Supplement 3
The Scientific Method and Presentation of Results, Student Handout

I. Components of an Experiment

Hypothesis
Scientists attempt to explain phenomena or observations by proposing hypotheses, or tentative explanations. A hypothesis must be *testable*, either by making observations, or by conducting manipulated experiments and collecting evidence. Analysis of evidence or experimental data determines whether or not to accept or reject a hypothesis. However, one cannot PROVE a hypothesis to be 100% true, one can only support it, and thus scientists may only accept or reject a hypothesis.

Prediction
Scientists devise experiments based on a predicted outcome if the hypothesis were correct. The prediction may be written in the form of if/then statements, such as: "*If* drug A is superior to drug B in eliminating cancer cells (hypothesis), *then* the patients treated with drug A will have a lower recurrence of cancer than patients treated with drug B (prediction)." But an 'if/then' format is not necessarily required, a prediction can be a simple statement for what the researcher expects to find if the hypothesis is correct, such as 'Patients taking drug A will have a lower recurrence of cancer than patients taking drug B".

Null hypothesis (H_o)
Predicts an experiment outcome of no difference or no effect. Because it is much easier to demonstrate something is false than it is to support that something is true, a null hypothesis is written in such a way that it can be easily falsified or rejected. "There will be no difference in cancer recurrence in patients taking drug A vs. patients taking drug B." When a null hypothesis is rejected, the conclusion is there *is* a difference or an effect, and an alternate hypothesis may be supported and thus accepted. Statistical procedures always test the null hypothesis (see explanation below on statistical procedures).

Alternate hypothesis (H_A)
In some experiments, there may be more than one alternative hypotheses stated to account for different possible outcomes. H_1: "If drug A is superior to drug B in eliminating cancer cells, then the patients treated with drug A will have a lower recurrence of cancer than patients treated with drug B." H_2: "If drug B is superior to drug A in eliminating cancer cells, then the patients treated with drug B will have a lower recurrence of cancer than patients treated with drug A."

Experiment
A set of prescribed observations or steps performed in order to examine a specific problem, answer a question, or test a hypothesis. An experiment is a way to disprove a theory or hypothesis that is no longer supported by current evidence.

Procedure or Methods
Describes exactly how the steps performed in an experiment were done. Procedures are carefully documented in detail so that they can be repeated and verified, or carried out by other researchers (also called 'experimental protocol').

Materials
All the chemicals, reagents, instrumentation and equipment that will be used in carrying out an experiment, carefully documented in detail so that an experiment can be repeated.

Independent Variable
In manipulative experiments, an independent variable is the factor or condition that the researcher controls and changes in order to see the effect or consequence. May be called the control or treatment variable.

Dependent Variable
In manipulative experiments, a dependent variable is the factor or condition that is expected to change in response to differing values or conditions of the manipulated independent variable. Also called the response variable.

Control
Some experimental designs include a control group in which all the same conditions of the experiment are held constant, except that the independent variable (treatment, manipulation, or factor being examined) is omitted (or held at an established level). The control serves as a benchmark that allows scientists to decide whether the predicted effect is really due to the independent variable (treatment, manipulation, or factor being examined). An example would be to compare the effects of taking a drug compared to taking a placebo (the control).

Level of Treatment
The value set for the independent variable is called the level of treatment. For example: the different concentrations of sucrose solution used in an Osmolarity experiment.

Sample size (n)
The number of subjects used in a treatment group or study, or in some cases sample size refers to the number of replications or trials performed in a study.

Replications/Trials
Scientific investigations are not valid if the conclusions drawn from them are based on only a few subjects, or a few replications or trials. Generally, the same procedure will be repeated several times to provide stronger, more consistent results, and to allow for statistical tests to be performed.

Statistical procedures
Mathematical procedures such as T-tests and Chi-square tests (among many others) are performed on the data collected in an experiment to determine whether two values are significantly different. Statistical procedures always test the null hypothesis of no difference; when a test is reported as not statistically significant one accepts the null. When a test is reported as statistically significant, this is indicates a significant difference between treatment groups and one would reject the null and accept an alternate hypothesis. The level of accepted statistical significance is typically $p < 0.05$ (which corresponds to a 95% probability or confidence level that the null hypothesis is incorrect). Statistical procedures require minimum sample sizes in order to provide valid results.

