Scientific Investigations and Thinking

Science is the systematic study of the structure and behavior of the physical and natural world through observation and experimentation.

- **Observation** involves carefully watching something and taking notes about the event in order to gain information.
- **Experimentation** involves changing something in a situation in the expectation that the change will provide more information about the nature of the situation.

Science must be **guided by natural law and must be testable** against the observable world. Its conclusions are **falsifiable**. Falsifiability does not mean that the conclusion is false, rather it means that if it is false, then observation or experiment will at some point demonstrate its falsehood.

Science seeks to avoid inference. To infer means to draw either a conclusion with only partial evidence or a second conclusion based on the first conclusion without actually testing the accuracy of the second conclusion. For example, one could infer that, because ice floats in water, it will float in any liquid. Experimentation would reveal that, although ice floats in many liquids, there are a number of liquids it will sink in.

In this lab, students will explore the following topics:
1. The Language of Science
2. The Scientific Method
3. Data Collecting, Processing, Presenting, and Interpreting

Part 1: The Language of Science

One of the main reasons students find the study of science challenging is that the words are difficult to write, spell, and read. Scientific vocabulary is, in some respects, a language unto itself. It is a hodgepodge of prefixes, root words, and suffixes that have been borrowed from other languages, especially Latin and Greek.

The good news is that these prefixes, root words, and suffixes have specific meanings. Learning the meanings of these word fragments will make it much easier to understand scientific vocabulary. On the next page is a list of many of the common word fragments used by scientists. Use that list to translate the meanings of the following scientific words.

Word	Meaning	Word	Meaning	Word	Meaning
a or an	not, non, without	epi	on, upon	mono	one, single
aero	needing oxygen or air	gastro	stomach	morph	form
amphi	both, doubly	genesis	origin, beginning	multi	many
angio	vessel	gymno	naked	phage	to eat
anther	flower, male	hemo	blood	philia	like, love
anti	against	hepatic	liver	phobia	dislike, fear
aqua	water	herba	plants	photo	light
arche	beginning, origin	hetero	different, other	phyll	leaf
arthro	joint	homo	alike, similar, same	phyte (phyta)	plant
auto	self	hydro	water	plasm	form
bi	two, twice, double	hyper	Above, excessive	pod (poda)	foot or feet
bio	life, living	hypo	below	poly	many
carne	flesh	intra	within, inside	proto	primitive, first
cephal	head	itis	inflammation of	sperm	seed
chloro	green	lateral	side	sub	lesser, below
cide	killer, kill, killing	logy	study of	synthesis	to make
cyto	cell	lys, lysis	break down	taxy (taxo)	arrangement
derm	skin	macro	large	therm	heat
di	two, double	meso	middle	troph	eat, consume
ecto (exo)	outer, external	meta	after, beyond	vore	swallow, devour
endo	inner, inside	meter	measurement	wort	plant or herb
endo	internal	micro	small	zoo, zoa	animal

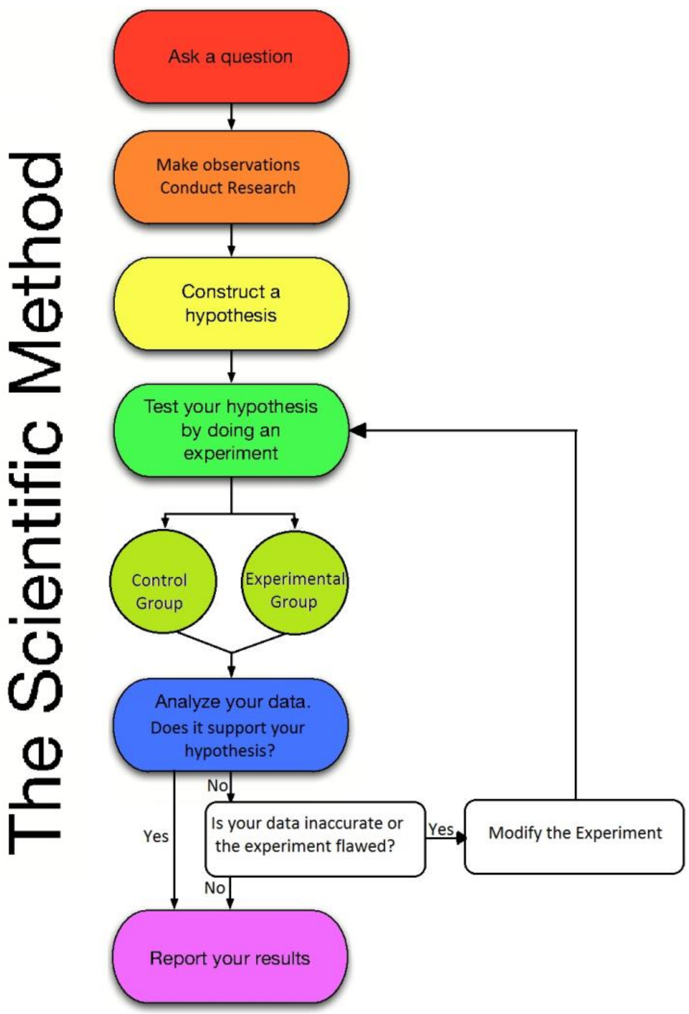
1. Zoology ____
2. Protozoa ____
3. Spermatogenesis ____
4. Insecticide ____
5. Bilateral ____
6. Endotherm ____
7. Ectotherm ____
8. Arthropod ____
9. Gastropoda____
10. Amphibios (amphibian) ____
11. Hypothermia ____
12. Metamorphosis ____
13. Herbivore ____
14. Carnivore ____

