

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 following the “**Scientific Method.**” However, science is less rigidly structured than many realize.

All hypothesis-based science does have in common is ...

THE HYPOTHESIS

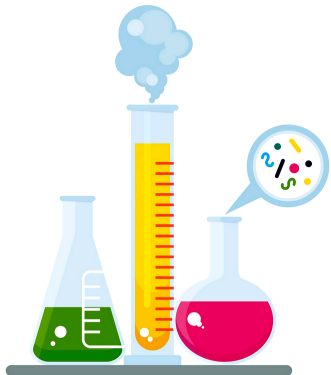


Experimental Research Involves Conducting Experiments



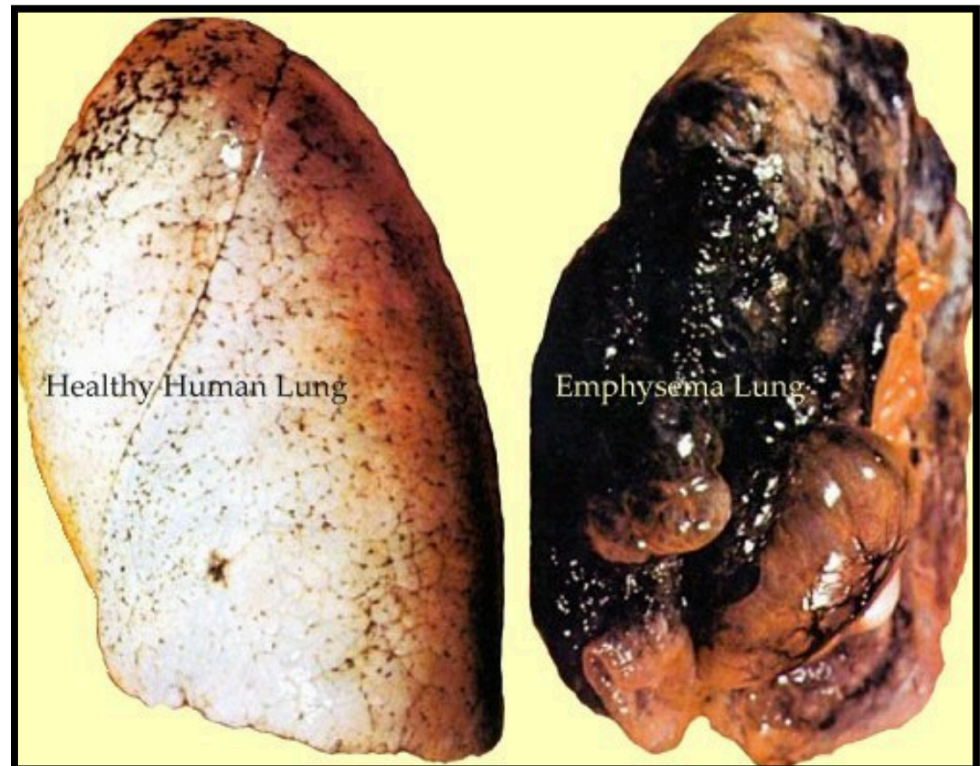
■ Experimental Science (Hypothesis-based Science)

- ◆ **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** (it is **NOT** just an “educated guess”)
 - ◆ A hypothesis is a testable statement that **explains** the **cause and effect 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** (**hypothesis**) for the relationship between the treatment and the effect 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.

Types of Research

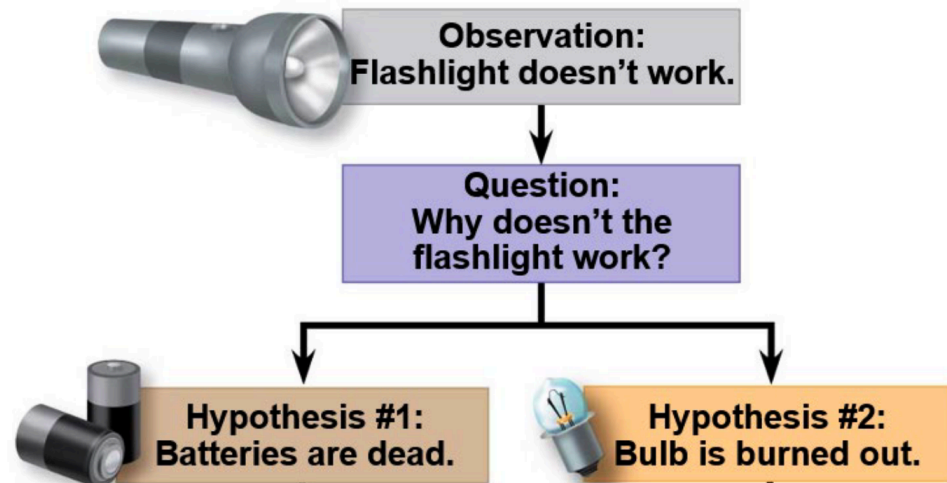
◆ Basics of a possible Experimental Study

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.

Hypothesis-Based (Experimental) 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.



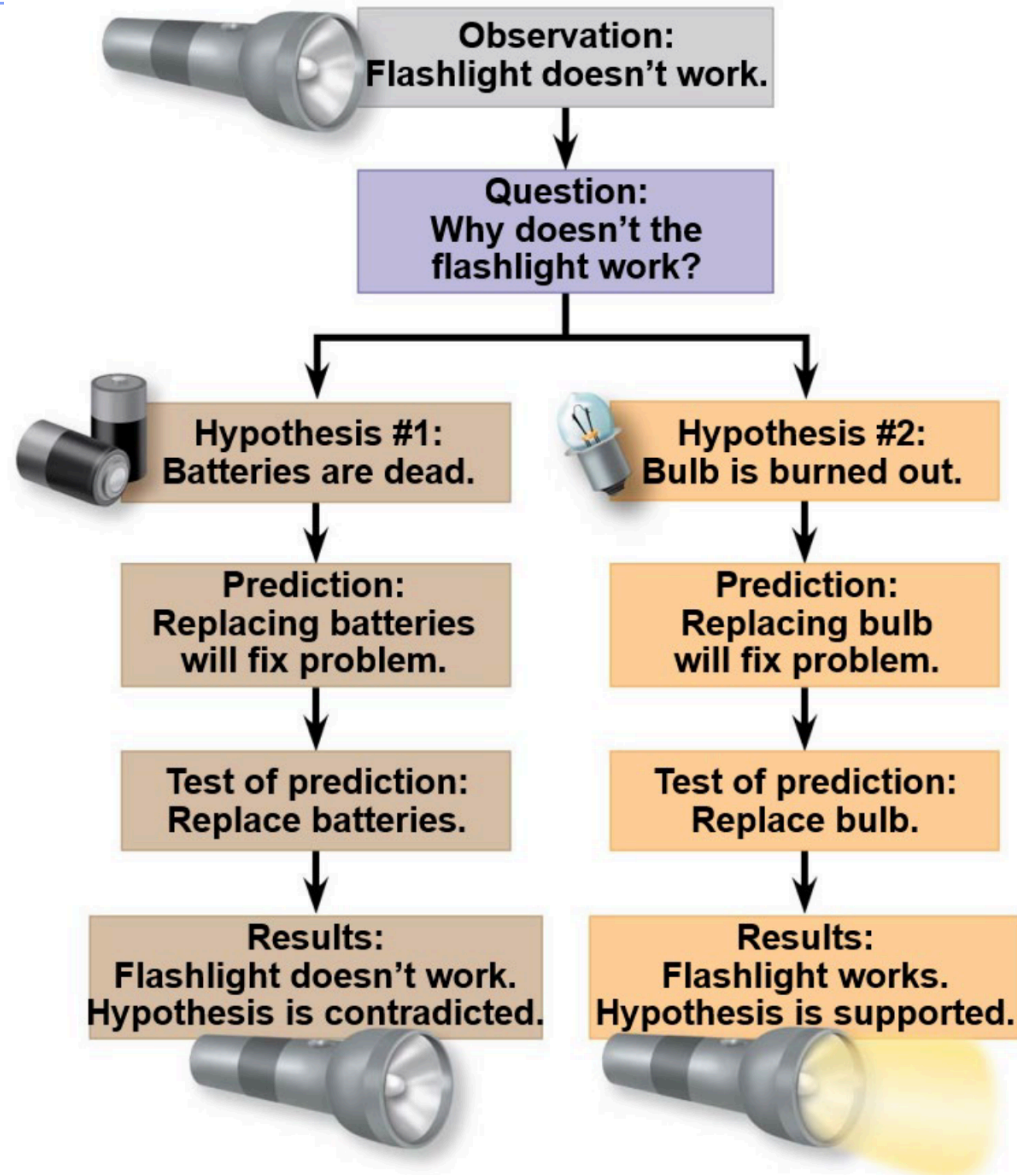
- these can be supported by collecting and analyzing data through observation (Discovery Science) but, even better, ..
- ◆ A scientific hypothesis leads to predictions that can be tested engaging in experimentation (Experimental Science)



A hypothesis MUST be testable & falsifiable.

