IB Biology Lab "Tool-Kit"

NAME: _____

Lab Safety

According to Issaquah School District policy, each student must have returned a lab safety contract, signed by student and parent before being allowed to do lab work.

PERSONAL SAFETY

- ✓ Every person shall wear eye protection devices when using corrosive, toxic, reactive, or irritating chemicals and during hazardous activities.
- ✓ Wash your hands before removing your goggles and leaving the laboratory.
- ✓ Never be a practical joker in the laboratory.
- ✓ Laboratory aprons must be worn when working with hazardous solutions.
- ✓ If you do not understand how or why to do a task, ask your instructor for help. If there is any doubt in your mind, ask your instructor.
- ✓ Some chemicals can be harmful to a fetus. If pregnant, or suspect pregnancy, notify your science teacher or school counselor.
- ✓ Tie back long hair. Secure loose clothing to the body and remove loose fitting coats and jackets.
- ✓ In classrooms functioning as a laboratory, no eating or drink will be allowed.

ROOM SAFETY

- ✓ Learn the location of the eyewash station and fire extinguishing devices and how to use them.
- ✓ Before leaving the laboratory, be certain that gas and water lines at your station are shut tightly and that all equipment and supplies are placed in their proper places.
- ✓ Off-limits designation for any area or demonstration is to be strictly observed by students.
- ✓ Know the emergency evacuation route and meeting point.

LAB SAFETY SKILLS

- ✓ Follow your instructor's oral and written instructions before, during and after all laboratory activities.
- ✓ Read an assigned investigation carefully before beginning it, noting all cautions listed.
- ✓ Work deliberately and with definite purpose, but do not hurry.
- ✓ Keep the workspace at your station and your apparatus clean and in good order.
- ✓ Read the label carefully before taking anything from a bottle or container. Using the wrong material could result in serious injury.
- ✓ Know what you are doing. Be wary of what neighboring students are doing.

MATERIALS SAFETY

- ✓ All chemicals should be regarded as hazardous unless your instructor informs you otherwise.
- ✓ Never mix or heat chemicals unless you are directed to do so.
- ✓ When mixing concentrated acids and water, always pour acids into water slowly and stir constantly.
- ✓ When observing the odor of any liquid, do not smell it directly. Use your hand to fan the odor towards you.
- ✓ Never taste a chemical or a solution or touch chemicals with your hands unless directed to do so by your instructor.
- ✓ When heating a test tube, do not heat just one spot on the test tube. Never have the open end of the test tube pointed at anyone. Never look directly down into a test tube.
- ✓ Always allow ample time for cooling after materials have been heated.
- ✓ Dispose of all materials as instructor designates.

NOTIFY YOUR INSTRUCTOR OF ANY ACCIDENT OR POTENTIALLY HAZARDOUS SITUATION.

IF ANY CHEMICAL IS SPLASHED ON YOU SKIN OR IN YOUR EYES,
FLOOD WITH WATER IMMEDIATELY, THEN NOTIFY YOUR INSTRUCTOR

EXPERIMENTAL DESIGN

Step 1: Observation

- Many types of observation can be made on biological systems. They may involve:
  - observation of certain behaviors in wild populations
  - physiological measurements made during previous experiments
  - 'accidental' results obtained when seeking answers to completely unrelated questions
- The observations may lead to the formation of questions about the system being studied

Step 2: Defining the Problem

Every scientific investigation begins with the question that the scientist wants to answer. The questions addressed by scientific inquiry are based on observations or information gained through previous research. Just because a question can be answered doesn't mean that it can be answered scientifically.

Which of the following do you think can be answered by scientific inquiry.

- ☐ What is the cause of AIDS?
- ☐ Are serial killers evil by nature?
- ☐ Why is the grass green?
- ☐ What is the best recipe for chocolate chip cookies?
- ☐ When will the Big Earthquake hit San Francisco?
- ☐ How can the maximum yield be obtained from a peanut field?
- ☐ Does watching television cause children to have shorter attention spans?

How did you decide what questions can be answered scientifically?

Step 3: Identifying the Responding (Dependent) Variable

The responding variable is what the investigator measures (or counts or records). It is what the investigator thinks will vary during the experiment. For example, she may want to study peanut plant growth. One possible responding variable is the height of the peanut plants.

Name some other aspects of peanut plants growth that can be measured:

-
-
-

All of these aspects of peanut plant growth can be measured and can be used as responding variables in an experiment. There are different responding variables possible in an experiment. The investigator can choose the one she thinks is most importance, or she can choose to measure more than one responding variable.

Step 4: Identifying the Manipulated (Independent) Variable

The manipulated variable is what the investigator deliberately varies during the experiment. It is chosen because the investigator thinks it might affect the responding variable.

Name some factors that might affect the numbers of peanuts produced by peanut plants:

-
-
-

In many cases, the investigator does not change the manipulated variable directly. She collects data and uses the data to evaluate the hypothesis, rather than doing a direct experiment. For example, the hypothesis that more crimes are committed during a full moon can be tested scientifically. The number of crimes committed is the responding variable and can be measured from police reports. The phase of the moon is the manipulated variable. The investigator cannot deliberately change the phase of the moon, but can collect data during any phase he chooses.

Although many hypotheses about biological phenomena cannot be tested by direct manipulation of a variable, they can be evaluated scientifically by collecting data that could prove the hypothesis false. This is an important method in the study of evolution, where the investigator is attempting to test hypotheses about events of the past.

The investigator can measure as many responding variables as she thinks are important indicators of peanut growth. By contrast she must choose only one manipulated variable to investigate in an experiment. For example, if the scientist wants to investigate the effect that the amount of fertilizer has on peanut growth, she will use different amounts of fertilizer on different plants; the manipulated variable is amount of fertilizer.

Why is the scientist limited to one manipulated variable per experiment?

Time is frequently used as the manipulated variable. The investigator hypothesizes that the responding variable will change over the course of time. For example, he may want to study the diversity of soil bacteria found during different months of the year. However, the units of time used may be anywhere from seconds to years, depending upon the system being studied.

Identify the manipulated and responding variables in the following examples.

- Height of bean plants is recorded daily for 2 weeks.
  Manipulated variable:_____
  Responding variable:_____

- Guinea pigs are kept at different temperatures for 6 weeks. Percent weight gain is recorded.
  Manipulated variable:_____
  Responding variable:_____

- The diversity of algal species is calculated for a coastal area before and after an oil spill.
  Manipulated variable:_____
  Responding variable:_____

- Light absorption by a pigment is measured for red, blue, green, and yellow light.
  Manipulated variable:_____
  Responding variable:_____

Step 5: Identifying the Controlled Variables

A third type of variable is the controlled variable. Controlled variables are factors that are kept equal in all treatments, so that any changes in the responding variable can be attributed to the changes the investigator made in the manipulated variable.

Materials used and measurement techniques are NOT controlled variables (they are validity measures). While materials and techniques must be consistent, a true variable is something that could directly influence the responding variable, not just how it is measured.

Since the investigator's purpose is to study the effect of one particular manipulated variable, he must try to eliminate the possibility that other variables are influencing the outcome. This is accomplished by keeping the other variables at constant levels, in other words, by standardizing these variables. For example, if the scientist has chosen the amount of fertilizer as the manipulated variable, he wants to be sure that there are no differences in the type of fertilizer used. He would use the same formulation and same brand of fertilizer throughout the experiment.

What other variables would have to be standardized in this experiment?

List three validity measures that could be used in this experiment.

Step 6: Writing the Hypothesis

A hypothesis is simply a statement of the scientist's educated guess at the answer to the question. The nature of science is such that we can prove a hypothesis false by presenting evidence from an investigation that does not support the hypothesis. But we cannot prove a hypothesis true. We can only support the hypothesis with evidence from this particular investigation.

Scientific knowledge is thus 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 be able to prove any hypothesis false. Current scientific studies you read about in the newspaper (for example, investigations of the effects of caffeine) are sometimes quite preliminary and therefore tentative in nature. Often, studies are published whose results contradict each other. However, this does not mean that scientific knowledge is flimsy and unreliable. Much of the information in your textbook, for example, is based upon many experiments carried out by numerous scientists over a period of time.

The scientific method, then applies only to hypotheses that can be proven false through experimentation. (There are other types of scientific investigation, such as observation and comparison that do not involve hypothesis testing.) It is essential to understand this in order to understand what is and is not possible to learn through science. Consider, for example, this hypothesis: More people behave immorally when there is a full moon than at any other time of the month. The phase of the moon is certainly a well-defined and measurable factor, but morality is not scientifically measurable. Thus there is no experiment that can be performed to test the hypothesis.

Which of the following would be useful as scientific hypotheses?

- Mice require calcium for developing strong bones.
- Dogs are happy when you feed them steak.
- An active volcano can be prevented from erupting by throwing a virgin into it during each full moon.
- The higher the intelligence of an animal, the more easily it can be domesticated.
- HIV (human immunodeficiency virus) can be transmitted by cat fleas.

The investigator devises an experiment or collects data that could prove the hypothesis false. He should also think through the possible outcomes of the experiment (whether the hypothesis is supported or proven false) and make predictions about the effect of the manipulated variable on the responding variable in each situation. For example, a scientist has made the following hypothesis:

"Increasing the amount of fertilizer applied will increase the number of peanuts produced." He has designed an experiment in which different amounts of fertilizer are added to plots of land and the number of peanuts yielded per plot is measured. The predictions should state specifically how the responding variable will change in relation to the manipulated variable and must be stated as an "If … Then" statement. The general format for an "If … Then" statement is "if the manipulated variable is changed in this way, then the responding variable will change this way." For example, if the amount of fertilizer applied to a field is doubled, then the number of peanuts produced will double. Or, if the temperature of the reactants in a chemical reaction increases, then the rate of the reaction will increase.

Write a hypothesis for each of the following:

- Guinea pigs are kept at different temperatures for 6 weeks. Percent weight gain is recorded.

- Batches of seeds are soaked in salt solutions of different concentrations and the number of seeds that germinate is counted for each batch.

Step 7: Setting the Levels of Treatment

Once the investigator has decided what the manipulated variable for an experiment should be, he must also determine how to change or vary the manipulated variable. The values set for the manipulated variable are called the levels of treatment. For example, an experiment measuring the effect of fertilizer on peanut yield has five treatments. In each treatment, peanuts are grown on a 100-m2 plot of ground, and a different amount of fertilizer is applied to each plot. The levels of treatment in this experiment are set as 200 g, 400 g, 600 g, 800 g, and 1000 g fertilizer/100 m2.

The investigator's judgment in setting levels of treatment is usually based on prior knowledge of the system. For example, if the purpose of the experiment is to investigate the effect of temperature on weight gain in guinea pigs, the scientist should have enough knowledge of guinea pigs to use appropriate temperatures. Subjecting the animals to extremely high or low temperatures can kill them and no useful data would be obtained. Likewise, the scientist attempting to determine how much fertilizer to apply to peanut fields needs to know something about the amounts typically used so he could vary the treatments around those levels.

Step 8: Identifying the Control Group

It is also necessary to include control groups in an experiment. CONTROL GROUPS ARE DIFFERENT THAN CONTROLLED VARIABLES. A control group is a treatment in which the manipulated variable is either eliminated or is set at a standard value. The results of the control group are compared to the results of the experimental treatments. In the fertilizer example, the investigator must be sure that the peanuts don't grow just as well with no fertilizer at all. The control would be a treatment in which no fertilizer is applied. An experiment on the effect of temperature on guinea pigs, however, cannot have a "no temperature" treatment. Instead, the scientist will use a standard temperature as the control and will compare weight gain at other temperatures to weight gain at the standard temperature.

Tell what an appropriate control group would be for each of the following examples.

- The effect of light intensity on photosynthesis is measured by collecting oxygen produced by a plant.

- The effect of NutraSweet sweetener on tumor development in laboratory rats is investigated.

Step 9: Determining Replication

Another essential aspect of experimental design is replication. Replicating the experiment means that the scientist repeats the experiment numerous times using exactly the same conditions to see if the results are consistent. Being able to replicate a result increases our confidence in it. However, we shouldn't expect to get exactly the same answer each time, because a certain amount of

variation is normal in biological systems. Replicating the experiment lets us see how much variation there is and obtain an average result from different trials.

A concept related to replication is sample size. It is risky to draw conclusions based upon too few samples. For instance, suppose a scientist is testing the effects of fertilizer on peanut production. He plants four peanut plants and applies a different amount of fertilizer to each plant. Two of the plants die.

Can he conclude that the amounts of fertilizer used on those plants were lethal? What other factors might have affected the results?

In IB Biology, the minimum sample size for each level of treatment of the manipulated variable is 5.

Step 10: Writing the Method
After formulating a hypothesis and selecting the manipulated and responding variables, the investigator must find a method to measure the responding variable; otherwise, there is no experiment. Methods are learned by reading articles published by other scientists and by talking to other scientists who are knowledgeable in the field. For example, a scientist who is testing the effect of fertilizer on peanuts would read about peanut growth and various factors that affect it. He would learn the accepted methods for evaluating peanut yield. He would also read about different types of fertilizers and their composition, their uses on different soil types, and methods of application. The scientist might also get in touch with other scientists who study peanuts and fertilizers and learn about their work. Scientists often do this by attending conferences where other scientists present results of investigations they have completed.

SI Units and How to Use Them

When you make quantitative observations you are expected to use the appropriate units. The system of units used is the International System of Units - SI units (Système International d'Unités). In the table below you are given some of the more common SI units you will need to use.

