Introducing Mendelian Genetics Through a Learning Cycle

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A primary goal of biology instruction is to engage students in investigations that are real to them so they learn specific biological concepts and theories as well as develop an understanding of the nature of scientific processes and develop skill in using those processes (e.g. American Association for the Advancement of Science 1989; National Research Council 1990). One instructional method that has been found to be successful at engaging students in meaningful inquiries is the learning cycle. Learning cycles consist of three instructional phases: exploration, term introduction, and concept application (Atkin & Karplus 1962; Karplus & Thier 1967; Lawson 1988, 1991; Lawson, Abraham & Renner 1989; Science Curriculum Improvement Study 1974). During exploration, students investigate new phenomena that may raise questions and may enable them to discover patterns in those new phenomena. Term introduction allows teachers to introduce biological terms related to the discovered patterns, while concept application activities enable students to attempt to apply newly constructed concepts to new contexts to broaden and deepen their understanding.

Student perceptions of differences between learning cycle and traditional verification labs were identified by Abraham (1982). Using a Q-sort instrument, chemistry students ranked 25 statements according to how accurately they characterized their lab activities. The following statements were ranked significantly higher by the verification lab group:

- The instructor is concerned with correctness of the data.
- The instructor lectures to the whole class.
- During the lab, students record information as requested by the instructor.
- Experiments help students develop skill in the techniques or procedures of chemistry.
- Students usually know the general outcome before doing the experiment.

The following statements were ranked significantly higher by the learning cycle lab group:

- Students are asked to design their own experiments.
- The instructor requires students to explain why certain things happen.
- Lab reports require students to use evidence to back up their conclusions.
- Students propose their own explanations for observed phenomena.

Thus the verification labs were characterized by correctness, lecture and the development of lab techniques, while the learning cycle labs were characterized by experimentation, explanation, observation and the use of evidence.

Effectiveness of the learning cycle method has been assessed in several studies since it was first proposed in the late 1960s in several contents and at virtually all educational levels. Space does not permit a review of these studies here, but a review of more than 60 such studies can be found in Lawson, Abraham and Renner (1989). The Lawson, Abraham and Renner review concluded that the learning cycle method is very effective in terms of improving students' attitudes, achievement and scientific reasoning skills. Perhaps one of the most important of these studies was conducted by Renner et al. (1973). In the study, elementary science students who had used the learning cycle activities contained in the Science Curriculum Improvement Study (SCIS) program for at least four years were compared to students who had been taught textbook science for the same length of time. SCIS students were found to have greater skill in using the processes of observing, classifying, measuring, experimenting, interpreting and predicting. The study then looked at the possible transfer of these skills to other areas of the curriculum. Scores on the Stanford Achievement Test administered during the fifth grade showed the SCIS students' scores to be significantly better than those of control students in mathematics applications, paragraph meaning and social studies skills—all areas that require the application of reasoning skills. In another important study, Brown, Weber and Renner (1975) found no significant difference between the attitudes of the SCIS students and those of professional scientists.

The learning cycle has many advantages over traditional instructional approaches, especially when the development of thinking skills is an important goal. Because many studies have shown that a large proportion of the secondary and college population have poorly developed thinking skills, it seems reasonable to conclude that the learning cycle deserves more widespread implementation in science classrooms.

How can the learning cycle method be used to provoke student inquiry into concepts of Mendelian genetics? A recently developed learning cycle designed to do just that starts by posing the descriptive question, "How do characteristics vary within species?" Students intuitively know that all members of a species share many characteristics, but all members are not identical. Variations in characteristics exist, but is

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there a pattern to that variation? And if so, what is it? To answer these questions, students explore the characteristics of a variety of mollusks (sea shells) and color frequencies of kernels on ears of Indian corn. This exploration allows students to discover a pattern of variation in which few shells are found at the extremes of the range in variation but many are found in the center of the range. The discovery allows the teacher to introduce the term *normal variation* and to raise the causal question, "What might be happening in nature to cause this pattern of normal variation?" The 1:2:1 pattern of kernel color variation on some ears of Indian corn looks somewhat normal, but the 2:1 and 1:1 ratios of others are not at all normal. These conflicting observations raise the corresponding question, "What might be causing these patterns?" Students generate alternative hypotheses to try to answer these questions and then try to put some of their hypotheses to an initial test. Along the way, the teacher has an opportunity to introduce several principles of Mendelian genetics, and the students have opportunities to try to apply them to explain their observations.

Details of this learning cycle will be presented in two sections. The first section, titled *Student Materials*, includes an introduction, a materials list, a procedure to guide the student inquiry, and a set of application questions to extend the lesson. The second section, *Teacher Materials*, includes content-related background and teaching tips for each phase of the learning cycle. The lesson is one of a collection of 38 learning cycles developed for use in introductory biology classes (Lawson 1994).