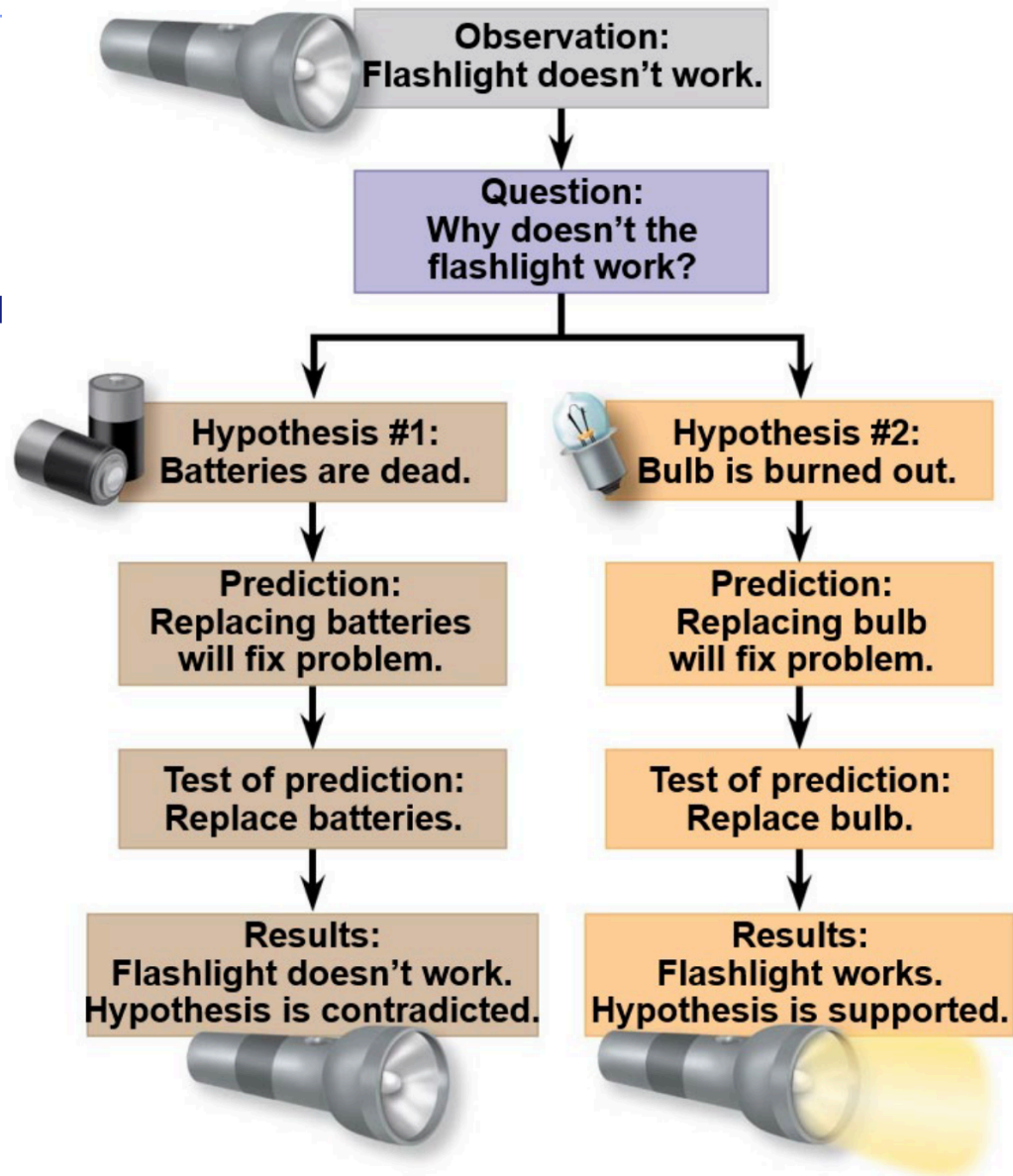
✓ There must be some way to check the validity of the explanation (hypothesis).

✓ *IF* the proposed explanation (hypothesis) is incorrect, then there must exist some observation or experiment that could reveal that this explanation is actually NOT true.

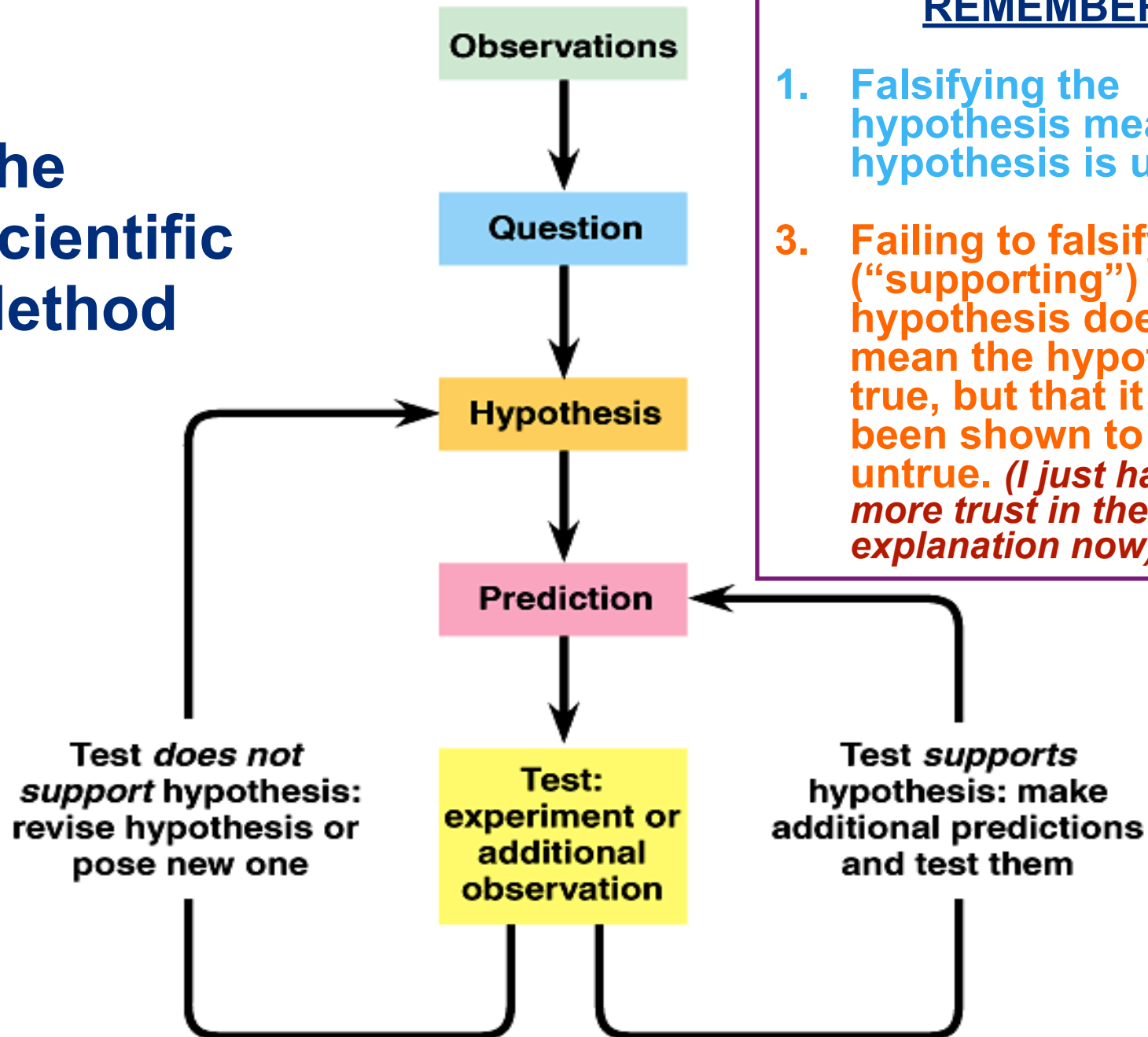


FAILURE TO FALSIFY A HYPOTHESIS DOES NOT PROVE THAT HYPOTHESIS!!!

- 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.
3. 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.



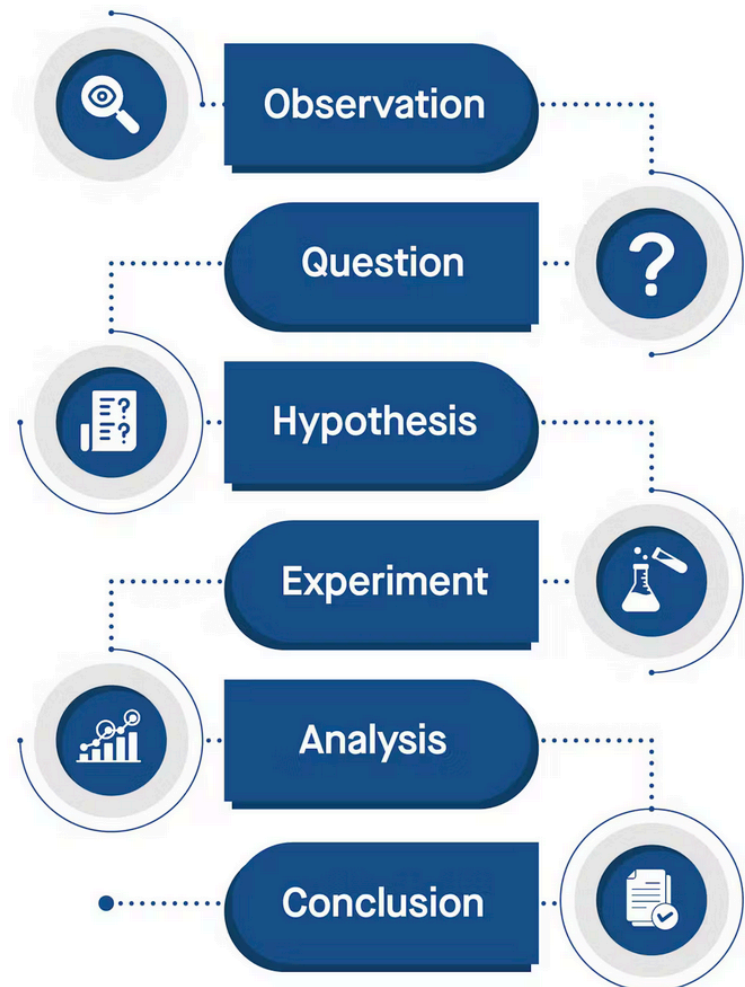
The Scientific Method - Review

When following the Scientific Method, hypotheses are proven or not proven wrong!

