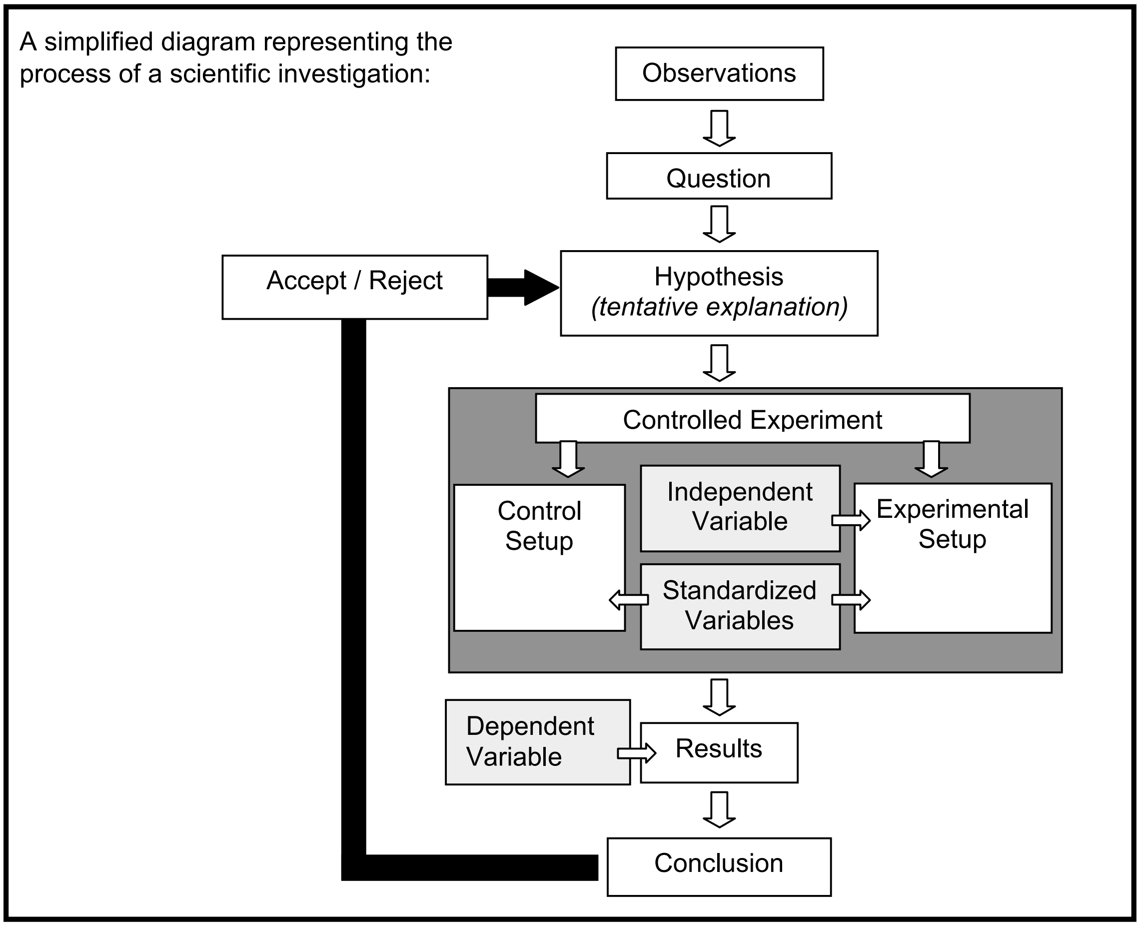
The Process of Scientific Inquiry
– Collecting, Graphing, & Interpreting Data

Introduction:

The purpose of this exercise is to introduce the process of scientific inquiry and the skills needed to perform scientific investigations.

Many people mistakenly view science as an accumulation of indisputable facts. Actually, **science** is a *process* used to answer questions, solve problems, and better understand events in nature. Scientific research constantly challenges our present understanding of the physical realm and, thereby, adds to and refines our understanding of why things happen.



The process of scientific inquiry involves observation and experimentation. To conduct a scientific investigation, a researcher must possess several skills that you will practice today. These include the abilities to:

1) Make accurate measurements.
2) Make careful observations.
3) Ask focused questions.
4) Formulate testable hypotheses.
5) Design and conduct controlled experiments.
6) Present data.
7) Interpret results.

