equipment? Can cost to taxpayers be determined?

6. Have students investigate litter barrels if used in your area. Are they effective in controlling litter? Are waste containers in your school effective?

7. Does your community have laws prohibiting littering of roadways? (Nearly all do.) Can your students determine their effectiveness? How many persons are cited for littering violations each year? How does the amount of money collected from such fines compare to cleanup cost?

8. Are there recycling areas in your community? Is the public aware of them? What percentage of the population uses them? Can students discover the relative savings in energy, raw materials, and expense in recycling vs. manufacturing from raw materials? Literature on recycling is available from commercial companies. Have students compare claims.

9. Help students locate magazine articles, etc. which discuss pros and cons of laws prohibiting nonreturnable drink containers. What are the possible ramifications of such laws on employment in bottling plants or similar industries? Would less aluminum be required for containers and, if so, would fewer people be required in the aluminum industry?

Litter *is* a problem in need of a solution, and one of the best ways to attack it may well be to involve our young people. Activities like the above not only increase understanding of the litter problem; they also help shape student attitudes and behavior. ■

Vials A and B: 4 cm × 1.5 cm
Vials C and D: 4 cm × 2.5 cm
Vials E and F: 4 cm × 3.5 cm
Vials G and H: 3 cm × 3 cm
Vials I and J: 2 cm × 2 cm
Vials K and L: controls; no paper

The flies were then left to breed for three generations (a period of about 45 days). During this time, flies were neither added to nor removed from the vials.

In class, we computed algebraically the theoretical combinations to be expected over three generations, given random breeding. For the *P* generation, the possibilities for mating and their theoretical outcomes are as follows:

$WW \times WW$ = 100%pure winged
$WW \times ww$ = 100% hybrid winged
$ww \times ww$ = 100% wingless

The F_1 generation should therefore exhibit a 2:1 ratio of winged to wingless fruit flies.

The possibilities for mating and the theoretical outcomes that can occur after two generations (F_2), and in succeeding generations are as follows:

$WW \times WW$ = 4 winged, 0 wingless
$WW \times Ww$ = 4 winged, 0 wingless
$Ww \times Ww$ = 3 winged, 1 wingless
$ww \times ww$ = 0 winged, 4 wingless
$Ww \times ww$ = 2 winged, 2 wingless
$WW \times ww$ = 4 winged, 0 wingless
17 total 7 total

The F_2 generation and succeeding ones should therefore exhibit a 2:43 to 1 ratio of winged to wingless flies (or 17/24 to 7/24). It can be shown that equilibrium will be reached after a single generation of random mating, regardless of the initial composition of the population.

The live flies in each vial were counted after two and again after three generations. In the control vials, there was no significant difference between the observed populations and those predicted by simple Mendelian genetics. In some of the experimental vials, however, the story was different.

We could see that the winged flies were more likely to become stuck to the fly paper than were wingless flies. It seemed this should give the crawlers a clear breeding advantage over the winged insects.

When the live flies were counted in vials C–H, the observed ratios did not agree with those predicted for the control population. After only two generations, the number of wingless flies was greater than expected. A Chi-square test showed the difference to be significant at the 0.05 percent level. After three generations, there was a further increase in the ratio of wingless to winged flies. The difference was again found to be significant, this time at the 0.01 level. In vials G and H, this generation did not show any increase in wingless flies over that observed in the previous generation.

It was interesting to students that there was no observed difference between the control populations and those in vials (A, B), which had the smallest pieces of fly paper. ■

Author's note: This investigation was carried out with the cooperation of Lawrence Adelson and Julius Genachowski.

Making a game of population genetics

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The products of evolution and the adaptation of a population to its environment can be successfully demonstrated through museum and field trips. The mechanisms by which evolution occurs are, however, more difficult to convey to the beginning or nonbiology student. A discussion of mutation, natural selection, genetic drift, and migration—that is, population genetics—is predicated on an understanding of how genetic frequencies may vary.

Because there is not sufficient time in most nonmajor biology courses to develop an appropriate base for genetics, we have developed a game that illustrates the principles of population genetics and helps explain how evolution may occur through changes in gene frequencies. The game uses the basic concept of varying topography—a mountain—to represent the peak of adaptiveness.[1]

Materials needed per six students:

1. Diagram of a mountain—the "Peak of Adaptiveness" (Figure 1);

2. Two packs of cards: one (striped) represents environmental changes; the other (stippled) represents mechanisms that can alter gene frequency, such as natural selection and migration (Figure 2);

3. Markers of several colors (one per player) to represent different species;

4. Yellow sheets of paper (one per player) on which are listed possible hereditary characteristics (Figure 3);

5. White circular markers by which students keep track of each species' hereditary characteristics.

As shown in Figure 1, the "Peak of Adaptiveness" has six paths, representing six possible genetic states, ranging (bottom to top) from completely homozy-

[1] Wright, Sewall, "The Roles of Mutation, Inbreeding, Crossbreeding and Selection in Evolution." In *Evolution* by George E. Brosseau, Jr. Wm. C. Brown Publishers, Dubuque, Iowa. 1932.