Name	Unit	Symbol
Mass	kilogram	Kg
Length	metre	m
Time	second	s
Area	square metre	m^2
Volume	cubic decimetre	dm^3
Concentration	moles per cubic deci	mol dm^{-3}
Pressure	Pascal	Pa
Energy	joule	J

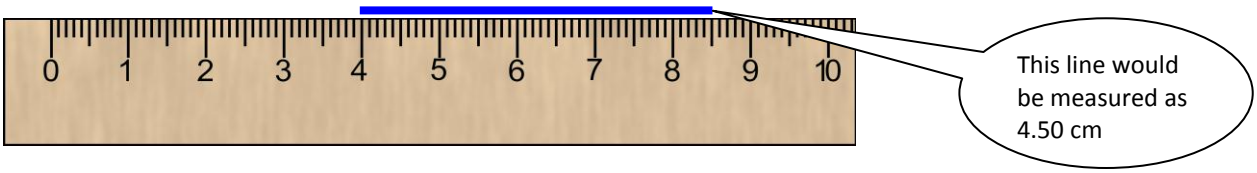
When measuring time, it is appropriate to use minutes, hours or days if the experiment spans a longer period. When showing lengths, it is appropriate to use the following units:

Unit name	Multiple or fraction of a metr	Symbol
kilometre	10^3	km
metre		m
centimetre	10^{-2}	cm
millimetre	10^{-3}	mm
micrometre	10^{-6}	µm
nanometre	10^{-9}	nm

Measurement Precision

- **Unless there is a digital display, always measure to one spot beyond the smallest unit of CERTAIN measurement of the tool.**

- For example, if you use a ruler that can accurately measure to the tenth of a centimeter, your measurement would be to the hundredth of a centimeter.



- You may need to estimate the degree of precision sometimes especially with stop watches. Digital stop watches are said to be accurate to 0.01s but your reaction time is only 0.1s.

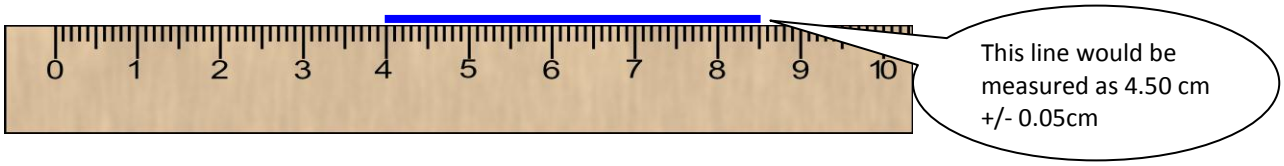
- For electronic probes you may have to go to the manufacturers specifications (on their web site or in the instructions manual).

Measurement Uncertainty

- Every measurement has an uncertainty associated with it, unless it is an exact, counted integer, such as the number of trials performed.

- The lower the accuracy and precision of a measurement instrument are, the larger the measurement uncertainty is.

- The numerical value of a ± uncertainty value tells you the range of the result. For example a result reported as 1.23 ± 0.05 means that the experimenter has some degree of confidence that the true value falls in between 1.18 and 1.28
- To determine uncertainty:
  - Find the smallest increment of measurement on your measurement device
  - Divide it by two
  - Round to the first non-zero number



- Experimental **uncertainties should be rounded to one significant figure**. Uncertainties are almost always quoted to one significant digit (example: ±0.05 s).

- Always round the measurement or result to the same decimal place as the uncertainty. It would be confusing to suggest that you knew the digit in the hundredths (or thousandths) place when you admit that you unsure of the tenths place.

  Wrong: 1.237 s ± 0.1 s
  Correct: 1.2 s ± 0.1 s

Complete this table as a reference for measuring tools used in the IB Biology class.

MEASURING DEVICE	MEASURES	UNIT(S)	UNCERTAINTY
Gram Scale			
Meter Stick	Length		
Ruler			

MEASURING DEVICE	MEASURES	UNIT(S)	UNCERTAINTY
Stop Watch			
Glass thermometer			
Metal thermometer			
10 graduated cylinder	Volume		
100 graduated cylinder			
500 graduated cylinder			
2000 graduated cylinder			
15 beaker			
250 beaker			
1000 beaker			
250 flask			
1000 flask			
4000 flask			

Microscopy

Magnifying Power
A compound microscope has two sets of lenses. The lens you look through is called the **ocular.** The lens near the specimen being examined is called the **objective**. The objective lens is one of three or four lenses located on a rotating turret above the stage, and that vary in magnifying power. The lowest power is called the **low power objective (LP)**, and the highest power is the **high power objective (HP)**.

You can determine the magnifying power of the combination of the two lenses by multiplying the magnifying power of the ocular by the magnifying power of the objective that you are using. For example, if the magnifying power of the ocular is 10 (written 10X) and the magnifying power of an objective is 4 (4X), the magnifying power of that lens combination is 40X.

Field of View (FOV)
The **field of view** is the maximum area visible through the lenses of a microscope, and it is represented by a diameter. To determine the diameter of your field of view, place a transparent metric ruler under the low power (LP) objective of a microscope. Focus the microscope on the scale of the ruler, and measure the diameter of the field of vision in millimeters. Record this number.

When you are viewing an object under high power, it is sometimes not possible to determine the field of view directly. The higher the power of magnification, the smaller the field of view. The diameter of the field of view under high power must be calculated using the following equation.

$$\frac{\text{diameter (LP)} \times \text{magnification of LP objective}}{\text{magnification of HP objective}} = \text{diameter (HP)}$$

For example, if you determine that your field of view is 2.5 mm in diameter using a 10X ocular and 4X objective, you will be able to determine what the field of view will be with the high power objective by using the above formula. For this example, we will designate the high power objective as 40X.

$$\frac{2.5 \text{ mm} \times (4\times)}{(40\times)} = .25 \text{ mm, or } 250 \text{ µm}$$

Estimating the Size of the Specimen Under Observation

Objects observed with microscopes are often too small to be measured conveniently in millimeters. Because you are using a scale in millimeters, it is necessary to convert your measurement to micrometers. Remember that 1 µm = 0.001 mm.

To estimate the size of an object seen with a microscope, first estimate what fraction of the diameter of the field of vision that the object occupies. Then multiply the diameter you calculated in micrometers by that fraction. For example, if the field of vision's diameter is 400 µm and the object's estimated length is about one-tenth of that diameter, multiply the diameter by one-tenth to find the object's length.

$$400 \text{ µm} \times \frac{1}{10} = 40 \text{ µm}$$

SKYLINE MICROSCOPES QUICK REFERENCE SHEET

EYEPIECE MAGNIFICATION	OBJECTIVE MAGNIFICATION	TOTAL MAGNIFICATION	FIELD OF VIEW
10	4		*Measured*
10	10		*Calculated*
10	40		*Calculated*

Lab Drawings

Drawing Materials. All drawings should be done with a sharp pencil line on white, unlined paper. Diagrams in pen are unacceptable because they cannot be corrected. Lines are clear and not smudged. There are almost no erasures or stray marks on the paper. Color can be used carefully to enhance the drawing. Stippling is used instead of shading.

Positioning. Center your drawing on the page. Do not draw in a corner. This will leave plenty of room for the addition of labels.

Size. Make a large, clear drawing; it should occupy at least half a page.

Labels. Use a ruler to draw straight, horizontal lines to the right of the side of the drawing. The labels should form a vertical list. All labels should be printed (not cursive).

Accuracy. Look carefully at the specimen before you start and try to get the proportions right. Draw what you see; as you see it, not what you imagine should be there. Avoid making "idealized" drawings. You are not necessarily drawing everything that is seen in the field of view. Draw only what is asked for. Show only as much as necessary for an understanding of the structure – a small section shown in detail will often suffice. It is time consuming and unnecessary, for example, to reproduce accurately the entire contents of a microscopic field.

Do not copy textbook drawings. They are often diagrams! A drawing is different from a diagram. Whilst a drawing is an accurate record of your observations of a particular biological specimen, showing only the features that can be seen clearly, a diagram is a more stylized representation of a structure. In a diagram, it is customary to include all the essential features known to be associated with the specimen, whether visible or not.

Technique. Keep looking back at your specimen whilst you are drawing. If using a microscope, while you are observing increase the magnification to observe more details and reduce the magnification to get a more general view. Use the focusing controls on the microscope to observe at different depths of the specimen. Move the specimen around; do not just concentrate on one part. Observe the general appearance first.

When drawing low power plans do not draw individual cells. Show only the distribution of tissues.

When making high power drawings, draw only a few representative cells; indicate thickness of walls, membranes, etc.

Title. The title should state what has been drawn and what lens power it was drawn under (for example, phrased as: drawn as seen through 400X magnification). Title is informative, centered, and larger than other text. The title should always include the scientific name (which is *italicized* or underlined).

Scale. Include a linear magnification that indicates how many times larger the drawing is compared to life size and a scale line that indicates relative size. To determine magnification compared to life size, use the equation:

Measurement of the scale line you drew with a ruler.

The estimated size of the object being drawn as determined by figuring how much of the field of view it fills.

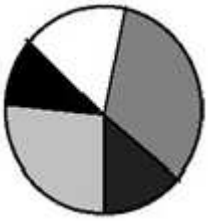
Actual size of line / size the line represents = magnification

Be sure these numbers are in the same unit of measurement. If not, convert first before calculating linear magnification!

Since you are calculating magnification from an estimate, you must round your answer to one signification digit.

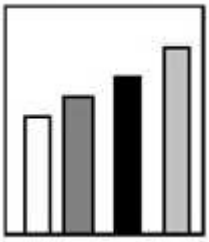
Graphing

Pie Charts



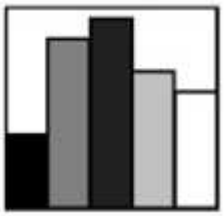
Designed to show a percent of a whole, where the whole equals 100%. Pie charts are used to compare data, but cannot be used to see how a manipulated variable affects a responding variable. Pie charts do not show change with respect to another variable, such as time.

Bar Graphs



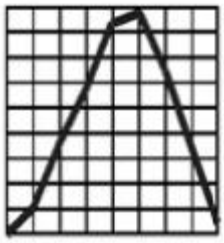
Designed to make comparisons of data. The data represented in bar graphs are not necessarily dependent on any other variables and the groupings are usually *qualitative* (i.e. grouped into categories, like blood types or color). The bars do NOT touch.

Histogram



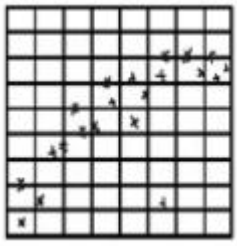
Histograms are similar to bar graphs except the data represented in histogram is usually in groups of continuous numerical (*quantitative*) data. In this case, the bars do touch.

Line Graphs



A line graph consists of a series of points plotted on the grid and then connected together by a line or a curve. Line graphs are only used when both variables are quantitative. Line graphs show trends, such as how things change over time. They are the best type of graphs to use to show how one factor affects another factor. They are typically used to express the relationship between responding and manipulated variables. For example, a line graph would be used to show a baby's increase in mass (responding variable) over time (manipulated variable) or how the chances of birth defects decrease (responding variable) with an increase in a mother's folic acid intake (manipulated variable).

Scatter Plot



The points are plotted on the grid, but they are usually not joined with a line or a curve. Line graphs are only used when both variables are quantitative. These graphs are useful for showing if a relationship exists between two variables, especially when it is not possible to alter either of the variables (i.e. in descriptive studies).

How do I know which type of graph to use? Follow this key…

1. Is the data a percent that sums to 100%?
    a. If yes…….. Pie chart
    b. If no…….. Go to #2

2. Are <u>both</u> your manipulated and responding variables quantitative?
    a. If no…….. Bar graph
    b. If yes …….. Go to #3

3. Are your manipulated variable levels continuous or clumped into groups?
    a. Continuous…….. Scatter plot/line
    b. Clumped …….. Histogram

Some terms and phrases that could be useful when describing trends in a line graph are:-

rapidly slowly regularly unevenly erratically smoothly

became constant reached a peak fluctuated levelled off

Formatting a Graph

Graphs (called figures) should have a concise, explanatory title. They should be numbered consecutively in your report

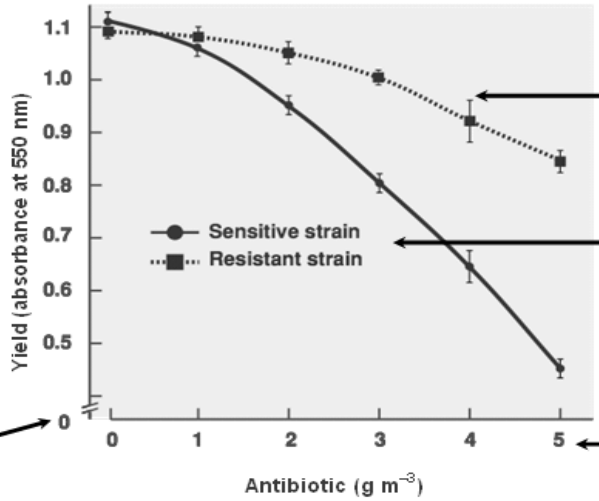
Plot points accurately. Different responses can be distinguished using different symbols, lines or bar colors.

Label both axes (provide SI units of measurement if necessary)

The responding **variable** is plotted on the vertical (y) axis

A break in an axis allows economical use of space if there are no data in the "broken" area. A floating axis (where zero points do not meet) allows data points to be plotted away from the vertical axis.

Fig. 1: Yield of two bacterial strains at different antibiotic levels. Vertical bars show standard errors (n = 6)



The **manipulated variable**, e.g. treatment, is on the horizontal (x) axis

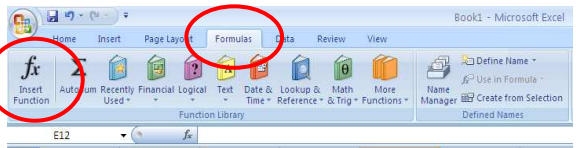
The spread of the data around the plotted mean value can be shown on the graph. The standard deviation values are plotted as error bars.

A key identifies symbols. This information sometimes appears in the title.

Each axis should have an appropriate scale. Decide on the scale by finding the maximum and minimum values for each variable.

