What is

Science?

What is Science?

Science is a process of questioning.

Science as Inquiry

- **Biology = the Study of Life**

  (From the Greek *bios=life* and *logos=the study of*)

- **At the heart of science is <u>INQUIRY</u>**
  - **Inquiry is a process of investigation, with thoughtful questions leading to a search for answers.**

http://www.beavercreek.k12.oh.us/403920961229503/lib/403920961229503/j0439363.jpg

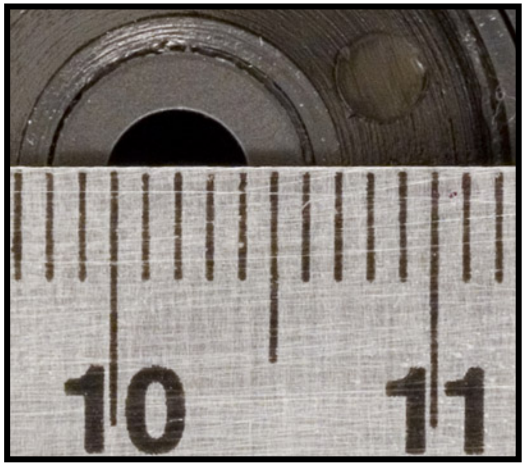
Observations & Data

- **Observations** = The use of the senses to gather and record information about structures or processes.
- **Data** = Recorded Observations
- **Scientific instruments** vastly **increase** the range of possible **observations**

http://www.chanceglass.co.uk/dev/microscope

Observations & Data

- **Quantitative Data** = Observations recorded as measurements.
  - In science, such measurements often recorded using the Metric System.
    - All numerical measurements must always be reported alongside the proper **units**!



- **Qualitative Data** = Data in the form of descriptions instead of measurements.

- **All data most useful when:**
  - Clearly organized,
  - consistently recorded,
  - and reliable.

Science involves questioning in order to describe or explain

- **Scientific Method**: A process of critical thinking that uses observations and experiments to investigate testable predictions about physical universe.

- **Two type main types of scientific inquiry**:

1. Discovery Science
   (Descriptive Science)
2. Hypothesis-Based Science
   (Experimental Research)

DISCOVERY SCIENCE / OBSERVATIONAL RESEARCH

- **Discovery Science**
  - Accurately describes natural structures & processes.
  - Based on recorded observations
  - Data collected is analyzed
    - In these studies, Investigators observe subjects and measure variables of interest without assigning treatments to the subjects.
    - The researcher does NOT manipulate any variable in order to observe its effect on other variables
      - No experiment is conducted
        - Ex: Jane Goodall's studies on Chimpanzees

Discovery Science

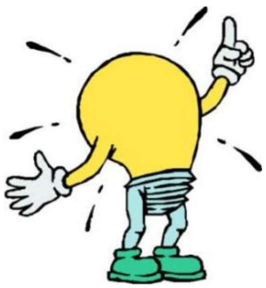
- Sometimes discoveries happen by accident.
  - In 1928, Alexander Flemings discovered that mold had contaminated his culture of bacteria.
  - No bacteria were growing near the mold.
  - Without meaning too, Fleming discovered this antibacterial substance that was being produced by the fungus to kill the bacteria, later named penicillin.

- Penicillin - the first discovered antibiotic - revolutionized medicine.

Inferences in Science

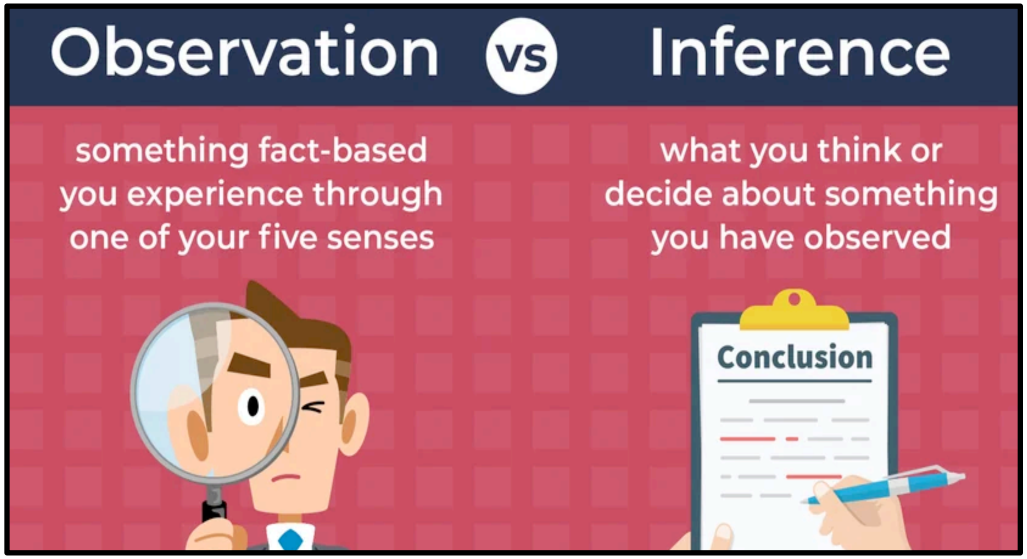
Inference = A logical conclusion based on observations

- Inferences must not stretch too far beyond the data.
- Scientific inferences must be based on logical principles of reasoning.
- Inferences derived must match with observed evidence.
  - Often, a person makes an inference by relating observations to their prior knowledge.
    - For instance, you infer someone is at the door when you hear the doorbell ring because you know the same thing has happened before.
    - For instance, Fleming inferred that the fungus might be secreting a substance that was deadly to the bacteria in his petri dish
  - Inferences help convert general questions into more specific questions that can be explored in depth.
    - Flemings observations of bacteria dying near the fungus in the petri dish lead to him asking "What substance produced by this particular mold kills bacteria?"



Inferences in Science

- It is important not to confuse inferences with the observations on which they are based.
  - Hearing the doorbell ring is an observation.
  - Inferring that someone is at the door, though reasonable, has less certainty.
    - Maybe an electrical short circuit is causing the bell to ring
- Scientists are skeptical of inferences that "stretch" far beyond the data.
  - For Ex: Inferring solely from Fleming's observation that some molds can produce antibiotics capable of curing bacterial diseases in humans.
    - It took much more research before this conclusion was accepted by science.



Inferences in Science

- Examine the picnic table below.
  - What can you infer from the place settings and other objects you observe on the table?
    - Can you infer anything from what is present or absent?
    - Can you make reasonable inferences about the weather and time of day when this photograph was taken?

Observation: Two meals are sitting on a table. The table and food is outdoors. It's daylight.

Inference: Two people are having lunch together.

Inferences have <u>less certainty</u> than observations.

➡ It could be that 4 people are sharing the food in two plates.

➡ It would a stretch to infer that the people got kidnapped before they could eat lunch.

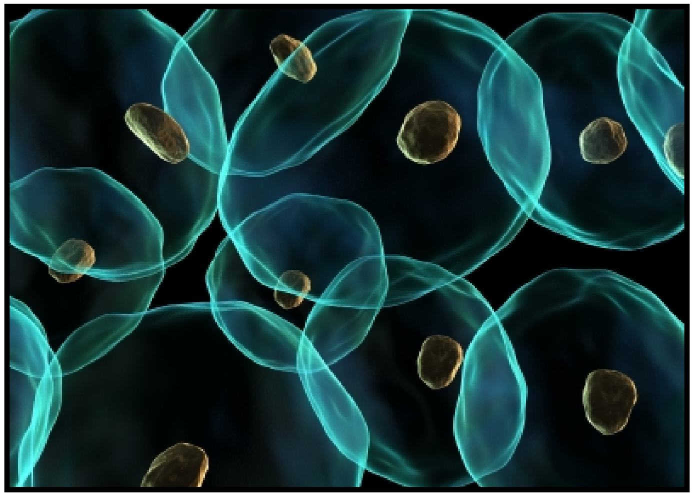
Generalizations in Discovery Science

Generalization = A general conclusion reached by scientists after they putting together the data from many specific observations.

In the 1800's, scientists noticed in both plants and animals tiny units called cells.

But it was the accumulation of many observations that gave them the confidence to make the generalization that…

"all living things are made of of cell"



This generalization became part of what is known as the **Cell Theory**, one of the most important products of discovery science in the nineteenth century.

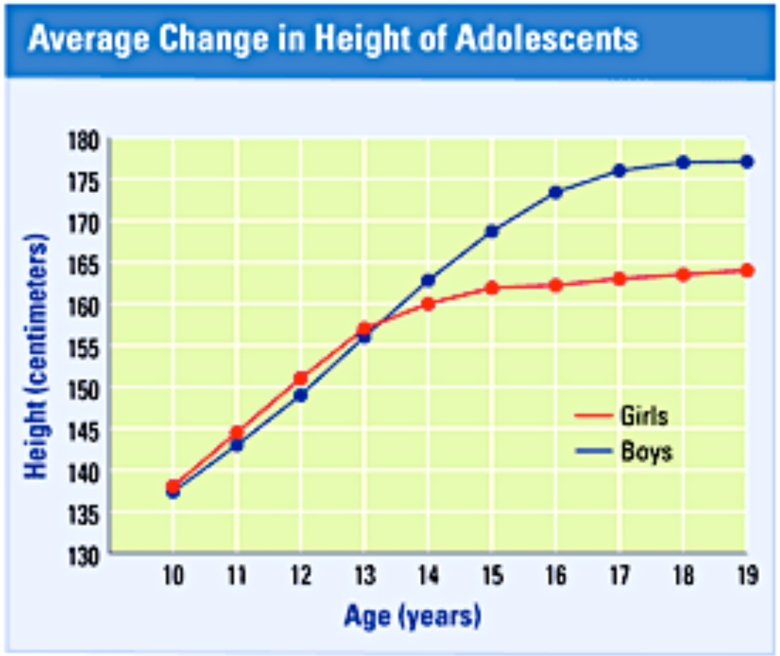
Generalizations in Discovery Science

Though the cell theory derives from a generalization made from qualitative data (the cell-based organization of tissues), generalizations can be made from quantitative data as well.

- **This usually requires combining measurements from a very large sample or multiple samples**
  - ➡ **To look for general patterns in measurements, it often helps to put the data in a graph.**

Ex: This graph compares the changes in heights of teenage boys and girls over time. Each point on the graph is an average measurement for many thousand boys or girls. The graph makes it easier to spot the reason for the generalization that girls, on average, stop growing at a younger age than boys.

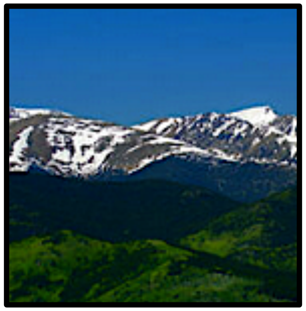
Of course, there are individual exceptions. But the generalization still holds across this very large sample of teens.



Generalizations & Inferences in Science

- Observations, data collection and analysis, inferences, and generalizations all advance our understanding of the natural world.
  - These processes of Discovery Science are often just the beginning of a scientific inquiry.
    - For example, trees do not grow above a certain altitude in several mountain ranges. Observations of this "treeline" phenomenon in many mountain ranges in Western North America may lead you to a generalization: At a particular latitude, trees don't generally grow above a certain altitude.

    - Next, you might infer that environmental conditions at high altitude are unfavorable to tree growth.
      - But which environmental factors influence tree growth most? Low temperatures? "Thin" atmosphere? Strong winds? Lack of soil? A combination of factors?



Generalizations & Inferences in Science

- **Discovering something interesting inspires curious minds to seek an explanation.**
  - **It is one thing to describe and measure the growth of a plant toward light (discovery science). But what causes this phenomenon?**
  - **How can scientists explain the plant's ability to detect and respond to the direction of light?**
    - **Questions related to causes of phenomenon are at the center of hypothesis-based science *(experimental science)***
      - **Through experimental science, different explanations for cause and effect relationships between variables are tested.**

Hypothesis-Based Science

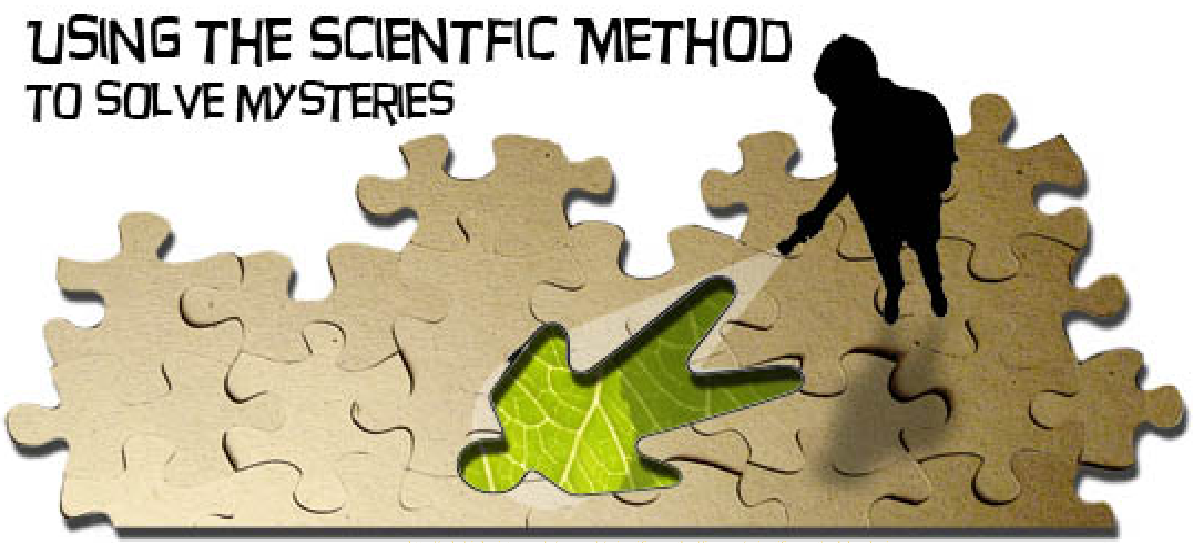
Discovering something interesting inspires us humans to seek explanations.