Student Material

How Do Characteristics Vary Within Species?

When organisms in a particular environment share many characteristics, interbreed in nature, and produce fertile offspring, they are said to be all of one kind—one species. But how similar are all the members of a single species? Obviously they are not all identical. Humans are all one species yet differences among us in skin color, eye color, height, weight, and so on are obvious. Or, for example, suppose you find two trees that appear the same except one has leaves that average 5 cm across and the other has leaves that average 3 cm across. Are the trees still of the same species? In what ways can individuals of a single species differ? Are these differences systematic or random? What are possible causes of these differences?

Objectives

1. To investigate and discover patterns of variation within a variety of species.
2. To learn to graph data that organize and summarize within species variation.
3. To propose and initially test alternative hypotheses to explain the observed patterns of variation.

Materials

assorted shells
pairs of dice
coins
metric rulers
ears of Indian corn

Procedure

1. The first question we would like to address is this: *What is the pattern(s) of variation of characteristics within species?* In order to answer this question select a lab partner and obtain a large sample of several different kinds of shells.
2. Sort the shells into groups that you think may represent separate species. List characteristics used for your sorting.
3. How many species do you think are present? Explain.
4. Select one species that exhibits differences that can be observed and/or measured.
5. Collect as many individuals of that species as you can throughout the lab. If possible, your sample should contain at least 100 specimens.
6. For each specimen, determine the value of the characteristics chosen. Record the frequency of occurrence of the values in the table below.
7. What characteristic did you measure?
8. Plot your data on a frequency graph. Title the graph and label both axes.
9. What is the average, median, mode and range of your data? (Note: Your instructor may want you to skip this step until you have completed Questions 10–15.)
10. The graphs for each species will be collected, put on the board, compared, and contrasted. The graphs should enable us to answer the question, *What is the pattern(s) of variation of characteristics within species?* and should raise additional questions such as *What causes the observed pattern(s) of variation?* To help answer this question do the next activity with the dice.
11. Take two die and roll them. Note the numbers that turn up on each dice. Add these numbers and record the sum. Repeat this 100 times and plot the data on a frequency graph. Compare this graph with the previous graphs. Do the patterns suggest a mechanism for the observed variation within species? Explain.
12. Obtain an ear of Indian corn. Count the number of kernels of each color on the ear. How many kernels of each color were there? Plot these data on a frequency graph. Approximately what ratio of colors did you find?
13. Take two coins and flip them 100 times. Note the number of times a flip results in one head and one tail, two heads, two tails. Record these numbers and plot them on a frequency graph.
14. Compare your graphs with your previous graphs. How are they similar, different?
15. Compare your results to those of other students. Do these data suggest a cause for the observed patterns of variation? Explain.

Table 1. Frequency of occurrence of values.

Values	*Frequency*

Application Questions

1. What is the difference between a sample and a population?
2. How could you obtain a representative (unbiased) sample of the population of students at your school?
3. Genotype refers to the collection of genes in an individual's body cells. Each body cell has the same collection of genes—the same genotype. Sex cells, or gametes, have only ½ of the genes of a body cell. Given the following genotypes, how many different kinds of gametes are possible? Assume that in this case the genes assort themselves independently of one another (i.e. there is no linkage).

Parental Genotypes:

a. Dd b. DdEe c. DdEeff

4. What is the probability of getting the gamete de from each of the following genotypes?
   a. DDEe b. Ddee c. ddee
5. What is the probability of each of the following sets of parents producing the given genotypes in their offspring?

	Parents	*Offspring Genotype*
a.	DD × Dd	Dd
b.	Dd × Dd	Dd
c.	DdEe × DdEE	DdEe
d.	DdEe × Dd Ee	DDEE