Graphing in Excel 2010

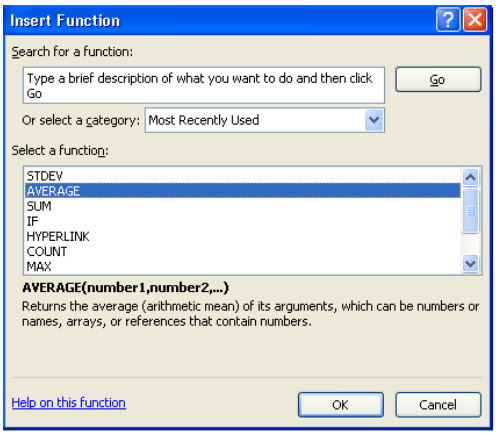
1. Open Excel and enter your data in columns. You can label the columns if you prefer.
2. To calculate mean:
    a. Click on the box in which you want the mean to be placed
    b. Click the formulas tab at the top of the screen
    c. Select the "insert function button"



	A	B	C	D	E	F	G
1		BOY	GIRL				
2		12	15				
3		12	76				
4		45	58				
5		78	36				
6		5	12				
7		45	6				
8		78	53				
9		97	79				
10							

d. A new box pops up. Search to find the AVERAGE option, click OK

e. Highlight the data of which you want the average to be calculated, click OK



3. To calculate standard deviation

a. Click on the box in which you want the SD to be placed

b. Click the formulas tab at the top of the screen

c. Select the "insert function button"

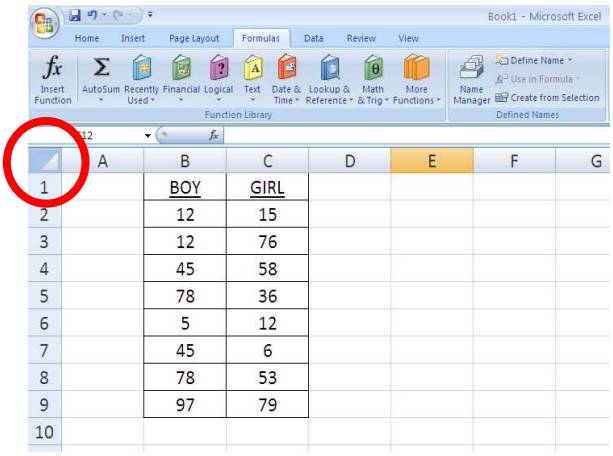
d. Search to find the STDEV option, click OK

e. Highlight the data of which you want the SD to be calculated, click OK.

NOTE: be sure not to select the mean as one of your data points for calculating standard deviation. This is a common mistake.

4. To select the correct number of digits for your answer (remember, you want correct precision)

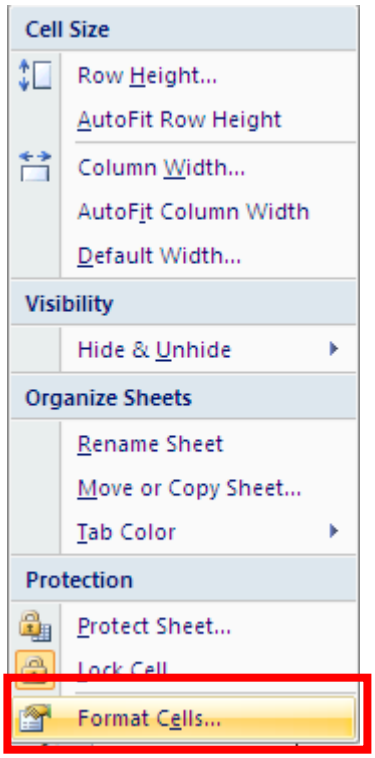
a. Select the top box between row 1 and column A. This should highlight your entire spreadsheet.

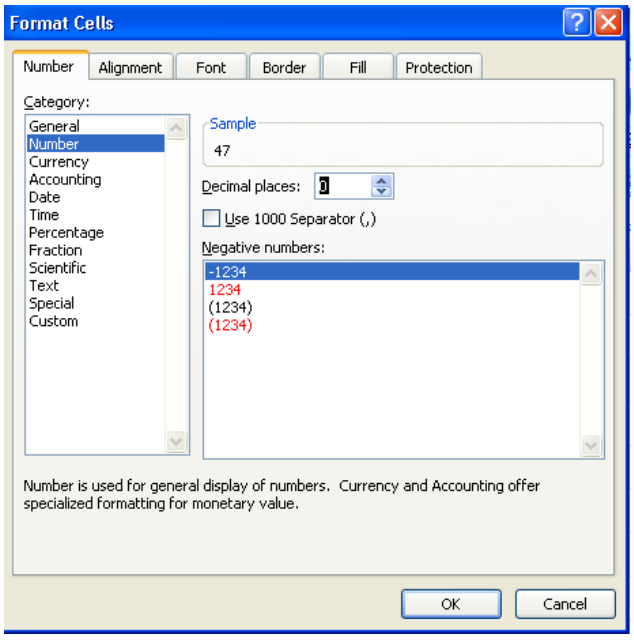


b. Click the HOME tab along the top

c. Select format cells and then format cells again.

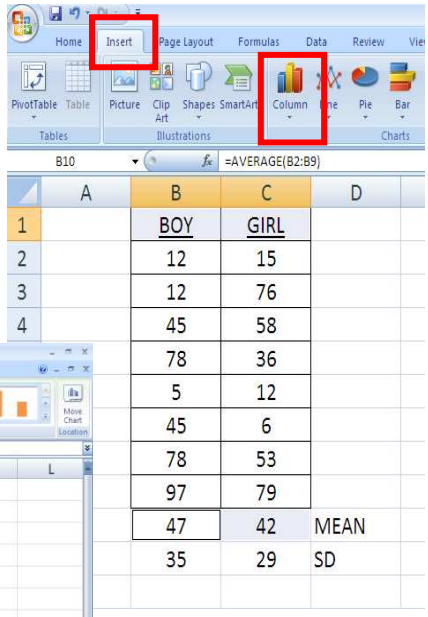
d. Select number, and indicate the number of decimal places you want included. Hit OK.



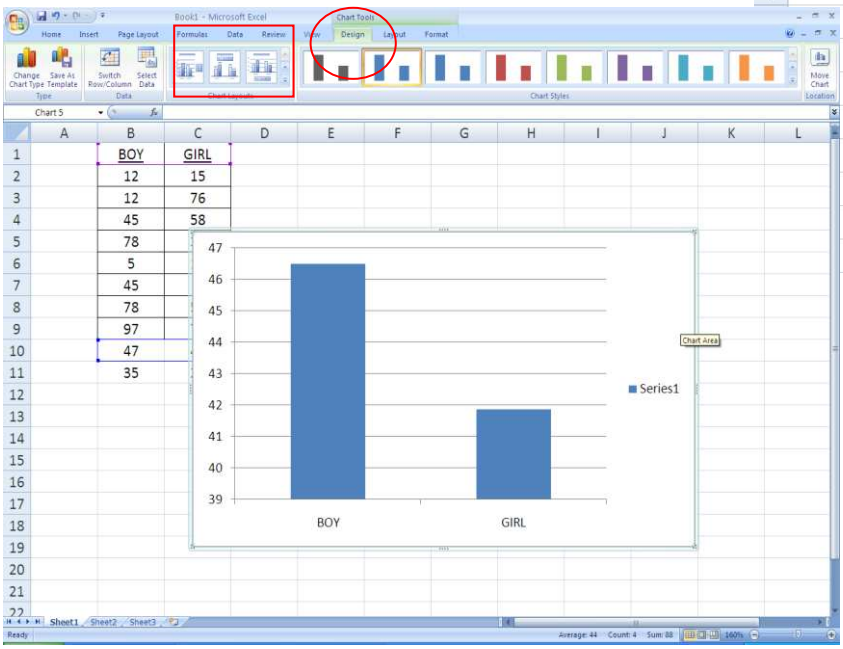


5. To graph

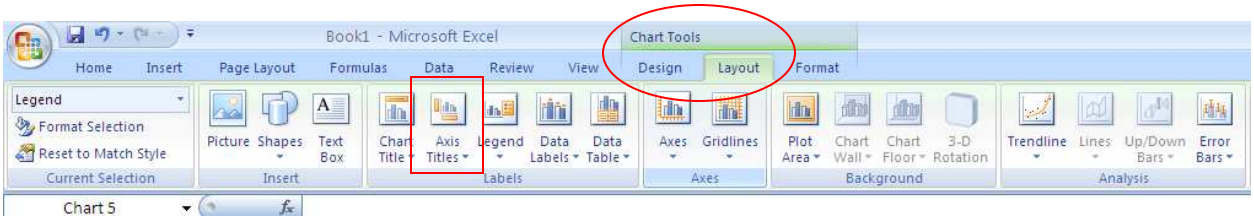
   a. Along the top, select INSERT
   b. Highlight the column headings (i.e. boy/girl), hold down the CTRL key and highlight the means
   c. Select the type of graph you want
   d. When you click on the graph, a new set of tools opens up, called CHART TOOLS. From this you can change the chart layout (do this to add a title) or bar colors.



	A	B	C	D
1		BOY	GIRL	
2		12	15	
3		12	76	
4		45	58	
		78	36	
		5	12	
		45	6	
		78	53	
		97	79	
		47	42	MEAN
		35	29	SD

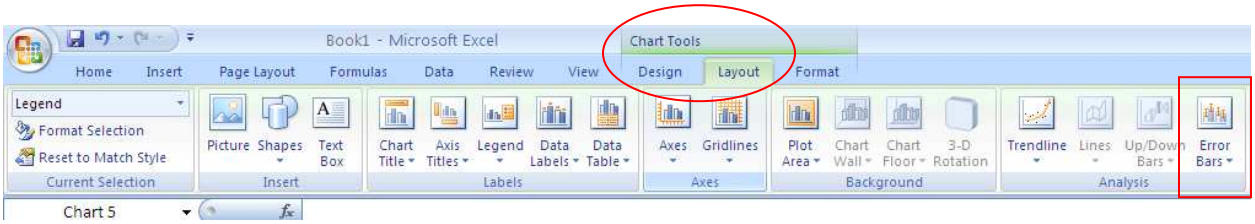


   f. Within your graph, click on and delete the key that says “series 1”
   g. To add axis labs, select the LAYOUT tab under CHART TOOLS and choose the “axis titles” option.

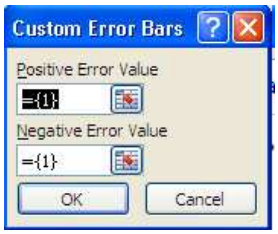


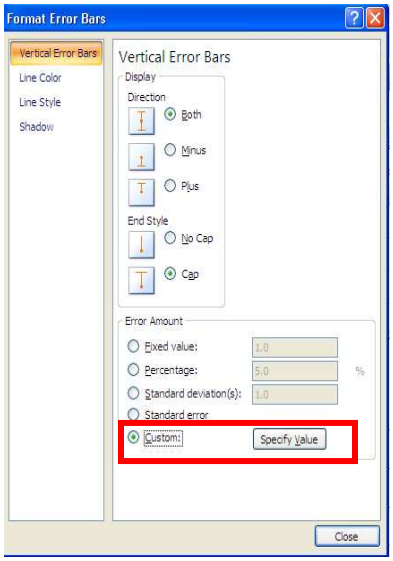
6. To add SD error bars

   a. Click anywhere on the graph to open the chart tools
   b. Click the layout tab
   c. Select error bars and then more error bar options.



d. Select custom and specify value →
e. A little box comes up that looks like:





f. Delete what is in each box
g. For EACH box (positive and negative) highlight the boxes that include the standard deviations. Highlight them all at once.
h. Hit ok.

Statistics: *Percentage Change*

A percentage change is a way to express a change in a variable. It represents the relative change between an old value and an new one.

$$\text{Percentage change} = \frac{\Delta V}{V_1} = \frac{V_2 - V_1}{V_1} \times 100.$$

V1 = the old value, the original value
V2 = the new value

Statistics: *Mean*

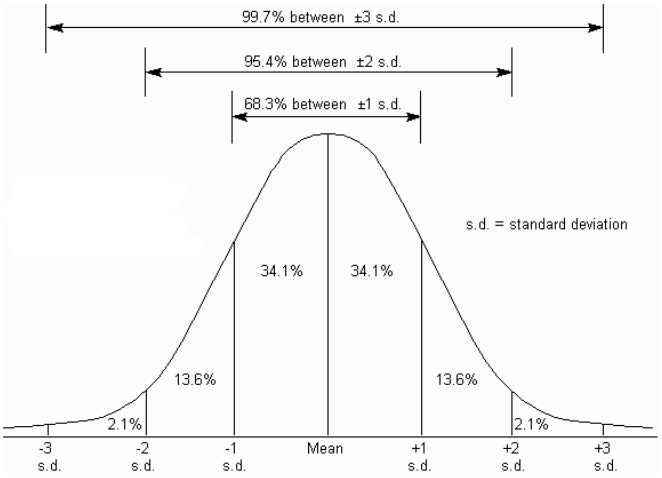
- The sum of all the data points divided by the number of data points.

$$\bar{x} = \frac{\Sigma x}{n}$$

- Measure of central tendency for normally distributed data.
- DO NOT calculate a mean from values that are already averages.
- DO NOT calculate a mean when the measurement scale is not linear (i.e. pH units are not measured on a linear scale).

Statistics: *Standard Deviation*

Averages do not tell us everything about a sample. Samples can be very uniform with the data all bunched around the mean or they can be spread out a long way from the mean. The statistic that measures this spread is called the standard deviation. The wider the spread of scores, the larger the standard deviation. For data that has a normal distribution, 68% of the data lies within one standard deviation of the mean.



MEN	WOMEN
0.90	1.50
2.00	3.00
1.40	3.00
2.00	2.50
3.00	3.00
2.00	3.00
3.00	4.00
4.00	3.00
3.70	2.00

HOW TO CALCULATE STANDARD DEVIATION:

Calculate the standard deviation by subtracting the mean of a distribution from the value of each individual variable in the distribution, squaring each resulting difference, summing these squared differences, then dividing this sum by the number of variables, and finally taking the square root of this quotient.