Discovery science seeks DESCRIBE nature, but Hypothesis-based Science seeks to EXPLAIN nature.

Hypothesis-based Science depends on the "Scientific Method." However, science is less rigidly structured than many realize.

All hypothesis-based science does have in common is …

THE HYPOTHESIS



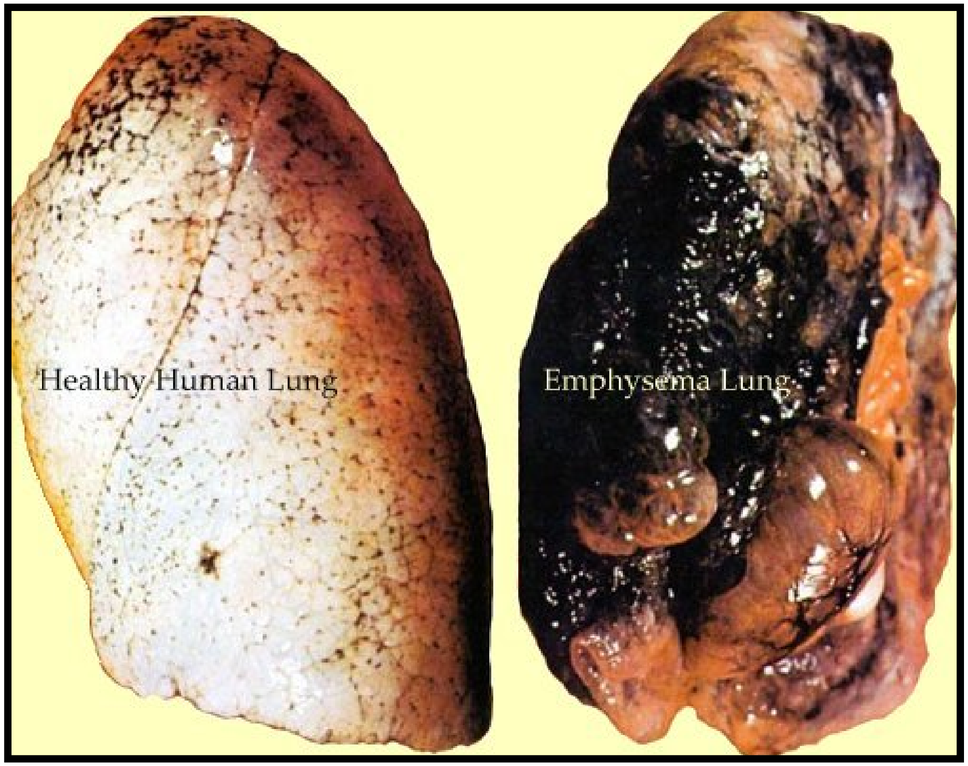
http://askabiologist.asu.edu/research/scientific_method/images/scientific_method_header.jpg

Experimental Research Involves Conducting Experiments

- Experimental Science (Hypothesis-based Science)
  - Experiment = a methodical procedure carried out with the goal of verifying, falsifying, or establishing the accuracy of a hypothesis.
    - A Hypothesis is a proposed explanation for an observed phenomenon
      - A hypothesis is a testable statement about the relationship between two or more variables.
    - Experimentation is the step in the scientific method that helps people decide if a hypothesis is false
      - If not proven false, the hypothesis is supported but it can never be proven correct!
        - In an experiment, investigators apply a treatment to subjects divided into experimental groups (groups of people, bacteria, plots of land, etc) and then proceed to observe the effect of the treatments on the subjects in order to test if the proposed explanation for the relationship between the treatment and the effect (hypothesis) was valid or not.

Comparing the Types of Research

- For example, suppose we want to study the effect of smoking on lung capacity in women…
  - What would be a descriptive study on this?
  - What would be an experiment on this?



Types of Research

- **Basics of a possible Descriptive/Observational Study**

Observational Study

- Find 100 women age 30 of which 50 have been smoking a pack a day for 10 years while the other 50 have been smoke free for 10 years.
- Measure lung capacity for each of the 100 women.
- Analyze, interpret, and draw conclusions from data.

4

Types of Research

- **Basics of a possible Experimental Study**

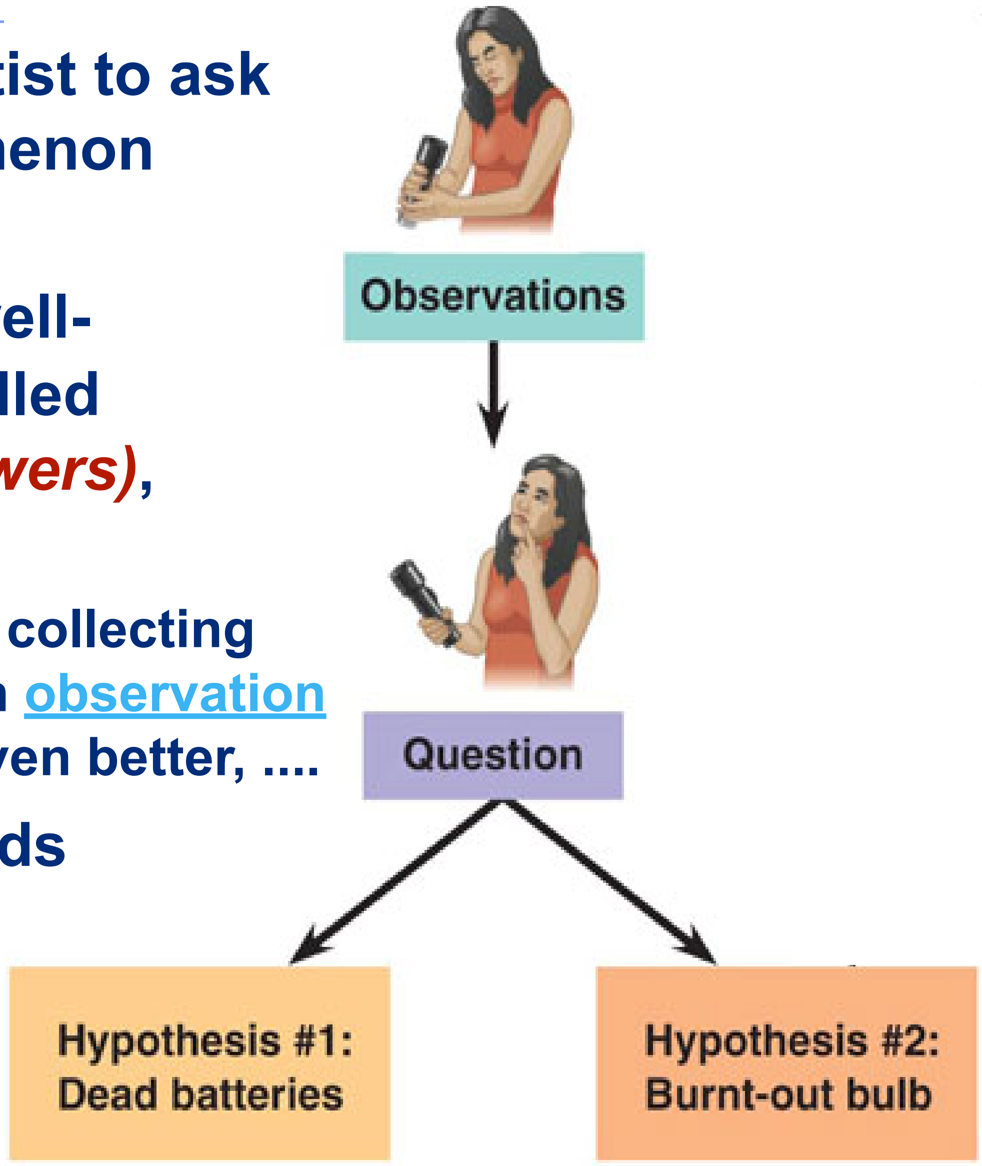
Experiment

- Find 100 women age 20 who do not currently smoke.
- Randomly assign 50 of the 100 women to the smoking treatment and the other 50 to the no smoking treatment.
- Those in the smoking group smoke a pack a day for 10 years while those in the control group remain smoke free for 10 years.
- Measure lung capacity for each of the 100 women.
- Analyze, interpret, and draw conclusions from data.

3

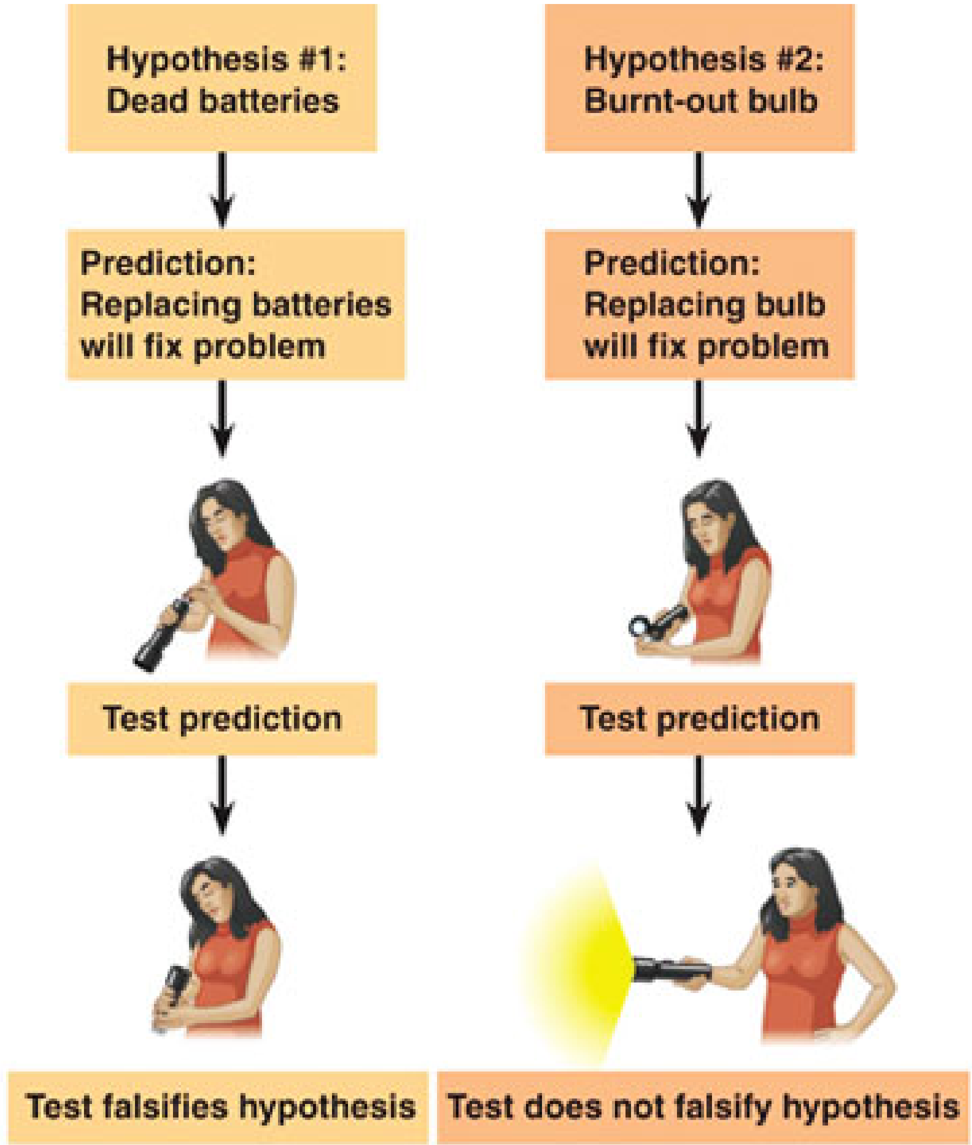
Hypothesis-Based Science

- Observations lead a scientist to ask questions about a phenomenon observed.
- Next, scientists propose well-reasoned explanations, called hypotheses *(possible answers)*, to those questions.
  - these can be supported by collecting and analyzing data through observation (Discovery Science) but, even better, ...
- A scientific hypothesis leads to predictions that can be tested engaging in experimentation (Experimental Science)



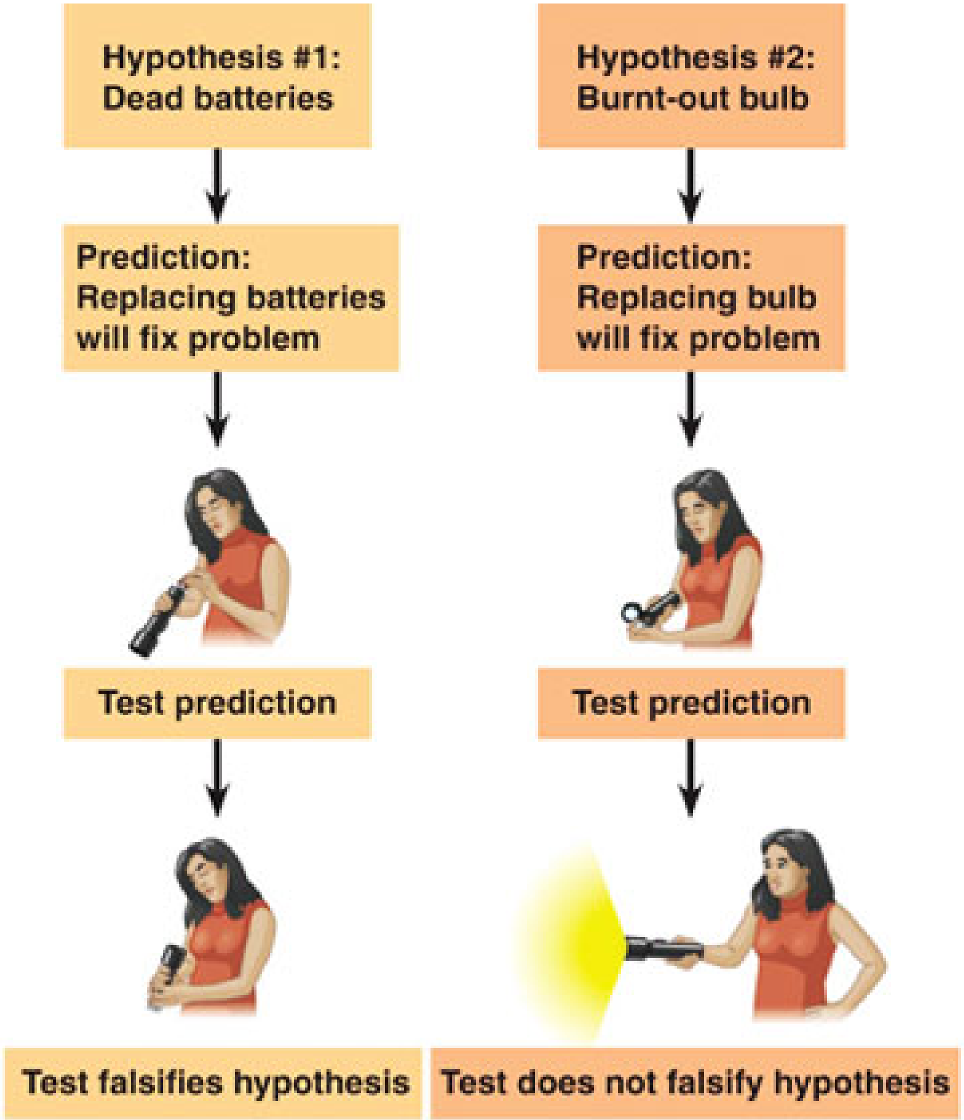
A hypothesis <u>MUST</u> be testable & falsifiable.