A: The Process of Scientific Inquiry – Making observations

All scientists rely on observational skills to gather information. To make an observation is to notice something. An observation can be information directly perceived through the senses (touch, smell, taste, hearing, or sight) or information detected with instruments which extend our senses (microscope, telescope, light meter, pH meter, chemical test, etc). Good observations are complete and detailed. Observations are most reliable when they can be quantified or measured. For example the observation “the water is 4^oC” is better than the observation “the water is cold”. This activity will provide you with practice making observations.

Presenting observational data

Scientists present data in tables and graphs. Organizing and summarizing measurements in this fashion allows the investigators to easily analyze data and to communicate their findings to others.

Tables

A table should contain the following information:

1) **Title** describing the subject of the table.
2) **Column and row labels** that show what information is provided in the table.
3) **Units of measure** identified within the column and row labels.
4) **Data**.

Procedure

Using the method described in your lab manual for measuring long bones, measure the **maximum hand span** (from thumb-tip to pinkie-tip) **in millimeters** (mm) for the dominant hand from **ten classmates**. Record these observations in Table 1.

Calculate the **average** hand span for your data set.

Classify each measurement into **1-cm size classes**. (15.0–15.9 cm; 16.0–16.9 cm; etc.)

Title →

Table 1. Dominant hand span of DeAnza biology lab students.

Label with unit of measure

Data

#	Name	Hand (R/L)	Span (mm)	Size Class (cm)
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				
10.				
	Average			

Graphs

It is usually very difficult to recognize patterns or trends in columns of raw numbers. Graphs are frequently used to organize and quickly visualize your findings. The two most common types of graphs are bar graphs (for distinct classes of data) and line graphs (for a progressive series of data). Other types of graphs include pie charts and 3-dimensional graphs.

All types of graphs should contain the following information:

1) **Title** describing the subject of the graph.
   Graphs and other illustrations in publications are called *Figures*.
2) An **X-axis** (horizontal line) and a **Y-axis** (vertical line).
   - The **scale** of each axis must have an **appropriate range of units** (the largest datum should almost reach the maximum value of the scale).
   - Each scale should be divided into **equal intervals** unless otherwise indicated.
3) **Axes labeled** with name of the variable and its appropriate **units**.
4) Graph type (line, bar) that is appropriate for data type. For your measurements in this activity, a bar graph world be most appropriate since the data are classed into distinct size classes rather than a continuous change.
5) **Key** if more than one set of data is presented on one graph. E.g., if you decided to separate the measurements for right-handed and left-handed individuals.

Create an appropriate scale for the Y-axis of Figure 1 and plot a **bar graph** of your hand span **size class** data from Table 1. (I.e., 15-cm size class = hand spans 15–15.9 cm.) Also make a note on the graph showing the average hand span size.