Part 2: The Scientific Method

The scientific method is a body of techniques for investigating natural phenomena, acquiring new knowledge, or correcting and integrating previous knowledge. The scientific method is a stable investigation tool that has characterized natural science since the 17th century. Because science builds on previous knowledge, it consistently improves our understanding of the world.

To be termed scientific, a method of inquiry must be based on empirical and measurable evidence. Scientists seek to let reality speak for itself, supporting a hypothesis when the hypothesis's predictions are confirmed and challenging a hypothesis when its predictions prove false. Scientific inquiry is intended to be as objective as possible in order to reduce biased interpretations of results. Another basic expectation is that scientists will document, archive, and share all data and methodology so other scientists can scrutinize the experimental design and reproduce and verify the experimental results.

Scientific researchers propose hypotheses as explanations of phenomena and design experimental studies to test these hypotheses through predictions that can be derived from them. These steps must be repeatable, to guard against mistake or confusion in any particular scientist.



A well-designed experiment contains the following things:

- A clearly stated, testable hypothesis.
- An experiment that consists of variables, invariables, experimental groups, and control groups.
  - **Independent Variable** – What is being varied during the experiment. What the investigator thinks will affect the dependent variable.
  - **Dependent Variable** – What will be measured. What the investigator thinks will be affected during the experiment.
  - **Invariables** – things held the same for all study organisms.
  - **Control group** – the study organisms that are not subjected to the independent variable.
  - **Experimental group(s)** – the study organisms that are subjected to the independent variable.
- Careful collection of appropriate data
- Data analysis
- Conclusion, based upon experimental data analysis, regarding the validity of the hypothesis

Let us consider the following example. We have been assured that Brand X plant food is good for plants and promotes their growth. The instructions say that the plant food should be used every 4th watering. This leads us to the following hypothesis: "If some Brand X plant food is good for plants, then more would probably be better for plant growth." To conduct an experiment to test this hypothesis, we would need to account for the following:

- **Independent Variable** – the quantity of Brand X plant food given to our test plants. Plants will receive Brand X plant food solution at the following levels:
  - Every watering
  - Every other watering
  - Every third watering, etc.
- **Dependent Variable** – what will be measured (data collection). We will measure what we think will be effected during the experiment. This would depend upon the purpose of our experiment.
  A florist would be more interested in producing a showy plant for sale.
  A nutritionist would be more interested in the nutritional value of the plant represented by the dry weight.
  A plant physiologist might be interested in the photosynthetic tissue quantity versus the actual biomass of the plant which would require a correlation between the leaf surface area and dry weight.
  Depending on our purpose, we need to collect some or all of the following data:
  - Height of plants
  - Total leaf surface area
  - Circumference of base of stalk
  - Wet weight of plant
  - Dry weight of plant
- **Invariables** – all other conditions will need to remain constant for all plant groups. This would include amount of light, temperature, type of soil, wind, humidity, age at the start of the experiment, genetic composition, etc.
- **Control Group** – one set of plants will receive plain water only.
- **Experimental Groups** – the plant groups that will receive an assigned schedule for watering with Brand X plant food.

Part 3: Data Collecting, Processing, Presenting, and Interpreting

After planning and conducting a well-designed experiment, you must collect the data and process it in a way that will honestly reveal whether your hypothesis was right or wrong. Reminder: data speaks for itself and is neutral. It is unethical to ignore, discard, modify or distort the data to fit your own desires (bias). When the data suggests the hypothesis is incorrect, the investigator should review the experiment to be sure it was designed to test the hypothesis. If the design is good, then rerun the experiment. If the results are again the same, then the hypothesis is probably incorrect. On the other hand, if the data support the correctness of the hypothesis, repeat the experiment exactly as before to confirm the validity of the hypothesis.

Let us consider the scientific investigation we introduced earlier regarding plants fertilized with Brand X plant food.   The instructions say that the plant food should be used every 4^{th} watering. Our hypothesis is: “If some Brand X plant food is good for plants, then more would probably be better for plant growth.” We will have a control group that receives water only and 5 experimental groups that receive varying amounts of plant food. Each group will have 7 test subjects. All plants were the same age, species, and height at the beginning of the experiment. At the end of the experiment, the height of each plant was measured.

This data can best be presented in a table. Tables organize data in columns under heading that are clearly related to what the data actually represents. To be complete, a table should be able to stand alone and be understood by all. A table needs a clear title, distinct headings on columns, and standard units of measurement for numerical data. Any additional information needed to understand the table should be present in footnotes and/or a legend.