- ✓ There must be some way to <u>check the validity</u> of the explanation (hypothesis).
- ✓ *IF* the proposed explanation (hypothesis) is incorrect, then there must exist some observation or experiment that could <u>reveal that this explanation is actually NOT true</u>.

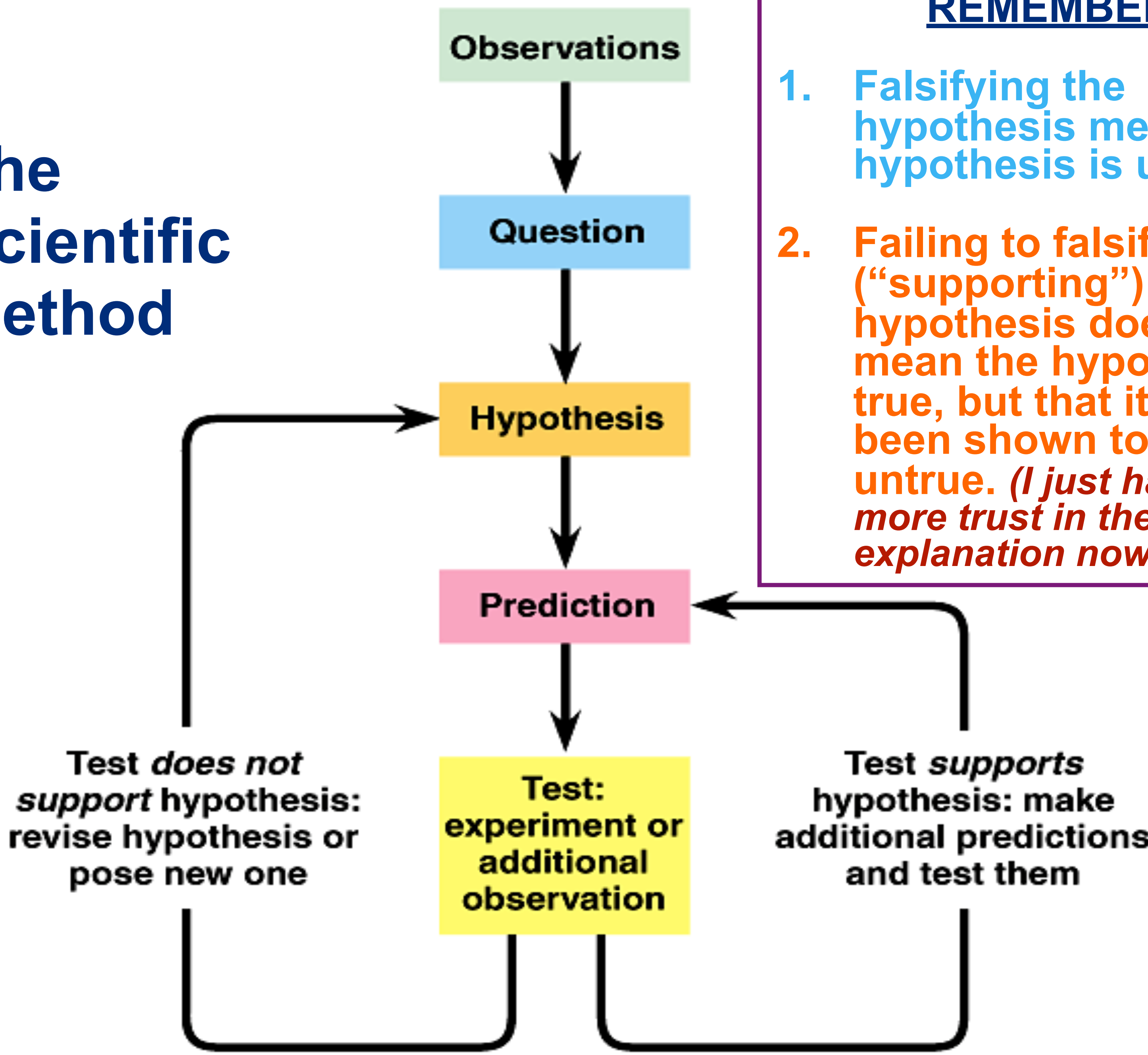


FAILURE TO FALSIFY A HYPOTHESIS DOES NOT PROVE THAT HYPOTHESIS!!!

- **If you replace the bulb, and it works, you have FAILED TO FALSIFY the hypothesis that your flashlight does not work because the light was burnt out.**
- **You HAVE FALSIFIED the hypothesis that the defective flashlight was caused by dead batteries.**
- **The RESULTS SUPPORT the hypothesis that your bulb was burnt out**
  - **This explanation is NOT PROVEN** ***(perhaps the first bulb was inserted correctly and not burnt out at all)***
  - **However, his explanation has become more VALID**



The Scientific Method



REMEMBER:

1. Falsifying the hypothesis means the hypothesis is untrue.
2. Failing to falsify ("supporting") the hypothesis does not mean the hypothesis is true, but that it hasn't been shown to be untrue. *(I just have more trust in the explanation now)*

Example of Hypothesis-Based Science

Michael Sheehan and Elizabeth Tibbetts study individual recognition in wasps.

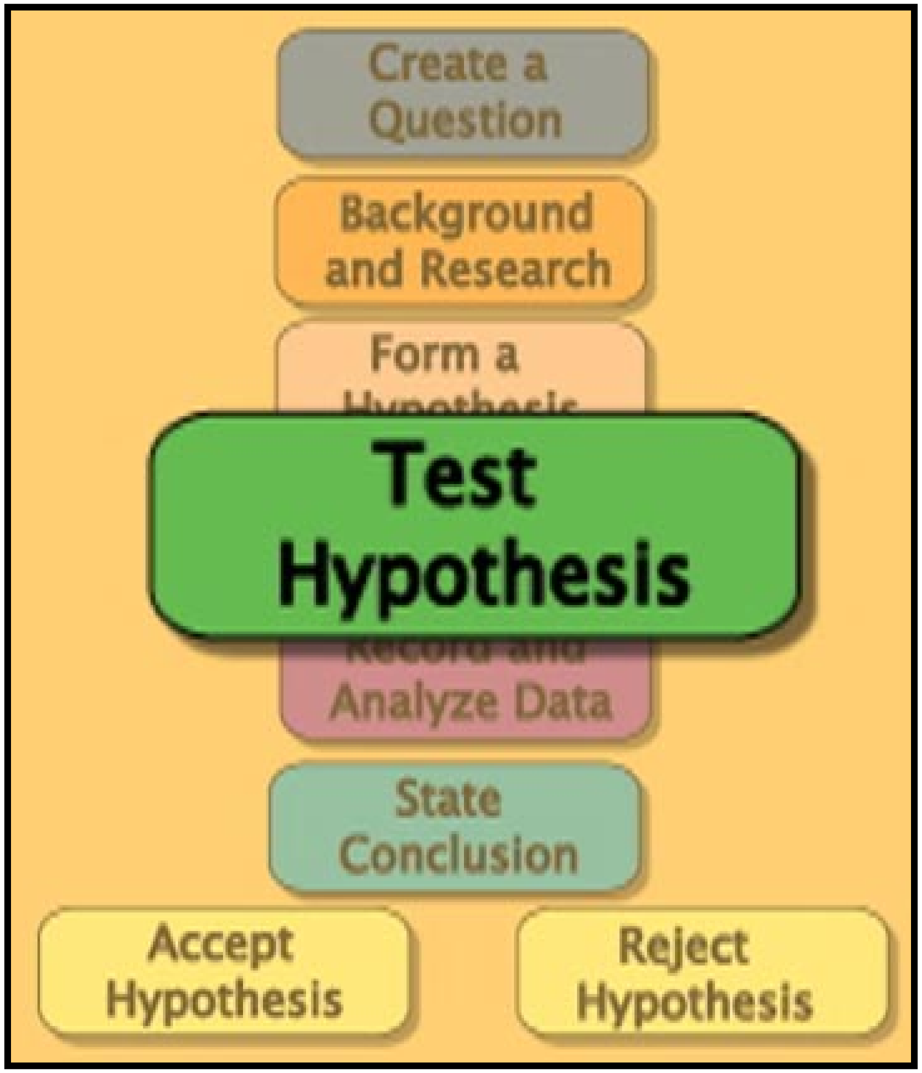
- **Observation** = Some wasps get attacked less often.
- **Question** = Why do some wasps get attacked less?
- **Hypothesis** = Distinctive-looking individuals benefit, because they get in fewer fights over dominance. (Educated guess/tentative explanation)
- **Logic/Reasoning** = With individual recognition, you only have to fight each wasp once since you know which is dominant.
- **Prediction** = The non-painted wasp will get attacked fewer times
- **Experiment** = They painted wasp faces, so that three in a group of four looked the same and one was different to see if the one different looking wasp was recognized upon a second encounter by being attacked a fewer number of repeated times.
- **Results** = Consistent with their hypothesis, the distinct-looking one was attacked less by the others.

The Scientific Method - Review

When following the Scientific Method, <u>hypotheses</u> are proven or not proven <u>wrong</u>!

Hypothesis are <u>NEVER</u> proven right.

Evidence only <u>supports</u> (gives <u>validity</u> to) a given hypothesis (explanation).



The Scientific Method - Review

The Scientific Process involves….

- Observations, Questions, Hypothesis (then prediction), Experimentation, Conclusions

Hypothesis - a testable explanatory statement that should be able to be proven false by experiment or observation if false.

- *Hypothesis must **not** be ambiguous!*

Good	Bad
1. Plants will grow taller when given Miracle Grow. 2. Girls will score higher on math tests than boys. 3. Hermit crabs choose colorful shells over drab shells.	1. Plants will grow better when given Miracle Grow. 2. Girls are smarter than boys. 3. Hermit crabs like colorful shells.

The Scientific Method - Review

- **After creating a hypothesis, a prediction is made.**
  - **A <u>prediction</u> is an expected outcome.**
    - **A hypothesis is then tested by <u>experimentation</u>**
      - a planned procedure designed to test the hypothesis.