1. Calculate the mean (M) of a set of data

MEN	WOMEN

2. Subtract the mean from each point of data to determine (X-M)

MEN	WOMEN

3. Square each of the resulting numbers to determine $(X-M)^2$

MEN	WOMEN

4. Add the values from the previous step together to get $\sum(X-M)^2$

MEN	WOMEN

5. Calculate (n-1) by subtracting 1 from your sample size. Your sample size is the total number of data points you collected.

MEN	WOMEN

6. Divide the answer from $\sum(X-M)^2$ by the answer from (n-1) to find $\frac{\sum(X-M)^2}{n-1}$

MEN	WOMEN

7. Calculate the square root of your previous answer to determine the standard deviation

MEN	WOMEN

SO WHAT?
On a graph…

If SD error bars overlap…
If SD error bars do not overlap …

$$S=\sqrt{\frac{\sum(X-M)^2}{n-1}}$$

Using EXCEL to calculate the mean and the standard deviation

Type the values you are trying to find the mean for in a column. You can label the column, but you don't have to.

Determine which box you want the mean to appear in. In the example, I want the mean to appear in box A12. In that box, type: **=AVERAGE(A2:A11)** and then hit **enter**. Basically you are telling Excel to average boxes A2 through A11.

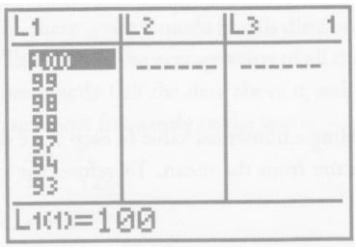
Determine which box you want the standard deviation to appear in. In the example, I want the standard deviation to appear in box A13. In that box, type: **=STDEV(A2:A11)** and then hit **enter.** You are giving Excel the box labels for the data for which you want to find the standard deviation.

Once you have the mean and standard deviation, you need to make sure that you set the values to the correct number of digits. EXCEL will default to giving you too many numbers after the decimal place. Your mean and standard deviation must have the same precision (number of digits after the decimal) as your data points. In the example to the right, since the raw data is a whole number, the mean and standard deviation must also be whole numbers. The mean would round to 133 and the standard deviation to +/- 3.

	A
1	Number of Pennies
2	134
3	130
4	136
5	132
6	131
7	137
8	131
9	135
10	130
11	129
12	132.5
13	2.798809

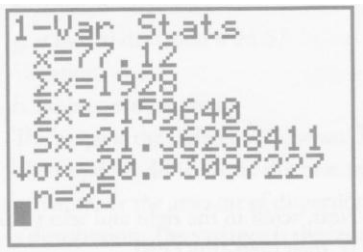
Using TI-83/84 to calculate the mean and the standard deviation

First you have to enter the data. Hit the STAT button and you will see the options EDIT, CALC and TESTS atop the screen. Use the left and right arrows (if necessary) to move the cursor to EDIT, then select 1: Edit...



Now you will see a table with the headings L_1 and L_2. Enter the values under L_1 (if you want to clear pre-existing data first, move the cursor to the top of the column, hit CLEAR and then ENTER.)
Once all the data is entered, go back to the STAT menu, but this time move the cursor to CALC instead of EDIT.

Once you're in the CALC menu, select *1-Var Stats*, then hit ENTER. The calculator will display the *x*-mean, some other stuff, and then the standard deviation (s_x). **Note that s_x is what we want!** This is followed by something called sigma $_x$ (which is what you would get as standard deviation if you had used *n* instead of *n*-1), and finally the sample size.



Using TI-INSPIRE to calculate the mean and the standard deviation

Create a new list and type your data into columns. You MUST Name your list (arrow to the top of the column and enter the name of your list). Keep the name descriptive, but short.

Once your data is entered, hit MENU**,** #4 Statistics, #1 Stat Calculations, and choose #1 One-Variable Statistics. The choice *"Open Variable Statistics"* yields the following results back to the spreadsheet columns. One column will "label" these values, while the following column contains the actual values.

$\bar{x}$ = mean

s_x = the sample standard deviation

Statistics: *The Independent T-test*

The Student's *t*-test is a statistical test that compares the _____ and _____ _____ of two samples to see if there is a _____ between them. In an experiment, a t-test might be used to calculate whether or not differences seen between the control and each experimental group are a factor of the manipulated variable or simply the result of chance.

$$t = \frac{(x_1 - x_2)}{\sqrt{\frac{(s_1)^2}{n_1} + \frac{(s_2)^2}{n_2}}}$$

Where:

x_1 is the mean of sample 1
s_1 is the standard deviation of sample 1
n_1 is the sample size of sample 1
x_2 is the mean of sample 2
s_2 is the standard deviation of sample 2
n_2 is the sample size in sample 2

There are two hypothesis related to a T-test:

NULL HYPOTHESIS	**ALTERNATIVE HYPOTHESIS**

	Students in Room 1					Students in Room 2				
Student Height (cm)	145	140	138	142	154	148	153	157	161	162
	154	158	160	166	166	162	163	167	172	172

HOW TO CALCULATE T:

1. Calculate the mean (X) of a each sample

   Room 1: _____ Room 2: _____

2. Find the *absolute value* of the difference between the means

3. Work out the standard deviation for each sample (use a calculator…)

   Room 1: _____ Room 2: _____

4. Square the standard deviation for each group

5. Divide each squared standard deviations by the sample size of that group.

6. Add these two values

7. Take the square root of the number

8. Divide the difference in the means (step 2) by the standard error of the difference (step 7)

9. Determine the degrees of freedom (df) for the test. In the t-test, the degrees of freedom is the sum of the sample sizes of both groups minus 2.

10. Given the df, look up the critical t-value in a standard table of significance

Use the 95% (p=0.05) confidence limit

11. Check your answers on-line using the t-test calculator posted at www.biologyforlife.com

SO WHAT?

If your calculated t value is _____ than the number in the table, you conclude that the difference between the means for the two groups is _____

_____different. Meaning:

_____

_____

If your calculated t value is _____ than the number in the table, you conclude that the difference between the means for the two groups is _____ different.

Meaning: _____

_____

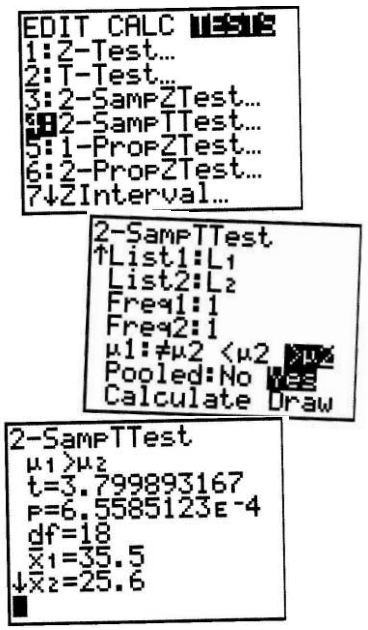
Do not worry if you do not understand *how* or *why* the test works .... Follow the instructions CAREFULLY

T Test Critical Values

df	.10	.05
1	3.078	6.314
2	1.886	2.920
3	1.638	2.353
4	1.533	2.132
5	1.476	2.015
6	1.440	1.943
7	1.415	1.895
8	1.397	1.860
9	1.383	1.833
10	1.372	1.812
11	1.363	1.796
12	1.356	1.782
13	1.350	1.771
14	1.345	1.761
15	1.341	1.753
16	1.337	1.746
17	1.333	1.740
18	1.330	1.734
19	1.328	1.729
20	1.325	1.725
21	1.323	1.721
22	1.321	1.717
23	1.319	1.714
24	1.318	1.711
25	1.316	1.708
26	1.315	1.706
27	1.314	1.703
28	1.313	1.701
29	1.311	1.699
30	1.310	1.697
40	1.303	1.684
60	1.296	1.671
120	1.289	1.658
c	1.282	1.645

Performing a T-test with the TI-83/84

1. Hit the STAT button on the calculator
2. Select option 4 to clear any past lists of data.
3. Select option 1 to EDIT your lists.
4. Enter your data for each group as List 1 and List 2
5. Hit STAT button and use the arrow key to move over to the TESTS option
6. Scroll down to option 4, the 2-sample T test and hit ENTER
7. Scroll to the bottom of the screen and hit ENTER over the CALCULATE option
8. Your results are given.
    - T = calculated T value
    - df = Degrees of Freedom
    - X1 = mean of list 1
    - X2 = mean of list 2
    - Sx1 = standard deviation of list 1
    - Sx2 = standard deviation of list 2



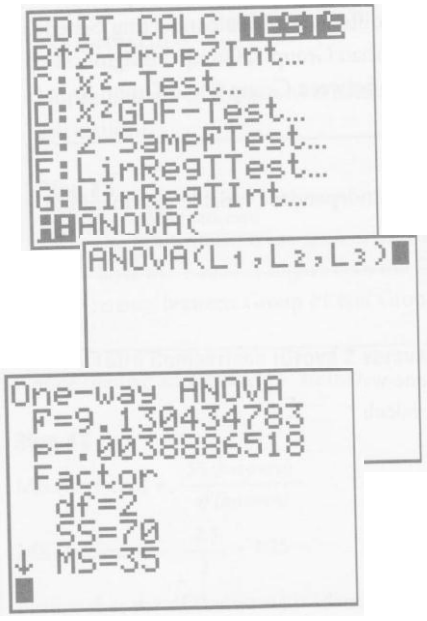
Statistics: *ANOVA (analysis of variance)*

The ANOVA test is a statistical test that can be done in place of multiple T-tests when comparing the means of more than two groups at a time. The t-test tells us if the variation between *two* groups is "significant". If you have 5 levels of a manipulated variable in an experiment, you would need to compare the mean of EACH LEVEL OF THE MV to the mean of EACH OTHER LEVEL OF THE MV. That's 10 T-tests!

Multiple t-tests are not the answer because as the number of groups grows, the number of needed pair comparisons grows quickly. If we did 10 t-tests, we should not be surprised to observe things that happen only 5% of the time. The ANOVA statistic prevents up from having to do multiple t-tests puts all the data into one number.

> NULL HYPOTHESIS: no significant difference exists between more than two means; no single level of the MV leads to a result different than the other levels of the MV.
>
> ALTERNATIVE HYPOTHESIS: a significant difference exists between means; at least one level of the MV leads to a result different than the other levels of the MV.

The math required of the ANOVA test is beyond the scope of this class. There are excellent on-line ANOVA calculators that will do the math and draw a conclusion for you. The TI 83/84 calculators can also calculate the ANOVA statistic.



Performing an ANOVA test with the TI-83/84

1. Hit the STAT button on the calculator
2. Select option 4 to clear any past lists of data.
3. Select option 1 to EDIT your lists.
4. Enter your data for each group as Lists.
   The data for each level of the MV should be placed in its own list.
5. Hit STAT button and use the arrow key to move over to the TESTS option
6. Scroll down to option H, the ANOVA and hit ENTER
7. Enter the lists you want to include in the ANOVA
8. Your results are given.

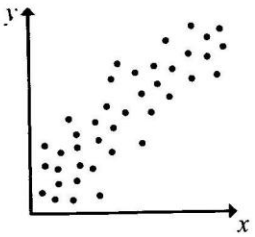
The ANOVA test will result in a "p-value." If the p-value you get is less than 0.05, we reject the null hypothesis and conclude that there is a significant difference between the means being compared. Likewise, if the p-value you get is more than 0.05, you would accept the null hypothesis and conclude that there is no significance difference between the means.

Statistics: *Correlations*

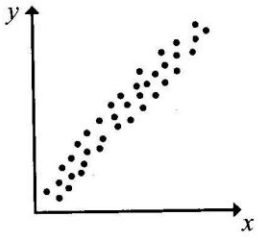
One of the most common errors we find in the press is the confusion between *correlation* and *causation* in scientific and health-related studies. In theory, these are easy to distinguish — an action or occurrence can *cause* another (such as smoking causes lung cancer), or it can *correlate* with another (such as smoking is correlated with alcoholism). If one action causes another, then they are most certainly correlated. But just because two things occur together does not mean that one caused the other, even if it seems to make sense.

One way to get a general idea about whether or not two variables are related is to plot them on a "scatterplot". If the dots on the scatterplot tend to go from the lower left to the upper right it means that as one variable goes up the other variable tends to go up also. This is a called a "direct (or positive) relationship." On the other hand, if the dots on the scatterplot tend to go from the upper left corner to the lower right corner of the scatterplot, it means that as values on one variable go up values on the other variable go down. This is called an "indirect (or negative) relationship."

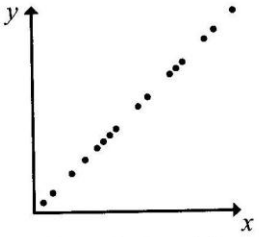
I. Positive Correlations Between *x* and *y*



(a) weak positive correlation between *x* and *y*

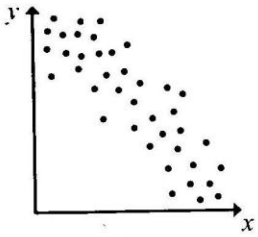


(b) strong positive correlation between *x* and *y*

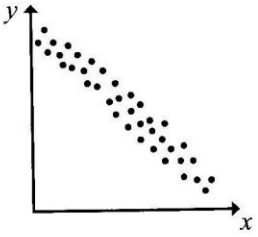


(c) perfect positive correlation between *x* and *y*

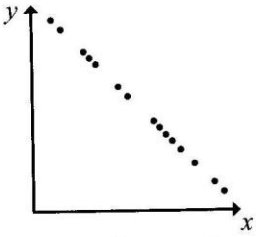
II. Negative Correlations Between *x* and *y*



(d) weak negative correlation between *x* and *y*

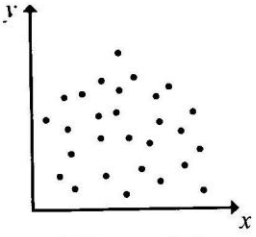


(e) strong negative correlation between *x* and *y*



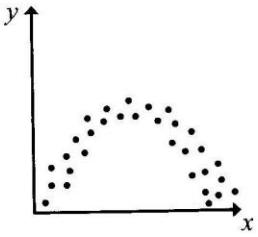
(f) perfect negative correlation between *x* and *y*

III. No Correlation



(g) No correlation between *x* and *y*

IV. No Linear Correlation



(h) No linear correlation between *x* and *y*

Example 1: "girls who watch soap operas are more likely to have eating disorders"

Is there a direct or indirect correlation?

