not represent an example of evolution in the simulated population.
Answer	*A good definition of evolution is change in a population's gene pool over time. The data from this activity show that over even a few generations, the gene pool, which can be represented by p and q values, can change dramatically, and thus evolution is occurring.*

increased presence of homozygous recessive individuals. Whatever trait is determined by the recessive allele becomes more common overall.

Beyond an updated simulation of natural selection and evolution, this activity provides opportunities for students to practice their skills in mathematical analysis of data, graphing, and, most importantly, critical thinking. The ability to think analytically is an essential skill of any good scientist. A student must be able to make connections between concepts in science, as well as draw conclusions about the natural world. Provided in Table 2 is a series of sample questions that engage students to make connections and draw conclusions about the principles of evolution. The questions and this lab activity align with the standards set forth in the *Next Generation Science Standards*. These standards describe expectations for students to evaluate ecosystems and variations in ecosystem diversity in response to changing biological and physical conditions, as well as the impact of human activities on populations (NGSS Lead States, 2013).

○ Additional Resources

The examples of natural selection that we present to our classes, such as the reduction in horn size of bighorn sheep through hunting, are popular with our students, but there are any number of other reported examples of rapid phenotypic changes in populations that could alternatively or additionally be used to set the stage for this activity (Allendorf & Hard, 2009). Jachmann et al. (1995) reported on the changing frequency of tuskless female elephants during the period 1969–1993 in a South Luangwa National Park in Zambia, which was likely in response to ivory hunting. More recently, Laurian et al. (2000) examined the effects of human hunting on adult sex ratios in two Canadian populations of moose (*Alces alces*).

○ Alternative Classroom Management

With modest additions, this activity lends itself to the 5E model of instruction developed by the Biological Sciences Curriculum Study

Table 3. Student understanding is developed by the 5 E method as the students build a body of knowledge through Engaging, Exploring, Explaining, and Elaborating. Evaluation, formative and summative, is ongoing throughout the lesson.

Instructional Component	Purpose	Student Activity	Follow-up
Engage	Generate interest and curiosity in genetic diversity	View video of bighorn sheep release into the wild	Q: Why is release of the sheep necessary? A: The release increases the genetic diversity of the herd.
Explore	Ask more questions, such as "What causes genetic diversity to decrease?"	Complete worksheet listing human activities and their effects on genetic diversity	Depending on the level of the student, use of a partially completed or blank T-chart facilitates student exploration
Explain	Introduce population genetics	Initial population set-up with candy pieces	Record population data including p and q values of first generation
Elaborate	Introduce a selective factor that alters the population	"Hunting" activity; repeat as necessary	Calculate new p and q values
Evaluate	Examine questions related to gathered data	See Table 2	Follow-up with discussion of other human activities that affect various populations

(Bybee et al., 2006). A plan for implementing 5E instruction with this activity is shown in Table 3.

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