An Introduction to Scientific Investigation[1]

Laboratory Objectives

1. Identify questions that can be answered through scientific investigation and explain what characterizes a good question.
2. Define hypothesis and explain what characterizes a good scientific hypothesis.
3. Identify and describe the elements of a scientific experiment.
4. Organize and present data in tables and graphs.
5. Analyze and discuss results.
6. Design a scientific experiment.

Introduction:

Biology is the study of the phenomena of life. Biological scientists--researchers, teachers, or students--observe living systems and organisms and ask questions about such observations. Scientific investigation is a way of answering those questions. It assumes that biological systems are understandable and can be explained by fundamental rules or laws. Scientific investigations follow some general guidelines that are referred to as the scientific method. Scientists may not always follow the guidelines in a strict fashion, but each of the elements of the process should be present. Science is a creative human endeavor that involves asking questions, making observations, developing hypotheses, and testing those hypotheses. Scientists closely scrutinize investigations in their field. Each scientist must present his or her work at scientific meetings or in professional publications to provide evidence from observations and experiments that support their explanation of biological phenomena.

In this lab, you will not only review the process that scientists use to ask and answer questions about the living world, but you will develop the skills to conduct and critique scientific investigations. Science is a collaborative effort in which scientists work together and share their results. Like scientists, you will work in research teams in this laboratory and others, collaborating as you ask questions and solve problems. Throughout the laboratory experience, you will be investigating biology using the methodology of scientists, asking questions, proposing explanations, designing experiments, predicting results, collecting and analyzing data, and interpreting your results in light of your hypotheses.

While the scientific method may vary from one study to the next, or from one discipline to another, its basic components are shown below:

Observation

Asking Questions

Formulating Hypotheses

Predictions

Experimentation/Testing Hypotheses

Conclusions

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1 Portions based on materials by Dr. Andrew Marry, Department of Biosciences, Minnesota State University Moorhead

I. Observation; Asking Questions:

The questions that are answered by scientific investigation are based on observations, information gained through previous research, or a combination of both. Just because a question can be answered, however, does not mean that it can be answered scientifically.

Activity I.

Discuss the questions at the end of section IV with your lab team and decide which of them can be answered scientifically. State “yes” or “no” and give your reasons.

II. Developing Hypotheses:

As questions are asked, scientists attempt to answer them by proposing possible explanations. A hypothesis is a tentative explanation for what we observe or a proposed answer to a question. Consider question 2 “Why is grass green?”. A possible hypothesis based on this question might be "Chlorophyll located in leaf cells causes grass to be green." The hypothesis has suggested a possible explanation for the observed green grass.

A hypothesis is usable only if it can be proven false. This is called being falsifiable. The nature of science is such that we can prove a hypothesis false by presenting evidence from an investigation that does not support it. In our example, if all chlorophyll is removed from the leaves of a test plant and the plant remains green, then the hypothesis has been proven false. *We cannot, however, prove that a hypothesis is true*. We can only support the hypothesis with evidence from our investigation. In our example, if chlorophyll is extracted from the test plant and the plant now appears white, then the hypothesis has not been proven true, but has been supported by the evidence. New evidence from additional experiments might falsify this hypothesis at a later date.

Scientific knowledge is an accumulation of evidence in support of hypotheses; it is not to be regarded as absolute truth. Hypotheses are accepted only on a trial basis. Future investigations may falsify any hypotheses. However, this does not mean that scientific knowledge is flimsy and unreliable. Much of the information in your textbook, for example, is based on many experiments carried out by numerous scientists over a period of years. On the other hand, current scientific studies you read about in the newspaper--for example, investigations of the effects of caffeine--are much more preliminary and therefore more tentative. You may even read about studies with contradictory results. These are based on hypotheses still under investigation.

There are limits to the ability of science to answer questions. Science is only one of many ways of knowing about the world in which we live. Recall that scientific inquiries are limited to hypotheses that are testable and potentially falsifiable.

Activity II.

Working in your groups, write hypotheses in the space provided for the questions that your group felt could be answered by scientific inquiry.

III. The Elements of an Experiment:

Once a problem has been defined and one or more hypotheses have been proposed, the scientist turns his or her attention to testing the hypotheses. An experiment involves defining variables, outlining a procedure, and determining what control treatment to be used as the experiment is performed. Once the experiment is defined, the investigator predicts the outcome of the experiment based on the hypotheses. A crucial step in designing an experiment is identifying the variables involved. There are three categories of variables: dependent, independent, and constants.

The Dependent Variable

The dependent variable is what the investigator measures (counts, records). It is what the investigator thinks will be affected during the experiment. For example, the investigator may want to study soybean growth. There are several measurable characteristics of soybean growth such as height, weight and soybean production. For any experiment, there may be a number of possible dependent variables. The investigator must choose the one or ones that he or she thinks is most important. More than one dependent variable may be chosen.