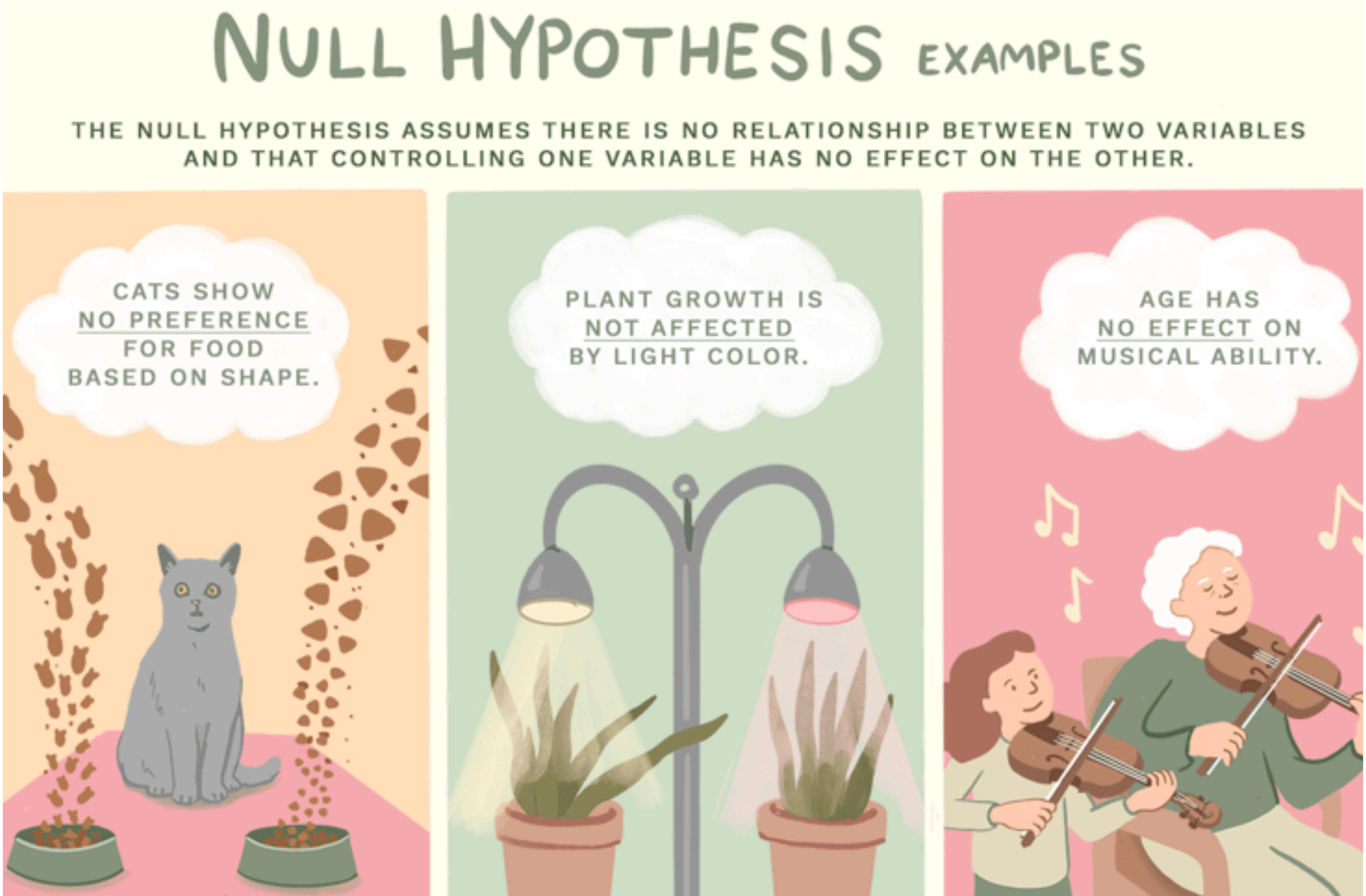
Elaboration on Hypotheses

- **Actually, whenever we talk about an hypothesis, we are really thinking simultaneously about *two* hypotheses.**
  - **In science you cannot assume there exists a relationship between variables *(that one causes a change in the other)* without evidence to back up your explanation.**
    - **Let's say that you think that there exists a relationship between two variables in your study. One of two explanations might be true:**

1. **Variable A and variable B are *not* related.**
2. **Variable A and variable B *are* related**

Null & Alternative Hypothesis

- **The hypothesis that describes the starting baseline *(with no assumptions of connections between two variables)* is the *null* hypothesis.**
  - H_O or H_0
  - This explanation states that "X has NO effect on Y"
- **The explanation that there *IS* a connection between two variables then is the *alternative* hypothesis**
  - H_A or H_1
  - "That X has an effect on Y"



- The Null Hypothesis is what gets tested in an experiment.

Null & Alternative Hypothesis

- **Caution:**
  - Often the hypothesis that a scientist may hope or predict is supported by the data is the H_A - that there will be a change in Y if you manipulate/ change X.
    - BUT, a scientist cannot say that a cause and effect relationship exists between two variables unless the hypothesis which states that there is no relationship between the variables is first proven false.
      - A scientist needs data (evidence) to reject the null before considering an alternate hypothesis/explanation
  - In some studies though, a scientist might hope the H_0 is supported and that there will be no difference or change in Y if you manipulate/change X.
    - In this situation, the scientist hopes the data supports the null hypothesis.

Null & Alternative Hypothesis

- The null hypothesis is often what the researcher tries to disprove, reject or nullify.
  - This is the baseline - one variable does not influence another variable in any way
- The alternative hypothesis is often what the researcher really thinks explains a phenomenon.
  - In the conclusion of an experiment, a scientist makes a determination about the null hypothesis, rejecting or failing to reject the H_O (not the H_A)
    - EXAMPLE OF NULL HYPOTHESIS:
      - H_0: Tomato plants do not exhibit a higher rate of fruit production when planted in compost rather than soil.
    - EXAMPLES OF THE ALTERNATE HYPOTHESIS:
      - H_1 or H_A: Tomato plants exhibit a higher rate of fruit production when planted in compost rather than in soil.

Types of data (information) in Experiments

- Variables are conditions, characteristics, or values that can change
  - Scientists want to explain which variables influence which other variables so we can reach a greater understanding of nature and the universe.

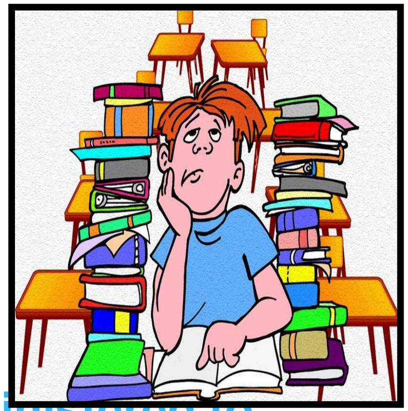
Variables that Help Explain Phenomena

- **Many variables may influence another given variable.**
  - **What could potentially effect the growth of plant in height?**
    - Amount of Sunlight Exposure per day
    - Wavelength of Light
    - Amount of Daily Rainfall
    - Potassium content in soil
    - Volume of soil in pot
    - Time of day when watered
    - Shape of pot
    - Species of plant
    - Humidity in air
    - Temperature of air

- **However, you cannot assume one variable affects another though just because you think it should! *Evidence is needed!***
  - **By conducting experiments, scientists test the effects of one of these variables on plant height to see if indeed there is a causal link between that one variable and plant height.**

Variables that Help Explain Phenomena

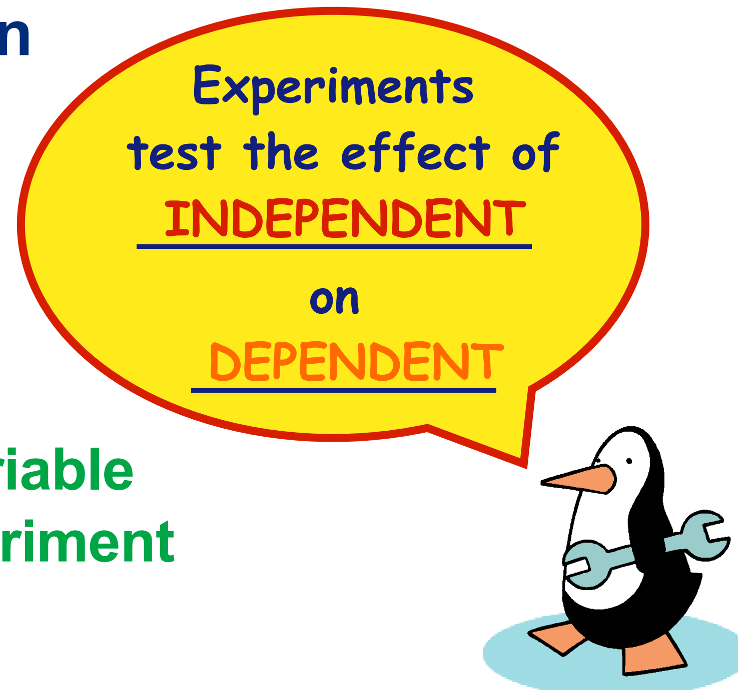
- What are the variables dealt with in an experiment?
- Independent Variable
  - The independent variable is the variable that is <u>manipulated</u> by the experimenter.
    - Ex: In a study on the impact of sleep deprivation on a calculus test performance, the amount of sleep deprivation is the independent variable.
  - The variable scientists changes & deliberately sets to certain <u>treatment levels</u>



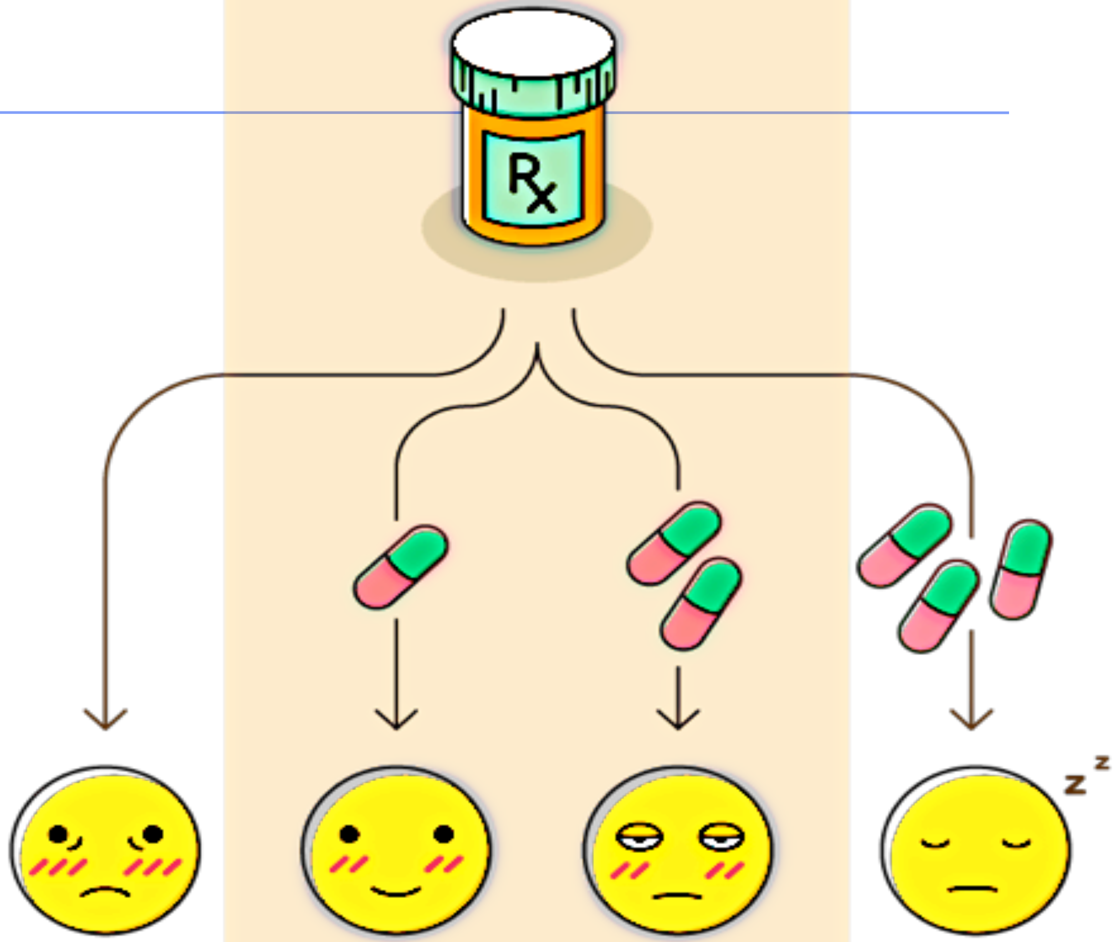
    - <u>Treatments</u> (the level of Independent Variable) are administered to subjects by 'level', where level implies <u>amount or magnitude</u>
      - Ex: if the experimental units were given 5mg, 10mg, 15mg of a medication, those amounts would be three treatment levels
  - This variable changes in a predictable way since it only changes because a scientist chooses to change it in a specific way
    - The <u>experiment</u> will test if the Independent Variable effects or does not effect another specific variable.
      - Always graphed on the X-axis

Variables that Help Explain Phenomena

- **Dependent Variable**
  - The dependent variable is the variable that is <u>measured</u> by the experimenter.
    - Ex: In our previous example, the calculus test scores collected would be the dependent variable.
  - This is the <u>data we collect</u> in an experiment
  - This variable changes in unpredictable ways
    - We don't know how or if it will change as the independent variable is altered until we run the experiment
      - Placed along the Y-axis



VARIABLE IS MANIPULATED
(INDEPENDENT VARIABLE)



Experiment testing the effects of histamine levels on drowsiness

VARIABLE IS MEASURED
(DEPENDENT VARIABLE)

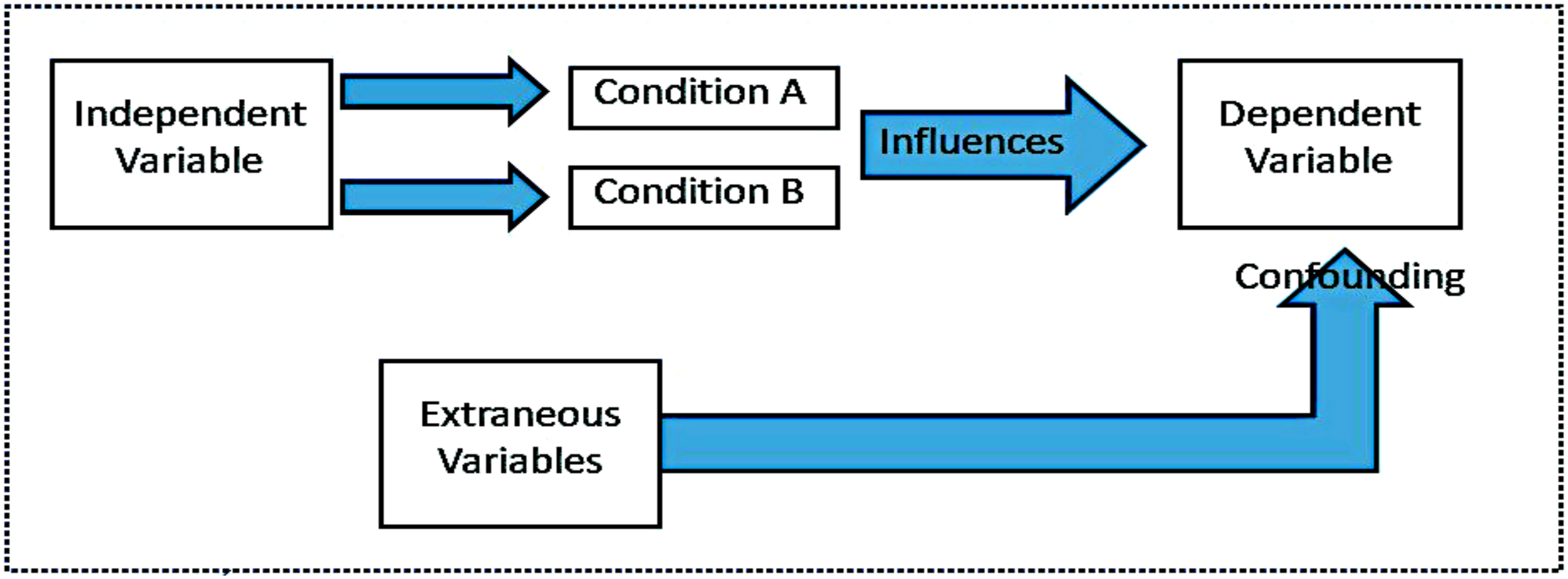
Type of Variables

- **The independent and dependent variables are *NOT* the only variables present in experiments.**
  - **When conducting an experiment, you want to make sure that you have tested the effects of your independent variable on your dependent variable and not accidentally tested the effects of another variable on your dependent variable.**
- **Extraneous Variables Exist too**