II. Presenting and Analyzing Results

Once data are collected, they must be analyzed and interpreted to evaluate whether the null or alternate hypothesis has been supported or falsified. Tables and graphs have two primary functions: 1) they help describe, analyze, or interpret results; and, 2) they enhance the clarity with which you communicate the results to a reader or audience. In many experiments this semester (and in future courses), you will design tables and graphs to display your results. Whether data are shown using a table or a graph depends on which method most effectively demonstrates the trend or result you need to convey; typically scientists use <u>either</u> a table or a graph to show the same data, but not both (that would be redundant).

Tables

Tables are information presented in columns and rows of text and/or numbers rather than as a graph or image. They are also useful for displaying several dependent variables.

The following guidelines will help you construct a table:

- You should sketch your table on paper to determine the best possible organization and layout before constructing it on the computer using Excel or Word.
- Include only data that are important in presenting the results and for further discussion. Information that is not essential (i.e.: test tube numbers, simple calculations, or data with no differences) should be omitted.
- In most cases, values of the same kind should read down the column, not across a row.
- The headings of each column should include units of measurement, if appropriate.
- Tables are numbered consecutively in the order that they are first referred to in the text of the lab report or scientific paper.
- A title at the top of the table is a clear, concise sentence that provides enough information to allow the table to be understandable apart from the text.
- In addition to providing Tables (or graphs), you must also summarize the data and refer to each table in the text of your paper or lab report.

Table title and description (at the TOP of the Table)

Table 1. Rate of chemotaxis to serine by four *Yersinia* species as measured by increase in colony swarm size (mm) over 12 hours.

	Average Swarm Size (mm)			
Time (hours)	*Y. bercovieri*	*Y. fredericksii*	*Y. Intermedia*	*Y. mollareti*
1	0.8	0.2	0.9	0.8
2	1.5	0.3	1.7	1.5
3	2.4	0.4	2.8	2.3
4	3.3	0.7	3.7	3.1
6	4.6	0.9	5.5	4.8
8	6.2	1.5	7.5	6.0
12	9.9	2.1	11.1	9.2

Graphs

Graphs are 'graphical' representations of data, and are referred to as 'Figures'. Other types of Figures include drawings, photos, diagrams, and maps. A graph shows a visual summary of the results of an experiment, or of relationships among the dependent and independent variable(s). Often trends or relationships in the data are not easy to see in a table, but may be shown quite clearly in a graph. Making a graph may be one of the first steps in analyzing or interpreting your results, and helps you determine whether the data support or falsify your hypothesis. Graphs also provide an effective way to communicate your results in a lab report or scientific paper.

The following guidelines will help you construct a graph:

- Use graph paper and a ruler to plot values accurately. Sketch your graph by hand to determine the best way to make the graph before constructing the figure on the computer.
- Which variable goes on the X axis? **When one variable is clearly dependent upon another** (e.g.
  height depends on age, but it is hard to imagine age depending on height), **the convention is to plot the dependent variable on the Y axis and the independent variable on the X axis**. Sometimes there is no clear independent variable (e.g. length vs. width of leaves: does width depend on width, or vice-versa?). In these cases it makes no difference which variable is on which axis; the variables are inter-dependent, and an X, Y plot of these shows the relationship BETWEEN them (rather than the effect of one upon the other.)
- The numerical range for each axis should be appropriate for the data being plotted. Generally, begin both axes of the graph with zero. Then choose your intervals and range to maximize the use of the graph space. Choose intervals that are logically spaced to allow easy interpretation of the graph.
- Label the axes to indicate the variable and the units of measurement. Include a legend of colors or shading used to indicate different conditions of the experiment.
- Choose the type of graph that best presents your data. Line graphs and bar graphs are most frequently used. The choice of the graph depends on the nature of the variable being graphed.
- Figures are numbered consecutively in the order that they are first referred to in the text of a lab report or scientific paper.
- Figures are numbered separately from Tables.
- A title and description **at the bottom of the figure** is a clear, concise sentence that provides enough information to allow the table to be understandable apart from the text.
- In addition to providing Figures (or tables), you must also summarize the data and refer to each Figure in the text of your paper or lab report.

Line Graphs

Line graphs show change in the quantity of the chosen variable and emphasize the rise and fall of the values over their range. Use a line graph to present continuous data.

- Plot separate points.
- Whether to connect the dots or draw a best fit curve depends on the type of data and how they were collected. To show trends, draw smooth curves or straight lines to fit the values plotted for any one data set. Connect the points dot to dot when emphasizing meaningful changes in values on the x-axis.

