Chapter 1

Short Investigative Exercises Designed to Get Students to Think

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Introduction

The primary objective of the following short exercises is the development of reasoning skills. They are designed for students who have little or no background in science. The time required to perform and to prepare each exercise is given below. The exercises are part of the curriculum of a special course in biology for students in the Educational Opportunity Program (EOP) at the University of Washington. The course is one component of a comprehensive program designed to prepare EOP students for standard courses in physics, chemistry and the various biological sciences. Students in the program are interested in pursuing a career in the health sciences or in the natural sciences. From our experience in working with these students we have observed that initially many share some general academic weaknesses: (1) weakness in mathematical and verbal skills; (2) lack of experience on which to build the abstractions of science; and (3) lack of confidence in being able to solve problems through their own reasoning. To remedy these difficulties, instruction must focus on concrete experiences with scientific subject matter, followed by homework assignments and discussion. The two guiding principles in developing the curriculum for our courses have been that concepts and reasoning should be addressed together, and abstraction and generalization should be preceded by direct experience. (For details of the curriculum see McDermott, Piternick and Rosenquist 1980).

Exercise I—Classification: Relationships of Organisms

Introduction

The objectives of this exercise are observation, comparison of organisms, and the design of a hierarchical system of classification based on valid criteria. This exercise is appropriate for students who have little or no background in biology, but it can be modified for more advanced students by including additional material. The exercise is based on the Learning Cycle, the three phases of which are exploration, concept introduction and concept application. During the exploration phase students explore new materials and new ideas with minimal guidance. During the concept introduction phase, the instructor encourages students to formulate a concept or principle based on the exploration activities. In the concept application phase the new concept is applied to additional examples. (See Karplus et al. 1977 and Lawson 1975 for details of the application of the Learning Cycle in biology instruction.) About one hour should be used for observation and one hour for discussion and application of the new concepts. The instructor's preparation time varies from two to three hours, depending on the number and type of organisms used.

Student Materials

In this unit you will study two important topics: 1) the characteristics used to group living things and 2) man's place among other living organisms.

A. *Objectives:*

1. To observe a variety of living organisms
2. To discover similarities and differences among these organisms
3. To develop *your own system* of grouping these oganisms
4. To learn some of the characteristics used by scientists today to group organisms
5. To compare the classification you invented with the accepted classification
6. To determine man's place in nature

B. *Procedure*

1. In the laboratory you will find a number of living organisms. A card placed near each organism will show a code letter and some numbered questions. Record the code letter in your notebook and answer the questions in writing.
2. Make simple sketches in your notebook. This will help you recall what you see.
3. Discuss with your partner:
   a. Is this organism an animal? Why or why not?
   b. Is it a plant? Why or why not?
   c. Which organism in the demonstration seems to be its closest relative and what are the reasons for your choice?
4. Write your answers to item #3 in your notebook.
5. After you have completed your observations, participate in a class discussion and correct your own records if necessary.
6. Study the models of various animals. Determine which one fits *you* most closely and state your reasons for your choice.
7. Determine which of the models fit any of the code letter animals you studied, and why. Discuss the reasons for your choice with your partner and write the answer in your notebook.

C. *Evaluation*

Turn in your notebooks on the due date with all of the answers and sketches.

Instructor's Materials

Use live animals if possible. Include a few organisms that are of special interest, e.g. an insectivorous plant, a tarantula, a termite colony, a pet snake, and a few "mystery creatures", e.g. a meal worm pupa, a sedentary polychaete with brightly colored tentacles, a tunicate. Scatter the representatives of the

Phylum Chordata, Phylum Mollusca and Phylum Arthropoda. If they are grouped together in the demonstration, students get too much help in devising their system of classification.

The organisms we use are listed below, but vary the list to suit your own objectives.

1. Yeast, dry
2. Several kinds of mushrooms
3. Several kinds of lichens
4. Filamentous green algae/and some brown algae
5. Several kinds of mosses
6. Several kinds of ferns
7. Branches of three or four different conifers
8. Potted plants, some in flower, some with berries; or flowering branches and branches with berries; one heather branch without and another with flowers.
9. Sea anemone
10. Earthworm
11. Polychaete
12. Chiton
13. Clam and/or mussel
14. Snail and slug
15. Tarantula and molted integument
16. Garden spider
17. Cricket
18. Fly
19. Termite colony
20. Centipede
21. Crayfish and molted integument
22. Isopod
23. Mealworm life cycle stages, in separate containers
24. Guppies
25. Frog
26. Salamander
27. Lizard
28. Turtle
29. Gerbil and other small mammals

Sample Questions—*On cards with the organisms:*

2. Mushrooms—"What feature that is found in plants is absent in these organisms?"
3. "Compare the green 'threads' closely with typical plants. In what respect are they different?"