- **These types of variables may influence the dependent variable measured as part of your experimental data collected.**
  - **For example, in an experiment on the effects of sleep deprivation on calculus test performance, other factors such the subjects' age, gender, anxiety level, and academic background may also have an impact on the test results.**

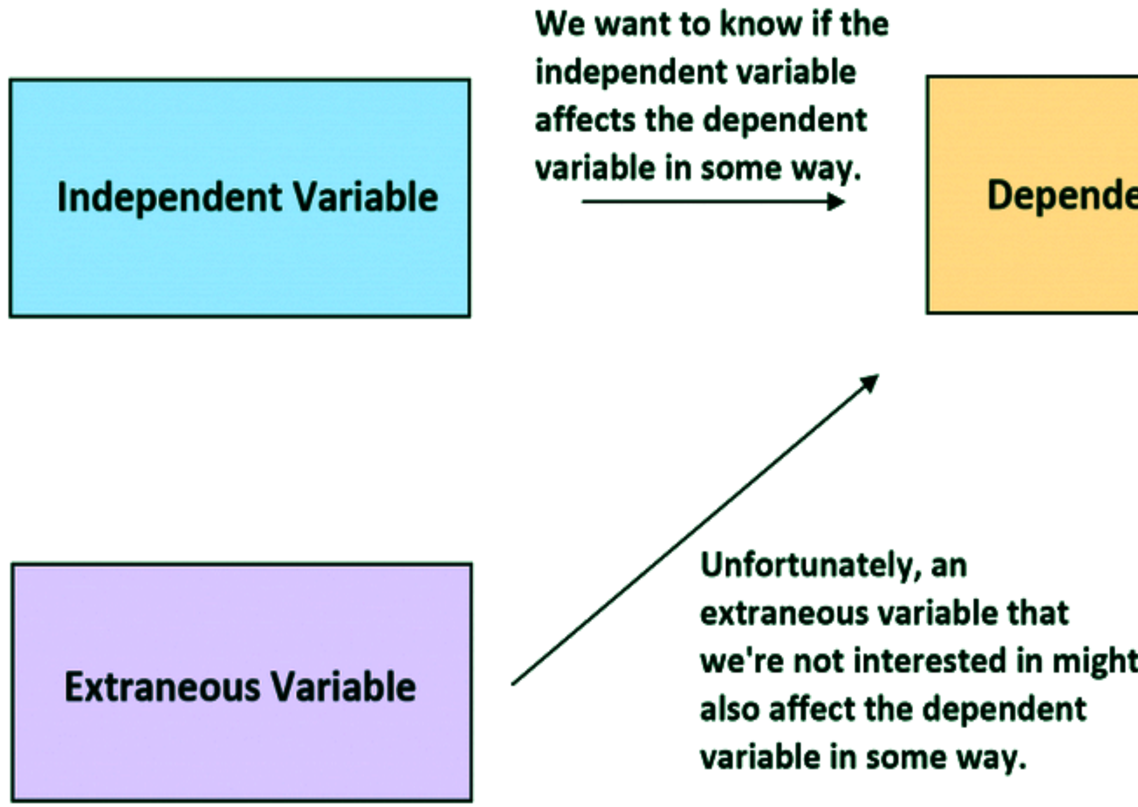
Extraneous Variables

- **Extraneous variables must be controlled for by the experimenter**
  - To control a variable means setting up your experiment so that all subjects experience the same amount of these variables *or* that these variables are allowed to fluctuate in the same way from subject in the experiment.
- **Controlled variables are called constants if they don't fluctuate over time.**
  - In the case of your subjects taking the calculus test, the experimenter might select participants that have the same academic background and age and give each the test in a room with the same temperature to ensure variations in these factors are not the reason for differences in test score results. *We want only the amount of sleep deprivation (the independent variable) to vary from one group of subjects to another.*



Extraneous Variables Must be Controlled

If an extraneous variable varies from group of subjects to group of subject then this variable can <u>influence</u> the dependent variable in one group of subjects differently from anther group of subjects in an experiment

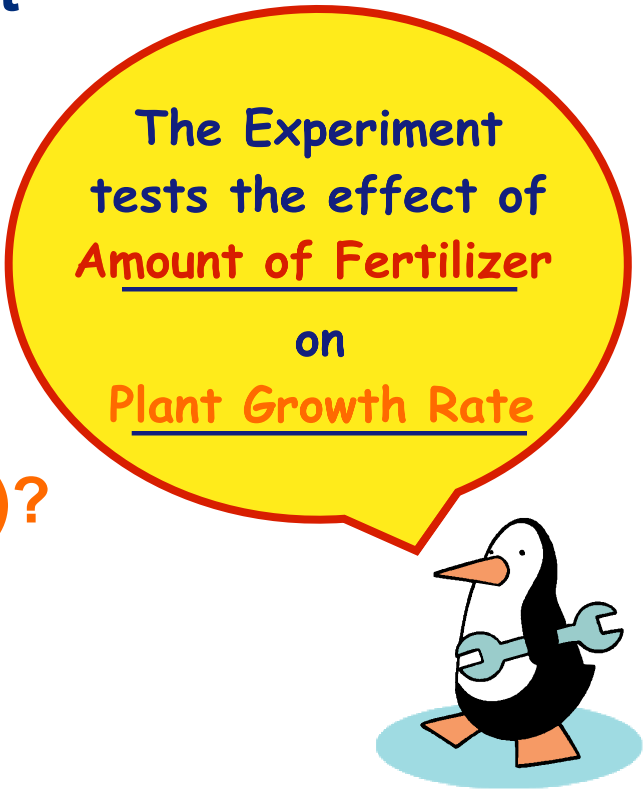


<u>Consequences</u>:

1. **the researcher may conclude erroneously that the independent variable had an effect on the dependent variable when it really did <u>not</u> (the extraneous variable did) or....**
2. **the researcher may conclude erroneously that the independent variable had no effect on the dependent variable when it really <u>did</u> (the extraneous variable influenced the dependent variable in such a way to counteract the changes the independent variable made)**

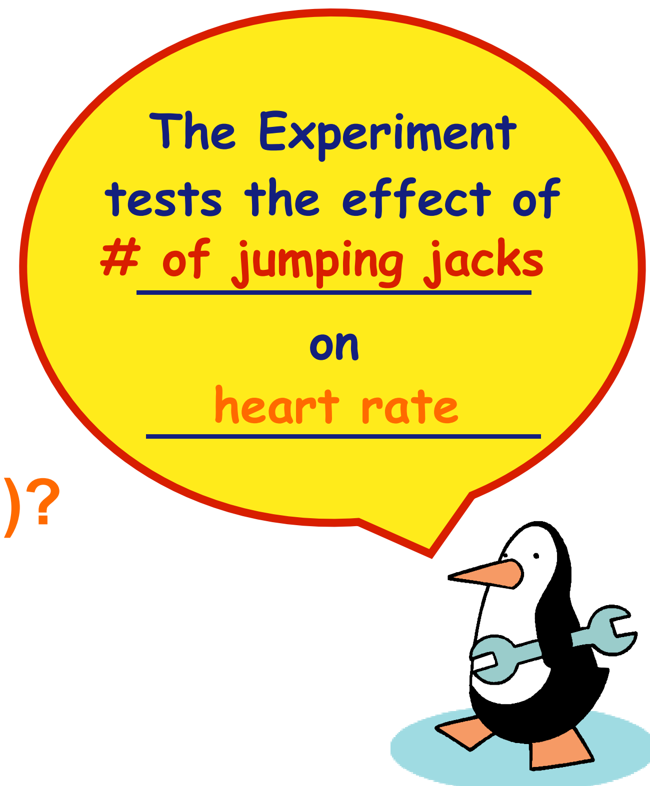
Examples of experiments 1

- How does fertilizer affect the growth rate of plants?
  - we set up an experiment testing different amounts of fertilizer on different plants & measuring the growth rate of the plants:
    - dependent variable (Y-axis)?
      - growth rate of plants
    - independent variable (X-axis)?
      - amount of fertilizer



Examples of experiments 2

- How does exercise affect heart rate of 10th grade student?
  - we set up an experiment testing the number of jumping jacks on the heart rate of students:
    - dependent variable (Y-axis)?
      - heart rate
    - independent variable (X-axis)?
      - minutes of exercise



Controlled Experiments

Suppose you were testing the effects of a drug. You believe that this medication will lower blood pressure. **You have your experimental group take the drug and measure their blood pressure before taking the medication as well after and blood pressure decreased.**

- **Did the blood pressure decrease of the medication and no other variable? Are you sure?**
  - **Might there be other variables that caused the decrease?**

What about the <u>Placebo Effect</u>? What if by being given a pill with medication in it, the subject psychologically <u>believed</u> their blood pressure should decrease and so they relax mentally causing their blood pressure to decrease but <u>not</u> because of the drug itself, only because of their own <u>psychological expectation</u>.

Controlled Experiments

One way to identify the effects specifically of the drug is to divide the subjects being tested into two groups.

- Scientists will try to control extraneous variables in both groups to keep the subjects and the environment as identical as possible
  - Subjects will be selected of the same age rage
  - Subjects will be selected who all have similarly healthy profiles
  - Subjects will be randomly assigned to both groups (that way both groups will contain subjects with similar variation in initial blood pressures - one group will not start out with subjects that have on average higher blood pressure than the other already)
  - Subjects will be held in a rooms with the same temperature
  - Researchers will read the same script of instructions
  - Subjects will be given pills that have the same shape and color (that way one group will not know they got the drug while the other one knows they did not)
  - Drug will be taken by subjects at the same time of the day.

Controlled Experiments

- Between the two groups:
  - One group gets a certain manipulated treatment level (level of the independent variable) and the other group gets either no treatment or the level of the independent variable that would occur naturally
    - In this experiment: Only one group will be given a pill that actually contains the drug while the other group gets a fake pill that looks the same but has no medicine in it!!!
      - The blood pressure (dependent variable) can be checked in the group receiving the manipulated treatment level (experimental group) and the group that does not receive the manipulated variable (control group).
        - The effects of the drug is now isolated since, though both groups take a pill, the medication is the *ONLY* variable that *differs* between the two groups.
          - If I see a difference in blood pressure between groups, it can only be because one group got medication.

Controlled Experiments

- Ideally experiments are made up of an experimental and a control group that <u>differ in only 1 factor</u>.
  - This factor is the variable the experiment is designed to <u>test</u> the effects of on the dependent variable measured.
    - The control group does <u>not</u> receive the manipulated variable.
- <u>Control group:</u> The group of subjects that is not manipulated.
  - The data from the control group can now be <u>compared</u> to the experimental group's data to see if the independent variable (level of treatment) influenced the dependent variable data as predicted or not.
- <u>Experimental group:</u> The group being treated or otherwise manipulated *(aka <u>treatment</u> group).*
  - This group is identical to the control group <u>EXCEPT</u> that it is manipulated.
    - It receives a certain level <u>treatment</u>.

Controlled Experiments

To test the effect excessive water drinking has on humans.

<u>Experimental Group:</u> Make a group of people drink a lot of water.

Based on the <u>effects</u> they display you might be inclined to <u>attribute to excessive water drinking</u>.

<u>HOWEVER</u>, how do you know that all the symptoms they display are from drinking lots of water?

Controlled Experiments

Maybe some of the symptoms they display are totally unrelated to water and are the result of some other factor
(like being together in an isolated group or being exposed to UV light if they are standing outside)

Therefore, in order to separate excessive water symptoms from other symptoms you gather a second group of people together and place them in exactly the same environment as the first group EXCEPT you do not give them excess water.

This latter group is your control group.

You can now be more confident in claiming that the differences in the dependent variable that you measured between your experimental group and your control group are due solely to excess water.

Another example of a controlled experiment…

<u>Hypothesis</u>: Plants will grow taller when given Miracle Grow.

Plants divided into groups A & B are given the same amount of light, water, and are stored at the same temperature.

Plants A are given Miracle Grow. Plants B aren't.

All the variables are kept constant except the one you are testing.

Another example of a controlled experiment…

Plants A & B are both given the same amount of light, water, and are stored at the same temperature. Plant A is given Miracle Grow.

Independent Variable - the factor you change, what you do to your exp. group.

