Scientific Process and Experimental Design

Strand Scientific Investigation

Topic Conducting controlled experiments

Primary SOL BIO.1 The student will demonstrate an understanding of scientific reasoning, logic, and the nature of science by planning and conducting investigations in which

a) observations of living organisms are recorded in the lab and in the field;
b) hypotheses are formulated based on direct observations and information from scientific literature;
c) variables are defined and investigations are designed to test hypotheses;
d) graphing and arithmetic calculations are used as tools in data analysis;
e) conclusions are formed based on recorded quantitative and qualitative data;
f) sources of error inherent in experimental design are identified and discussed;
g) validity of data is determined;
k) differentiation is made among a scientific hypothesis, theory, and law;
l) alternative scientific explanations and models are recognized and analyzed.

Background Information

Students use the scientific process and experimental design every day without realizing it. They make observations and ask questions; they formulate hypotheses; they manipulate variables; they accept or reject their original hypotheses based upon their observations and experiences; they (try to) control their environments. The responsibility of science educators is to enable students to understand, organize, and formalize in a meaningful way these techniques they are already using.

Explain to students that biology has its own standard way of communicating, as does every field of academic endeavor. For some types of research observations and manipulations, biologists use what is often called the "scientific method" or "scientific process." The scientific process has many forms. For this activity, the students will be using an eight step process. The scientific process and experimental design can be applied to all experiments done in biology. Applying this type of thoughtful reflection, in which we analyze *how* we communicate as well as *what* we communicate, gives us an effective tool for disseminating scientific information. (It is important to note that although this scientific process shows up frequently in biology, the method undergoes modification in its application in some other sciences, such as geology, astronomy, and paleontology.)

Materials

- Multiple sets of eight index cards, each card having one of the eight steps of the scientific process written on it, as follows:
  1. Ask questions.
  2. Conduct background research.

3. Collect observations.
4. Identify variables.
5. Formulate a hypothesis.
6. Design an experiment.
7. Analyze the data.
8. Draw conclusions.

- Live earthworms, crickets, or pill bugs
- Variety of items to be used to simulate environments, such as black construction paper, toilet paper tubes, wet paper towels, heat lamp, pine shavings, mulch
- Copies of the two attached handouts

Vocabulary

constant, control, dependent variable, hypothesis, independent variable, inference, observation, qualitative data, quantitative data, stimulus, trial

Student/Teacher Actions (what students and teachers should be doing to facilitate learning)

1. Group students into groups of eight. Introduce the eight steps of the scientific process being used for this activity by distributing sets of eight scientific processes index cards (see Materials) to each group so each student gets one card. Ask students in each group to line up in the "correct" order of the steps of the scientific process. Explain why there is no "correct" start or end point in the scientific process, discussing examples when the "most common" order is not used.
2. Provide groups of students with live earthworms, crickets, or pill bugs, and instruct them to make observations and inferences about the organisms. As they investigate, discuss as a class the difference between an observation and inference, the characteristics of life, and the organization of living things. Ask students how they can tell that the organisms are alive and how the organisms' behavior ensures their survival.
3. Ask each group to select a stimulus to investigate through a controlled experiment that will answer the question, "What is the effect of _____________ on earthworm/cricket/pill bug behavior?"
4. Give each student a copy of the attached Experimental Design handout to put in his/her notebook and reference throughout the school year. Have students use the handout to facilitate designing and conducting their inquiry lab experiments. (Use of the Experimental Design handout will allow you to check students' work frequently to be sure they are on track and will also expedite the grading process.)
5. After students have written their conclusions, discuss with them the validity of their experiments and results in terms of qualitative and quantitative data.

Assessment

- **Questions**
  - How does one determine whether a specimen is living or nonliving?
  - What is behavior?
  - How does an organism's behavior toward a stimulus ensure its survival?
  - How are the independent and dependent variables related?