Is it fair to conclude there is a causal relationship?

Example 2: "as ice cream sales increase, the rate of drowning deaths increases sharply."

Is there a direct or indirect correlation?

Is it fair to conclude there is a causal relationship?

Example 3: "people who have more years of education tend to have fewer years in jail"

Is there a direct or indirect correlation?

Is it fair to conclude there is a causal relationship?

How can one best determine if there is a causal relationship between two variables?

The most effective way of doing this is through a controlled study. In a controlled study, two groups of people who are comparable in almost every way are given two different sets of experiences (such one group watching soap operas and the other game shows), and the outcome is compared. If the two groups have substantially different outcomes, then the different experiences may have caused the different outcome.

Statistics: *Correlation Coefficient (r)*

A *really* smart guy named Karl Pearson figured out how to calculate a summary number that allows you to answer the question "How strong is the relationship of a correlation?" In honor of his genius, the statistic was named after him. It is called Pearson's Correlation Coefficient (r).

Correlation Coefficient: A single summary number that gives you a good idea about *how closely one variable is related to another variable.*

$$r = \frac{\Sigma XY - \frac{(\Sigma X)(\Sigma Y)}{n}}{\sqrt{\left[\left(\Sigma X^2 - \frac{(\Sigma X)^2}{n_x}\right)\left(\Sigma Y^2 - \frac{(\Sigma Y)^2}{n_y}\right)\right]}}$$

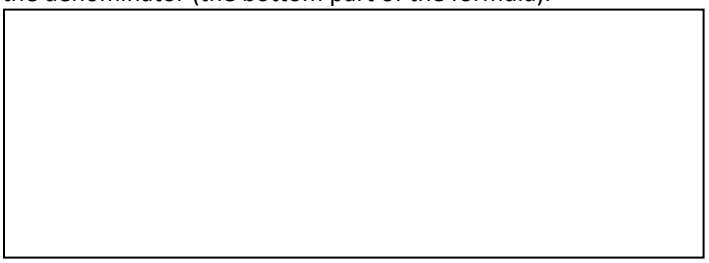
- ΣX This simply tells you to add up all the X scores
- ΣY This tells you to add up all the Y scores
- ΣX^2 This tells you to square each X score and then add them up
- ΣX^2 This tells you to square each Y score and then add them up
- ΣXY This tells you to multiply each X score by its associated Y score and then add the resulting products together (this is called a "cross-products")
- n This refers to the number of "pairs" of data you have.

Example of a way to set up data to make sure you don't make mistakes when using the computational formula to calculate Pearson's r

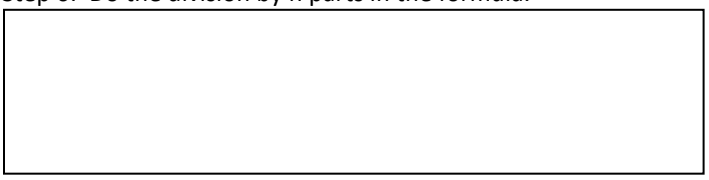
X	X^2	Y	Y^2	XY
5		45		
15		32		
18		37		
20		33		
25		24		
25		29		
30		26		
34		22		
38		24		
50		15		
$\Sigma X=$	$\Sigma X^2=$	$\Sigma Y=$	$\Sigma Y^2=$	$\Sigma XY=$

- Step 1: calculate and fill in the X^2 and Y^2 values
- Step 2: multiply each X score by its paired Y score which will give you the cross-products of X and Y.
- Step 3: fill in the last row of the table which contains all of you "Sum Of" statements. In other words, just add up all of the X scores to get the ΣX, all of the X^2 scores to get the Σ X^2 and etc.
- Step 4: Enter the numbers you have calculated in the spaces where they should go in the formula.

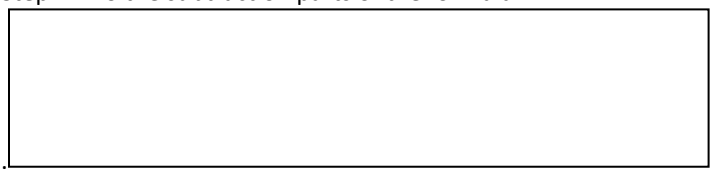
- Step 5: Multiply the (ΣX)(ΣY) in the numerator (the top part of the formula) and do the squaring to $(\Sigma X)^2$ and $(\Sigma Y)^2$ in the denominator (the bottom part of the formula).



- Step 6: Do the division by n parts in the formula.



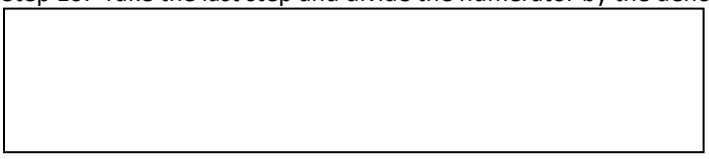
- Step 7: Do the subtraction parts of the formula



- Step 8: Multiply the numbers in the denominator.

- Step 9: Take the square root of the denominator.

- Step 10: Take the last step and divide the numerator by the denominator and you will get the Correlation Coefficient!



What Good Is A Correlation Coefficient?

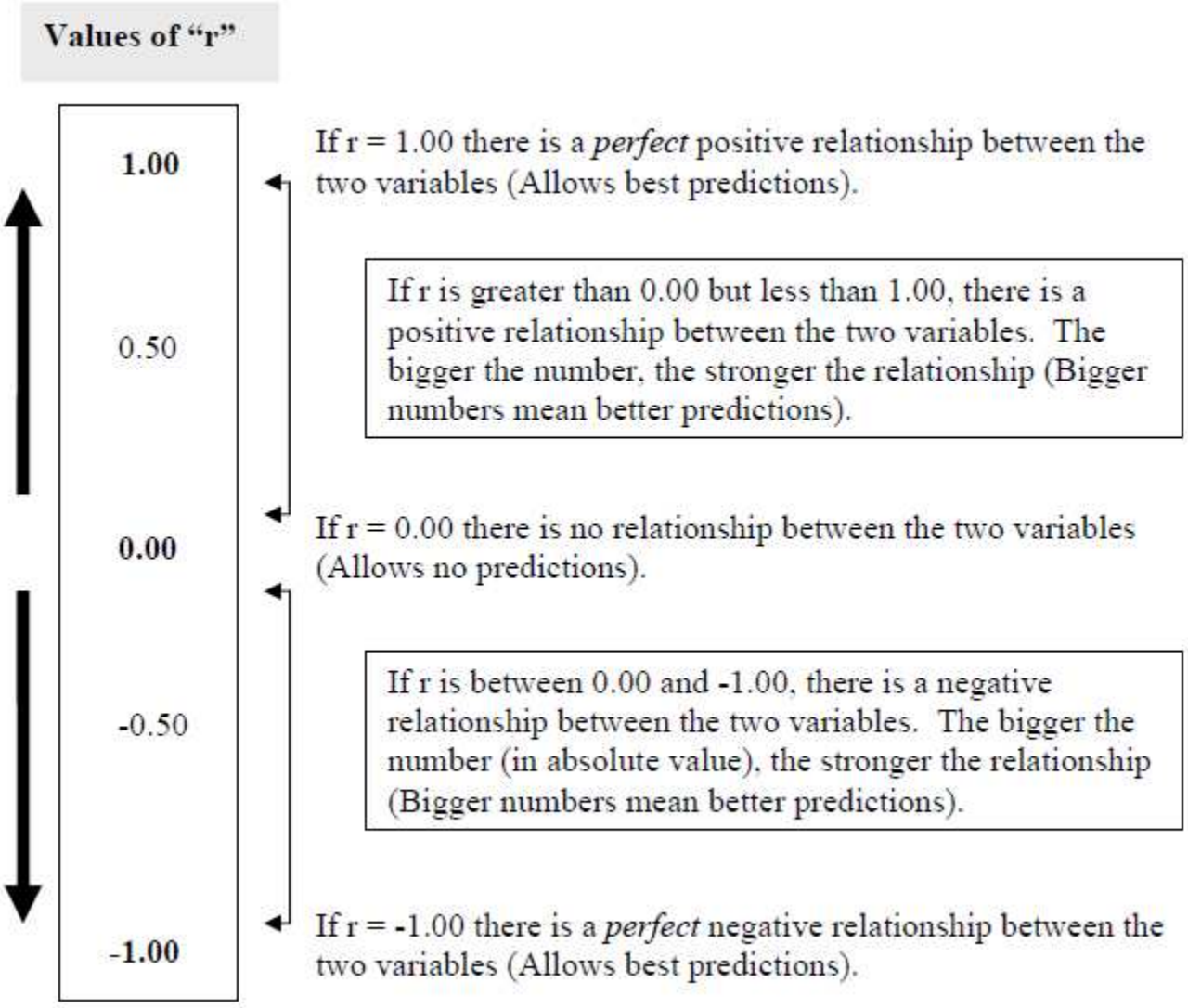
As can see above, we just did a whole lot of calculating just to end up with a single number. How ridiculous is that? Seems kind of like a waste of time, huh? Well, guess again! It is actually very cool! ("Yeah, right!" you say, but let me explain.)

Important Things Correlation Coefficients Tell You

1. *They Tell You The Direction Of A Relationship:* If your correlation coefficient is a negative number you can tell, just by looking at it, that there is an indirect, negative relationship between the two variables. As you may recall, a negative relationship means that as values on one variable increase (go up) the values on the other variable tend to decrease (go down) in a predictable manner. If your correlation coefficient is a positive number, then you know that you have a direct, positive relationship. This means that as one variable increases (or decreases) the values of the other variable tend to go in the same direction. If one increases, so does the other. If one decreases, so does the other in a predictable manner.

2. *Correlation Coefficients Always Fall Between -1.00 and +1.00:*
    a. A correlation coefficient of -1.00 tells you that there is a perfect negative relationship between the two variables. This means that as values on one variable increase there is a perfectly predictable decrease in values on the other variable. In other words, as one variable goes up, the other goes in the opposite direction (it goes down).
    b. A correlation coefficient of +1.00 tells you that there is a perfect positive relationship between the two variables. This means that as values on one variable increase there is a perfectly predictable increase in values on the other variable. In other words, as one variable goes up so does the other.
    c. A correlation coefficient of 0.00 tells you that there is a zero correlation, or no relationship, between the two variables. In other words, as one variable changes (goes up or down) you can't really say anything about what happens to the other variable.

3. *Larger Correlation Coefficients Mean Stronger Relationships*
    a. Most correlation coefficients (assuming there really is a relationship between the two variables you are examining) tend to be somewhat lower than plus or minus 1.00 (meaning that they are not perfect relationships) but are somewhat above 0.00. Remember that a correlation coefficient of 0.00 means that there is no relationship between your two variables based on the data you are looking at.
    b. The closer a correlation coefficient is to 0.00, the weaker the relationship is and the less able you are to tell exactly what happens to one variable based on knowledge of the other variable. The closer a correlation coefficient approaches plus or minus 1.00 the stronger the relationship is and the more accurately you are able to predict what happens to one variable based on the knowledge you have of the other variable.



Making Statistical Inferences from Pearson's r.

How do you determine whether or not your correlation is simply a chance occurrence or if it really is true of the population? You will need three things in order to determine whether you can infer that the relationship you found in your sample also is true (in other words, "is generalizable" in the larger population:

1. The Correlation Coefficient that you calculated
2. Something called the **"degrees of freedom" which is simply the number of pairs of data in your sample minus 2.**

DF =

3. A table of "Critical Values" of the correlation coefficient.

Pearson's R Critical Values

Just like the T-test, we'll always use the 0.05 level of significance

Values of *r* for the .05 and .01 Levels of Significance

df(*N* − 2)	.05	.01	*df*(*N* − 2)	.05	.01
1	.997	1.000	31	.344	.442
2	.950	.990	32	.339	.436
3	.878	.959	33	.334	.430
4	.812	.917	34	.329	.424
5	.755	.875	35	.325	.418
6	.707	.834	36	.320	.413
7	.666	.798	37	.316	.408
8	.632	.765	38	.312	.403
9	.602	.735	39	.308	.398
10	.576	.708	40	.304	.393
11	.553	.684	41	.301	.389
12	.533	.661	42	.297	.384
13	.514	.641	43	.294	.380
14	.497	.623	44	.291	.376
15	.482	.606	45	.288	.372
16	.468	.590	46	.285	.368
17	.456	.575	47	.282	.365
18	.444	.562	48	.279	.361
19	.433	.549	49	.276	.358
20	.423	.537	50	.273	.354
21	.413	.526	60	.250	.325
22	.404	.515	70	.232	.302
23	.396	.505	80	.217	.283
24	.388	.496	90	.205	.267
25	.381	.487	100	.195	.254
26	.374	.479	200	.138	.181
27	.367	.471	300	.113	.148
28	.361	.463	400	.098	.128
29	.355	.456	500	.088	.115
30	.349	.449	1000	.062	.081

The first thing you need to do is look down the degrees of freedom column until you see the row with the number of degrees of freedom that matches your sample degrees of freedom. Look across to the number listed under .05. This number is called "the critical value of r".

Critical r =

SO WHAT?

If your calculated r value is _____ the number in the table, you conclude that the correlation is _____ _____

_____

_____

If your calculated r value is _____ than the number in the table, you conclude that the correlation is _____ _____

_____

_____

Just to make sure that you are getting the idea here, try a few examples.

r = .43 n = 9 degrees of freedom?_____ Significant?

r = .87 n = 4 degrees of freedom?_____ Significant?

