happens to boundaries of territories if you remove the young?

5. What happens to the size of the territories if you gradually move the flowerpots closer together or further apart?

6. How do fish determine the boundaries of their territories? If rocks and plants are used, try moving them and observe what happens.

7. Try varying the size of flowerpots. Is one size more desirable to the fish than another?

8. Place a jar with a cichlid in it in the territory of another cichlid. What response does each fish give?

9. Using resources in the library, find examples of territoriality in other animals.

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DEMONSTRATING NATURAL SELECTION

Laboratory exercises used in basic biology courses to illustrate natural selection are relatively rare and usually time-consuming. Students in one of our beginning ecology courses generated a "hands-on" experiment that they felt gave them an excellent understanding of natural selection. We have modified the investigation and have used it with success in two lower-division biology courses.

The procedure is based on the fact that organisms which blend into their surroundings escape predation (Dice 1947; Kettlewell 1961; Keeton 1972). A chicken is placed in a cage that has a black floor with black gravel scattered on it. Corn kernels are scattered on the floor in known numbers. Some of the kernels are dyed black with food coloring so that they will blend into the black-gravel background. The chicken is left in the cage for a period of time and then removed. The number of kernels of both colors of corn are then counted and the data are analyzed to see if one color of corn was eaten (selected) in preference to the other.

In a typical experiment the students start in the morning with 1,000 kernels of corn of which 200 are dyed black and 800 are left a natural yellow color. The chicken is placed in the cage with the kernels for 12 hours and then the corn kernels are counted. Generally the chicken will eat about 100 kernels of which very few, if any, are black. The students can thus observe that the predator will indeed select against the obvious yellow kernel, thereby selecting for the concealingly colored black kernel.

The students can change the experimental design and increase the complexity to give them more insight into evolutionary processes. One class of students decided to use three colors of corn to simulate a single gene, two-allele system of incomplete dominance. Corn kernels were dyed green and black, and it was decided that the phenotypic expression of the genotypes were to be yellow *(YY)*, green *(Yy)* and black *(yy)*. The experiment was to be carried out over two consecutive days with the selection process occurring during the normal feeding time of the chicken. A total of 1,000 corn kernels was scattered in the cage at 8:00 A.M. (lights on) with beginning ratios (numbers) of kernels of .49 (490) yellow *(YY)*, .42 (420) green *(Yy)*, and .09 (90) black *(yy)*. At 6:00 P.M. on the first day the chicken was removed from the cage as was all the corn and gravel. New gravel and a reconstituted corn kernel sample of a 1,000 kernels (with the same ratios of colors as before) were placed in the cage with the chicken. The lights were turned out until 8:00 the next morning. At the end of both days the corn kernels were separated from the gravel and counted by different groups of students. The raw data obtained were mimeographed (table 1) and given to all the students.

Table 1. Number of corn kernels of different colors remaining after 12 hours of predation by a chicken. Kernels were placed on a black gravel background.

	Yellow *YY*	Green *Yy*	Black *yy*	Total
*Before selection	490	420	90	1000
After selection, day 1	409	410	85	904
After selection, day 2	400	419	87	906

*Number of corn kernels before selection was same on days 1 and 2.

Laboratory reports with data analysis were required. A large number of students used a chi-square test, that had previously been discussed in class, to analyze the data (Sokal and Rohlf 1969). The students hypothesized that the seeds left (observed) should be in the same frequency as at the start (expected). Therefore, the deviation between the observed and expected number of kernels would be due to random chance rather than a causative factor (that is, natural selection).

In analyzing the data in this manner (table 2) the students found that the deviations between expected and observed during the first day were due to random chance ($X^2 = 5.18$; $P > .05$; d.f. = 2) and, therefore, that no selection had occurred. This came as a surprise to the students for they felt the observed data really differed from that expected (tables 2 and 4).

The students thus had a practical lesson in how biologists use probabilities and statistics to solve problems. They

Table 2. Chi-square analysis of different colored kernels of corn remaining after 10 hours of predation by a chicken. Expected ratios, .49 yellow: .42 green: .09 black. Raw data in table 1.

