**Scientific Method and Designing Scientific Experiments**

(This lab is modified from *Inquiry Exercises for the College Biology Lab*, 2009 with permission from A. Daniel Johnson and NSTA Press)

In this unit, you will learn about the **scientific method** and formulating scientific questions and testable hypotheses and designing sound experiments to robustly test hypotheses. Although scientific papers and news reports can be good ways to communicate the results of scientific experiments, they are poor models of how scientific research gets done. No scientist is talented and intuitive enough to ask a perfect question, choose exactly the right methods, then get enough data from just one set of experiments to reach an unambiguous, publishable conclusion. In reality, scientists continuously refine their questions, and the scientific method is an iterative, continuous, and often non-linear process.

However, this does not mean it is impossible to get answers to scientific questions. Rather, our understanding of the world grows by an ongoing process. As our knowledge increases, old ideas get displaced, and the way we view the world changes. The biggest challenge scientists face is to look at all the data they collect, compare it with published observations by fellow scientists, then think about the data critically and creatively, and come up with the simplest explanation possible that accounts for all the observations.

The scientific method typically involves 4-7 steps (depending upon how they are defined):

1. **Observation and Questions.** Many scientific hypotheses and questions come from trying to understand observed patterns in the natural world or from building upon already known observations and/or results of past experiments. The ability to make systematic observations is a valuable skill to cultivate, even if you do not plan to become a scientist.
2. **Formulating Testable Hypotheses.** Hypotheses are any potential explanation for observed phenomena. A testable hypothesis is one that is stated in a way that makes predictions that can be tested. Usually, a testable hypothesis can be worded as an if/then statement. The hypothesis is the "if" part, while the "then" part provides one or more predictions that are based on that hypothesis. When hypotheses are tested, they can be shown to be incorrect (disproven). Yet the reverse is not true. Observations and data can support a hypothesis, but they can never prove that a hypothesis is true. That is the fundamental nature of science. Usually scientists have a null hypothesis and one or more alternative hypotheses that they will test.
   1. **Alternative Hypotheses (written as H1or Ha):** Alternative hypotheses are predicted answers to your research question or expected outcomes of an experiment. In order to develop alternative hypotheses, you need to think about the relevant variables, type of experiment or analysis to be done, the subject group being studied, and your experimental predictions.
   2. **Null Hypothesis (written as H0):** Null hypotheses state that there is no association between the variables or no difference between subjects that received different treatments (independent variable).
3. **Designing and Conducting Controlled Experiments That Test Your Hypothesis.** Do not just design experiments to support your hypothesis. Design experiments that could prove your hypothesis is wrong. If an experiment is to provide meaningful data, it must be designed properly. A well-designed experiment typically includes a **control group** as well as one or more **experimental groups**. The control group is your baseline for comparison with the experimental group. Ideally the experimental group differs from the control group by a single factor. In most experiments, you will manipulate one variable, and measure the effect on another. The manipulated variable is called the **independent variable**, while the response of the experimental group that you actually observe is the **dependent variable**.

**One thing to make note of is replication and sample size.** When designing an experiment, how many times do you need to repeat the experiment, or how many subjects per treatment group do you need to be sure of your results? If you take too many samples or have too large of a sample size, you may needlessly waste time, resources, and money. On the other hand, if you take too few samples, it may be difficult to draw meaningful conclusions from your results. Anytime you must compare groups, try to conduct at least **three replicate trials** (sample size) of your experiment. Then report the means for any dependent variables you measure. Note: sample sizes for well-designed experiments are often much larger and depend in part upon how much natural variation you expect among subjects or replicates by chance.