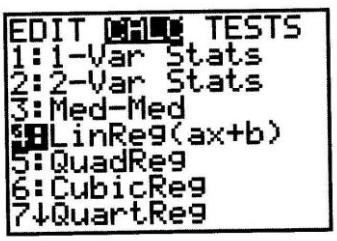
r = .83 n = 6 degrees of freedom?_____ Significant?

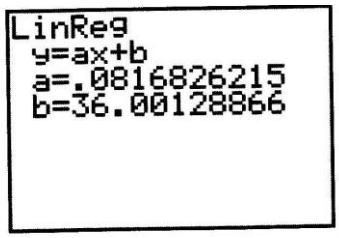
r = .10 n = 11 degrees of freedom?_____ Significant?

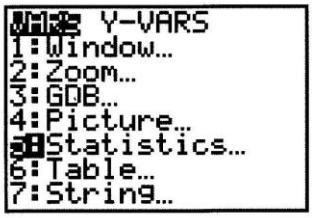
r = .72 n = 8 degrees of freedom?_____ Significant?

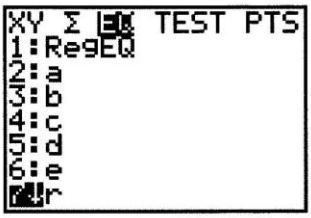
Performing an Correlation Coefficient test with the TI-83/84

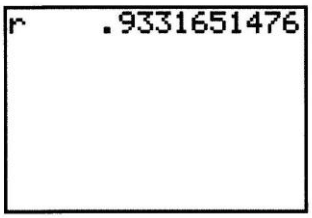
1. Hit the STAT button on the calculator
2. Select option 4 to clear any past lists of data.
3. Select option 1 to EDIT your lists.
4. Enter your data for each variable as Lists.
5. Hit STAT button and use the arrow key to move over to the CALC option
6. Scroll down to option 4, the LInReg (ax+b), press 4 and hit ENTER
7. Press VARS. Scroll down to 5: STATISTICS and press 5 and hit ENTER.
8. Scroll over to EQ. Then, scroll down to 7:r and press 7. ENTER again to get the correlation coefficient.











Statistics: *Chi-Square (X^2)*

Have you ever wondered why the package of M&Ms you just bought never seems to have enough of your favorite color? Or, why is it that you always seem to get the package of mostly brown M&Ms? Is the number of the different colors of M&Ms in a package really different from one package to the next, or does the Mars Company do something to insure that each package gets the correct number of each color of M&M? I'll bet like me, you've stayed up nights wondering about this! Well, I recently visited the M&M web page (http://www.mms.com/us/) and found that the Mars Company claims that each package of M&Ms they sell should have the following percentages of each color of M&M:

Brown	13%
Yellow	14%
Red	13%
Blue	24%
Orange	20%
Green	16%

Does the expected percentage of each color of M&M's in the bag match what we actually observe in a bag? Let's do a statistical test to find out!!

Chi-square Goodness of Fit is a statistical test commonly used to compare observed data with data we would expect to obtain. Were the deviations (differences between observed and expected) the result of chance, or were they due to other factors?

There are two hypothesis related to a X^2-test:

NULL HYPOTHESIS	**ALTERNATIVE HYPOTHESIS**

The formula for calculating chi-square is

$$X^2 = \sum \frac{(\text{Observed Value} - \text{Expected Value})^2}{(\text{Expected Value})}$$

1. The first step in the calculation of an X^2 value is to determine the expected numbers.
2. Then, use the following formula for each observed and expected category:

   $(O-E)^2 / E$

Chi Square Calculation Table for M&M Colors

M&M Color	Observed Values	Expected Values	$(O-E)^2 / E$
Brown			
Orange			
Green			
Total	**100%**	**100%**	

3. The results are added together to get a final X^2 value.

4. The calculated X^2 value is than compared to the _____ found in an X^2 distribution table. The X^2 distribution table represents a theoretical curve of expected results. The expected results are based on_____.

   Degrees of Freedom = _____.

   The X^2 distribution table is organized by the Level of Significance. The level of significance is the maximum tolerable probability of accepting a false null hypothesis. ***We always use 0.05.*** This means that we would accept the null hypothesis if the observed results were within _____of the expected results.

   Number of classes (n) = _____

   df = _____

5. If our calculated value is _____than the .05 level of significance, we can accept our null hypothesis.

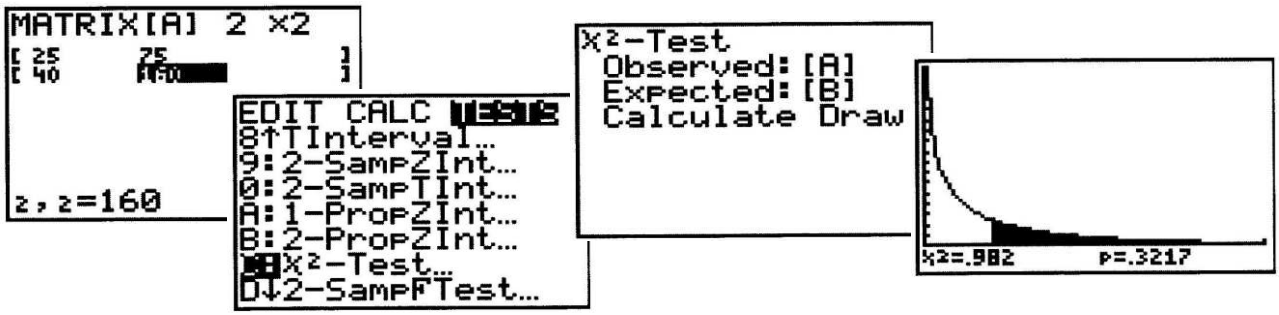
   If our calculated value is _____ than the .05 level of significance, we can reject our null hypothesis.

   The X^2 obtained was _____. The critical value X^2 (found in the distribution table) was _____. The calculated value is _____ than the .05 level of significance, so we can _____ the null hypothesis. In other words, the actual M&M's in the bag were _____ _____ than what we expected to see in the bag.

Performing an Chi-Square test with the TI-83/84

1. Press [2nd MATRIX]
2. Select [EDIT - > 1:A]
3. Copy the data by typing in each number and then pressing ENTER
4. Now press STAT. Under the TESTS sub-menu, scroll down and select C:X2 TEST. Press ENTER.
5. Move the cursor down to DRAW and press ENTER.

The Chi-Square test will result in a "p-value." If the p-value you get is less than 0.05, we reject the null hypothesis and conclude that there is a significant difference between the observed and expected values. Likewise, if the p-value you get is more than 0.05, you would accept the null hypothesis and conclude that there is no significance difference between the observed and expected.



Chi Square Critical Values

Just like the T-test, we'll always use the 0.05 level of significance

Table X The χ^2 Distribution

df	.25	.10	.05	.025	.01	.005
1	1.323	2.706	3.841	5.024	6.635	7.879
2	2.773	4.605	5.991	7.378	9.210	10.597
3	4.108	6.251	7.815	9.348	11.345	12.838
4	5.385	7.779	9.488	11.143	13.277	14.860
5	6.626	9.236	11.071	12.833	15.086	16.750
6	7.841	10.645	12.592	14.449	16.812	18.548
7	9.037	12.017	14.067	16.013	18.475	20.278
8	10.219	13.362	15.507	17.535	20.090	21.955
9	11.389	14.684	16.919	19.023	21.666	23.589
10	12.549	15.987	18.307	20.483	23.209	25.188
11	13.701	17.275	19.675	21.920	24.725	26.757
12	14.845	18.549	21.026	23.337	26.217	28.299
13	15.984	19.812	22.362	24.736	27.688	29.819
14	17.117	21.064	23.685	26.119	29.141	31.319
15	18.245	22.307	24.996	27.488	30.578	32.801
16	19.369	23.542	26.296	28.845	32.000	34.267
17	20.489	24.769	27.587	30.191	33.409	35.718
18	21.605	25.989	28.869	31.526	34.805	37.156
19	22.718	27.204	30.144	32.852	36.191	38.582
20	23.828	28.412	31.410	34.170	37.566	39.997
21	24.935	29.615	32.671	35.479	38.932	41.401
22	26.039	30.813	33.924	36.781	40.289	42.796
23	27.141	32.007	35.172	38.076	41.638	44.181
24	28.241	33.196	36.415	39.364	42.980	45.559
25	29.339	34.382	37.652	40.646	44.314	46.928
26	30.435	35.563	38.885	41.923	45.642	48.290
27	31.528	36.741	40.113	43.194	46.963	49.645
28	32.620	37.916	41.337	44.461	48.278	50.993
29	33.711	39.087	42.557	45.722	49.588	52.336
30	34.800	40.256	43.773	46.979	50.892	53.672
31	35.887	41.422	44.985	48.232	52.191	55.003
32	36.973	42.585	46.194	49.480	53.486	56.328
33	38.058	43.745	47.400	50.725	54.776	57.648
34	39.141	44.903	48.602	51.966	56.061	58.964
35	40.223	46.059	49.802	53.203	57.342	60.275
36	41.304	47.212	50.998	54.437	58.619	61.581
37	42.383	48.363	52.192	55.668	59.892	62.883
38	43.462	49.513	53.384	56.896	61.162	64.181
39	44.539	50.660	54.572	58.120	62.428	65.476
40	45.616	51.805	55.758	59.342	63.691	66.766
41	46.692	52.949	56.942	60.561	64.950	68.053
42	47.766	54.090	58.124	61.777	66.206	69.336
43	48.840	55.230	59.304	62.990	67.459	70.616
44	49.913	56.369	60.481	64.201	68.710	71.893
45	50.985	57.505	61.656	65.410	69.957	73.166

Report Writing

The purpose of writing a lab report is to determine how well you performed your investigation, how much you understood what happened during the process, and how well you can convey that information in an organized fashion. Remember that lab reports are individual assignments. You may have had a lab partner, but the work that you do and report on should be your own. Use the following "tool kit" as a guide when you write up your formal lab reports.

LOGISTICS:

- ☐ Raw data must be collected in a bound lab composition book
- ☐ Lab must be typed (with 1.5 line spacing) or neatly hand written
- ☐ Title of lab is clear and relevant
- ☐ Report has a logical order, with clear title and section headings
- ☐ The spelling, grammar, and flow of the writing must be correct.
- ☐ When you write a lab report, you will have already performed the investigation. Please use the past tense throughout the paper.

DESIGN ASPECT 1: ***Defining the Problem and Selecting Variables***

- ☐ Include a Background Information section. Introduce and explain the biological principles and/or concepts that are being investigated. Remember to cite your sources of information properly.

- ☐ Provide the scientific name of the organism being investigated (*Genus species*).

- ☐ State the **PROBLEM QUESTION (PQ)**. Be sure your problem question is focused enough so that it specifically states what was under investigation in the experiment. If a controlled experiment was done, the manipulated and responding variables must be clearly identified. Often, but not always, written as, "What is the effect of __MV__ on __RV__?"

There are two main types of investigations that you will perform in IB biology:

1. ***Experiments*** are studies that allow scientists to manipulate a variable and observe its effects. For example: Does changing light affect the growth of radishes? Experiments are powerful studies because they can establish whether a variable influences or determines an outcome.

2. Sometimes experiments are neither possible nor desirable. Human subjects, for example, are often unsuitable for experimentation for ethical reasons. Jane Goodall, wishing to discover the behavior and social structure of chimpanzees in their natural habitat, did not perform experiments with her subjects but instead observed them with minimal human interference. When subjects are studied "as is" rather than manipulated in controlled settings, they are part of ***descriptive studies***.

- ☐ In the case of a true experiment, you need to explain what you changed between groups, the **MANIPULATED VARIABLE (MV).** Indicate the manipulated variable and list the levels of the MV that you included in your experimental protocol. Provide the unit for your MV. Typically you should have a minimum of 5 levels of the MV. Explain how the range of levels of your MV was selected.

- ☐ If you performed a descriptive study, explain why no variable was or could be manipulated.

- ☐ If appropriate, indicate your **CONTROL GROUP** (CG). The control group is the one group to which all other groups will be compared. The control group receives the exact treatment as the experimental groups except it does not receive the change in the MV. The control group can be a level of the MV.

  Please note that the control *group* is NOT the same thing as a controlled *variable*.

  For some experiments, there is no control group and the comparison among the experimental groups is enough.

☐ You need to explain what was measured, the **RESPONDING VARIABLE (RV).** List what was measured (both qualitative and quantitative data) and explain how it was measured. Provide the unit for your RV. If no qualitative data was collected, say so, and explain why qualitative data was not gathered.

☐ For true experiments in which you are determining the effect of a MV on and RV, you need to include a **HYPOTHESIS.** A hypothesis predicts a relationship or trend. It will often take the form of a proposed relationship between two or more variables that can be tested by experiment. Hypothesis statements are often written as:

- If ___(MV)____ is related to ____(RV)___, then (predict the effect).
- If the ___(MV)____ is (described the changes), then the ____(RV)___ will (predict the effect).
- ___(RV)____ will (predict the effect) when ____(MV)___ (describe the changes).

☐ You must also provide an **EXPLANATION** for your hypothesis. This should be a brief discussion (paragraph form) about the science behind your hypothesis and prediction. You should site credible references that support your explanation (see section on citations).

DESIGN ASPECT 2: ***Controlling Variables***

☐ At least three **CONTROLLED VARIABLES (CV)** are required, but more may be necessary. The controlled variables you list must be relevant to your investigation. You need to control for all variables that may reasonably affect the outcome of the investigation. **Materials used and measurement techniques are NOT controlled variables** (they are validity measures). While materials and techniques must be consistent, a true variable is something that could directly influence the responding variable, not just how it is measured.

☐ You must explain <u>why</u> and <u>how</u> variables were controlled. When explaining why a variable needs to be controlled, describe how the variable could impact the results if it was not controlled. Often times, students create a table to organize this information:

CONTROLLED VARIABLES	**WHY** in must be controlled	**HOW** it was controlled
1.		
2.		
3.		