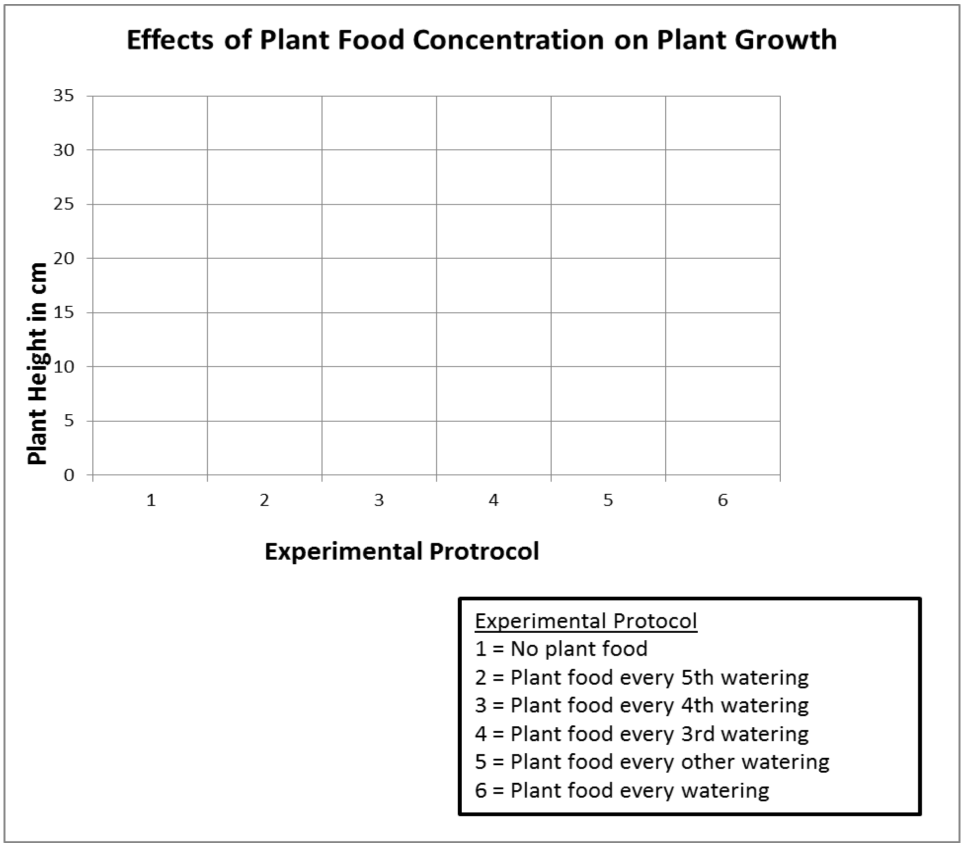
Experimental Protocol	**Plant height (in cm)**							Mean	Median	Mode
Just water	17	18	19	20	20	22	24			
Fertilizer every 5th watering	17	17	20	22	24	26	28			
Fertilizer every 4th watering	23	25	27	30	32	32	34			
Fertilizer every 3rd watering	16	17	18	18	25	26	27			
Fertilizer every other watering	9	11	13	15	16	17	17			
Fertilizer every watering	3	3	3	4	4	5	6			

Interpreting Data: While this is not a course in statistics, the ability to analyze experimental results is vital to science. We are going to use 3 simple statistical analyses to look at our data.
Mean – the average value. Calculate the average height of the plants in each group and record your data in the table.
Median – the middle most value. Since there were 7 plants, and the data is organized from shortest to tallest, one needs only to record the height of the plant in column 4 in the appropriate cell of the column labeled Median.
Mode – the most frequent single measurement. Look at the heights of the plants in each group and record the most frequent height in the table.

Graphs: A graph presents data in a visual way that provides a means of making a rapid assessment of a trend revealed by the data. There are many types of graphs (line graphs, bar graphs, etc.). The vertical scale of a graph is referred to as the ordinate (in math classes, this is often referred to as the y-axis). The abscissa is the horizontal scale (referred to as the x-axis in math classes). Often graphs use one axis to represent the frequency of the object being measured (dependent variable) while the other will represent some standard form of measurement such as time (in seconds, minutes, hours), dimensions (in millimeters, centimeters, meters), velocity (in meters/second), etc.

A graph must be able to stand alone on a sheet of paper just as a table does. Therefore, a graph should have both axes clearly labeled and a may need a legend that defines the symbols plotted on the graph.

We will construct a line graph for the MEAN plant height of each of our plant groups below.



Conclusion: Our initial hypothesis was**: "If some Brand X plant food is good for plants, then more would probably be better for plant growth."** Based upon your data analysis and constructed line graph, what is your conclusion about the hypothesis?

1. Should we reject or support our hypothesis? Why or Why not?

2. How would you suggest we proceed from this point? (Was the experiment correctly designed to test our hypothesis? Should we redesign and/or rerun the experiment or should we now simply accept or reject our hypothesis?)