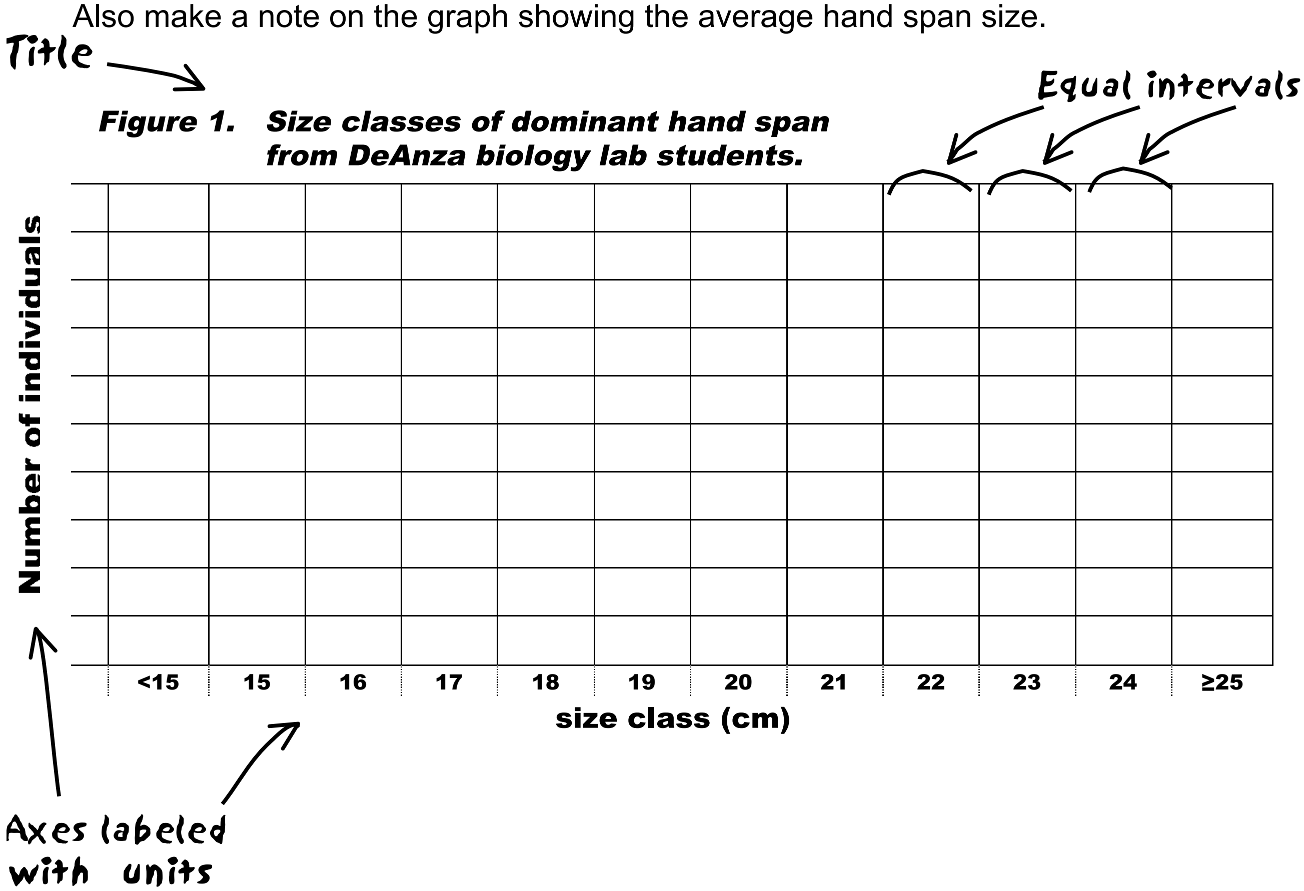


Figure 1. Size classes of dominant hand span from DeAnza biology lab students.

B: The Process of Scientific Inquiry – Asking questions and developing hypotheses

Observations lead to questions. Answers to questions inevitably lead to more questions.

Look back on your table and graph of observations in Part A. Look at your hands and your classmates' hands. Think of three questions about how hand span might relate to human biology.

Question 1.
Question 2.
Question 3.

You may think you have an answer to these questions. When scientists formulate a tentative explanation to a research question it is called a **hypothesis**. For example, suppose we pose the question "Is there a relationship between where a student sits in class and his/her final grade in Biology class?" A reasonable hypothesis could be "Students who sit in the front four rows of seats during lecture receive, on the average, higher grades than the students sitting in the back four rows".

Three important things to remember about hypotheses are:

1) A hypothesis should be consistent with existing observations and known information regarding the question. The better informed you are, the better your hypotheses!
2) A hypothesis must be presented as a statement of the predicted outcome, not as a question. A hypothesis is formulated before the experiment, not after the experiment.
3) A hypothesis must be **specific** and **testable**. The test results can prove the hypothesis wrong, or provide evidence to support the hypothesis, but a hypothesis cannot be proven true. It is ok if your results do not support your hypothesis. Valuable information can be gained when a hypothesis is proven false.

Write a **hypothesis** to address each of your above questions regarding hand span and human biology. Remember, it is a **testable prediction** that may **answer the question**.

Hypothesis for Question 1.
Hypothesis for Question 2.
Hypothesis for Question 3.

C: The Process of Scientific Inquiry – Experimentation

Once the question has been identified, a hypothesis formulated, and a testable prediction has been made, it is time to perform the test of that prediction! Part of the skill lies in deciding how you are going to measure the predicted response. For example, if you hypothesize that a high-fat diet will make your face break out, how will you measure the specific changes in your facial complexion?

Choose one of the hypotheses you wrote in Part B and describe how you might test it.

Test for Hypothesis ___.

