Lab 4: Using the Scientific Method

You have all asked questions, developed educated predictions, and even put your predictions to the test. In some laboratory exercises this semester, we will do this in a more rigorous way and call it the scientific method. You will use the scientific method to explore a variety of biological principles. As scientists, you will work in research teams, collaborating as you ask questions and solve problems. Before you begin to examine biological principles, you need to have a firm grasp of the scientific method. This laboratory is designed to introduce the main types of thinking involved in how a biologist attacks a problem.

Objectives

When you have successfully completed this lab, you should be able to:

1. Use the scientific method and understand which types of questions can be answered through scientific investigation.
2. Explain what characterizes a good scientific hypothesis.
3. Use experimental data to evaluate an hypothesis.
4. Write the Discussion section of a lab report.

We will also practice writing, data analysis and presentation skills introduced in earlier laboratory exercises.

Introduction

In the words of Vincient Dethier, a prominent insect physiologist, anyone can be a biologist - “Anyone with a genuine love of nature, an insatiable curiosity about life, a soaring imagination, devilish ingenuity, the patience of Job and the ability to read has the basic ingredients and most of the necessary accouterments to become a first class biologist” - in other words, you! After all, science is really little more than curiosity and common sense which assumes that biological systems are understandable.

The six steps involved in the scientific method are:

1) Observe nature
2) Ask questions
3) Formulate testable hypotheses
4) Conduct experiments to test these hypotheses
5) Make conclusions based on your experimental results
6) Formulate new, testable hypotheses based on your conclusions

Procedures

Section A - Questions and Hypotheses

1. Observe Nature

Science usually starts with observations of the natural world and makes generalizations from these observations. You have all observed animals and plants in nature, but now it’s time to get quantitative. Our observations are going to require measurements. Each measurement consists of a number and a unit, like “six feet.” Units, also called dimensions, can describe number of individuals, time, length, mass, temperature, and many other quantities. Speed, for instance, has the dimensions of length per unit time, so we talk about speeds with units of meters/second, miles/hour or furlongs/fortnight. Once you know what to measure, you gain insight into how to measure it. Consider speed again. Because its dimensions are length and time, you would need a ruler and stopwatch. Much of
the fun of designing a good experiment is determining how to measure the critical variables.

2. Ask Questions

Scientists are curious individuals whose curiosity is focused on understanding the natural world. They use previous research or personal observations of natural phenomena as a basis for asking questions about the underlying causes or reasons for these phenomena. For a question to be pursued by scientists, the phenomenon must be well defined and repeatable. The variables involved must be measurable.

There are limits to the ability of science to answer questions. Consider, for example, this question: Do high temperatures cause people to behave immorally? Can a scientist investigate this question? Temperature is well defined and measurable, but what is “moral behavior?” Is it measurable? Could people even agree on a definition of the term? Until “moral behavior” is defined, there are no experiments that could be designed to test this question. Which of the following questions do you think can be answered scientifically?

1. Does exposure to coal dust in mines cause an increase in respiratory disease?
2. Does good nutrition lead to increased growth in cattle?
3. Was Napoleon superstitious?
4. Do cactus spines deter herbivores?
5. Was the malignant tumor that was found in the lungs of a 70 year old woman caused by living with her chain-smoking husband for 50 years?

As you read and prepare to come to lab, jot down a few notes regarding the questions above for class discussion. How did you decide if these questions could be answered scientifically? For which of these above statements could you formulate a well defined, testable hypothesis? For each of the answerable questions, write a testable hypothesis (after reading the next paragraphs). Volunteers will read their hypotheses in class.

3. Formulate Testable Hypotheses

Scientists try to answer questions by suggesting possible explanations. Hypotheses are simply tentative explanations which could account for observed phenomena. Formulating testable hypotheses draws heavily upon the scientist’s creativity and imagination. A hypothesis can be described as a logical link between if and then. Consider question #4 above, “Do cactus spines deter herbivores?” One hypothesis based on this question might be “If the spines are removed from cacti, then herbivores will still not eat the cacti.”

A scientifically useful hypothesis must be testable and falsifiable (able to be proved false). To satisfy the requirement that an hypothesis be falsifiable, it must be possible for the test results to contradict the hypothesis. In our example, if spines are removed from test cacti and the plants are eaten by animals, then the hypothesis has been proved false or falsified.

Even though the hypothesis can be falsified, it can never be proved true. This is a very important point. The evidence from an investigation can only provide support for the hypothesis. If our cacti without spines were not eaten, then the hypothesis has not been proved, but it has been supported by the evidence. Other explanations still must be excluded and new evidence from additional experiments and observations might falsify this hypothesis at a later date. (Perhaps the herbivores weren’t hungry.) In science, a single experiment rarely provides results that clearly support or falsify the hypothesis. In most cases, the evidence serves to modify the hypothesis or the conditions of the experiment.