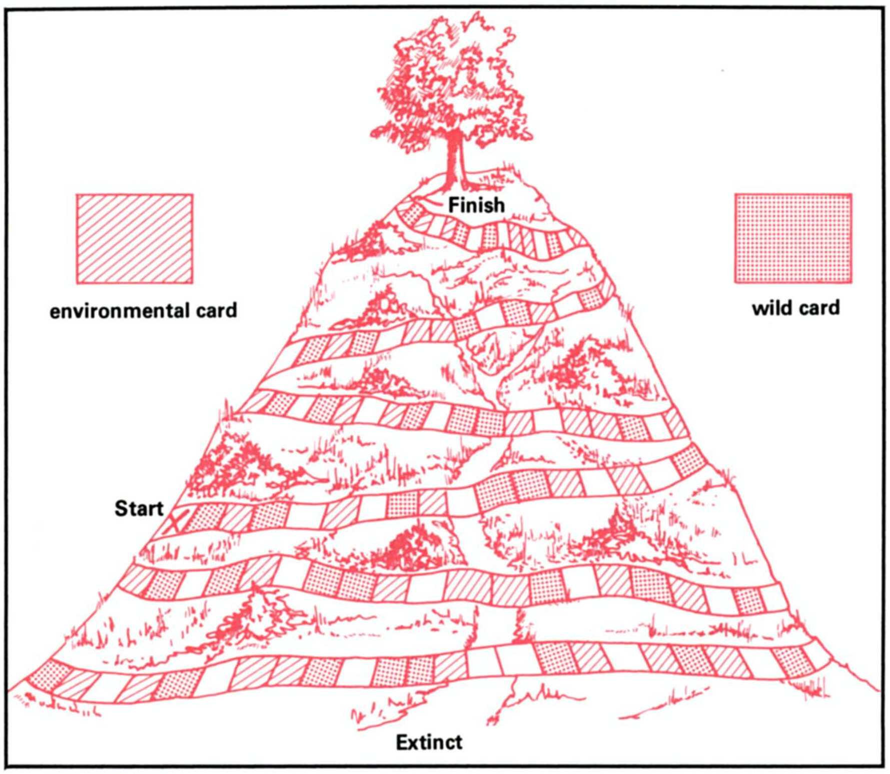

Figure 1. **Population genetics game uses mountain to represent "peak of adaptiveness."**

Wild Cards:

Migration
Several individuals have migrated into your population from another, resulting in a good deal of genetic exchange. You may change two of your homozygotes to heterozygotes. Your choice.

Natural Selection
Your population is large, so natural selection can maintain genetic plasticity. One of your homozygotes becomes a heterozygote. Your choice.

Genetic Drift
Your population is small, with a great deal of inbreeding. Due to chance alone, all of your genes become fixed or homozygous. If all your genes but one are homozygous, genetic drift has just resulted in your extinction. If not, change one of your heterozygotes to a homozygote.

Meiotic Drive
Some of your gametes are dying before maturation, so only certain parts of your genotype are transmitted to your progeny. Since your population is large, retreat only 2 spaces.

Mutation
A reverse mutation has occurred in your population. Change one of your heterozygotes to a homozygote.

Environmental Cards:

Dispersal
The local environment is quite stable. If heterozygous or recessive for dispersal, advance 4 spaces; if dominant, retreat 3 spaces.

Reproduction
An epidemic moved through the population killing many males. If homozygous polygynous or heterozygous, advance 2 spaces; if recessive monogynous, retreat 2 spaces.

Temperature
Another ice age is beginning. If heterozygous for temperature or homozygous for cold, advance 4 spaces; if recessive, retreat 4 spaces.

Light
The tree canopy is beginning to close over the forest floor. If shade-adapted or heterozygous, advance 2 spaces; if light adapted, retreat 2 spaces.

Food Resource
If you are homozygous recessive for food resource, you have just outcompeted any other player(s) also homozygous recessive for food resource. Send them all back 3 spaces.

Figure 2. **Sample "cards of play."**

gous to completely heterozygous for selected traits. In this game, any species that becomes completely homozygous for all selected traits may become extinct (thereby putting the player out of the game). On the other hand, the first player whose species becomes completely heterozygous achieves the "Peak of Adaptiveness" and wins the game.

Playing the game

To play, each student chooses a colored marker to represent his species, and places it on the board at the *Start* position. He then selects a folded piece of paper that designates the initial genotype of his species in terms of six characteristics, which include, for example, its light and moisture tolerance and its reproductive habits. This initial description (of clearly an imaginary creature) always includes two homozygous dominant, two homozygous recessive, and two heterozygous traits. Students keep track of these traits by placing white circular markers on the appropriate circles on their yellow sheets (Figure 3).