	Yellow *YY*	Green *Yy*	Black *yy*	*Total*
	DAY 1			
Expected	442.96	379.68	81.36	904
Observed	409	410	85	904
X^2	2.6	2.42	0.16	5.18
	DAY 2			
Expected	443.94	380.52	81.54	906
Observed	400	419	87	906
X^2	4.35	3.53	0.37	8.25
	COMBINED			
Expected	886.90	760.20	162.90	1810
Observed	809	829	172	1810
X^2	6.84	6.23	0.51	13.58

$X^2_{.05[2]} = 5.99$

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also saw that selection for the black seeds had occurred during the second day, for the deviations between the observed and expected numbers were statistically significant and not due to random chance ($X^2 = 8.25$; $P < .025$) (table 2). Some of the students combined the data from both days and analyzed it as one experiment ("combined," table 2). This analysis clearly showed that selection had occurred. It also provoked a great deal of discussion as to whether or not combining the data was permissible.

Other students based their analyses on seeds eaten (table 3). In this analysis the difference between the number of seeds eaten (observed) and seeds expected to be eaten was highly significant ($P < .005$) for both days. Therefore, natural selection had operated with the selecting agent (chicken) selecting for the black kernels of corn. The students were cautioned that although this method of analysis was correct it could not be used in field analyses unless the investigator knew for sure that the missing organisms (corn kernels) had been eaten.

Table 3. Chi-square analysis of different colored kernels of corn eaten during 12 hours of predation by a chicken. Expected ratios, .49 yellow: .42 green: .09 black. Raw data in table 1.

	Yellow *YY*	Green *Yy*	Black *yy*	*Total*
DAY 1				
Expected	47.04	40.32	8.64	96
Observed	81	20	5	96
X^2	24.52	10.24	1.53	36.29
DAY 2				
Expected	46.06	39.48	8.1	94
Observed	90	1	3	94
X^2	41.92	37.51	3.21	82.64
COMBINED				
Expected	98	84	18	200
Observed	171	21	8	200
X^2	54.38	47.25	5.55	107.18

$X^2_{.05[2]} = 5.99$

In this experiment the students observed how natural selection immediately changes the frequency of alleles, genotypes, and phenotypes in the population of corn kernels. They also were able to calculate, by using the Hardy-Weinberg theorem, how the selection created change in these frequencies in succeeding generations (table 4). After selection the frequencies of the genotypes had changed and the frequencies of the alleles can be determined by using the formulaes

$$f(Y) = f(YY) + \tfrac{1}{2} f(Yy); \text{ and}$$

$$f(y) = 1 - f(Y).$$

If it is assumed that the conditions of Hardy-Weinberg theorem are met (Ehrlich and Holm 1963), particularly that no more selection occurs, then the frequency of colors of corn kernels in the next generation can be determined by expanding the binomial, $(fY + fy)^2$. From this analysis they were able to determine how the genotype of a population changes (see Dobzhansky 1961).

In discussion of the experiment it has been found that students are impressed with the close relationship between what they observe to happen in the laboratory to what has been observed to happen in nature. The investigation of industrial melanism in certain species of moths is one the students particularly feel coincides closely with the experiment (Kettlewell 1961). In general, the students realize that the experiment is an artificial situation and have made suggestions as to how it can be made more natural (for example, use of natural corn kernel colors).

Table 4. Frequencies of alleles and genotypes of colored corn kernels before and after selection, and for the next generation as predicted by Hardy-Weinberg theorem. Raw data in table 1.

	Alleles		Phenotype (Genotype)		
			Yellow	Green	Black
	Y	*y*	*YY*	*Yy*	*yy*
DAY 1					
Before selection	.70	.30	.49	.42	.09
After selection	.679	.321	.452	.453	.095
[a]Next generation			.461	.436	.103
DAY 2					
Before selection	.70	.30	.49	.42	.09
After selection	.673	.327	.442	.462	.096
[b]Next generation			.453	.440	.107
COMBINED					
Before selection	.70	.30	.49	.42	.09
After selection	.676	.324	.447	.458	.095
[c]Next generation			.457	.438	.105

[a]$(.679Y + .321y)^2$
[b]$(.673Y + .327y)^2$
[c]$(.676Y + .324y)^2$

Students also suggested a variety of other modifications in the experiment. Obvious ones were to change the "predator," the "prey," and the initial frequencies. Some students suggested determining whether or not the amount of selection varied with time. This could be investigated by simply not reconstituting the corn kernels and counting them over a longer time period. The students could depict the data obtained in graphical form; this has been found to help them considerably in their analysis of the experiment. It would also be of interest to determine the difference in amount of selection with change in degree of fidelity of background matching (for example, removal of gravel; see Norris and Lowe [1964] for others).

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