- **What is the Independent variable?**
  - **Miracle Grow**

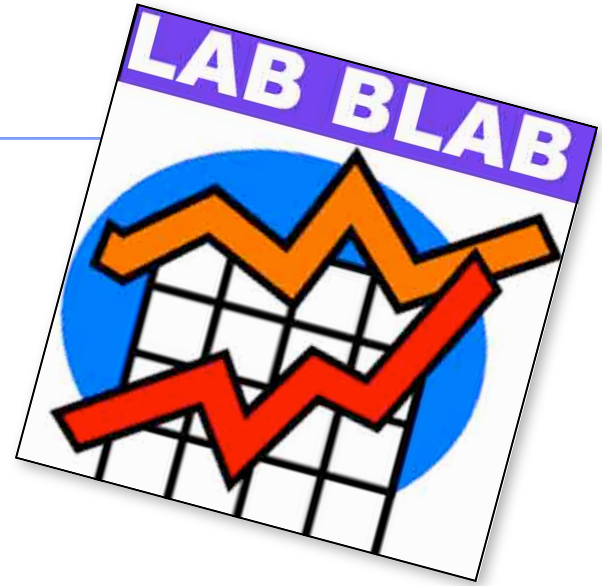
Dependent Variable - what happens as a result of that treatment, what you are measuring

- **What is the dependent Variable?**
  - **Height of the plant**

Necessity of a Control

Controls are needed to <u>eliminate alternate explanations</u> for the experimental results ***(changes in the dependent variable)*** **obtained.**

Types of Research & Graphing Your Data

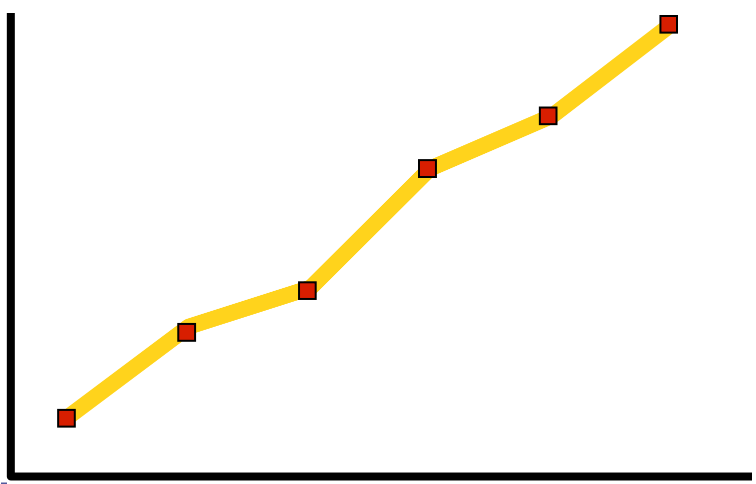


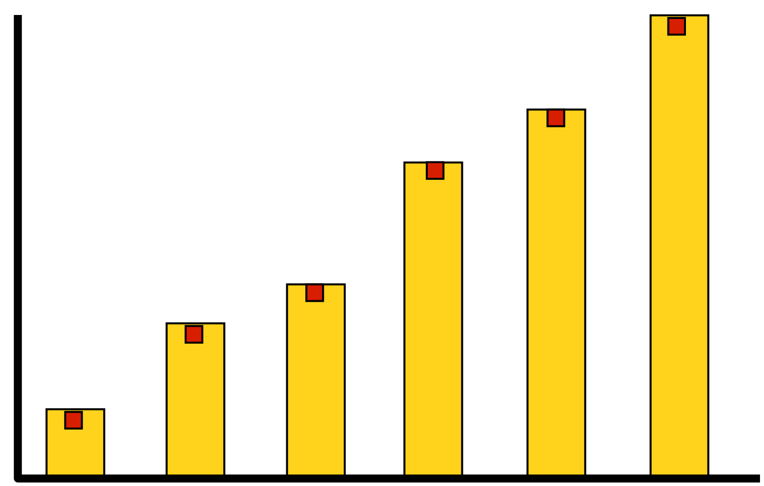
Graphs can show patterns & trends

A picture is worth a thousand words!

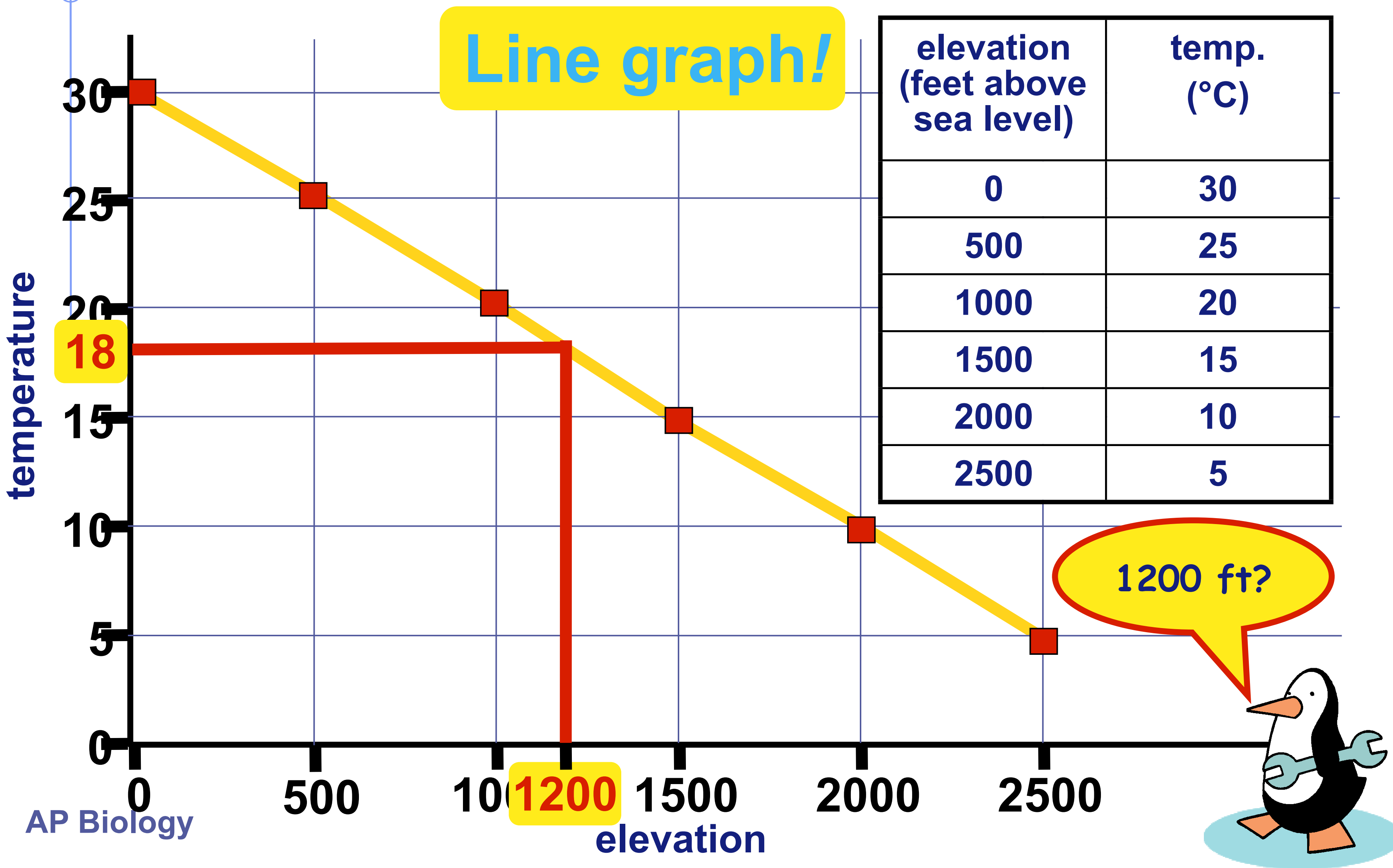
Making pictures out of data

- A scientist carefully collects and organizes data from the experiment often in tables or graphs.
- Graphs Examples:
  - line graphs
    - graphing data that shows continuous change
  - bar graphs (or histograms)
    - graphing data that is in disconnected groups



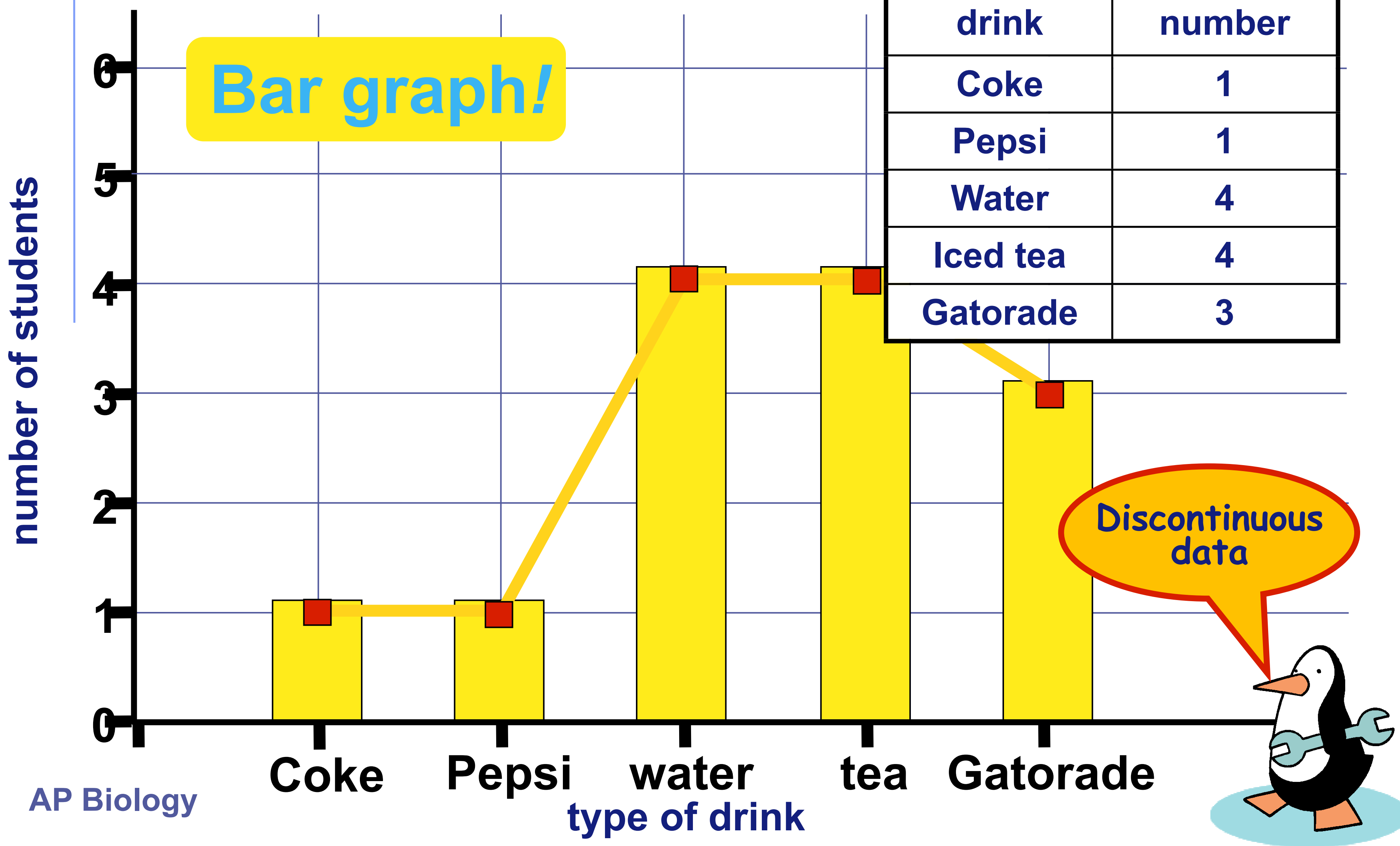


How does elevation affect temperature?



elevation (feet above sea level)	temp. (°C)
0	30
500	25
1000	20
1500	15
2000	10
2500	5

Which drink do you like best?



drink	number
Coke	1
Pepsi	1
Water	4
Iced tea	4
Gatorade	3

Collecting & Graphing Data

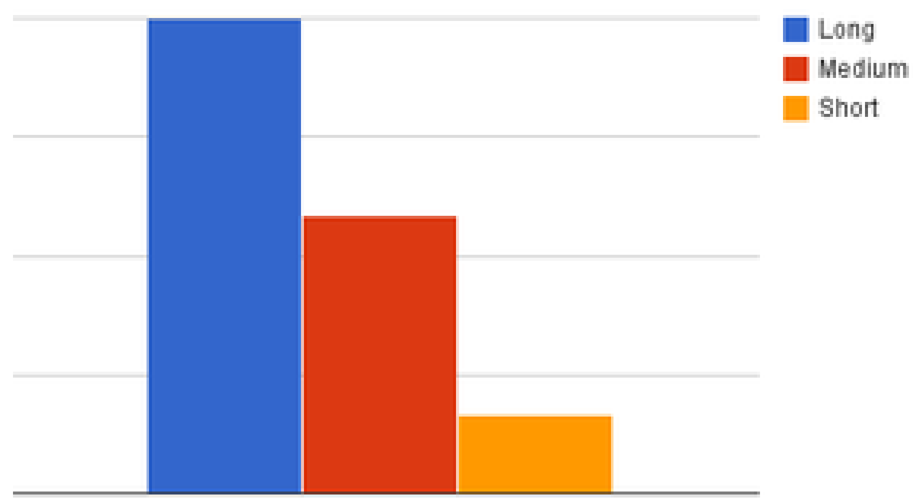
- <u>Collecting Data</u>
  - The graph you choose depends on the data and what you want to illustrate/show.

Data can be powerfully displayed as a graph

- Based on the data, a scientist determines whether the hypothesis was supported or refuted.
- In science, every conclusion must assume that the conclusion is only "true to the best of our knowledge" not proven.