*Hypothesis are **NEVER** proven right.*

Evidence only supports (gives validity to) a given hypothesis (explanation).

SCIENTIFIC METHOD



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

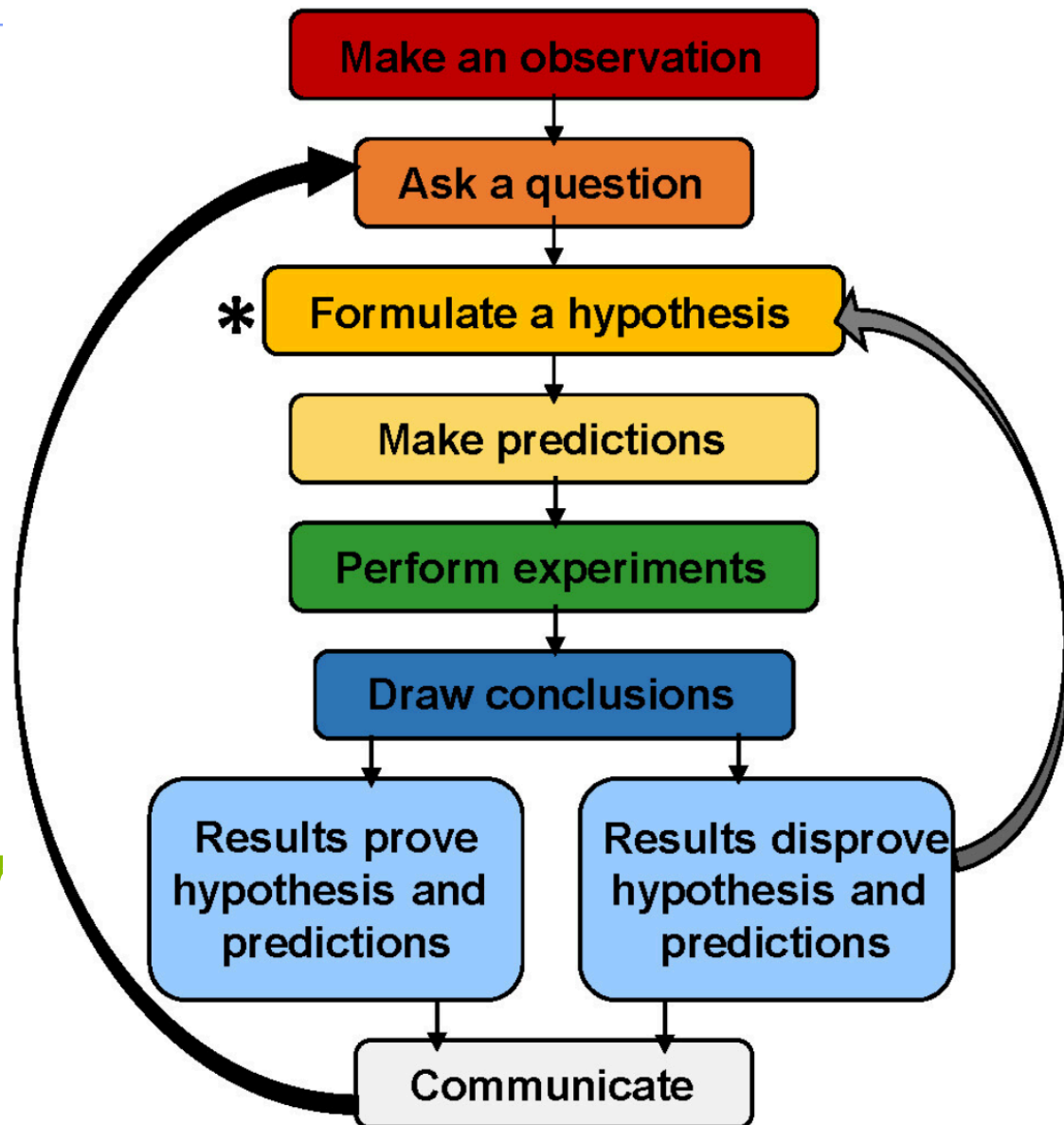
1. Plants will grow taller when given Miracle Grow.
2. Girls will score higher on math tests than boys.
3. Hermit crabs choose colorful shells over drab shells.

Bad

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 prediction is an expected outcome.
- A hypothesis is then tested by experimentation: *a planned procedure designed to test the hypothesis.*



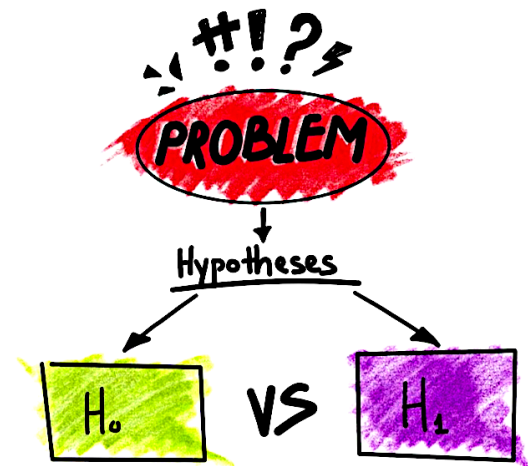
Elaboration on Hypotheses



- ◆ 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 a cause and effect or correlational relationship between two variables*) is the null hypothesis.
 - ◆ H_0 or H_0
 - ◆ This explanation states that “X has NO effect on Y”
 - ◆ H_0 represent the claim which is either very well-established or the default state of the claim in the real world in which there is no already established relationship between 2 variables.
- ◆ The explanation that there IS a relationship between two variables then is the alternative hypothesis
 - ◆ H_A or H_1
 - ◆ “That X has an effect on Y”
 - ◆ H_A represents the new claim that needs to be established before being considered valid.



HYPOTHESIS

A hypothesis is a tentative statement or explanation that proposes a possible relationship between variables and is subject to testing and verification.

OVERVIEW

A hypothesis is a testable prediction that seeks to explain a phenomenon or make a statement about the relationship between variables. It is formulated based on prior knowledge, observations, or theories. Hypotheses serve as a starting point for scientific investigation, and their validity is assessed through empirical evidence.

EXAMPLES

Null Hypothesis: The null hypothesis is a statement that suggests **no** significant relationship or effect between variables.

Alternative Hypothesis: The alternative hypothesis is a statement that proposes a specific relationship or effect between variables, challenging the null hypothesis.

Null & Alternative Hypothesis

- ◆ The null hypothesis is often what the researcher tries to disprove, reject or nullify.
 - ◆ **This is the baseline for new claims - 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_0 (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.

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 first before considering an alternate hypothesis/explanation
- ◆ In some studies though, a scientist might hope the H_0 is supported - 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.
 - ◆ The idea behind the scientific method is that researchers have to make an objective (not subjective) determination of which hypothesis is supported or not based only on the evidence/D.V. data recorded.
 - ◆ Data is to be collected through a well-designed experiment and analyzed, with the help of more-objective methods of statistical analyses, to determine if a hypothesis is false or not false, regardless of what a researcher wishes is to be “true.”

NULL HYPOTHESIS EXAMPLES

THE NULL HYPOTHESIS ASSUMES THERE IS NO RELATIONSHIP BETWEEN TWO VARIABLES AND THAT CONTROLLING ONE VARIABLE HAS NO EFFECT ON THE OTHER.



- ◆ **The Null Hypothesis is what gets tested in an experiment.**
 - ◆ It will be falsified or will fail to be falsified depending on experimental results

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.