Scientists often propose and reject a variety of hypotheses before they design a single test. Examine the following statements and note which would be useful as scientific hypotheses and could be investigated using scientific procedures. Give the reason for each of your answers by stating whether it could be falsified and which factors are measurable and controllable.

1. Male seahorses incubate the eggs to give the tired females a chance to rest.
2. Students who sit in the front of the classroom get better grades than those who sit in the back.

3. In nutrient-poor soils, sulfur dioxide pollution results in increased growth in soybeans.

4. Dinosaurs became extinct because a supernatural power was dissatisfied with their progress.

5. Humans first inhabited North America about 12,000 years ago.

The class will discuss these ideas, so make notes to prepare for the discussion.

Section B - Experimental Design

Designing an experiment to test your hypothesis is the most creative aspect of science. Many times scientists think of interesting questions that can’t be answered or experiments that are impractical. Examples: “Does heat increase immorality” or “What percent of all women over 25 have tumors observable by CAT scan?” Other ideas might never receive approval from the animal rights committees. “Does sacrificing a bull by throwing it into a volcano decrease the lava flow during the eruption?”

Scientists usually design, critique, and modify an experiment before they commit the time and resources to perform it. Designing an experiment begins with defining variables. The investigator generally manipulates one or more variables, minimizes variation in other variables, and measures responses in a third set of variables. Variables that are manipulated by the investigator are independent variables. Variables that are held constant are known as fixed variables, and variables that measure responses to the experiment are dependent variables.

Independent variables are the responses to the experiment. For example, if a scientist investigates the ability of a new fertilizer to increase growth of soybeans, the height of the plants or the weight of the seeds produced by the plants are dependent variables. Last week, the dependent variable was the amount of water which entered each sucrose solution by osmosis. It was what you measured.

Fixed variables last week in your osmosis experiment included which balance was used to weigh the sucrose-containing bags, the volume of water added to each beaker, and which student blotted and weighed each solution, etc. Think about the potential weight variations you could have produced if one student in your group always neglected to blot the dialysis bag before weighing and another student blotted the bag properly. This fixed variable is not an important part of your hypothesis, but it is a variable you must control. Before weighing, each bag must be treated identically.
Prepare for class discussion by thinking about these questions:

1. What other fixed variables should the soybean scientist include?

2. What is an example of a variable that is completely irrelevant, and is neither fixed nor dependent nor independent?

3. What does a fixed variable become if the scientist decides to also manipulate its conditions?

4. What is a placebo?

Then, analyze the following experiment. Identify independent, dependent, and fixed variables. Is there a problem in the experimental design?

Dr. Chaleb intends to study the effects of household bleach on various items of laundry. He plans to wash clothing items in a Maytag washer without bleach, and compare their color to other items of clothing washed in a Kenmore washer which automatically adds bleach. The items will be compared to determine whether bleach reduces brightness of colors.

Identify:

Independent variable

Dependent variable

Fixed variables

Is there a problem in the experimental design? Explain your answer.

One of the most difficult questions to answer when designing an experiment is how many samples, or replicates, to take. Generally, the same procedure will not produce exactly the same results each time it is run. If you take too many samples, you may be wasting time, materials and money. On the other hand, if you take too few samples, it may be difficult to draw any meaningful conclusions from your results. Sampling is a compromise between accuracy and effort, and scientists often find that they do not take enough samples because of their failure to plan ahead. In our biology laboratory you will find that the sample sizes of experiments will be greatly influenced by lab time, materials, space and whether or not you have taken the time to read your instructions thoroughly ahead of time. In Biology 107 experiments, a minimum of three trials is required. Students are encouraged to improve their lab report, and therefore their grade, by using more than three trials.

Section C - Analyzing Your Results

Every good experiment produces data. Generally, you cannot just look over the raw data and decide whether the hypothesis is supported or rejected. Instead, the data must be condensed into a form that can be used to evaluate the hypothesis. Scientists commonly use three different ways of condensing and presenting numeric data: graphs, tables, and statistical tests. You were introduced to some basics of data analysis in the Excel data lab. Now, we will extend our discussion of how to understand the data from an experiment.

Descriptive statistics summarize, organize, and simplify data. They measure either the central tendency (e.g., mean) or the spread of the values (e.g., standard deviation). There are three different metrics that measure central tendency of a dataset.

**Median**

If all observations are arranged in rank order from smallest to largest, the median is that value with 50% of the observations above it and 50% of the observations below it.