- If more than one set of data is presented on a graph, use different colors or symbols and provide a key or legend to indicate which set is which.
- A boxed graph, instead of one with only two sides, makes it easier to see the values in the right side of the graph.

Example of a Line graph:

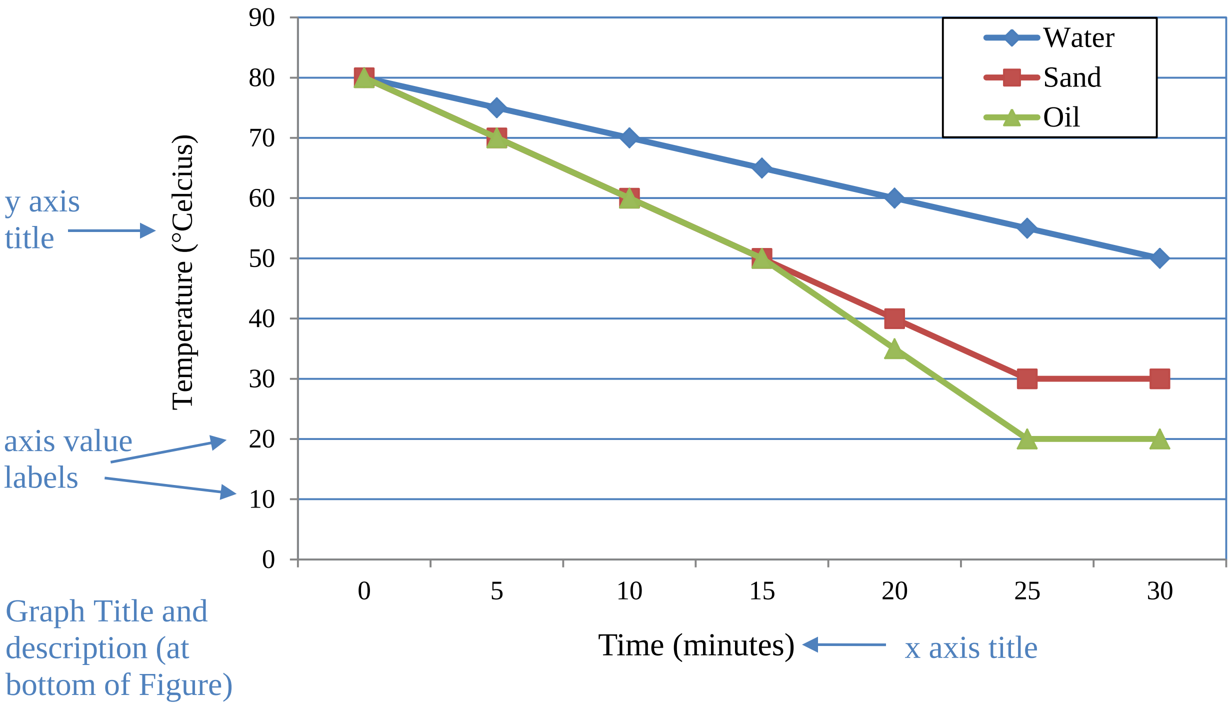

Figure 1. Temperature of beakers filled with water, sand, or oil which were heated to 80° C and then allowed to cool for 30 min.

Bar Graphs

Bar graphs are constructed following the same principles as for line graphs, except that vertical bars, in series, are drawn down to the horizontal axis. Bar graphs are often used for data that represents separate or discontinuous groups or non-numerical categories, thus emphasizing the discrete differences between groups. Bar graphs are also used when the values on the x-axis are numerical but grouped together.

Below is an example of a **grouped bar graph**; note the multiple bars grouped above each amino acid used in the experiment.