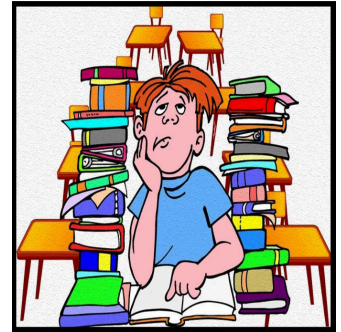
Variables that Help Explain Phenomena

- 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 manipulated 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 treatment levels
 - Treatments (the level of Independent Variable) are administered to subjects by 'level', where level implies amount or magnitude
 - ◆ 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 experiment 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

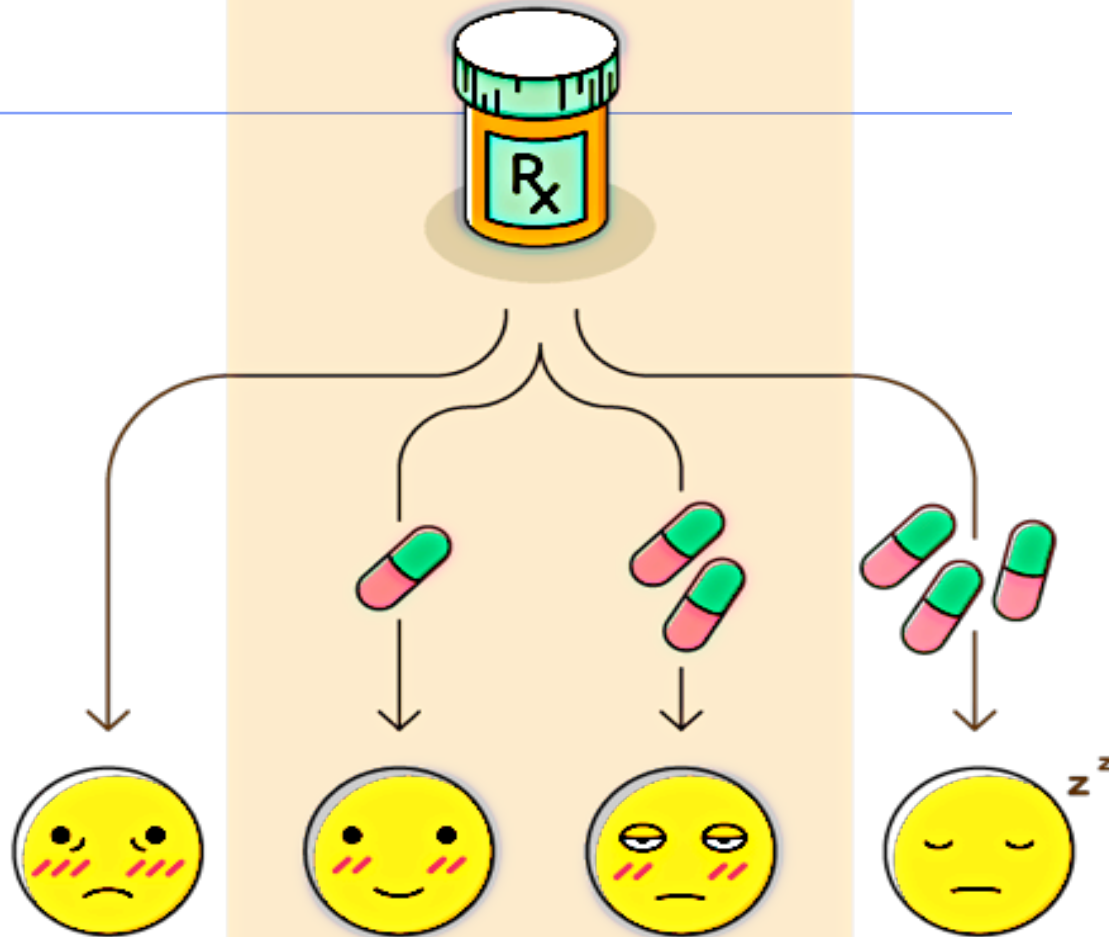
■ Dependent Variable

- ◆ The dependent variable is the variable that is measured by the experimenter.
 - Ex: In our previous example, the calculus test scores collected would be the dependent variable.
- ◆ This is the data we collect 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

Experiments
test the effect of
INDEPENDENT
on
DEPENDENT



**VARIABLE IS MANIPULATED
(INDEPENDENT VARIABLE)**



Experiment testing the effects of histamine levels on drowsiness

General “Formula” For Writing a Hypothesis

A **hypothesis** **EXPLAINS** the effect of the Independent Variable on the Dependent Variable.

- Hypothesis are not questions.
- Hypothesis are composed of a clear explanatory sentence:
“**Altering the independent variable in X way causes the dependent variable to change in Y way.**”
- **Hypothesis are NOT predictions.** Hypothesis are not written as an If...then statement.
 - Predictions are “if...then” statements, and are derived from hypothesis... Given the hypothesis, “**IF I change the I.V. in X way, THEN the D.V. will change in Y ways**”
- While an experiment tests if the prediction is false or not false (valid), indirectly, an experiment is testing the validity of the **hypothesis** from which the prediction was derived

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.

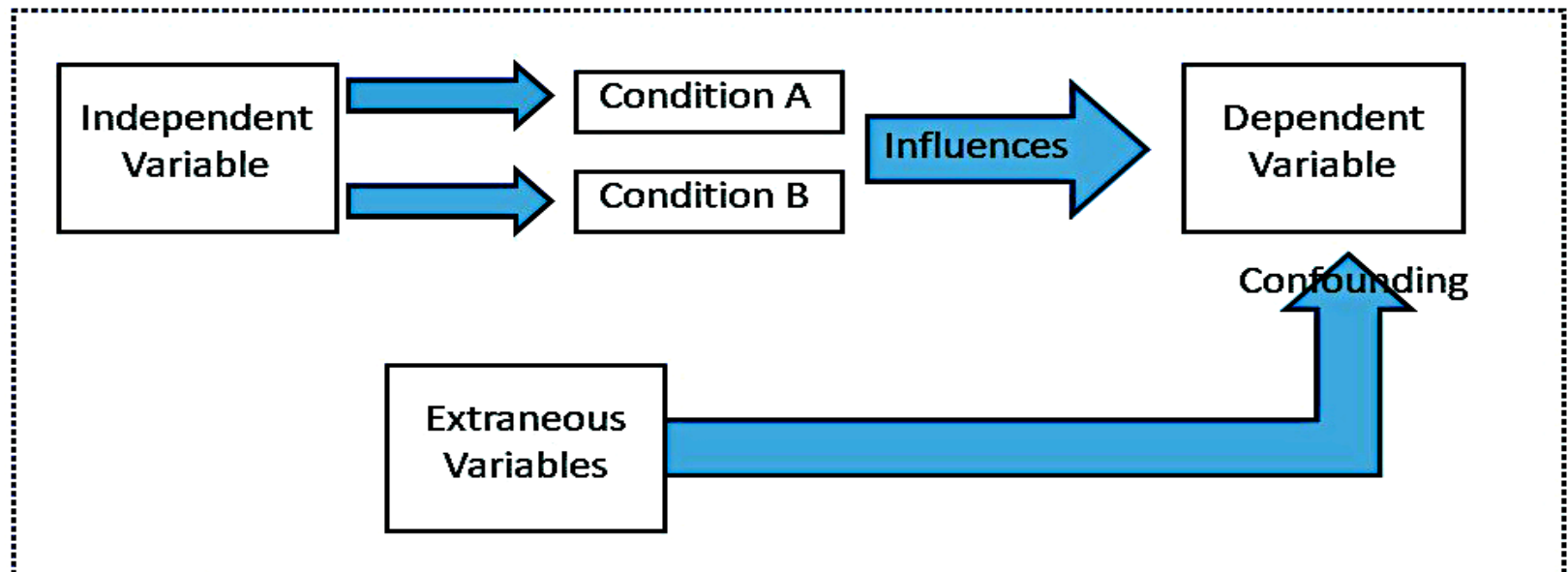
- **Extraneous Variables Exist too**

- 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 in your experiment experience the SAME amount of these variables or experience these variables fluctuating in the SAME way in the experiment !!!!!!!!!!!!!
- ◆ **Controlled variables are called constants if they don't fluctuate over time in your experiment.**
 - 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 in a predetermined way 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 might influence the dependent variable in one group of subjects differently from another group of subjects in an experiment...

Independent Variable

We want to know if the independent variable affects the dependent variable in some way.

Dependent Variable

Extraneous Variable

Unfortunately, an extraneous variable that we're not interested in might also affect the dependent variable in some way.

Consequences of FAILING to Control Extraneous Variables:

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

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

- Which extraneous variables do I need to control? What are my constants? (List ~ 3)

- ◆ Ex: same amount of daily sunlight exposure,

The Experiment
tests the effect of
Amount of Fertilizer
on
Plant Growth Rate



Examples of experiments 2

■ How does exercise affect heart rate of 10th-grade students?

◆ 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

■ **Which extraneous variables do I need to control? What are my constants? (List ~ 3)**

◆ Ex: same amount of daily sunlight exposure,

The Experiment
tests the effect of
of jumping jacks

on

heart rate



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 because of the medication and no other variable? Are you sure?
 - Might there be other variables that caused the decrease?



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

Controlled Experiments

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

- First: Scientists will try to control extraneous variables in both groups to keep the subjects and the environment identical as possible
 - ✓ Subjects will be selected of the same age range
 - ✓ 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

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

Controlled Experiments

To test the effect excessive water drinking has on humans.



Experimental Group: Make a group of people drink a lot of water.

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



HOWEVER, 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...