7. "Are all of these flowering plants? Justify your conclusion."
15. "What is the relationship between the animal and the other object in the container?"
20. "Why is this not a 'worm'?"
22. "Why is this not an insect?"

Procedure

1. *Exploration phase.* Students observe the organisms, answer questions on the cards displayed with the organisms, and discuss their ideas with a partner and/or the instructor.
2. *Concept introduction phase.* Students present their ideas on criteria to determine the relationship between the organisms to the whole class. The instructor must accept *all* points of view and slowly guide the class to distinguish useful criteria (e.g. presence of a vertebral column, exoskeleton, jointed appendages) from useless ones (e.g. color, living in water, presence of wings.)
3. *Concept application phase.* In the concept application phase students examine some models of animals, but diagrams can be used instead. (We use models of amphioxus, an insect, and annelid, a nematode, a mollusk and a coelenterate.) They are asked to select the one which represents the structure of their own body. The initial response is "none", but after some discussion, they agree that the amphioxus model "fits". The instructor then asks what changes should be made in order to have the model represent only the Class Mammalia. After this has been done, the model of an insect is changed to fit *any* class of the Phylum Arthropoda.

Exercise II—Control of Variables: Enzyme Action

Introduction

The objective of this exercise is to introduce the design of controlled experiments. In addition, it provides the opportunity for self-regulation. Self-regulation involves the student in analyzing a problem situation, considering tentative solutions, evaluating their effectiveness, and using new approaches if necessary. (See Karplus et al. 1977 for a detailed discussion of teaching for self-regulation.) The exercise is appropriate for students at the introductory level who have had little or no laboratory experience. It takes about two hours to do the experiment, discuss the results, improve the experimental procedures, repeat the experiments and revise the conclusions. One hour is sufficient to assemble the experiment, make the solutions and test them.

Student Materials

Students are prepared for the exercise by a short reading assignment on structure and function of the digestive system. Two or three days before the exercise they are given a homework assignment asking them to plan experiments to answer the following questions:

1. Can the enzyme pepsin catalyze the breakdown of protein if it is in a test tube, or does it act only in the stomach?
2. Does the enzyme pepsin catalyze the breakdown of starch and/or fat? Does it catalyze the breakdown of the proteins in milk?
3. Is the enzyme active when there is no hydrochloric acid present? Does hydrochloric acid break down protein if there is no enzyme?
4. Does the enzyme act at temperatures other than body temperature? If so, how do changes in temperature affect its activity?
5. How far can the enzyme be diluted before it loses its activity?

Instructor's Materials

Equipment and materials for pepsin experiment:

For the class:
Waterbaths (37°C and 70°C) with test tube racks

For each group of four students:
One test tube rack

Ten test tubes

One wax pencil

30 ml 1% pepsin solution and 5 ml plastic syringe (or pipette)

30 ml 1% HCl and 5 ml plastic syringe (or pipette)

15 ml hard-boiled egg white homogenized in water (50 gm/100 ml) and medicine dropper

20 ml distilled water and 5 ml plastic syringe (or pipette)

For the group answering question 2:
Homogenized egg yolk

Cornstarch suspension

Cream

Whole milk

Skimmed milk

For the group answering question 5:
1 ml plastic pipettes

Equipment and materials for catalase experiment:

For each group of four students:
One test tube rack

Six test tubes with 1 ml hydrogen peroxide in each

Wax pencil

Small pieces of raw, frozen and boiled liver; small pebbles for control tube

Procedure

1. At the beginning of the laboratory period divide the class into four groups, assign question #1 and one of the other questions above to each group.
2. Explain how the solutions were prepared. Instruct students to test enzyme activity at body temperature (37°C) using 2 ml of the 1% pepsin solution, 2 ml 1% HCl and 1 ml of egg white substrate (10 drops).
3. Respond to specific questions by students as they plan their own experiments, but do not design the experiment for them.
4. Allow about 45 minutes for planning and doing the experiments.