6. In cats, the gene for lack of color is recessive to the gene for normal coloration. If two heterozygous (means they have one of each kind of gene) cats have kittens,
   a. and a kitten has normal coloration, what is the probability that it is a carrier of the recessive gene?
   b. What is the probability that a kitten will lack color?
7. In certain bean plants, the gene L for large pods is dominant over the gene for short pods (1).
   a. If both individuals are heterozygous, what will be the genotypic and phenotypic ratios of the offspring?
   b. If a homozygous (i.e. both genes are the same) long and a homozygous short are crossed, what will be the genotype and phenotype of the offspring?
8. Eye color of the imaginary Grizzly Gronk population of the White Mountains varies. Some Gronks have purple eyes, some have white eyes, and some have orange eyes. Professor Greengenes has discovered that whenever two purple-eyed Gronks mate, they always produce purple-eyed offspring. Likewise, whenever two orange-eyed Gronks mate, they always produce orange-eyed Gronks. But when white-eyed Gronks mate, they are able to produce offspring with three colors of eyes.
   a. Use Mendelian theory to explain how eye color is determined among Gronks (i.e. what is the genotype of the white-eyed Gronks and how can they mate to reproduce offspring of all three colors of eyes?).
   b. Use your theory to predict the phenotypic ratio of offspring if purple-eyed and white-eyed Gronks were mated.
9. Assume that beak color in a population of birds is determined by one pair of genes that produces phenotype color variation from brown to white. A single allele (B), which makes up 50% of the alleles in the population, produces brown pigment such that a bird with the BB genotype will have a dark beak. A Bb bird will have a tan beak and a bb bird will have a white beak (i.e. no pigment is produced). Given a randomly mating population of birds, what phenotypic ratio of beak colors would you expect in the population? Show your work.
10. What form would the frequency distribution of shades of beak color look like if beak color were determined by the additive effect of six or more gene pairs? (No calculation needed.) Why?

Teacher Material

How Do Characteristics Vary Within Species?

Background Information for the Teacher

Observable characteristics are the product of an organism's genetics and environment. When continuous varying population characteristics such as height or weight of individuals are plotted on a frequency graph, the values often distribute themselves in a "bell-shaped" or normal distribution. This pattern can be partially explained by assuming that the characteristic under consideration is determined by multiple pairs of genes that are passed from parents to the offspring with each gene (allele) independently combining with others in a random fashion, much like the sum of the numbers on two dice rolled on a table.

Observed patterns of either-or characteristics such as sex, handedness, tongue-rolling ability, or kernel color on ears of Indian corn can be explained by assuming that the offspring characteristic is determined by a single pair of genes (or very few genes) that somehow combine their effects in the offspring (blending inheritance) or, in some cases, one gene of the pair may dominate the other to produce its effect as though the other gene were not present. Combinations of dominant and recessive gene pairs result in simple ratios of offspring characteristics (e.g. 1:1, 3:1, 1:0) that depend upon the precise combination of dominant and recessive genes.

Gregor Mendel is normally credited with inventing these concepts of inheritance. They can be summarized by the following eight postulates of classical genetics theory:

1. Inherited characteristics are determined by particles called *genes*.
2. Genes are passed from parent to offspring in cells called *gametes* (egg and sperm).
3. An individual has at least one pair of genes for each characteristic in each cell except in the gametes.
4. Sometimes one gene of a pair (an allele) masks the expression of the second allele (*dominant/recessive*).
5. During gamete formation, paired genes separate. A gamete receives one gene of each pair.
6. There is an equal probability that a gamete will receive either one of the genes of a pair.
7. When considering two pairs of genes, the genes of each pair *assort independently* to the gametes.
8. Gene pairs separated during gamete formation *recombine randomly* during fertilization.

You may wish to provide these eight postulates to your students at the conclusion of the term introduction phase as a summary of the major ideas. Do *not* introduce them prior to that time as doing so would restrict student thinking and detract from the naturally motivating exploratory nature of the activity.

Advance Preparation

Assorted shells are available from Delta Education (P.O. Box 915, Hudson, NH 03051-0915, (800) 258-1302, FAX (603) 880-6520). Indian corn is available from Carolina Biological Supply Company (Gladstone, OR 97027, (800) 547-1733, FAX (503) 656-4208, or 2700 York Rd., Burlington, NC 27215, (800) 334-5551, FAX (919) 584-3399). Ears of corn with 3:1, 1:1 and 1:2:1 ratios of colored kernels should be purchased. Remove the labels before the ears are given to the students.

Teaching Tips

Exploration

1. Use the introduction from the student material as a basis for introducing the lesson. Then have each group of two or three students obtain a bag of 300–400 shells of 8–10 species.
2. Although students may need suggestions on what sort of shell characteristic to measure (e.g. length, width, # of ribs, shades of color), encourage groups to select different characteristics. You may need to go over definitions and methods of calculating or identifying the mean, median, mode and range of their distribution. Or you may decide to omit this step or assign it later, perhaps as a homework assignment.