Hypothesis: 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 (Group)

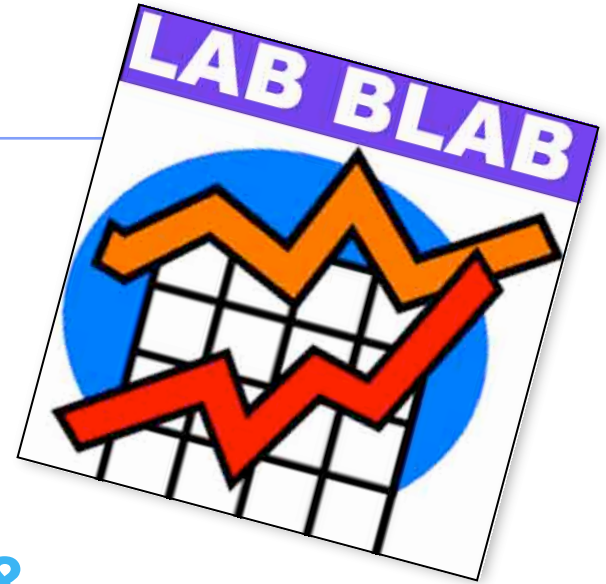
Controls are needed to eliminate alternate explanations for the experimental results obtained.

(I eliminate being able to claim that another variable - besides the I.V. - is the reason for the changes in the D.V. - if any are noted - measured in my experimental group)

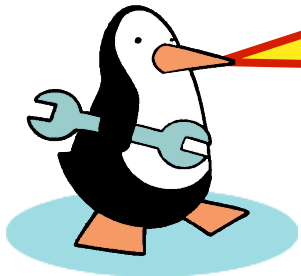


Types of Research & Graphing Your Data

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 to note trends in & summarize the data.

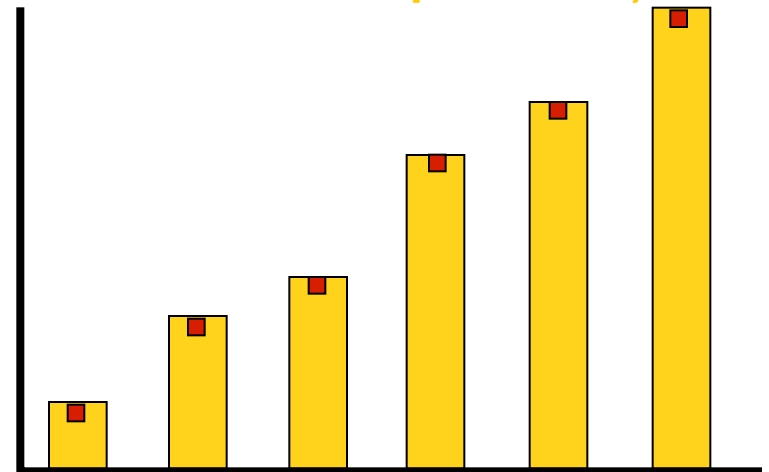
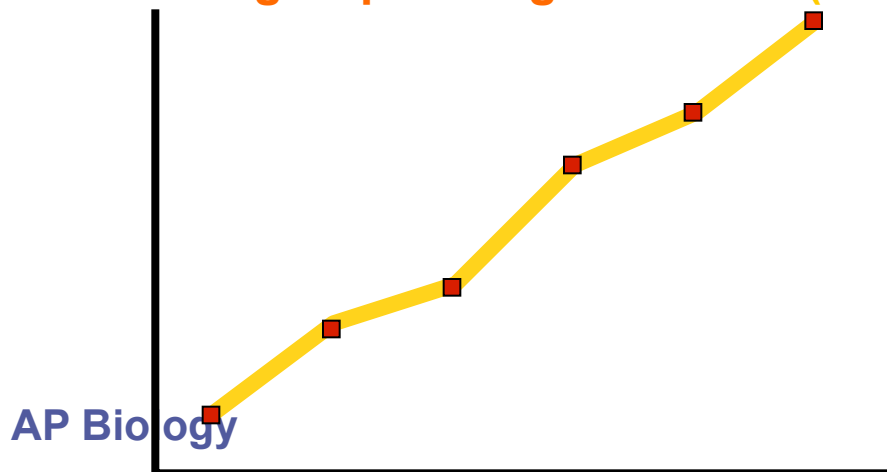
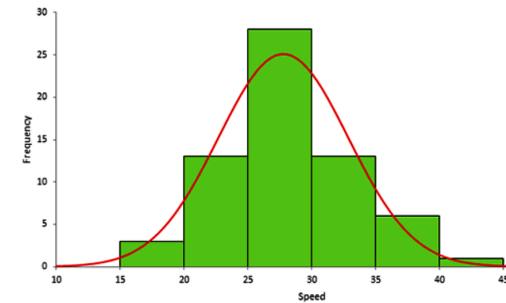
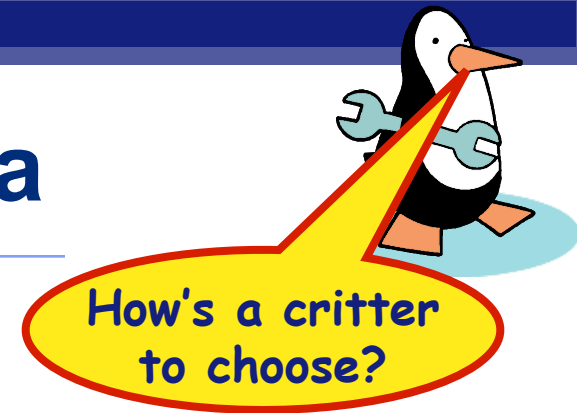
- **Graphs Examples:**

- ◆ line graphs (or histograms: attached bars)

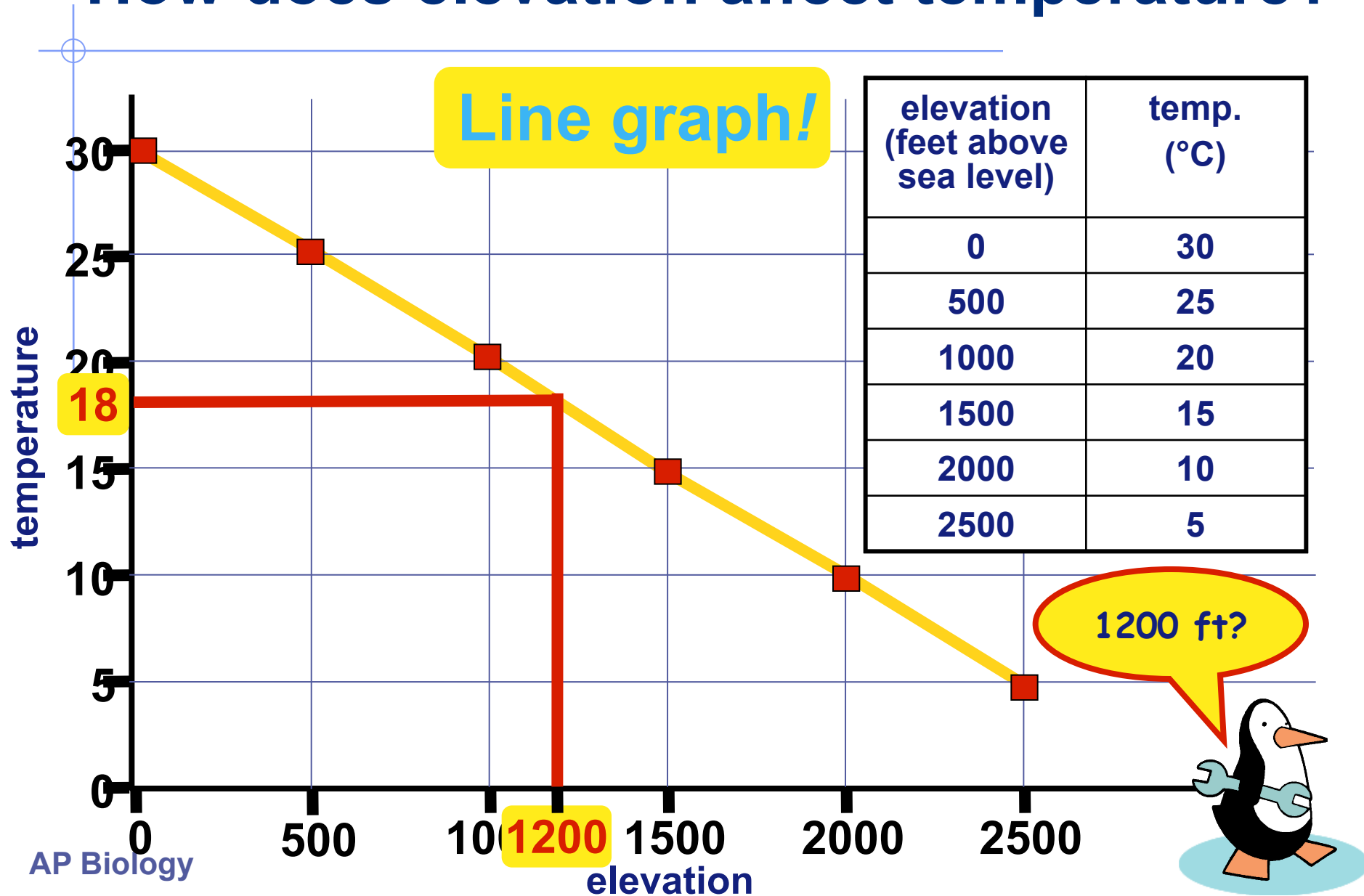
- used when graphing data that shows continuous change along the x-axis (data is numerical)