Discussion

1. Start with the results of testing the digestion of starch, fat and milk proteins. Interpret the results. Have students report the details of their experimental procedure and ask the other groups to evaluate them, e.g.: "Was anything changed besides the substrate? At what temperature did you do the experiment?"
2. Next discuss the results of testing the enzyme's activity without the acid and the effect of the acid without the enzyme. Students will usually prepare the tubes with 2 ml of enzyme (or acid) solution plus the egg white substrate, but not add 2 ml of water to keep the enzyme (or acid) concentration unchanged. The class should be led to recognize that more than one change was made in the experimental system and to suggest how the experiment can be improved. Repeat the experiment and compare the results.
3. Students are now prepared to evaluate the results of testing enzyme activity at various dilutions. Was the enzyme diluted to one-half, one-fourth, or one-tenth strength in a separate tube and was 2 ml of this solution used? or was it "diluted" by adding 1 ml, 1/2 ml, 1/10 ml, respectively, instead of 2 ml? If 1 ml instead of 2 ml was combined with 2 ml of HCl and 1 ml of egg white, was the enzyme concentration in this tube actually half of the concentration in the control tube? If necessary, improve the experimental design, repeat the experiment and compare the results.
4. When testing the enzyme at various temperatures, the students will usually mix all solutions *at room temperature* and then transfer them to the water baths or the refrigerator. Nevertheless, the class accepts the conclusion that pepsin is active at 70°C and acts rapidly at 5°C. Repeat the experiment with a thermometer in each tube which students read at 30-second intervals. Then have the class improve the experiment, repeat it and revise the conclusions.

Application of the concept of enzyme action

During the next class meeting we test raw, frozen and boiled liver for activity of the enzyme catalase. Have students first *predict* the effects of freezing and boiling on catalase activity and then test their predictions. Ask them what substance (or substances) in the pepsin experiment is analogous to the oxygen bubbles seen in the catalase experiment and be prepared for some interesting answers.

Exercise III—Genetics: Understanding Independent Assortment, Polygenic Inheritance and Sex-Linked Inheritance

Introduction

The objectives of this exercise are to teach the students to make models of several genetic crosses, to use the models to obtain progeny, and finally to *predict* progeny ratios. It is designed for beginning students with little or no background in biology. At least two hours are needed to set up the models, gather the data and discuss them. We often use about 30 minutes at the beginning of the next class meeting to review and to complete the discussion. Time to prepare the exercise is about 15 minutes.

Student Materials and Preparation

Unit: Genetics

A. *Objectives:* After completion of this unit you should be able to do the following:
   1. Define the terms:
      a. gamete
      b. homologous chromosomes
      c. genes
      d. gene locus
      e. allele
      f. hybrid
      g. monohybrid cross
      h. dihybrid cross
      i. dominant
      j. recessive
      k. intermediate inheritance
      l. multiple alleles
      m. polygenic inheritance
      n. sex-linked inheritance
      o. genotype
      p. phenotype
   2. Explain in detail how haploid gametes are formed as a result of meiosis
   3. Explain what combination of chromosomes may be present in the gametes of an individual of a certain genotype
   4. Predict the genotypes and phenotypes of offspring of certain crosses
   5. Explain sex-linked inheritance
   6. Explain intermediate inheritance
   7. Explain a case of inheritance by multiple alleles
   8. Explain polygenic inheritance

B. *Procedure:*

1. Read the assignment on meiosis very carefully as the process of meiosis is the key to understanding how genes are transmitted from generation to generation.
2. Make a model of meiosis using pipe cleaners, first for *one* pair of homologous chromosomes and then for two pairs of homologous chromosomes. Show all possible combinations of the chromosomes in the gametes.
3. Add small beads symbolizing genes to each of the two pairs of homologous chromosomes. Set up your model to show two parent individuals heterozygous for two pairs of genes. Determine the expected ratio of (a) genotypes and (b) phenotypes. Have an instructor check your model and then copy it in your notebook.
4. With paper bags and marbles make a model for a monohybrid cross. Remove one marble from each bag. What process does this activity represent? Record the proportions of genotypes and determine the proportions of phenotypes. Calculate the ratio of dominant to recessive individuals. Add your numbers to the class data. Calculate the ratio for the class data.
5. Next set up a model for a dihybrid cross. Repeat all the steps in #4 above.
6. Set up a model for sex-linked inheritance. Assume that a woman who is a carrier of the gene for color blindness marries a man with normal color vision. Predict the genotypes and phenotypes of (a) the sons and (b) the daughters. Remove marbles from the bags to represent 20 individuals. Were your *predictions* correct?
7. Prepare to participate in the class discussion of the results.
8. Make a model for inheritance of human skin color, starting with two parents heterozygous for 5 pairs of genes. Record the genotypes for 20 offspring. Determine the phenotypes. Participate in the class discusion of the results.