LABEL LABEL LABEL

- **<u>What labels are needed?</u>**
  1. **Title** ***(The effect of Independent Variable on Dependent Variable)***
  2. **Label X-Axis - Independent Variable**
  3. **Label Y-Axis - Dependent Variable**
  4. **Always include units of measurement on x and y axis**
  5. **Include a key (legend) to identify meaning of lines or bars**
  6. **Make sure there is even spacing in x and y unit increments**



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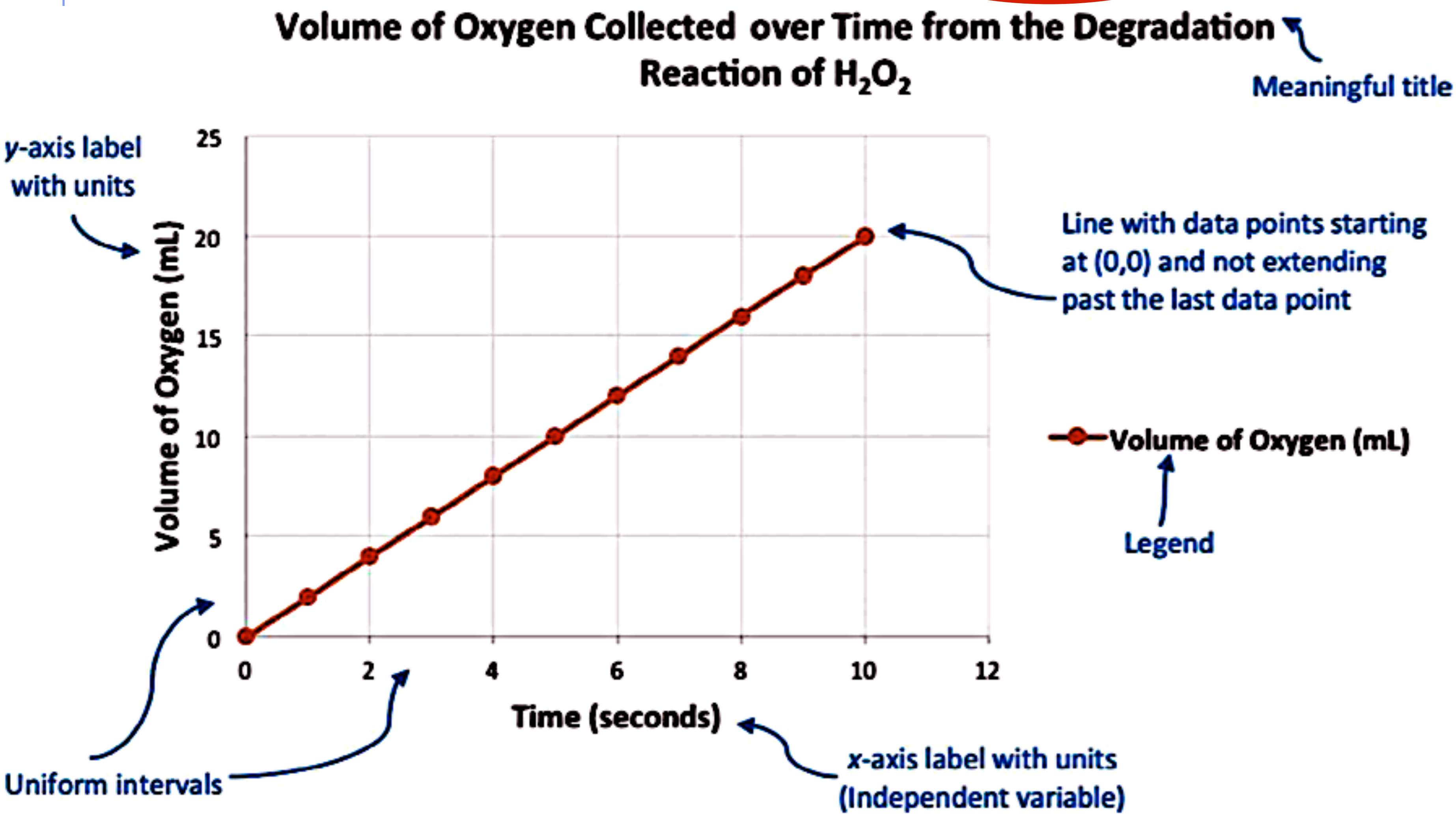


Figure 1.4: Example of an Effective Graph

LABEL LABEL LABEL

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

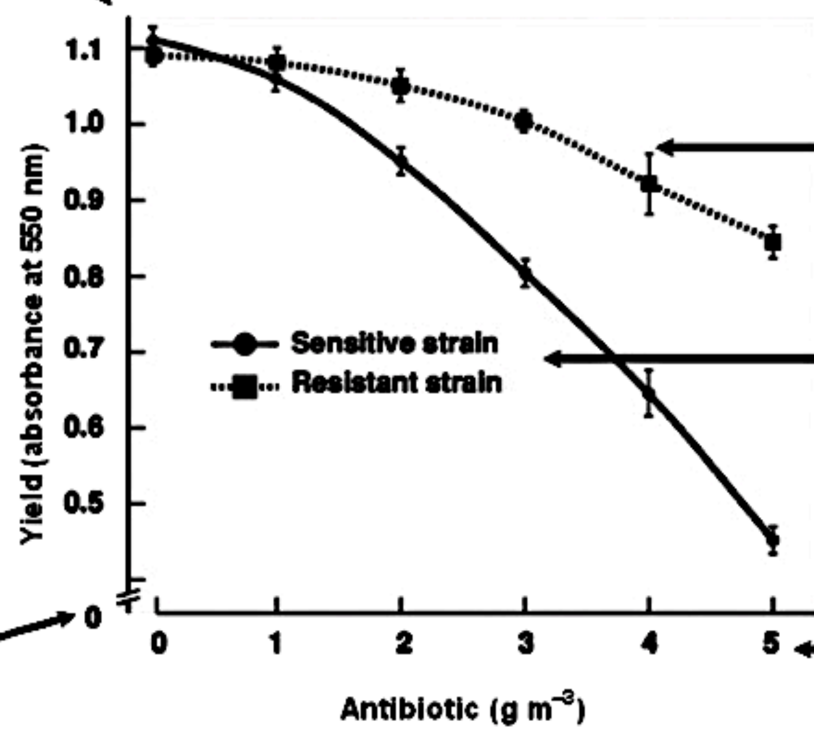
Plot points accurately. Different responses can be distinguished using different symbols, lines or bar colors.

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.

Evidence & Hypothesis in Science

- Unconfirmed observations filling supermarket tabloids would have believe that some of your classmates are alien hybrids from space.

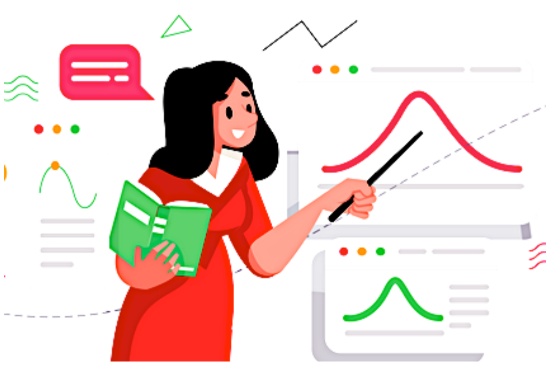
  - Most people, especially if they understand science, do not find the eyewitness accounts and computer-rigged photos to be convincing evidence.
- But judgments are harder when you read well-designed ads for a food supplement, testimony from "experts," impressive graphs or quotes.
  - To avoid wasting money and endangering your health, you need to know how to judge the quality of the evidence

Evidence & Hypothesis in Science

- Evidence is the information upon which inferences are based.
  - In science, evidence consists of a collected body of data from observations and experiments.
    - And such evidence becomes convincing scientists until the observations and experiments have been repeated multiple times with similar results.
      - Repeatability is a hallmark of scientific evidence.
- What Makes a Hypothesis Scientific?
  - Magazines and television programs have no shortage of hypotheses that are claimed to be scientific.
    - Scientific hypothesis can be or have been tested

Evidence & Hypothesis in Science

- In science, the only hypotheses that count are those that meet this standard of testability.
  - You saw this process at work in both the flashlight.
    - Each hypothesis led to a prediction that could be tested in an experiment.
    - Each experiment could also either support or contradict the hypotheses.
  - In contrast, try to think of a way to test the hypothesis that invisible "space aliens" were fooling with your flashlight.
    - How could you show that such an idea is false?

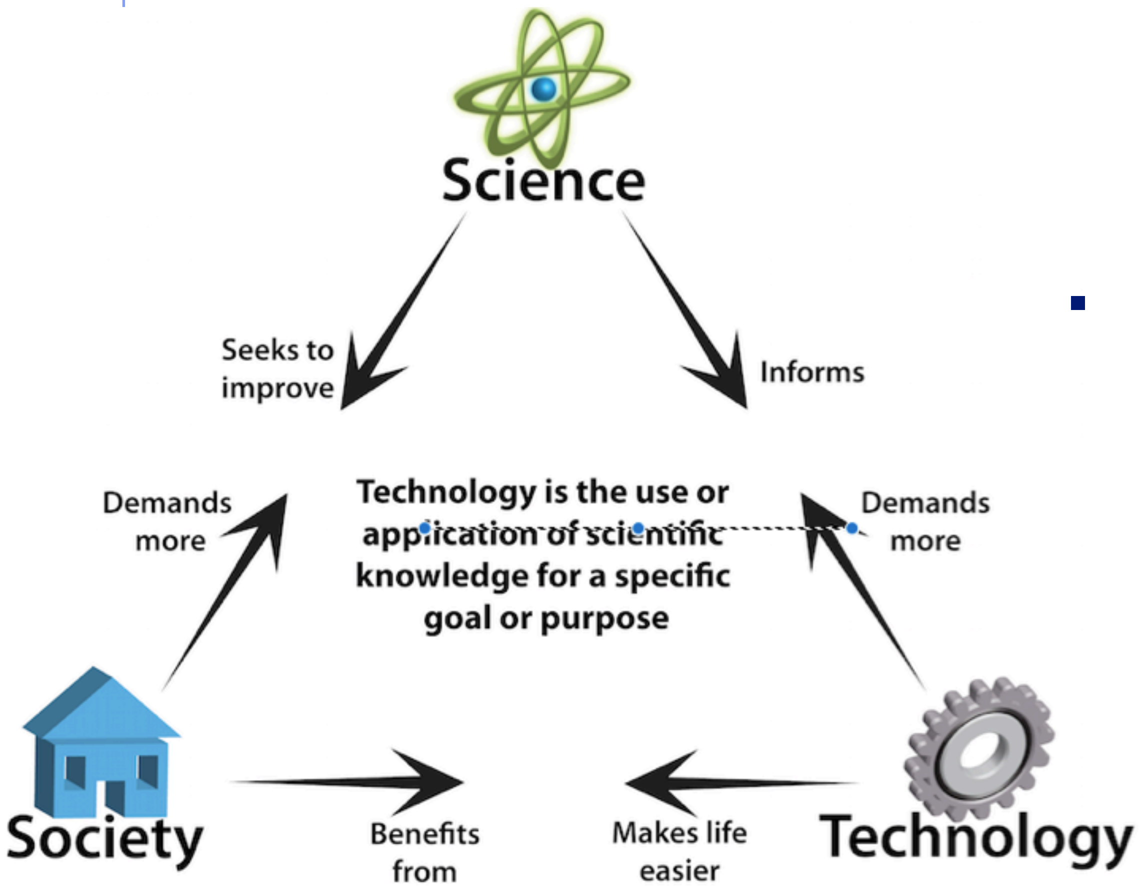


A scientific hypothesis must be falsifiable

- There must be some observation or experiment that could reveal if such a hypothesis is false.

Hypothesis Can Be Revised Over Time

- **Even hypotheses that stand up to repeated testing may later be revised or even rejected.**
  - **One way such change occurs is when new research tools, new technology, make new kinds of observations and experiments possible so new or better data can be collected.**

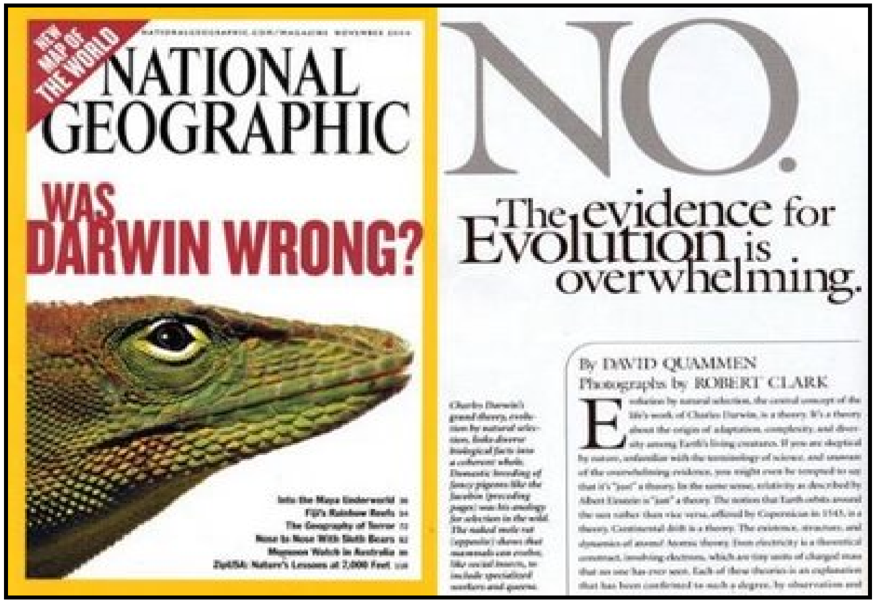


  - **Ex: A few decades ago, most biologists accepted the hypothesis that fungi are closely related to plants. The evidence included some similarities in structure, growth pattern, and reproduction.**
    - **That hypothesis has been challenged by new methods that make it possible to analyze and compare the DNA of diverse organisms.**

Theories in Science

A hypothesis gains credibility by surviving repeated attempts to falsify it while testing eliminates (falsifies) alternative hypotheses.