- ◆ bar graphs

- used when graphing data that is in discontinuous or in disconnected groups along the x-axis (data can be numerical or qualitative)

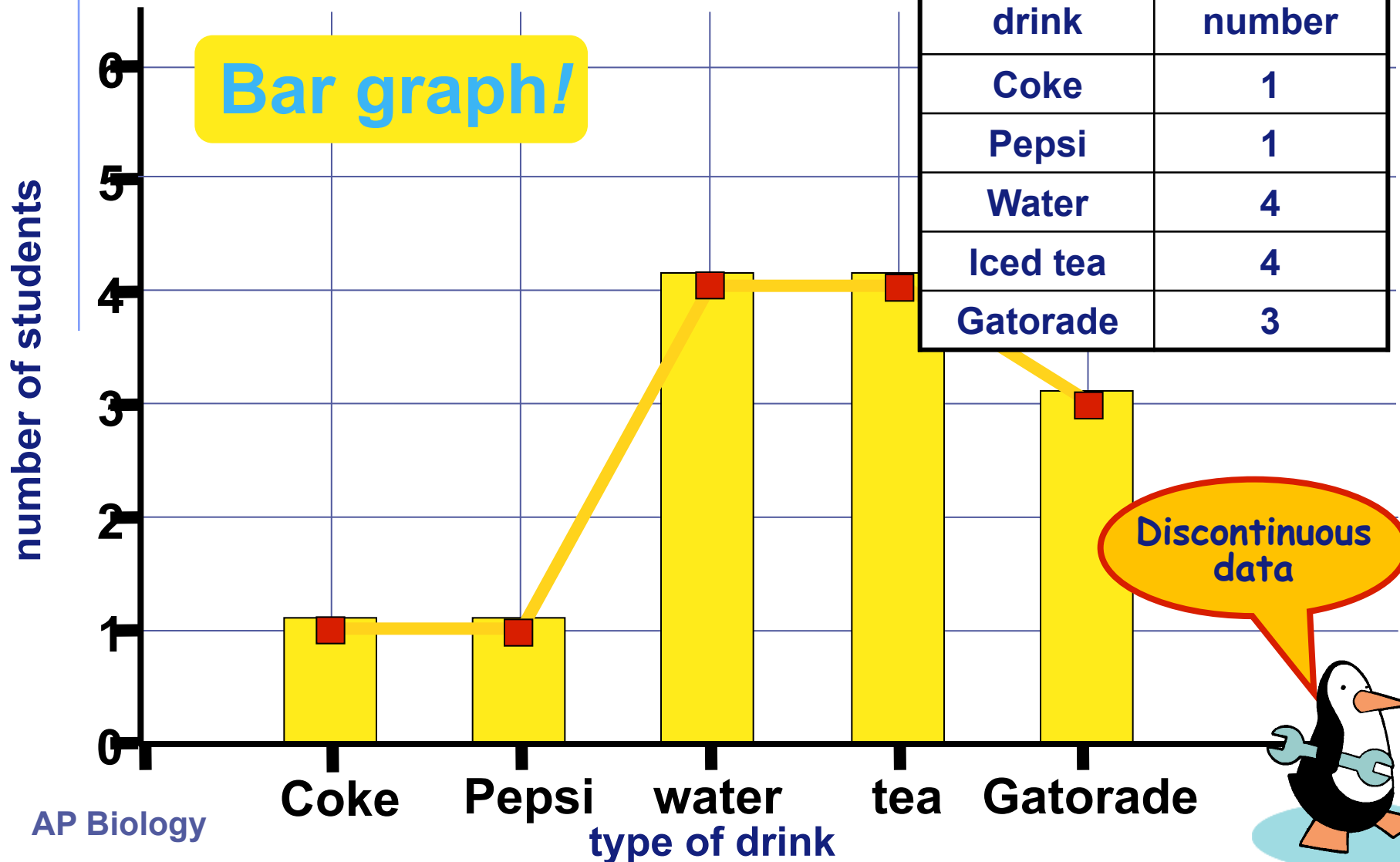


How does elevation affect temperature?



Which drink do you like best?

Bar graph!



Collecting & Graphing Data

■ Collecting Data

- ◆ The graph you choose depends on the data and what you want to illustrate/show.

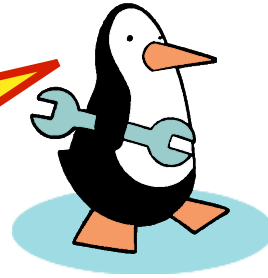
- ◆ Based on the data, a scientist determines whether the hypothesis was supported or refuted.
- ◆ In science, every conclusion must assume that the conclusion is only “true” to the best of our knowledge; supported by data, but not proven.

Data can be powerfully displayed as a graph



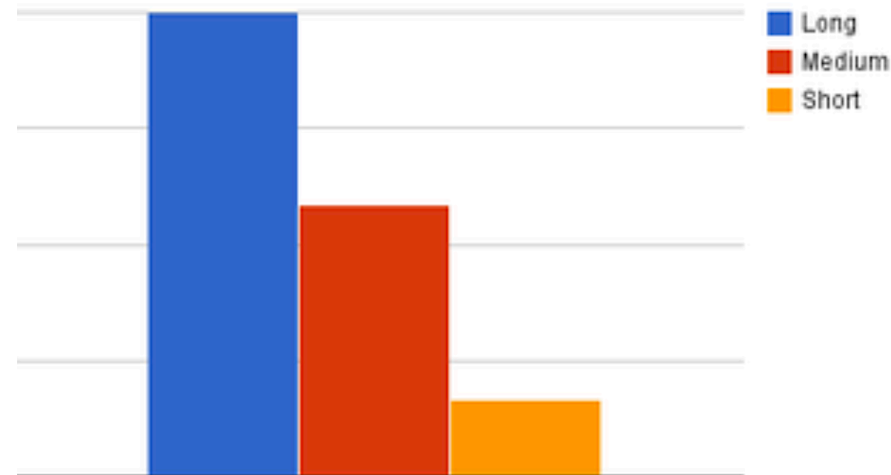
LABEL LABEL LABEL

Always label
your graph!



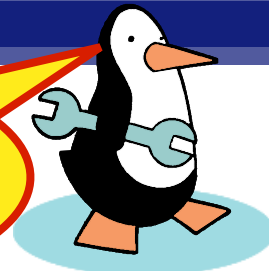
■ What labels are needed?

1. **Title** (*The effect of the Independent Variable on the 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**



LABEL LABEL LABEL

Always label
your graph!



Volume of Oxygen Collected over Time from the Degradation Reaction of H_2O_2

Meaningful title

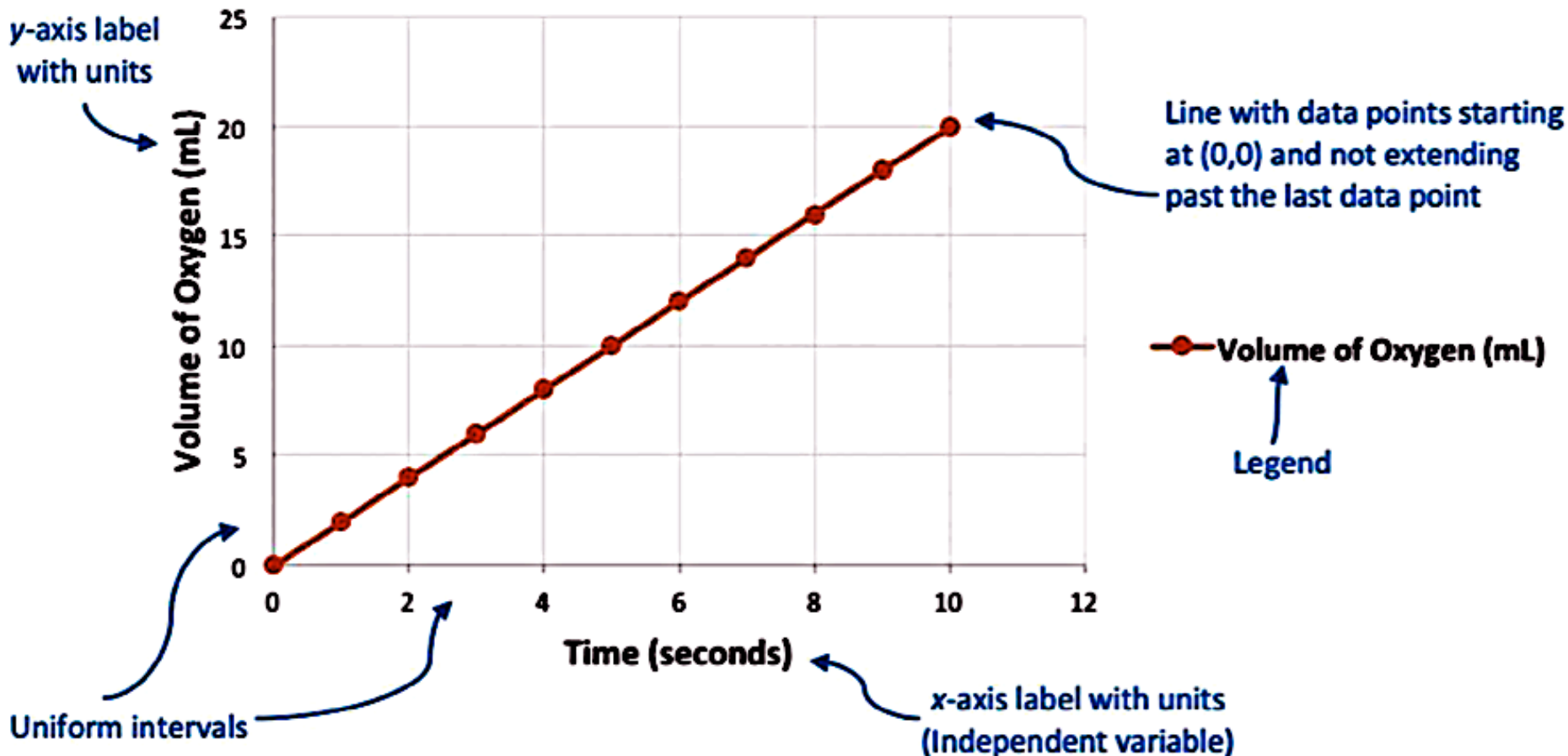
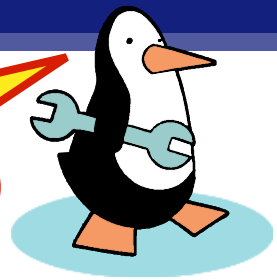