DESIGN ASPECT 3: ***Developing a Method for Collection of Data***

> Before performing and writing about your experiment, you may need to run some **PRE-TRIALS**. A pretrial is a pretest of the experimental methods that you conduct to tweak the procedure before actual data collection begins. Pre-trials will help you determine specific details of your experiment and increase your change of success with your experimental design because you can work out any kinks before collecting data.

☐ Make a list of the **MATERIALS** needed in the investigation. Be as specific as possible (example: '50 mL beaker' instead of 'beaker'); include the volumes of tubes and cylinders, the concentrations of solutions, the model and manufacturer of any complex apparatus. If you have to decide <u>how much</u> of a substance or a solution to use, state your reasoning or show the calculations.

☐ Include **DIAGRAMS OR PHOTOGRAPHS**. Be sure your diagram includes a title and any necessary labels. Photographs are an excellent way to document your experiment. Consider taking the following photographs:

- You, the researcher, shown working on your experiment
- Experimental setup, to show the overall environment
- Individual photos of the experimental and control groups throughout your experiment

- Close-ups of how data were collect (for example, a close-up photograph of your hands holding the instrument to take measurements)

- State or discuss the **PROCEDURE** that you used in the experiment. Be sure your procedure explains how you changed the manipulated variable. This can be in paragraph form or a list of step-by-step directions. Provide enough detail so that another person could repeat your work by reading your report.

  - If you use a known, published protocol than you must provide a full citation as a reference.

  - Your procedure must include at least three clear **VALIDITY MEASURES (VM)** (i.e. cleaning test tubes prior to use, cleaning the microscope lenses, using the same ruler, etc). Validity measures are things kept constant to make sure experimental measurements are valid and consistent.

  - Your procedure must **CLEARLY STATE HOW YOU COLLECTED DATA**. What measuring device did you use, what data did you record, when did you collect data? What qualitative observations did you look for?

  - Explain how you set up so you had **MULTIPLE TRIALS** of data collection. The procedure must allow collection of "sufficient relevant data". The definition of "sufficient relevant data" depends on the context. The planned investigation should anticipate the collection of enough data so that the problem question can be suitably addressed and an evaluation of the reliability of the data can be made. As a rule, the lower limit is a sample size of five. Very small samples run from 5 to 20, small samples run from 20 to 30, and big samples run from 30 upwards. Obviously, this will vary within the limits of the time available for an investigation.

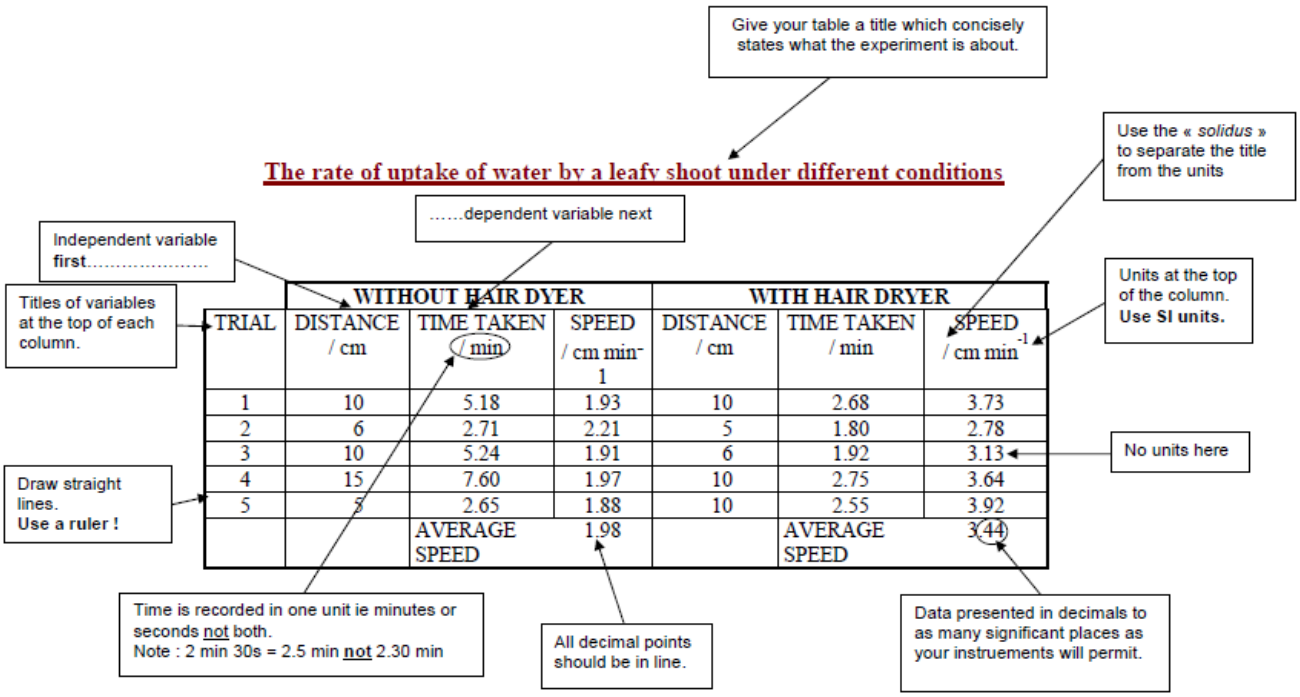
  - If you will be **COMBINING DATA** with data collected by other students in the class, you should indicate that, "pooling data was done to ensure collection of significant, relevant data" (IB Biology subject guide, 2009, page 26). Be sure to cite this reference if you pool data.

  - If you are **SAMPLING** only a portion of a population, you must explain <u>how</u> and <u>why</u> you ensured that the sample was randomly selected.

  - Your procedure must be safe and ethical. Organisms, including humans, cannot be subject to harm in your investigation. List any **SAFETY PRECAUTIONS** that were taken during the lab. If necessary, address the IBO *animal experimentation policy*.

DATA COLLECTION AND PROCESSING ASPECT 1: *Recording Raw Data*

- Create a formal **DATA TABLE** in which to present the raw, unmodified data you collected. Be sure your table:
  - Is easy to understand
  - Has a specific title
  - Is titled in sequential order as "Table 1: *title*." "Table 2*: title*"
  - Has column headings
  - Includes the unit of measurement of the MV and RV (always in metric units)
  - Includes the measurement uncertainty of the measurement tools used (or, if the data was a count, indicates that "counts have no measurable uncertainty"). Uncertainly is usually stated in a column heading or as a footnote at the bottom of the table. Additional information about measurement uncertainty can be found later in this booklet.
  - Has a consistent and correct number of digits for each measurement
  - Has decimal points aligning down a column (if applicable) and numbers centered in the column
  - Indicates which data was collected by which student IF the data was collected and pooled across multiple students.



	WITHOUT HAIR DYER			WITH HAIR DRYER		
TRIAL	DISTANCE / cm	TIME TAKEN / min	SPEED / cm min^{-1}	DISTANCE / cm	TIME TAKEN / min	SPEED / cm min^{-1}
1	10	5.18	1.93	10	2.68	3.73
2	6	2.71	2.21	5	1.80	2.78
3	10	5.24	1.91	6	1.92	3.13
4	15	7.60	1.97	10	2.75	3.64
5	5	2.65	1.88	10	2.55	3.92
		AVERAGE SPEED	1.98		AVERAGE SPEED	3.44

- Your report must include **QUALITATIVE DATA**. This might be a paragraph in which you describe:
  - Observations about the procedure or deviations from the procedure
  - Observations about results not directly relating to the RV
  - Specific qualitative data for each trial

- **LAB DRAWINGS** are considered data by the IB Organization. Biological drawings can be made from biological specimens viewed with a microscope, binocular microscope or hand-lens. They should always be accurate records of the observed features of a specimen. Not all labs will include a lab drawing. Additional information about lab drawings can be found later in this handbook.

DATA COLLECTION AND PROCESSING ASPECT 2: ***Processing Raw Data***

- **STATISTICS** are useful mathematical tools which are used to analyze data. Common statistics used in biology are:
  - Mean
  - Range
  - Median
  - Percent change
  - Standard deviation (to determine amount of variation around a mean)
  - T-test (to compare two means to determine if they are statistically different from each other). Chi-square (to determine if "observed" results are significantly different from "expected" results)
  - Correlation coefficient (to determine the extent two variables are related to each other).
  - Chi-square (to compare observed with theoretically expected results)

  Use only the statistical tests appropriate to investigate and address your problem question. Additional information about statistics can be found later in this booklet.

- When a t-test, chi-square or correlation coefficient is calculated, you must indicate the significance level at which your critical value is determined (we typically use the 95% confidence interval, 0.05).

- For each statistic you calculate, you must **EXPLAIN WHY YOU ELECTED TO DO THAT CALCULATION**. What does the calculation tell you about the data?

DATA COLLECTION AND PROCESSING ASPECT 3: ***Presenting Processed Data***

- Show an **EXAMPLE CALCULATION** for each statistic you calculate. Use plenty of room; make sure they are labeled, are clear and are legible. Show the units of measurements in all calculations. Pay attention to the number of digits! Don't lose accuracy by carelessly rounding off. Do not truncate.

- Present your data processing results in a **TABLE**. The initial raw data and the processed (calculated) data may be shown in one table provided they are clearly distinguishable. Be sure your processed data table:
  - Is easy to understand
  - Has a specific title
  - Has column headings
  - Includes the unit of measurement
  - Has a consistent and correct number of digits for each measurement (to the same precision as your raw data)
  - Has decimal points aligning down a column (if applicable) and numbers centered in the column

- You must also present your results in a **GRAPH**.
  - Use the correct type of graph for the type of data you are presenting.
  - Graphs must be clear and easy to understand. Please avoid "creative" or "funny" coloring of graphs.
  - Graphs need to have appropriate scales, labeled axes with units, and accurately plotted data points.
  - Graphs are titled in sequential order as "Figure 1: *title*." "Figure 2*: title*"
  - If necessary, add smooth lines or curves to show the overall trend of the data.
  - If a mean is calculated, only graph the mean, not all data points. When a mean is graphed, its associated standard deviation error bar must also be included (and labeled as such).
  - Legends (keys) are not always necessary. Delete "series 1" and "series 2" boxes from graphs created in Excel.

CONCLUSION AND EVALUATION ASPECT 1: ***Concluding***

- Write one (or more) paragraphs in which you **DRAW CONCLUSIONS FROM YOUR RESULTS**. Your conclusion should be clearly related to the research question and the purpose of the experiment.
  - Answer the problem question
  - Be accurate (i.e., if you used a T-test, be sure your conclusion matches what the T-test tells you; don't say there is a difference if the T-test says the difference is insignificant).
  - Was your hypothesis supported or refuted? Use the appropriate language, i.e. "Supports my hypothesis" (not 'proves' or 'is correct'). The word *prove* is much too strong for a single study on a topic.
  - Provide a brief explanation as to how you came to this conclusion from your results. In other words, sum up the evidence and explain observations, trends or patterns revealed by the data. Summarize the processed data: mean, range and standard deviation. Refer directly to tables and graphs by referencing tables and figures (i.e. "as seen in Figure 1…")
  - Summarize the results of the statistical test(s) was the effect of the MV significant or not?

- If possible, **CITE LITERATURE** related to your conclusion. Does you result coincide with published results? Does it refute published results?

CONCLUSION AND EVALUATION ASPECT 2: ***EVALUATING PROCEDURE***

- In general, how much **CONFIDENCE** do you have in the results? Avoid giving your confidence as a percentage; use words such as "very" or "somewhat." Are your results fairly conclusive, or are other interpretations/results possible?

- Why are you (or aren't you) confident? What did you do to make sure your results are valid? Was the range of the MV levels appropriate? Was the data collected relevant to the problem question?

- Explain any anomalous data points

- Identify and discuss significant **ERRORS** that actually affected your data collection. You must identify the source of error and tie it to how it likely affected your results. Avoid hypothetical errors ("could have" or "I might have") without evidence to back it up. Common errors include:

- *Human error*: Human error can occur when tools or instruments are used or read incorrectly. Human errors can be systematic because the experimenter does not know how to use the apparatus properly or they can be random because the power of concentration of the experimenter is fading. Automated measuring using a data-logger system can help reduce the likelihood of this error; alternatively you can take a break from measuring from time to time. Do not list time constraints or time management as errors - they should be eliminated with good practical skills. The focus here should be on *the investigation*.
- *Calibration error*: Some instruments need calibrating before you use them. If this is done incorrectly it can increase the risk of systematic error.
- *Random errors*: In biological investigations, the changes in the material used or the conditions in which they are carried out can cause a lot of errors. Biological material is notably variable.
- *The act of measuring*: Could the measurement uncertainty have affected the results? Why or why not?
- *Uncontrolled variables*: What variables were not controlled? What effect might each of these uncontrolled variables have had on your data? On the conclusion?
- *Systematic errors*: could the measurement uncertainty have affected the results? Why or why not? Did systematic errors affect the data? The conclusion?

Errors and their effect on the results can be clearly presented in a table.

- What are the **LIMITATIONS** of your conclusion? Can the results be generalized to other situations/conditions? How might your results explain a process in the "real world"?

CONCLUSION AND EVALUATION ASPECT 3: *IMPROVING THE INVESTIGATION*

- What could you do to make **IMPROVEMENTS** to the investigation? Suggestions for improvements should be based on the weaknesses and limitations identified in aspect 2.

- As appropriate, address modifications to the experimental technique and the data range. Suggest future experiments.

- Propose only realistic and specific modifications. "More time" and "be more careful" are inadequate.

REFERENCES AND CITATIONS

- IN TEXT CITATIONS

It is permissible in the design and conclusion sections to use brief quotations. Sometimes a book or reference has a phrase or sentence that expresses exactly the thought you are trying to convey; you may use that phrase or sentence *IF* you use quotation marks and cite a reference at the end of the sentence. It is *NOT* appropriate to borrow extensive passages (more than two sentences) from a text or web site.

You should also acknowledge where ideas or knowledge not originally your own come from, even if you state your understanding of the idea in your own words. This is usually done by putting the first author's last name and the date of the paper in parentheses at the end of the sentence containing the idea.