1. **Collect/record, Analyze, and Synthesize Data from your Experiment.** Experiments should produce quantifiable data (something that can be measured – like speed or distance travelled). Raw data usually are not very meaningful to someone who is unfamiliar with the project. Data must be organized in a way that presents your significant findings clearly and concisely. The most common ways to summarize results are figures, graphs, and tables. You can create graphs and tables by hand, but a spreadsheet program allows you to create and revise figures more quickly. There are also statistical methods for summarizing and presenting data that are widely used and understood. Your instructor may ask you to complete a statistics tutorial as part of this unit.
2. **Conclusion.** You will analyze your data and determine whether you support or reject your hypotheses. This is where you make conclusions and decide whether you need to refine your hypotheses and conduct addition experiments. The scientific process is iterative.
3. **Report your findings.**

**Lab Learning Objectives:**

By the end of this lab you should be able to:

1. Make a summarize observations of a biological phenomenon;
2. Come up with a scientific question based on your observations;
3. Formulate clear and testable alternative and null hypotheses;
4. Design an experiment with dependent, independent, and control variables;
5. Analyze, summarize, and report results of your experiment in a lab report;

**Background:**

Like ants, bees, and other social (colony-forming) insects, termites exhibit some very complex behaviors. A few years ago, an entomologist spilled a few termites onto her desk, and noticed that some followed lines drawn in her lab notebook. In subsequent trials, though, the termites seemed to ignore drawn trails, and just wandered aimlessly. This week your goal is to try to unravel this simple biological observation. As you work, focus on developing a reasonable hypothesis, testing it, and learning to interpret and communicate your results.

The termites (Class Insecta; Order Isoptera) you will be studying today are harmless. They do not bite or carry human disease. However, when prying apart decayed wood to search for termites be careful not to get wood splinters in your fingers.

**Part 1: Observation: Do Termites Follow Trails?**

In this first exercise, you will try to replicate the original observation that worker termites follow trails.

1. You will need plain white paper, pencils, and pens of various kinds. Take a single sheet of paper and draw "test trails" in the middle of the sheet with a few different writing utensils. Try to make the trails the same length and width. Try using different medias and colors.
2. Obtain a single termite from the colony in the container - termites are soft-bodied, so handle them gently.
3. Place the termite near the trail. Watch it for a few minutes and see whether or not it tries to follow the trails. Record your observations in your lab notebook:

**Discuss as a lab group:** What did termites do when offered trails to follow? Do you think that termites will in fact follow a trail?

**Part 2: Generating Hypotheses and Conducting Experiments**

Part1 illustrated an essential step in the scientific method that is often forgotten: making observations. Before basing a hypothesis on someone else's observations, you should always try to replicate that person's results. At the least, you will have some baseline observations of your own from which to construct a more reasonable hypothesis. You might also discover that, in your hands, something entirely different occurs. For example, you might have observed that termites seemed to avoid drawn trails. If so, you might generate a hypothesis about why they avoid a trail, and your hypothesis would probably be very different than if you simply assumed the previous observer was right.

1. Develop testable hypotheses: Based on your observations, think of a testable hypothesis for why termites follow trails. Remember, a testable hypothesis consists of a tentative explanation that accounts for your observations, followed by a prediction that can be tested experimentally.

*Null Hypotheses:*

*Alternative Hypotheses:*

1. Design an Experiment to Test your Hypotheses. Remember to identify your variables, and it is best to only vary one independent variable. To increase sample size, both you and your partner should repeat the experiment \_ times (ask TA as it depends upon the experiment) and pool your data with the class.

Independent variable: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Dependent variable: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Control group: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Write out your methods. Be sure that they are clear, concise, and could easily be replicated. Think about how many repetitions you will conduct and how you will keep your measurements consistent. You will want a data set large enough to draw inferences (but also small enough to fit into the lab timeframe):

Record your results and observations in your lab notebook in the table below:

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Once you have recorded your results, discuss them with your lab group. What are reasonable conclusions you can make about the data?

Below is an example raw data table.

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| --- | --- | --- |
| **Number of times a color was selected (N = 10 trials/termite)** | | |
|  | **Red Pen** | **Red Pencil** |
| **Termite 1** | 3 | 3 |
| **Termite 2** | 4 | 1 |
| **Termite 3** | 1 | 7 |
| **Termite 4** | 4 | 1 |
| **Termite 5** | 0 | 6 |
| **Termite 6** | 3 | 5 |
| **Mean ± Standard Deviation** | 2.50 ± 1.64 | 3.83 ± 2.56 |
| **p-value** |  |  |