    - Why is quantitative data more accurate than qualitative data?
    - Why is a control critical to a valid experiment?
    - Why are constants critical to a valid experiment?
    - Why is it important to conduct several trials in an experiment?
    - How many trials do you think are necessary to reduce the effect of invalid data?
- **Journal/Writing Prompts**
    - Write down three problems you have had in your personal life over the past month. These could be problems related to relationships, school work, sports, video games, clothes, music, or other matters that are uniquely yours. From your list of problems, choose one, and develop it, using the eight steps of the scientific process.
    - Behavior is what you do and how you do it. Complete the sentence: "My behavior ensures my survival in biology this year because…." Explain your sentence.
- **Other**
    - Use the attached I Am…. Who Is…? activity for assessment. Directions: This is a whole-class activity. Give each pair of students one card. Select one pair to begin by reading the "Who is…?" question on their card. The pair who has the card with the answer will then read their entire card. Continue the process until the pair that began answers a question. Then, have pairs exchange cards, or involve other pairs who have not yet participated, and repeat the activity.
    - Hold a class discussion about ways to apply the scientific process to everyday problems and situations.
    - Show students graphs and/or tables of sample data and have them (1) identify the independent variable, dependent variable, and outliers, and (2) describe the experiment that might have produced these results.

Extensions and Connections (for all students)
- Ask students to investigate examples of scientific investigations that do not follow this "experimental process," such as investigations in astronomy, chemistry, or geology.
- Ask students to investigate the fields of qualitative analysis and statistical data interpretation (descriptive and inferential), if time and abilities allow.
- Ask students to investigate the definition and examples of pseudoscience. Discuss sample stories, identifying what makes each story more or less believable.

Strategies for Differentiation
The following are some quick ways to add inquiry into any traditional cookbook lab or to differentiate for students who may need support.
- Provide the procedure, but mix up the steps.
- Provide the procedure, but do not provide the data table.
- Have the class design the experiment, with one student providing the first step, another providing the next step, and so forth.
- Provide only the data table.
- Provide an experiment for students to use as a model for their own experiment.
- Provide the independent variables, dependent variables, and expected results for which students must design the experiment and create the data table to match.

Experimental Design

1. **Title your lab report by stating the problem as a question.**
   - For example, "What is the effect of ___________ on earthworm/cricket/pill bug behavior?"
2. **List and identify the experimental variables.**
   - The independent variable(s)
   - The dependent variable(s)
   - The constants
   - The control
3. **Write a hypothesis.**
   - Explain how the independent variable and the dependent variable are related (e.g., "If the IV…, then the DV….").

STOP. Seek approval from your teacher before continuing.

4. **Explain your experimental design.**
   - How will you verify your prediction (be specific)?
   - Why did you use the experimental apparatus as you designed it?
   - How many times will you repeat your trials?
5. **Create a data table to organize your observations.**

STOP. Seek approval from your teacher before continuing.

6. **Analyze your data graphically.**
   - Use the mean in your graphical analysis, if you ran multiple trials.
   - Identify any outliers or invalid data in your experiment.
7. **Write a conclusion, including answers to these questions in your paragraph.**
   - How did the data support or invalidate your hypothesis?
   - How can you explain your results? (PAUSE and THINK before you answer.)
   - What sources of error were present in your experiment?
   - How would you design this experiment differently a second time?

STOP. Submit your lab report to your teacher for final grading.

I am…. Who is…?

Copy cards on cardstock, and cut out.

I am the **scientific process.** Who is the variable that is manipulated in an experiment?	I am the **independent variable.** Who is the responding variable that is measured in an experiment?	I am the **dependent variable.** Who is the baseline variable that is used as a comparison against the experimental group exposed to the independent variable?	I am the **control.** Who is the variable(s) kept the same so all experimental groups are identical except for the independent variable?
I am the **constants.** Who is a well-educated guess based on background research?	I am the **hypothesis.** Who is the most reliable resource for students conducting scientific investigations?	I am a **professional journal.** Who is the outline that includes the identification of variables, materials, and procedure?	I am an **experimental design.** Who is the possible cause of invalid data in an experiment?
I am a **source of error.** Who is one way to improve the validity of an experiment by running multiple tests and finding the mean?	I am **repeated trials.** Who is something that triggers a response in an organism?	I am a **stimulus.** Who is the use of one's senses to gather data?	I am an **observation.** Who is an interpretation of an observation based on past experiences?
I am an **inference**. Who is data that is acquired and recorded using numbers?	I am **quantitative data.** Who is data that is acquired and recorded using descriptions?	I am **qualitative data.** Who is a well-tested hypothesis accepted by a large majority of scientists?	I am a **theory.** Who is an organized set of steps to analyze a problem or answer a question?