Independent Variable

The independent variable is what the investigator varies during the experiment. It is what the investigator thinks will affect the dependent variable. Unlike the dependent variable, the investigator must choose only one independent variable to investigate. For example, if the scientist wants to investigate the effect that the amount of fertilizer has on soybean growth, the scientist will use different amounts of fertilizer. The scientist can measure, as many dependent variables as he or she thinks are important in indicating soybean growth. Remember, there may be several dependent variables, but there may be only one independent variable.

Constant(s)

Since there can be only one independent variable, all independent variables other than the one being studied must be held constant so that they do not affect the outcome of the experiment. For example, consider an experiment studying fertilizer effects on soybean growth, where the scientist has chosen the amount of fertilizer as the independent variable. The scientist must be sure that there are no differences in the type of fertilizer used. There are many other variables that have to be held constant in this experiment. All plants should be the same and have the same light exposure, soil type, amount of water and temperature. It is impossible to hold everything constant, but scientists try to control as much as they can.

Activity III.

Working in your groups, identify the independent and dependent variables, and list the parameters that may have to be held constant for the questions that your group felt could be answered by scientific inquiry.

IV. Choosing or Designing the Procedure:

After formulating a hypothesis and selecting the variables, the investigator must find a method that may be used to measure the dependent variable. Procedures are developed by reading articles published by other scientists, by talking to other scientists who are knowledgeable in the field, and by one's own ideas. In a biology class, procedures are usually described in the lab manual or by your instructor. When performing investigations, the scientist usually outlines the procedures in a notebook, recording any modifications as the experiments are performed and procedures are revised. The process of outlining the procedure includes deciding on the number of replications, and determining the control treatment.

Replication

Another essential aspect of experimental design or procedure is replication. This means that the scientist repeats the experiment numerous times using exactly the same conditions to determine if the results are consistent. Being able to replicate a result increases our confidence in it. However, we should not expect to get exactly the same answer each time because a certain amount of variation is normal in biological systems. Replicating the experiment enables us to see how much variation there is and to obtain an average result from different trials.

Control Treatment

We have already discussed constant variables, factors that are kept equal in all treatments so that any effect of the dependent variable can be attributed to the independent variable. It is also necessary to include control treatments in an experiment. A control is a treatment in which the independent variable is either eliminated or set at a standard value. The results from the control treatment are what the experimental data are compared to once the data has been collected.

Activity IV.

Working in your groups, identify an appropriate control treatment for the questions that your group felt could be answered by scientific inquiry.

QUESTIONS

1. Is communism evil?

Activity I:

Activity II:

Activity III:

Activity IV:

2. Why is grass green?

Activity I:

Activity II:

Activity III:

Activity IV:

3. Was the malignant tumor found in the lungs of a 70-year-old man caused by his 45-year habit of smoking cigarettes?

Activity I:

Activity II:

Activity III:

Activity IV:

4. Does watching television as a child lower your I.Q.?

Activity I:

Activity II:

Activity III:

Activity IV:

5. Are children more assertive in 1st grade if they spend a year in nursery school at age 4?
Activity I:

Activity II:

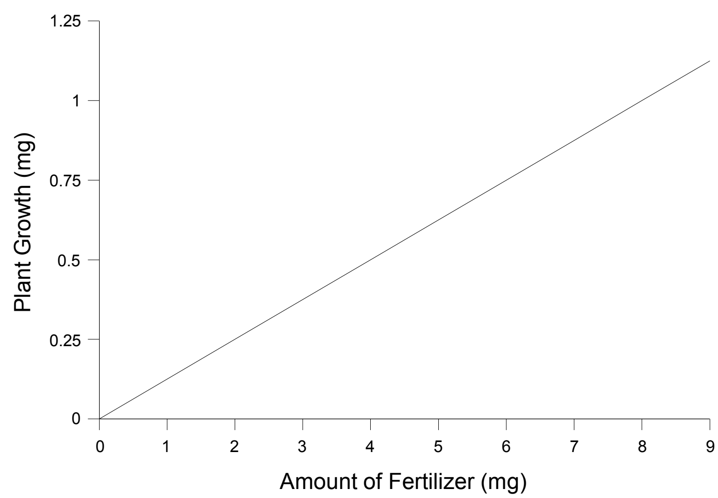
Activity III:

Activity IV:

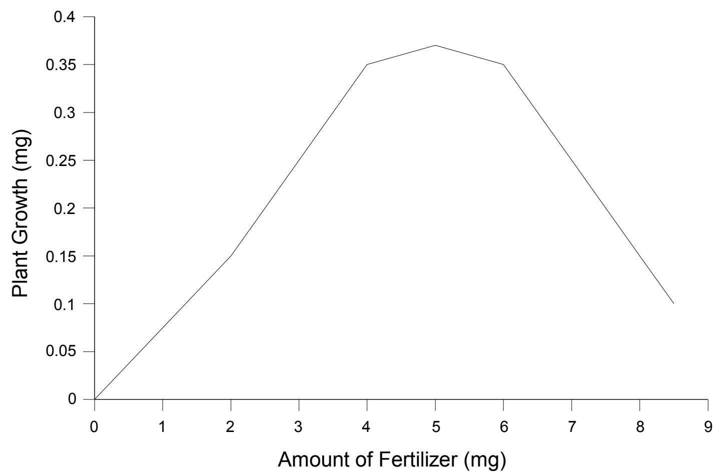
V. Making Predictions:

The process of designing the experiment is closely linked with making predictions about results of the experiments being designed. The scientist applies his or her present knowledge to predict the effect of the independent variable on the dependent variable. The prediction is a statement of the expected results of the experiment based on the hypothesis. The prediction is often an "if/then" statement: "If the hypothesis is true, then the results of the experiment will be..." In the fertilizer experiment, the hypothesis might be: "Applying greater concentrations of fertilizer to plants increases plant growth." One possible prediction may be that as the amount of fertilizer is increased, the growth of the soybeans will increase in a linear fashion.

If predictions are confirmed, the scientist has supported the hypothesis. If the predictions are not supported, the hypothesis is falsified. Either way, the scientist has increased knowledge of the process being studied. Many times the falsification of a hypothesis can provide more information than confirmation since the ideas and data must be critically evaluated in light of new information. For example, according to the above prediction, you would expect the following graph:



However, the actual data may produce this graph:



The scientist has learned that the prediction of “greater applications of fertilizer cause increased growth” is true only to a point. The scientist may now wish to identify this point specifically by finding out what would be the optimum amount of fertilizer to apply. The scientist may also want to extend the research in a new direction and discover why the highest fertilizer applications actually decrease the weight of the plants.

The necessary components of the scientific process discussed to this point are:
1. Using observations to ask good questions.
2. Proposing explanations for observed phenomena in the form of hypotheses.
3. Determining the components of an experiment.
4. Making predictions based on possible experiments.

Having made predictions about the results of an experiment, the next step in the scientific process is to perform the experiment. As the investigation takes place, observations are made, results are recorded and the hypotheses is either supported or falsified.

<u>VI. Reading a scientific study</u>:
Read the article provided by your instructor. After reading the study, answer the following:

1. What is the hypotheses?

2. What is the dependent variable?

3. What is the independent variable?

4. What were the constant variables?

5. What was the control treatment?

6. How many replicates were conducted? Why?

VII. Designing an Experiment:

In this exercise will practice investigating a question using what you have learned thus far about the scientific process.

Materials

Clock with a second hand/timer

Introduction

Cardiovascular fitness can be determined by measuring a person's heart rate and respiration rate before and after a given time of aerobic exercise. A person who is more fit may have a relatively slower pulse and a lower respiratory rate after exercise; along with this, his or her pulse should return to normal more quickly than a person who is less fit. Your assignment is to investigate the impact of some well-defined, measurable, controllable, independent variable on cardiovascular fitness.

The sit/stand experiment

The subject should perform a trial of one or two repetitions before conducting the actual test to clarify form.

-Sit on chair with feet shoulder width apart close to chair.
-Keep arms crossed in front of you.
-Stand up without pushing off with arms at a rate of 30 sit/stands per minute.
-Repeat until 60 seconds expires.

Test administrator provides test instructions to subject, keeps time, monitors sit/stand rate and announces when time has been completely.

Procedure for measuring pulse

-The subject should be sitting quietly while the pulse is counted.
-Use three fingers to find the pulse in the radial artery, in the wrist above thumb.
-Count the number of beats per 15 seconds and multiply by 4 to determine beats per minute.

Performing the experiment

The class will split into two groups. Each member of the group is a possible test subject. All students in the group will be the investigators.

In your research teams, take about 5 minutes to discuss several specific questions that you can ask and independent variables related to the broad topic of cardiovascular fitness. For example, one of your questions might be: "Does cigarette smoking have an effect on cardiovascular fitness?" Make an effort to choose questions that will allow divide the class into two groups for easy comparison.

In your groups, design an experiment. Record the components of your experiment by completing the information on your report sheet. Propose your experimental procedure to your laboratory instructor before beginning your experiment. You should have your data table ready to collect data before you begin your experiment. Remember to identify the following:

Hypotheses:

Dependent variable(s):

Independent variable:

Controlled variables:

Control treatment:

Predictions

Predict the results of the experiment based on your hypothesis (If/Then).

Results

Create a table to collect your data. You may also want to graph your data at the end of the experiment:

VII. Interpreting Results:

The last component of a scientific investigation is to interpret the results and discuss their implications in light of the hypothesis and its supporting literature. The investigator studies the tables and graphs and determines if the hypothesis has been supported or falsified. If the hypothesis has been falsified, the investigator must suggest alternate hypotheses for testing. If the hypothesis has been supported, the investigator may suggest additional experiments to strengthen the hypothesis, using the same or alternate methods.

1. Using your tables and graphs, analyze your results and discuss your conclusions.
2. Critique your experiment. What weakness do you see in the experiment?

Weakness in Experiment:

Suggest improvements:

3. Write a summary statement for your experiment. Use your results to support or falsify your hypothesis.

4. Be prepared to present your conclusions to the class.

5. Suggest additional and modified hypotheses that might be tested. Briefly describe your next experiment.