- A THEORY:
  - supported by a large body of evidence in comparison to a hypothesis
  - broader in scope than hypothesis
  - more general than a hypothesis.



- A theory is an explanation for natural events that is based on a large number of observations.

Theories in Science

- Theories **EXPLAIN** what we observe.
  - Ex: the Germ Theory explains why we get sick and why we get infections - it uses observation of viruses and bacteria as well as data from those who get ill to create a theory on what causes the illness.

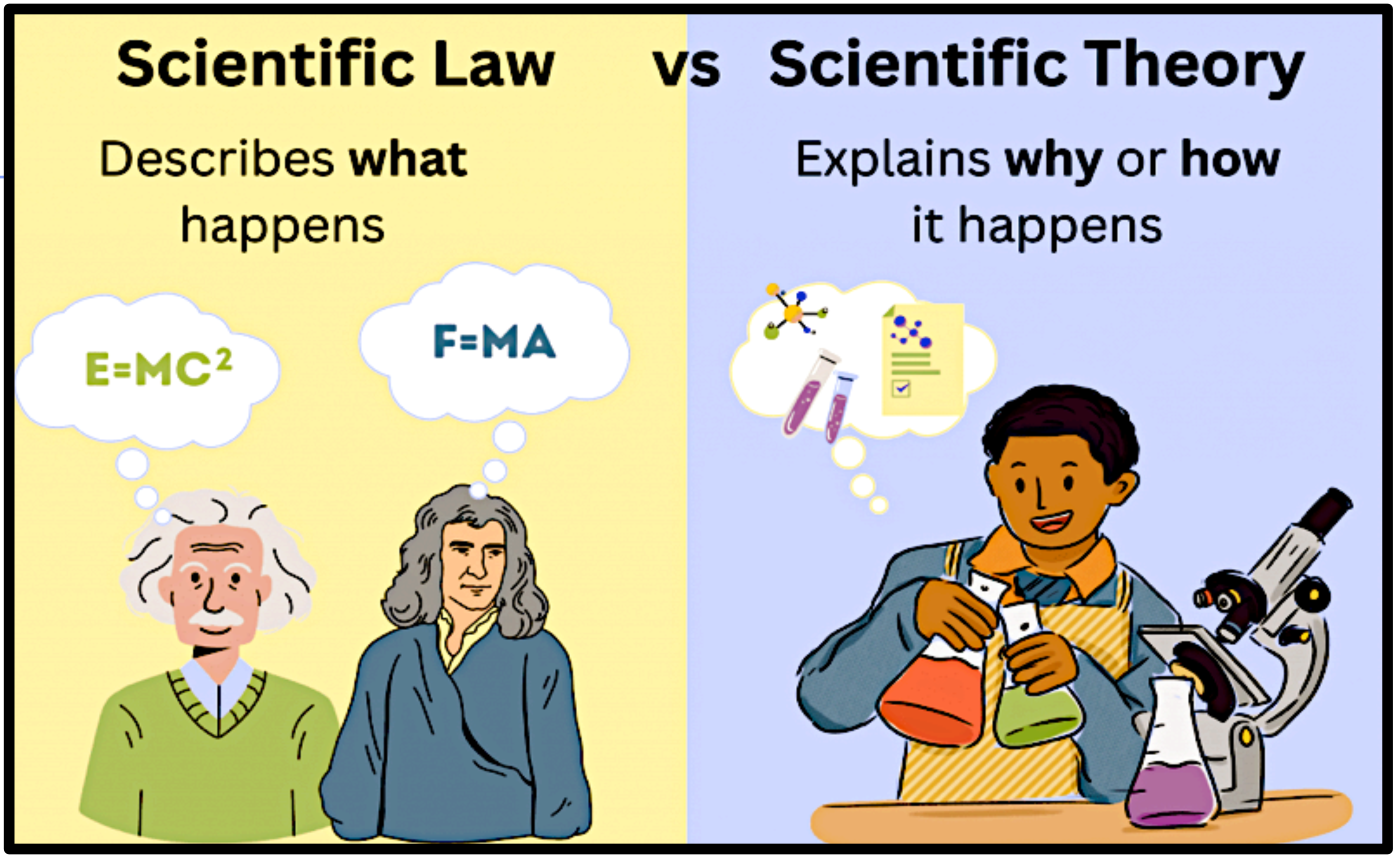
Theories in Science

- In science, a theory is a well-tested explanation that makes sense of a great variety of scientific observations.
  - Scientific theories in turn give rise to many mew hypotheses that can be tested.
    - This definition contrasts with the everyday use of word theory, which people use to mean "a speculation" like when people say: *"It's only a theory."*
  - Compared to a hypothesis, a theory is much broader in scope.
    - Hypothesis: "Mimicking poisonous snakes is an adaptation that protects nonpoisonous snakes from predators."
    - Theory: "Adaptations such as mimicry evolve by natural selection."
      - The theory of natural selection explains the evolution of the many cases of mimicry, as well as a variety of other adaptations of organisms to their environments.
- If new evidence that contradicts a theory is uncovered, scientists first verify the evidence many times. They then modify or discard the theory accordingly.

Credibility in Science

- Theories are changeable, expandable, and **FALSIFIABLE**. There must be some way that an observation or experiment could prove it to be false *(if it is a wrong explanation).*
  - Ex: Einstein's theory of Relativity made predictions about the results of experiments, which could have produced results that contradicted Einstein, so the theory was (and still is) falsifiable
  - Ex: The theory that ``the moon is populated by little green men who will hide whenever anyone on Earth looks for them'' is not falsifiable: *these green men are designed so that no one can ever see them.*
  - The theory that there are no little green men on the moon is scientific: *you can disprove it by catching one.*

1. Theories must explain a wide range of observations
2. Theories must be falsifiable
3. Theories can be changed if new evidence presents itself



A scientific law is a statement or mathematical equation that describes or predicts a natural phenomenon.

- Laws do not explain why or how a phenomenon occurs (unlike theories and hypotheses).
  - Another name for a scientific law is a law of nature or law of science.
    - Ex: Law of conservation of mass; law of conservation of energy; Newton's universal law of gravitation; Newton's laws of motion
- All scientific laws are based on empirical evidence and the scientific method.

Are there Limitations to what Science can Study?

- Science requires repeatable observations and testable hypotheses that are falsifiable if the explanation is incorrect.
    - These standards restrict science to searching for explanation based on natural laws for natural phenomena.
        - For example, science can neither verify or disprove that supernatural forces cause phenomenon witnessed in nature.
            - Supernatural explanations of natural events are simply outside the bounds of science.
        - For example, science cannot determine which ethical stance is good or bad
            - Science is not useful for making moral judgements
        - Science doesn't tell you *how* to use scientific knowledge

Are there Limitations to what Science can Study?

Science seeks natural explains for natural phenomena.

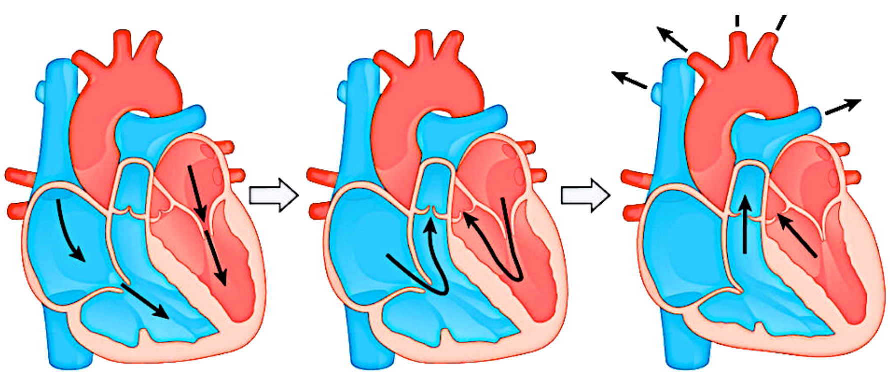
- ★ Science is systematic method of investigation that uses observation, hypothesis-testing, measurement, experimentation, analysis, logical arguments and theory building to more adequately explain natural phenomenon.

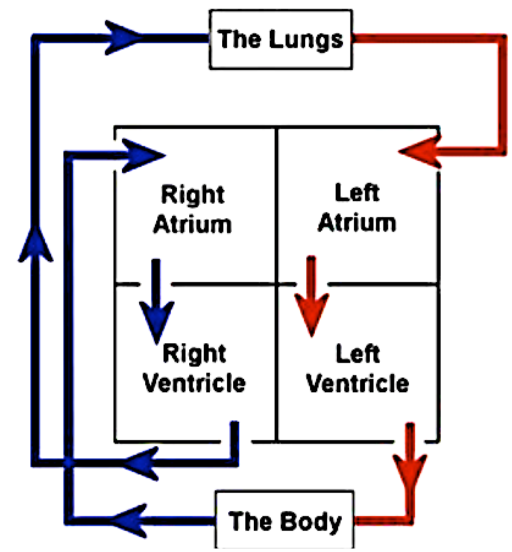
- ➡ Observations and experimental results must be REPEATABLE *(A sighting of the Virgin Mary cannot be repeated at will)*

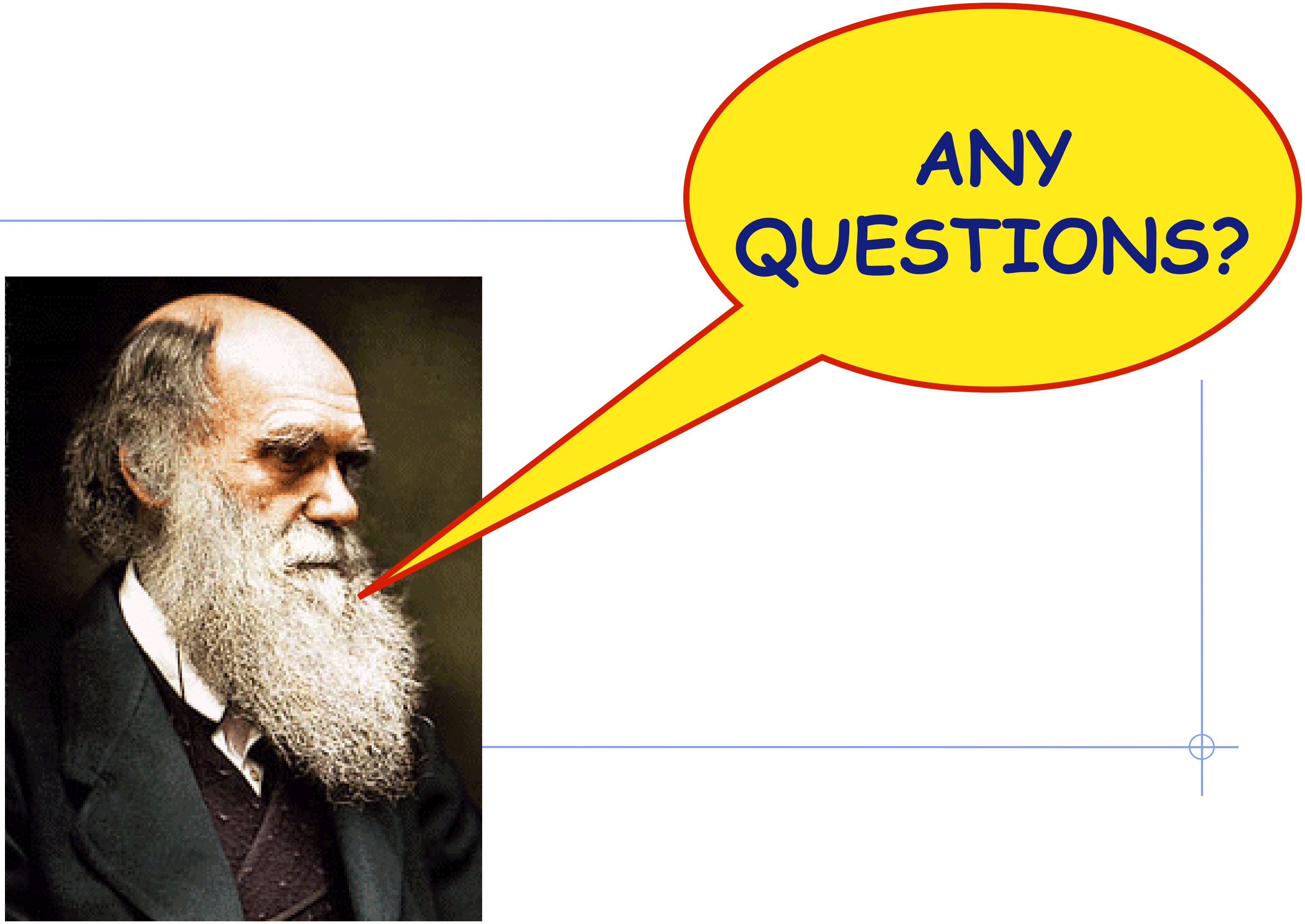
- ➡ Hypothesis must be TESTABLE & thus FALSIFYABLE if those explanations NOT true. *(What experiment could ever be done to falsify the existence of unicorns?)*

The Use of Models in Science

- Have you ever drawn a simple map for a friend who needed directions to your home? If so, you created a model.
- <u>Models</u> are physical, mental, or mathematical representations of how people understand a process or an idea.
  - Models can be very useful tools of scientific thinking.
    - Models describe or explain a process or structure.
  - A model can take the form of a diagram, graph, three-dimensional object, computer program, mathematical equation, flow chart, written description.
    - Ex: Two different models representing blood flow through the human heart.



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QUESTIONS?