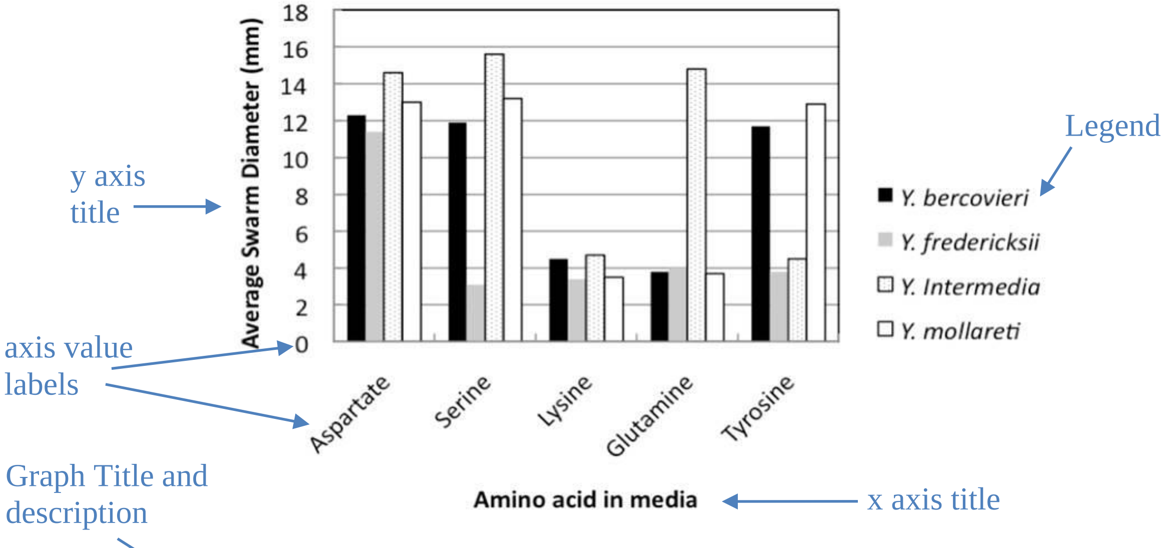

Figure 2. Chemotaxis to amino acids by four *Yersinia* species as measured by average colony swarm size (mm) at 12 hours.

Below is an example of a **stacked bar graph**; this works well when you want to conserve space or reduce clutter on the x axis.

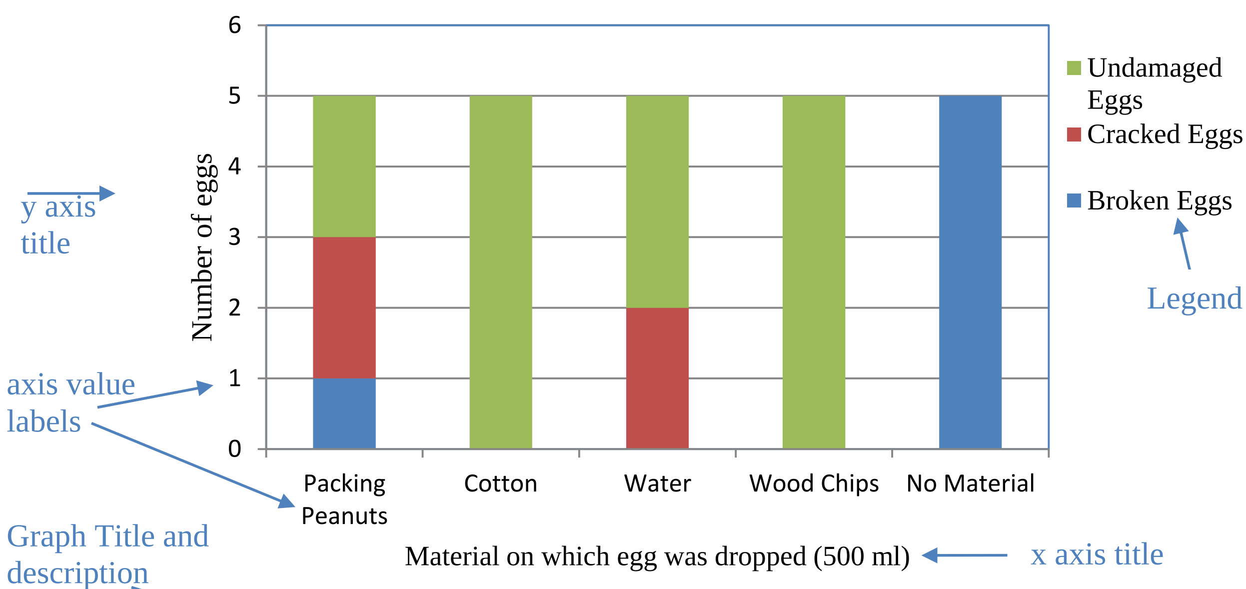

Figure 1. Condition of egg shell after being dropped onto 500 ml of different cushioning material (packing peanuts, cotton, water, or wood chips) and dropped onto a bare floor with no cushioning material.