**Mean** ($\bar{x}$)

The arithmetic average of all observations.

Most people are familiar with means, which are calculated by adding all of the values and dividing by the sample size. Medians are less widely known, but also measure central tendency; they can be very important, particularly if data sets are skewed. For example, if Bill Gates joined the laboratory session today, the mean income would change dramatically but the median would not change much.
When data represent samples of a population, or are independent estimates of a quantity, it is necessary to have a representative sample and avoid error resulting from small sample size. Recall our fertilizer experiment and imagine what you would think if the first time you used a new fertilizer you saw a 25% increase in the number of bean pods produced and the second time your increase was 3%. Would you average the two percentages and develop an advertising campaign to sell the new fertilizer saying it would produce a 14% increase in yields? Or would you run the experiment several more times to get a more accurate estimate of the actual increase in yield? What would you do if your next trial showed a 27% increase?

The measures of variability that we will be concerned with are:

**Range**
The difference between the smallest and largest value in a distribution of values

**Standard Deviation**
(S.D.) The deviation of the data from the mean. Recall that the formula for finding the standard deviation is:

\[
S. D. = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n - 1}}
\]

n = the number of trials or samples taken

\(\Sigma\) = the summation of all trials

\(\bar{x}\) = the mean or arithmetic average

\(x_i\) = the observed value that you measured

Although you always want to maximize the number of trials, to calculate the standard deviation (S.D.), you must have a minimum of three trials. If you have time, you may want to run more trials.

Graphs are visual depictions of data or of variable metrics. As discussed in the Excel data lab, there are two main types of graphs used in Biology 107: scatter plots and column graphs. Occasionally you may have reason to use a line graph (a variation of a scatter plot where the points are connected). A review of the Excel lab will remind you that graphs depict the independent variable on the horizontal (x) axis, and the dependent variable on the vertical (y) axis. Every graph should have labeled axes, the axis scale clearly shown, and a title explaining what the graph depicts.

Scatter plots are plots of individual, unconnected data points. These graphs will visually show both central tendencies and scatter around the central tendencies, but are often misinterpreted. They can show relationships between two variables without the requirement that one variable is an independent variable. Recall the scatter plots you generated in Lab #2. When you constructed a graph with height and forearm length, you did not have a dependent/independent relationship.

Column graphs show a separate bar for each condition of the experimental variable. The height of the bar is the mean of the dependent variable, and the standard deviation should almost always be included as a separate bar or T-shape on top of the bar representing the mean. An important difference between scatter and column graphs is that line graphs imply a continuous linear change between the condition of the independent variable, whereas column graphs do not.
For example, there is no intermittent stage between males and females. A column graph is appropriate to display the data shown below.

![Comparison of Handspan in Females and Males](image)

Graphs, diagrams, drawings and photographs are all called figures and should be numbered consecutively throughout a lab report or scientific paper. Each figure is given a caption or title that describes its contents, giving enough information to allow the figure to be self-explanatory. The graphs on this page and on page 36 are labeled properly for you to refer to later. Generally, the title of a figure is written above or below the figure.

Tables are constructed in a similar way. Every table should have a caption at the top which describes the information displayed. The data (measurements of your dependent variable) are listed in the body of the table. Look at the table on page 28 of your textbook. Above the table is a label “Table 2.1”. There is a title or heading at the top of the table, “Naturally Occurring Elements in the Human Body”, which describes what will be found on the table. Like figures, the tables in a scientific paper should be numbered consecutively.

Section D - Conclusions and Discussion

Once you have completed your experiments, you are in a position to draw conclusions based on your results. Specifically, you must attempt to interpret your results in the context of the specific hypothesis that you set out to address. Some of the issues to consider when making conclusions include:

What did you expect to find, and why?

How did your results compare with those expected?

How might you explain unexpected results?

How might you test these potential explanations?

Should your hypothesis be modified?

Lab Assignment - Exercise 4

This assignment is to be handed in next week at the beginning of lab (before your quiz). Each student must complete this assignment individually.

Last week you began working on your Osmosis Lab Report. You should have finished the Introduction and Methods sections and begun construction of your graphs. Now that you have spent a lab period discussing the scientific method and reviewing proper graph construction, you are ready to finish putting your lab report together. Be sure that you review the Biology 107 Syllabus that explains how lab reports will be graded. Following directions is one of the most important objectives of the laboratory section of Biology 107 and lab reports which are not properly constructed will lose points.

Make sure you re-read the instructions for completing your report (from last week’s Osmosis lab assignment). Refer to the Lab Manual Appendix and the Biology 107 web site (links page) for other helpful suggestions for how to write a good lab report.