C. *Evaluation*

No report required. Be sure that all of your models are described in your notebook. All of your results must be recorded and all calculations must be shown.

Instructor's Materials

1. Check each model of the monohybrid cross. If 20 marbles (10 of one and 10 of another color) are used, ask why this number is necessary. Also question the procedure if marbles are not replaced in the bags. If a two-bag—two-marble model is used, have the students explain why this is satisfactory.

2. Check each model of the dihybrid cross. Almost always, two additional marbles are placed in the two bags. Allow students to *discover* that this model is not satisfactory and discuss with their partner how to improve it. This is a good opportunity for self-regulation. By revising the model, students get a better understanding of the relationship between chromosome distribution at meiosis and independent assortment of genes located on different chromosomes resulting in the 9:3:3:1 ratio.
3. Summarize the data of the monohybrid and dihybrid crosses; compare the predicted ratios with actual ratios obtained in individual groups and in the class data. Briefly review the mechanism of sex determination and ask students to *predict* progeny genotypes and phenotypes for X-chromosome linked genes. (It is best to tell them to assume that the Y chromosome does not contain genes allelic to those on the X.)
4. Check each model of inheritance of human skin color. Ask, "Why are 5 bags used? Should there be marbles of different colors in each bag? How many marbles are needed in each bag? Should all marbles be of two colors (e.g. black and white) or should the marbles in bag 1 be black and white, in bag 2, red and green?" etc.
5. Compare the models in class discussion. Summarize the results and interpret them.

Exercise IV—Quantitative Skill

Introduction

Many students in our program have great difficulties with quantitative reasoning. The exercises designed to improve these skills must therefore start at a very elementary level. It is important to show students that they are able to do one of these exercises successfully and then proceed to the next. The short exercises do not constitute a single unit. They are parts of the subject matter units of the first half of the course. Each exercise requires about 15 minutes of class time to obtain data and 15–30 minutes of class time to discuss the homework assignments.

Instructor's Materials

Exercise IV a. Measuring the diameter of microscope fields at various magnifications using micrometer units and discovering a proportional relationship.

Students compare a small ruler calibrated in 1/10 mm with the standard metric ruler. Measuring microscope fields of stereo microscopes at 10, 20, and 25 magnification they discover that as the magnification increases by a factor of two, the field diameter is reduced to one half.

Exercise IV b. Determining the area covered by a cell and computing the number of cells in a standard square.

Students prepare slides of epithelial cells lining the mouth, determine the length and width of one cell, and use this cell as the unit to answer: "How many of these cells are needed to cover one square centimeter of the lining of your mouth?"

Exercise IV c. Calculating the enlargement made of a cell when it was drawn.

We ask the students to work out a procedure for themselves, but many need help with the assignment. When the assignment is completed, we briefly discuss why the exercise is a good illustration of the meaning of the process of arithmetrical division. We also point out the similarities between Exercises IV b and IV c.

Exercise IV d. Determining the volume occupied by a cell and calculating the number of cells in a standard volume.

Students study prepared smears of human blood, determine the diameter of red blood corpuscles, and obtain the thickness of the cell from a photograph or drawing of a wet mount of blood showing some red blood corpuscles in surface view and others in side view. The homework assignment has two parts: (1) calculate the volume of a red blood corpuscle using the formula for volume of a cylinder, or estimate it, assuming that the cells are rectangular solids, and (2) calculate how many red blood cells could be found in 1 cubic millimeter of blood.

In answering (2), almost all students neglect the blood plasma although they have read about the composition of blood and have seen the separation of plasma and cells in capillary tubes.

In the class discussion, the instructor provides the standard values for the mean diameter and mean volume of a red blood cell and the average number of red blood cells in a cubic millimeter of blood. In many cases the students' own values are fairly close to the standards for diameter and volume, but the number of cells/mm^3 is twice as high! It is usually necessary to show the capillary tubes again and draw attention to the ratio of cells to plasma before the error is corrected.

Exercise IV e. Application of the concepts of volume, area and proportion: The surface/volume ratio.

We do a short exercise comparing the surface/volume ratios of various rectangular solids and cubes that can be constructed from eight sugar cubes. After the class has discovered that the "worm shape" has the most favorable ratio, we apply the finding to shapes of cells and of organisms. The concept is applied again in a short experiment on the role of detergents in emulsification of fats which is done to illustrate the role of bile in fat digestion.

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