Possibly, the test of your hypothesis simply involved making more observations — e.g., measuring lots of hands! But commonly, the test of the hypothesis involves making deliberate manipulations. I.e., the investigator conducts an *experiment*.

Experimental design

In designing a **controlled experiment** the investigator must have two setups: first, an **experimental setup** that receives the test treatment (known as the **independent variable**); and second, a **control setup** that does not receive the test treatment (the independent variable is absent or set at a standard value). The two setups must be identical except for the independent variable so that the investigator is able to attribute changes between the two groups, the **dependent variable**, to the test treatment. All of the factors that are kept equal in the experimental and control setups are called **standardized variables**.

a) **Independent variable** – what the researcher deliberately alters during the experiment or the factor that is different between experimental groups.

b) **Standardized variables** – all factors that can vary, but are kept constant or equal during the experiment.

c) **Dependent variable** – what is measured, results of experiment.

Replication is another important element of experimental design. For a scientist to be confident in the results of an experiment, similar results must be obtained each time the experiment is performed. Similarly, **sample size** influences an investigator's confidence in an experiment with a larger sample providing a higher level of confidence than a smaller sample. Since class laboratory time, and therefore time to replicate experiments is limited, you will often be asked to compare your results to the results of other groups in class.

Statistics provide an essential tool for analyzing your experimental results. Most importantly, statistical formulas allow the investigator to mathematically calculate the chance that what appears to be an experimental correlation is simply a coincidence.

Experimental results

As with observations, experimental results are usually best organized and presented in tables and graphs. As described in Part A, an **experimental data table** should have a descriptive **title**, plus **column and row labels** that include **units of measure**.

Examine the experimental results presented in Table 2. Answer the following questions.

Table 2. The effect of ingested alcohol upon maze running performance in rats.

rat ID	previous maze experience (# trials)	total food ration (g food / kg body mass)	alcohol ingested (ml / kg body mass)	maze run time (minutes)
HC356	8	50	0	0.28
HC469	8	50	0	0.20
HC112	8	50	0	0.26
HC501	8	50	0.2	0.41
HC322	8	50	0.2	0.32
HC296	8	50	0.2	0.47
HC434	8	50	0.4	1.33
HC385	8	50	0.4	1.71
HC278	8	50	0.4	2.02
HC164	8	50	0.6	3.84
HC473	8	50	0.6	4.58
HC204	8	50	0.6	4.08
HC557	8	50	0.8	7.60
HC136	8	50	0.8	8.54
HC346	8	50	0.8	6.91
HC288	8	50	1.0	12.20
HC414	8	50	1.0	10.75
HC131	8	50	1.0	13.45

What hypothesis was being tested by this experiment?

Which column in Table 2 contains the independent variable?

Which column contains the dependent variable?

Which columns contain standardized variables?

Which rows in Table 2 have the control setup? How do you know?

As described more fully in Part A, all types of **graphs** should include the following:

1) A descriptive **title**.
2) An **X-axis** and a **Y-axis** with an **appropriate range of units** and **equal intervals** unless otherwise indicated.
3) The **axes labeled** with name of the variable and its appropriate **units**.
4) Graph type (line, bar) that is appropriate for the data type.
5) A **key** if more than one set of data is presented on one graph.

Additionally, for **graphs of experimental results**, the following rules apply:

6) The **X-axis** (horizontal line) contains the scale for the **independent variable**. If the data is for measurements made over a time interval, time is the independent variable.
7) The **Y-axis** (vertical line) contains the scale for the **dependent variable**.

Considering all of the factors above, use Figure 2 to create an appropriate line graph to present the data from Table 2.

Figure 2.

Was the hypothesis supported or refuted by this experiment? How so?

D: The Process of Scientific Inquiry – Human Experiments

Applying the scientific method and controlled experimental design to studying human biology is often problematic with special ethical and logistical considerations. Consider the following issues.

What limitations are on the standardized variables in a human experiment? How might the scientist deal with these limitations?
What problems arise in designing the control setup in human experiments? (Hint: Define the "placebo effect.") How must the scientist address these problems?
A medical researcher is conducting a controlled experiment to study the effectiveness of a new therapy on patients with a certain disease. What ethical issue arises if the experimental group starts to recover from the disease faster than the control group? How might this issue compromise the experiment?