Figure 1.4: Example of an Effective Graph

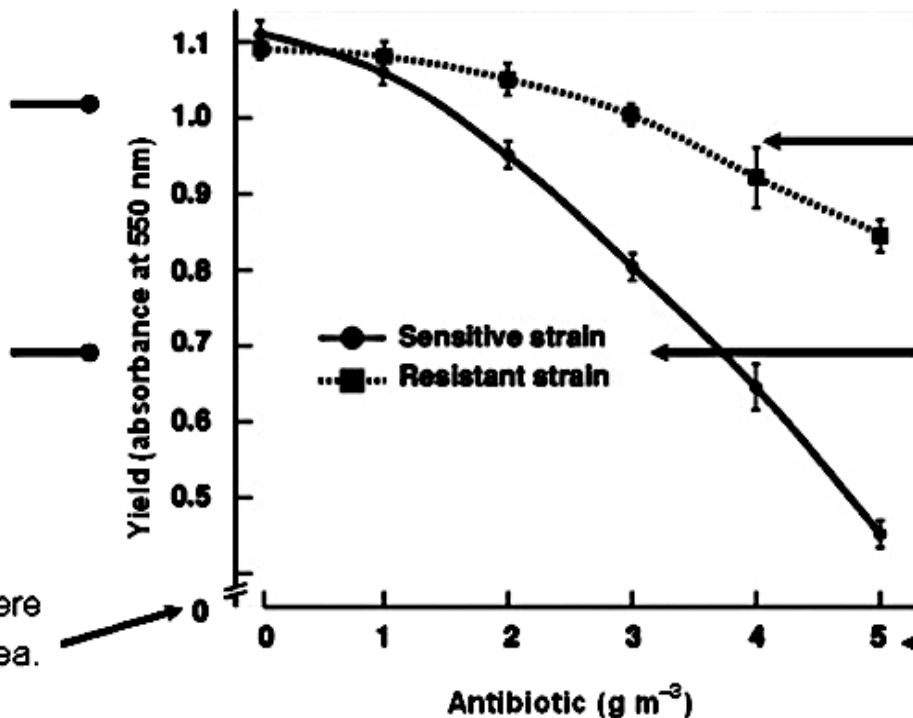
LABEL LABEL LABEL

Always label your graph!



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

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



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.

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

Plot points accurately.

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

Label both axes

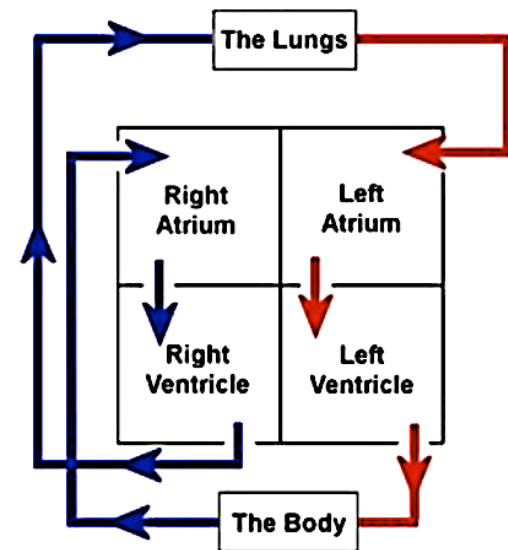
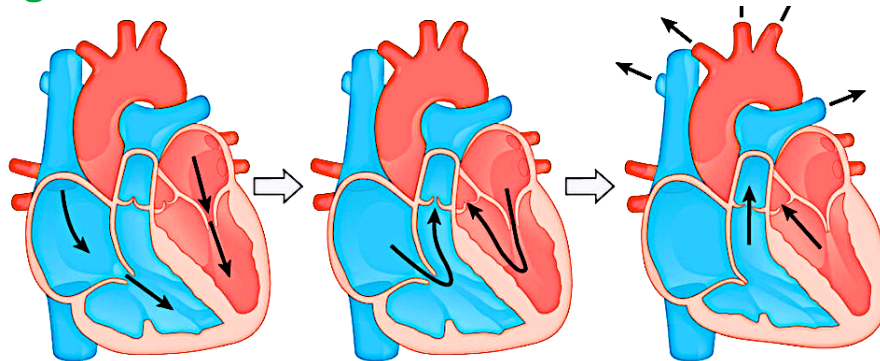
(provide SI units of measurement if necessary)

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.

Visuals In Science Include Models

- ➔ Have you ever drawn a simple map for a friend who needed directions to your home? If so, you created a model.
- **Models 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 are representations that 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: A 3D plastic structure representing heart anatomy
 - Ex: Two different models representing blood flow through the human heart.



Scientific
Theory

Scientific
Law

Explains why
phenomena
occur

Repeated successful
predictions

Describes what
phenomena
happen

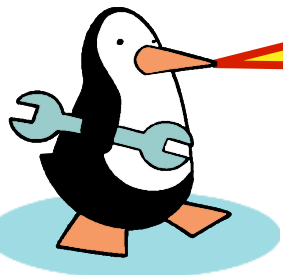
Hypothesis

Theory


Law

Hypothesis, Theories, Laws, and the limits of what science can study.

Terms are not
interchangeable & have
distinct meanings.

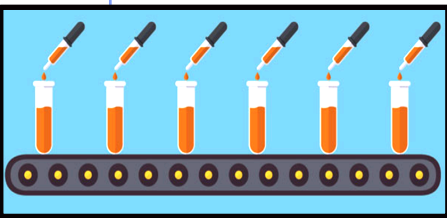


Evidence & Hypothesis in Science

- Unconfirmed reports of observations filling supermarket tabloids would have you 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

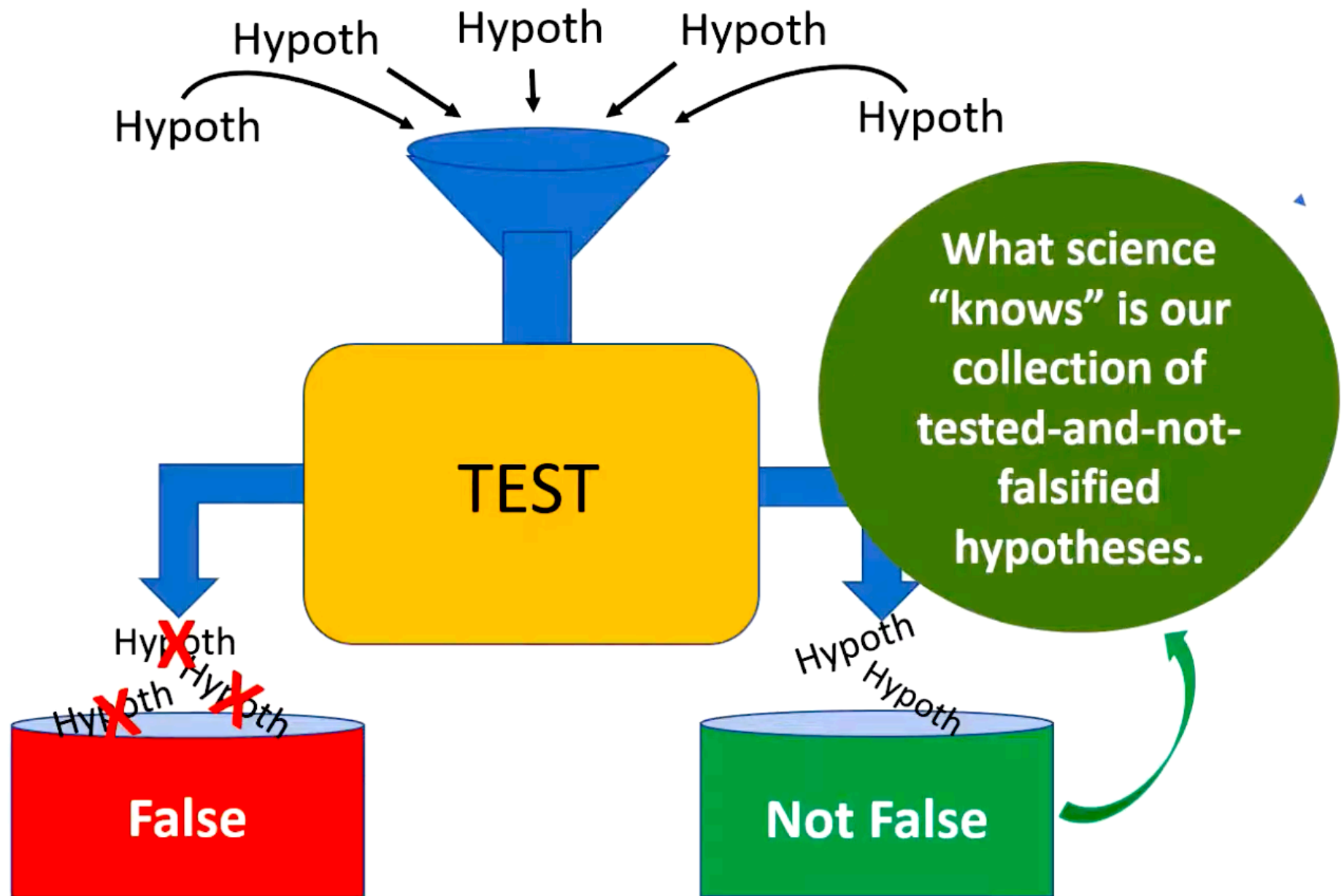
- Evidence is the information upon which inferences are based. **EVIDENCE**
- In science, evidence consists of a collected body of data from observations and experiments.
 - And such evidence becomes convincing scientists until the observations and experiments have been repeated multiple times with similar 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 tested
 - These explanations gain validity if they have been tested and supported by evidence.