Term Introduction

3. After the graphs have been drawn, have one member of each group tape their graph to the board so that all the graphs can be seen and discussed. Ask the students to try to state how the graphs are similar/different. Is there a similar pattern displayed by most of the graphs? The students should note that most graphs show that there are few shells with values at the extremes of the ranges but many near the middle. When this pattern is noted, tell students that this pattern is referred to as a *normal distribution* because it is what normally occurs when the values of continuous variables such as the ones measured here are plotted. Write the phrase *normal distribution* on the board. Ask them to think of other characteristics that might show normal distributions when similarly graphed.
4. Now pose the causal question, "What might be occurring in nature to cause values to be distributed normally?" Allow students to suggest alternative explanations. Do not hesitate to call on students who have not raised their hands. In fact, when attempting to elicit alternative hypotheses, it is best to call on students at random to elicit a broad range of ideas. Treat the process of alternative hypothesis generation as a brainstorming session in which all ideas are initially accepted without critique from you or from other students. This practice encourages student participation. The testing of ideas should come only after all the possibilities have been generated. Alternative hypotheses should be listed on the board. Ideas will typically center around environmental effects, e.g. the big shells got eaten and the little shells got smashed by waves so the middle-size shells survived best. A student may suggest a genetic cause but most likely

will not be able to explain how genetics could lead to a normal distribution. This is OK because the dice activity will be used shortly to help explicate the process.

5. Graphs that do not show normal distributions should also be discussed. Have the students speculate on why these non-normal patterns emerged. Do not press for agreed upon explanations at this point. Go on to Procedure Step 11 and ask students to think about how the dice-rolling activity might be related to the shell distributions.
6. After the dice-rolling activity is complete, have one graph from each group placed on the board. In a class discussion compare graphs and note the similarity in pattern. Again, a normal distribution will be seen. Ask again why the dice rolling seems to be related to the shell situation.
7. Go on to Procedure Steps 12–13. Again compare data and again ask students how the corn, dice and shell situations appear similar/different.
8. To introduce the general postulates and terms involved in classical gene theory to help explain the observed data patterns, ask students to imagine that one dice is analogous to the female egg and the other to the male sperm. Imagine that the numbers on the dice represent factors or *genes* that somehow dictate observable characteristics in offspring—the values of those characteristics being determined by the sum of the numbers shown in the combined egg and sperm. If one imagines that six possible "types" of sperm and six possible "types" of eggs (i.e. 1, 2, 3, 4, 5, 6) exist, then there are 36 total combinations of sperm and egg types: 1 combination totaling 2 (1 + 1 = 2); 2 combinations totaling 3 (1 + 2 = 3; 2 + 1 = 3); 3 combinations totaling 4 (1 + 3 = 4, 2 + 2 = 4, 3 + 1 = 4); 4 combinations of 5; etc. It helps if you draw the six hypothesized sperms on the board and the six hypothesized eggs. Use the arrows from the sperms to the eggs to represent possible combinations. Plot these combinations on a frequency graph to show students that a normal distribution results, as was the case for the shells. Thus, if we assume multiple genes exist and behave as the dice, then we have a theory to account for the observed normal distributions.
9. We now have a theory that appears to explain why we found the normal distributions for the continuously varying characteristics. But how can the 3:1, 1:2:1 and 1:1 corn kernel distributions be explained? Do we need a new theory or can the present theory be somehow modified to work? If you pose this question and stand back and let your students ponder for awhile, some student (one who most likely has heard the terms dominance and recessive before) will invariably come up with the idea that the corn may have fewer genes and that one may be dominating the expression of the other(s). When this happy idea strikes, you have an opportunity to explicate the process and introduce the terms *dominance*, *recessive* and *blending inheritance* to the entire class. The coin toss activity can be used as an analogue, much like the dice activity was used previously. The terms *allele*, *genotype* and *phenotype* can also be introduced.
10. You should emphasize the theoretical nature of the principles introduced in the sense that we really have not observed genes behaving in these ways and controlling various characteristics. Therefore, we do not have direct evidence that genes exist. But we can imagine that they do exist and we can indirectly argue that *if* they do exist, and *if* they behave as claimed, *then* specific patterns of characteristics should be observable (e.g. normal distributions, 3:1, and 1:2:1 ratios). Because these patterns were observed, we *therefore* have at least initial indirect evidence to support the theory. Making an argument of this if . . . then . . . therefore form will help some of your students begin to understand the hypothetico-deductive nature of modern science.

Concept Application

11. For concept application, patterns of inheritance should be discussed in other organisms (e.g. pea plants, chickens, cattle) and the application questions that appear at the end of the investigation should be assigned. Subsequent learning cycles may also enable students to apply some of the concepts introduced here (Lawson 1994).

Biological Terms
normal distribution
genes/alleles
independent assortment
random recombination
genotype
phenotype
dominant
recessive
blending inheritance

Thinking Skills
accurately describe nature
state causal questions
create alternative hypotheses
generate logical predictions
organize and analyze data
draw and apply conclusions

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