A student begins the game by rolling a die and moving the indicated number of spaces horizontally. If he lands on a striped or stippled square, he selects a card from the appropriately colored pack, and follows the instructions on the card. If he lands on a white square, no cards are drawn. A card is selected only once during each turn, regardless of where a student lands after following the instructions on a card.

Striped cards represent changing environmental conditions—for example, drought or epidemic. Because the ability of a population to tolerate changing environmental conditions (by having at least some viable offspring) depends on the plasticity of its genotype, heterozygotes are given the clear advantage in this game, and are most often instructed to move forward when the environment changes. Environmental cards govern only horizontal movement along a particular path. If a species reaches the end of a path without a change in gene frequency, it must return to the far left position at that level and begin again.

A change in the gene frequency of a population results in vertical movement to a new path and comes about because of selection of a "wild" card (stippled). "Wild" cards represent genetic mechanisms such as mutation, meiotic drive, or migration.

The game's purpose is to demonstrate the importance of genetic variability in the process of evolution. In nature, changes in gene frequencies occur at random with respect to the needs of the population, just as wild cards direct students regardless of their wishes. Changing gene frequencies may result in the population becoming better adapted to its environment or extinct.

It is important to note that most alleles are pleiotropic and the genetic traits used in the game are influenced by a great many alleles. The traits are represented as discrete entities only for illustrative purposes. The traits are continuous, and a single allelic change will exert only a small influence on the resulting phenotype or the adaptability of the organisms. If this change, albeit small, results in a slight reproductive advantage, the allele may appear with greater frequency in the population over time. It is the overall interaction among alleles and with the environment that results in the survival of the organism—so, at any instant in time, an individual may possess alleles with selective advantages and other alleles with disadvantages. The important end result is reproductive advantage—for it is this that decides which genotypes are passed to succeeding generations. ■

Hereditary characteristics	**Homozygous dominant**	**Heterozygous**	**Homozygous recessive**
Temperature tolerance	cold ●	temperate ●	tropical ○
Reproductive behavior	polygyny ●	intermediate ●	monogyny ○
Moisture tolerance	hydric ●	mesic ○	xeric ●
Food resources	omnivore ○	herbivore ●	carnivore ●
Light tolerance	shade-adapted ●	intermediate ○	light-adapted ●
Dispersal	widely-spread ○	intermediate ●	colonial ●

Figure 3. **Genetic trait sheet for marking initial genotype and recording changes as game progresses. (White circles indicate initial genotype: note that there are two traits indicated in each vertical column.)**

Ames window tunnel: appearance vs. reality

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Constructing an Ames window tunnel to illustrate illusion and perception in a lighted classroom can be a challenge. I make this statement after two years' work refining an Ames window as a demonstration activity in a science learning center.

An Ames window is a specially constructed, trapezoid-shaped window which rotates about a vertical axis. It was named after educator Adelbert Ames, Jr., who devised it to illustrate that what we think we see may not always correspond to reality. The original window was designed for viewing with both eyes in a darkened room from a distance of at least 6 meters, with a dim light uniformly highlighting the rotating window. An observer viewing the rotating window sees a sequence of images, which he interprets on the basis of previous experience. Most observers conclude that the window is oscillating from side to side about a vertical axis—an optical illusion due to the incorrect assumption that the window is rectangular.

To prevent students from knowing in advance what is actually happening, the experiment is set up within a tunnel. The tunnel also ensures that each observer will view the experiment from a similar vantage point.

Constructing the tunnel and Ames window

The following considerations are important in constructing the tunnel:

1. Tunnel dimensions should be practical for easy set-up and storage.

2. The interior of the tunnel should be finished with flat black paint.

3. All tunnel corners should be light-tight to exclude extraneous room light.

4. The light source within the tunnel should be of low illumination and hidden from the observer's sight when he or she is looking into the view port.

5. The tunnel view port should be located in line with the top of the horizontal divider between the upper and lower panes of the mounted Ames window.

6. The motor used to rotate the Ames window within the tunnel should operate smoothly at a constant speed of three to six revolutions per minute (RPM).

7. The motor housing and associated parts used in attaching the Ames window to the motor should be well-camouflaged within the tunnel so as not to distract the eye.

Materials:

14 square feet masonite, ⅛″
2 square feet plywood, ½″
16 feet pine strip, 1″ × 1″
16 feet external corner mold
20 wood screws, #5—½″
20 finish washers for #5 screws
1 quart flat black paint
10 feet, 18-gauge, two-wire electrical cable
1 night light with bakelite bulb cover
1 outlet tap
1 AC motor, 4 RPM
1 on/off line switch
1 automatic plug cap
1 alligator clamp
12 insulated staples

Instructions:

The tunnel was constructed using the specifications in Figure 1. The two sides, top, and bottom were constructed of masonite supported at the four internal corners with one-inch square pine strip. The four outer corners were covered with