> *"Monkeys prefer ripe bananas to unripe bananas (Taylor, 2006). According to Pugh (2007), this is due to the extra sugars present in ripe bananas. Murphy et al (2006) propose that monkeys may have a similar range of tastes to humans. It has yet been unproven whether or not monkeys find it funny when someone slips and falls on a discarded banana skin (Taylor, 2006). "*

- WORKS CITED LIST

Any source you mention in the text of your paper should be included in a list of references in a separate section at the end of the paper. These references are usually listed in alphabetical order by the first author's last name. Make sure all the authors of a paper or book are listed, and include the title of the book or article, the journal or publisher (and place), and

the date. If you used just part of a book, indicate the chapter or pages used. For web sites, give the exact electronic address and any other information you have about it (the author, the name of the organization that sponsors the site).

Examples:

- Book:
  - Author(s). Year. *Title*. Location: Publisher. Number of pages, or pages cited.
  - Hille, Bertil. 1992. *Ionic Channels of Excitable Membranes*. Second Edition. Sunderland, MA: Sinauer Associates, Inc. 607p.
- Article:
  - Author(s). Year. Title of Article. *Journal*, volume number, pages.
  - Huxley, A.F. and R. Stämpfli. 1949. Evidence for salutatory conduction in peripheral myelinated nerve fibres. *J Physiol. (Lond.)* 108: 315-339.
- Web page:
  - Name of web page. Creator or publisher. Date accessed. Web address.
  - The Animated Brain. Brainviews, Ltd. Saltatory conduction. July, 2012. http://www.brainviews.com/abFiles/AniSalt.htm
- Lecture or information from a teacher.
  - Name of teacher (alphabetically, by last name). The exact date and topic of the lecture (including the course in which it was given).
  - Or for individual answers to questions you asked a teacher, you can call it “personal communication” and give the date.

- Do not use Wikipedia as a resource site; however you may read it to gain understanding.

IB LAB SCORING CHECKLIST:

FORMAT

- ☐ Raw data collected directly into lab composition book
- ☐ Formal report is typed with 1.5 line spacing
- ☐ Logical order of report, with clear title and headings
- ☐ Clear spelling, grammar, and flow of the writing
- ☐ Sources have in correctly formatted in-text citations (last name, date)
- ☐ References correctly cited in an alphabetical "works cited" list
- ☐ Table(s) labeled sequentially as Tables (i.e. as Table 1… Table 2…)
- ☐ Picture(s), diagram(s) and graph(s) labeled sequentially as Figures
- ☐ If appropriate, scientific name of organism is provided; italics or underlined

CONTEXTUAL INFORMATION

- ☐ Brief (1-2 sentence) introduction to the topic of the report and how it fits with what is being learned in class
- ☐ Detailed and accurate biology background information relevant to the problem question is included (1-2 paragraphs)
- ☐ Hypothesis concerns effect of MV on RV
- ☐ Hypothesis explanation is valid
- ☐ Source(s) of background and hypothesis explanation information is cited

EXPLANATION OF SCORING:

- ☐ If no mark is made next to the box, it means that the full point was awarded for the indicated criteria. The work presented was accurate, thorough and detailed.
- ☑ If a slash mark is made across the box, it means that ½ of a point was awarded for the indicated criteria. The work is either incomplete or lacks detail.
- ◯☐ If a circle is made around the box, it means that no point was awarded for the indicated criteria. The work was either missing or incorrect.

MANIPULATIVE SKILLS

- ☐ Follow directions carefully
- ☐ Do not fabricate data
- ☐ Seek assistance when appropriate (independence is encouraged)
- ☐ Consistently carry out proper safety measures
- ☐ Properly use a wide range of experimental equipment
- ☐ Safely dispose and reduce waste
- ☐ Work in the lab in a way that does not put yourself or others in harm's way
- ☐ Follow the IBO animal experimentation policy
- ☐ Maintain a clean and organized lab station and work area

IB DESIGN ASPECT 1: *problem and variables*

- ☐ Problem question is stated with a clear and measurable MV and RV
- ☐ Problem question relates to the prompt given in class
- ☐ Manipulated variable correctly identified (*or if descriptive lab, describe why no MV*)
- ☐ At least 5 levels of the MV are listed (with unit)
- ☐ There is an explanation of how the range of MV levels was selected
- ☐ Responding variable is correctly identified
- ☐ Quantitative RV provided (with unit)
- ☐ Qualitative RV provided (or explain why none)

IB DESIGN ASPECT 2: *Control of Variables*

- ☐ 1st of at least 3 relevant controlled variables (which are not validity measures) is identified (CV-1)
- ☐ 2nd of at least 3 relevant controlled variables (which are not validity measures) is identified (CV-2)
- ☐ 3rd of at least 3 relevant controlled variables (which are not validity measures) is identified (CV-3)
- ☐ There is a clear explanation how the 1st of 3 relevant controlled variables was controlled
- ☐ There is a clear explanation how the 2nd of 3 relevant controlled variables was controlled
- ☐ There is a clear explanation how the 3rd of 3 relevant controlled variables was controlled

} *This info can be included in the procedure or in a separate section*

- ☐ There is a clear biological explanation why the 1st of 3 relevant controlled variables was controlled
- ☐ There is a clear biological explanation why the 2nd of 3 relevant controlled variables was controlled
- ☐ There is a clear biological explanation why the 3rd of 3 relevant controlled variables was controlled

- ☐ If possible, data is collected to show that the 1st of 3 relevant controlled variables was controlled
- ☐ If possible, data is collected to show that the 2nd of 3 relevant controlled variables was controlled
- ☐ If possible, data is collected to show that the 3rd of 3 relevant controlled variables was controlled

} *This data can be presented later in the lab report, alongside MV and RV data*

IB DESIGN ASPECT 3: ***Method for Collection of Data***

- ☐ The name and quantities of major apparatus used are listed, including size and graduation
- ☐ The reasoning behind the quantities of materials is given
- ☐ There is a titled and labeled picture or diagram of the set up ("Diagram" is not a good title)
- ☐ Procedure includes at least 3 validity measures (VM)
- ☐ Procedure describes how the MV was varied (MV) between 5 levels
- ☐ Procedure describes how data related to the MV was collected
- ☐ An adequately broad MV range is considered
- ☐ Sample size is at least 5 for each level of the MV (MT)
- ☐ Explanation of how and why you sampled data (if appropriate)
- ☐ Indication that data was pooled, with reference to IB subject guide (if appropriate)
- ☐ Directions about how to collect measurement data (with tool listed) (DC)
- ☐ Procedure worked! Sufficient data was collected using the procedure described.
- ☐ Reasonable safety precautions are provided

IB DATA ASPECT 1: ***Collecting a*****nd** ***Recording Raw Data***

- ☐ Data for the RV is independently collected
- ☐ Quantitative data for the MV is independently collected
- ☐ Quantitative data is collected for at least 5 levels of the MV
- ☐ Quantitative data is collected for at least 5 trials of each level of the MV
- ☐ Data table is neatly constructed, organized, and makes good use of space. Table does not break across a page.
- ☐ Specific title is included. The title indicates what data was collected. Note: table title is NOT the lab title.
- ☐ Logical set-up of columns and rows (i.e., MV ordered in first column, RV(s) in next column(s)) with headings at the top of each column
- ☐ Metric units for each piece of data are clearly and correctly identified (may be done at top of each column)
- ☐ Measurement uncertainty for both MV and RV is noted and correct (may be done at top of each column)
- ☐ Data is measured to a consistent, correct precision for the tool used; decimal points align
- ☐ Qualitative data is presented clearly
- ☐ If data was pooled between students, data collected by the author is clearly indicated

IB DATA ASPECT 2: ***Processing Raw Data***

- ☐ If appropriate, correct difference is calculated for each data point
- ☐ If appropriate, correct rate is calculated for each data point
- ☐ If appropriate, correct mean is calculated for each level of the MV
- ☐ If appropriate, correct standard deviation is calculated for each level of the MV
- ☐ If appropriate, correct t-value(s) calculated (if in excel, correct P value is given)
- ☐ If appropriate, correct ANOVA calculated (correct P value is given)
- ☐ If appropriate, correct correlation coefficient is calculated
- ☐ If appropriate, correct slope is calculated
- ☐ If appropriate, correct % error is calculated
- ☐ There is an explanation for EACH data processing calculation (How will the processing of the data help answer the problem question? What will the processed data "tell you"?)

IB DATA ASPECT 3: ***Processed Data Presentation***

- ☐ Working for processed data has been presented so that all the stages to the final result can be followed
- ☐ Processed data is organized into a easy to read table, with clearly labeled title and column headings (with units)
- ☐ Processed data has correct precision; decimal points align
- ☐ If appropriate, significance level (0.05), critical t-values and degrees of freedom are provided
- ☐ The correct type of graph is made for the type of data presented (i.e. bar, line, histogram, pie, etc…)
- ☐ Graph is neatly constructed, organized, and makes good use of space. If used, colors make the graph more readable.
- ☐ Specific title is included. The title indicates what data is presented. Graph title is NOT the lab title.
- ☐ RV on the Y axis and MV on the X axis
- ☐ Units are clearly and correctly identified along the X and Y axis
- ☐ The graph axes are proportional to the data
- ☐ The numbers on the graph have a consistent and correct precision

- ☐ All points are plotted clearly and correctly. The mean of the data is graphed (not each individual trial).
- ☐ Graph includes SD error bars, labeled as such
- ☐ If needed, a best fit line or smooth curves is added to the graph to show trends or relationships in the data
- ☐ "Series" boxes are deleted from graphs created in Excel

IB CONCLUSION ASPECT 1: ***Concluding***

- ☐ Correct conclusion is drawn; conclusion relates to the problem / purpose
- ☐ If a hypothesis is being tested, there is a statement whether the data supports or refutes the hypothesis (avoid "proves")
- ☐ Use data to support conclusion (mean, SD and T) with direct reference to figures and tables
- ☐ Interpret results of data processing (mean, standard deviation, T-test, ANOVA, correlation, slope, % error)
- ☐ Draw a conclusion based on statistical significance
- ☐ Compare different graphs, or describe the trends shown in graphs
- ☐ If appropriate, compare experimental results with that in a reliable and valid published source (cited appropriately)
- ☐ Provide a biological explanation for the results

IB CONCLUSION ASPECT 2: ***Evaluating Procedure***

- ☐ Confidence in results is stated
- ☐ Positive aspects of lab design are mentioned
- ☐ Appropriateness or limitations due to MV range and levels
- ☐ Anomalous data points explained (if appropriate)
- ☐ Implications of the uncertainties or standard deviations on the results and/or conclusion are explained
- ☐ 1st of at least 3 errors / limitations that actually affected data and/or conclusion (E)
- ☐ 2nd of at least 3 errors / limitations that actually affected data and/or conclusion (E)
- ☐ 3rd of at least 3 errors / limitations that actually affected data and/or conclusion (E)
- ☐ Description of how 1st of 3 errors / limitations may have impacted results and/or conclusion
- ☐ Description of how 2nd of 3 errors / limitations may have impacted results and/or conclusion
- ☐ Description of how 3rd of 3 errors / limitations may have impacted results and/or conclusion

IB CONCLUSION ASPECT 3: ***Improving the Investigation***

- ☐ 1st of at least 3 improvements to procedure are provided, based in errors / limitations described
- ☐ 2nd of at least 3 improvements to procedure are provided, based in errors / limitations described
- ☐ 3rd of at least 3 improvements to procedure are provided, based in errors / limitations described
- ☐ Suggestions are not vague ("be more careful" is unacceptable)
- ☐ Suggestions reduce errors, reduce uncertainty, or improve control of variables
- ☐ Suggest modifications to MV range

IB INTERNAL ASSESSMENT: EXPERIMENTAL DESIGN SCORE			
LEVEL	Defining the problem and selecting variables	Controlling variables	Developing a method for collection of data
Complete 2	Formulates a focused problem / research question and identifies the relevant variables.	Designs a method for the effective control of the variables.	Develops a method that allows for the collection of sufficient relevant data.
Partial 1	Formulates a problem / research question that is incomplete or identifies only some relevant variables.	Designs a method that makes some attempt to control the variables	Develops a method that allows for the collection of insufficient relevant data.
Not at all 0	Does not identify a problem / research question and does not identify any relevant variables.	Designs a method that does not control the variables.	Develops a method that does not allow for any relevant data to be collected.

IB INTERNAL ASSESSMENT: EXPERIMENTAL DATA COLLECTION AND PROCESSING SCORE			
LEVEL	Recording raw data	Processing raw data	Presenting processed data
Complete 2	Records appropriate quantitative and associated qualitative raw data, including units and uncertainties where relevant.	Processes the quantitative raw data correctly.	Presents processed data appropriately and, where relevant, includes errors and uncertainties.
Partial 1	Records appropriate quantitative and associated qualitative raw data, but with some mistakes or omissions.	Processes quantitative raw data, but with some mistakes and/or omissions.	Presents processed data appropriately, but with some mistakes and/or omissions.
Not at all 0	Does not record any appropriate quantitative raw data or raw data is incomprehensible.	No processing of quantitative raw data is carried out or major mistakes are made in processing.	Presents processed data inappropriately or incomprehensibly.

IB INTERNAL ASSESSMENT: EXPERIMENTAL CONCLUSION SCORE			
LEVEL	Concluding	Evaluating Procedure(s)	Improving the investigation
Complete 2	States a conclusion, with justification, based on a reasonable interpretation of the data.	Evaluates weaknesses and limitations.	Suggests realistic improvements in respect of identified weaknesses and limitations.
Partial 1	States a conclusion based on a reasonable interpretation of the data.	Identifies some weaknesses and limitations, but the evaluation is weak or missing.	Suggests only superficial improvements.
Not at all 0	States no conclusion or the conclusion is based on an unreasonable interpretation of the data.	Identifies irrelevant weaknesses and limitations.	Suggests unrealistic improvements.