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 fail to support 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 ever show that such an idea is false if it really is false?
 - A scientific hypothesis must be falsifiable
 - There must be some observation or experiment that could reveal if a truly false hypothesis is indeed false.



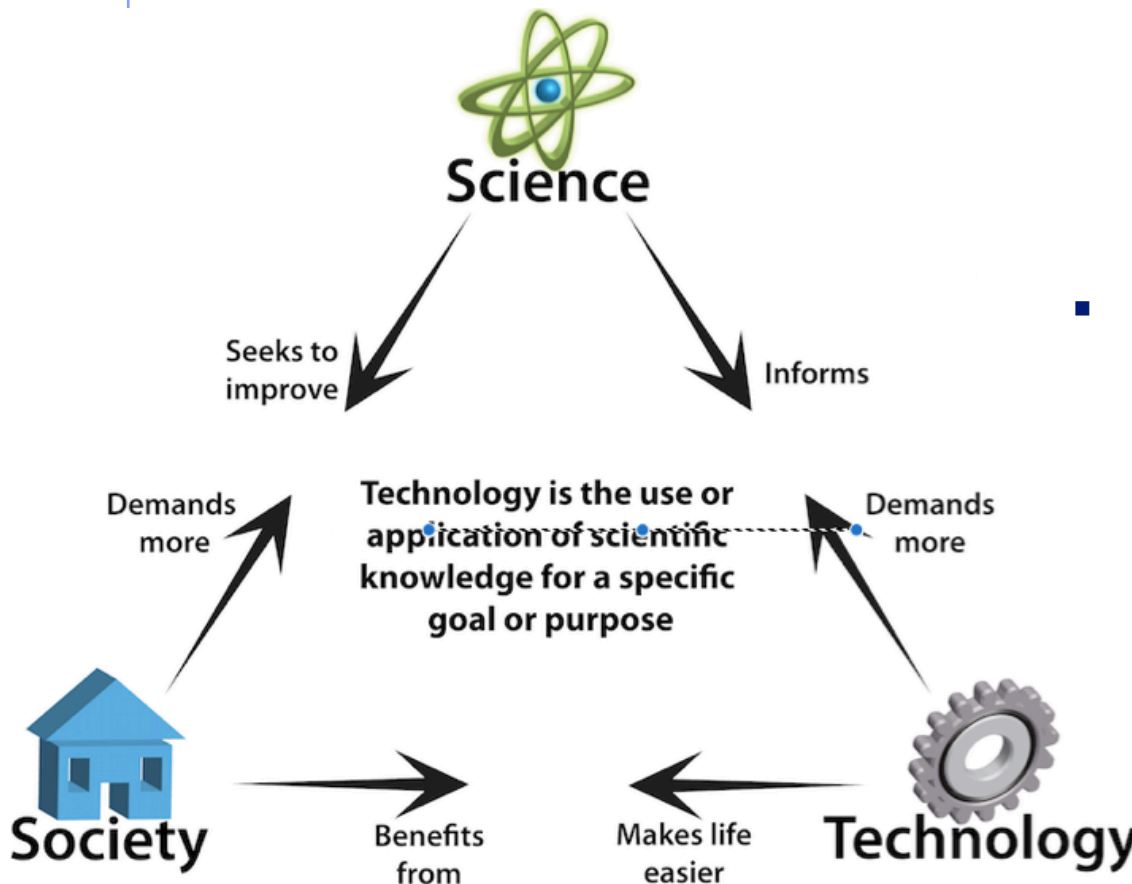


Hypothesis (Explanations) Can Be Revised Over Time

- 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 were 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 new 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

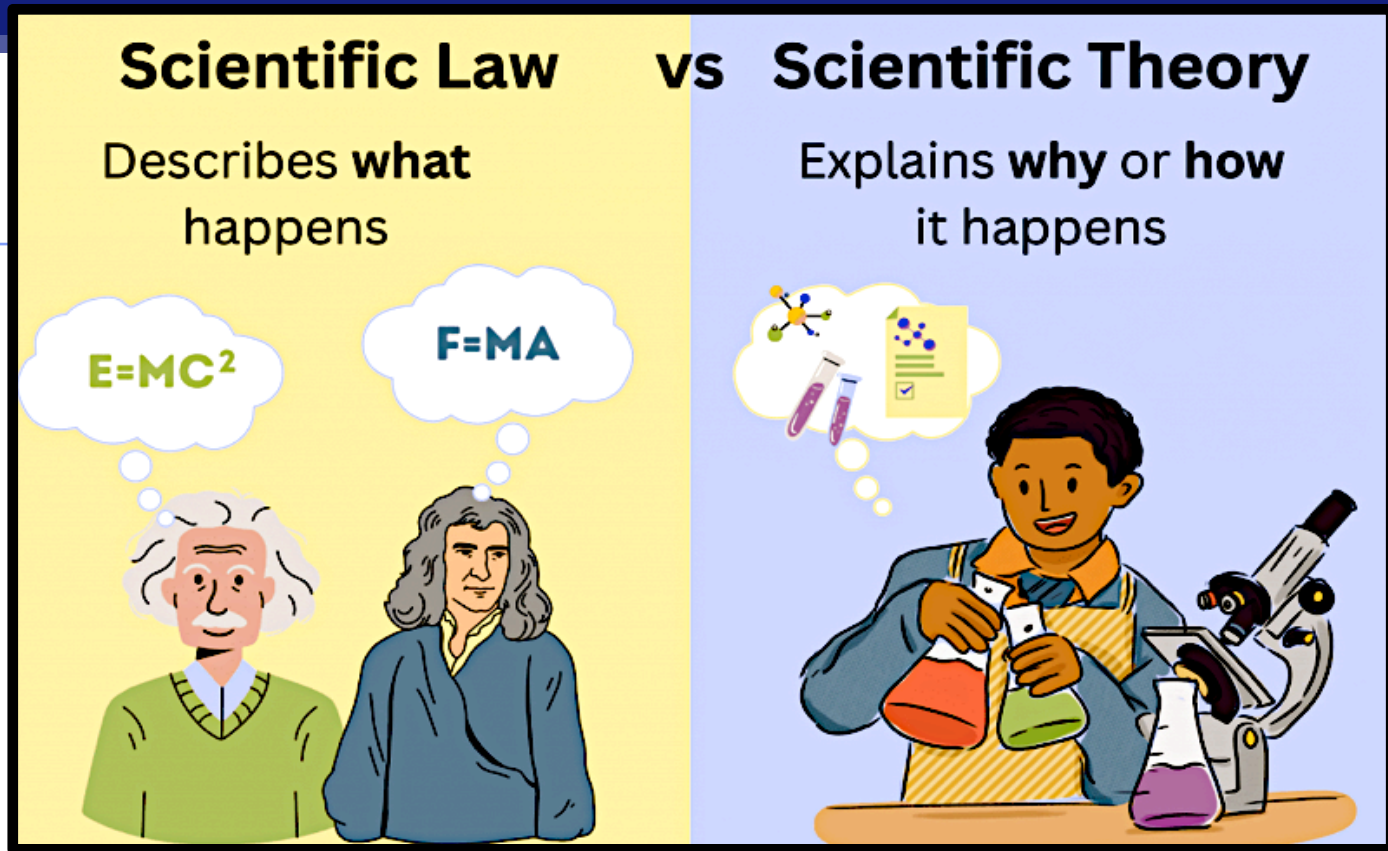
- ◆ Theories are changeable, expandable, and **FALSIFIABLE**. There must be some way that an observation or experiment could prove it to be false (*if it is a wrong explanation*).
 - Ex: Einstein's theory of Relativity made predictions about the results of experiments, which could have produced results 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.

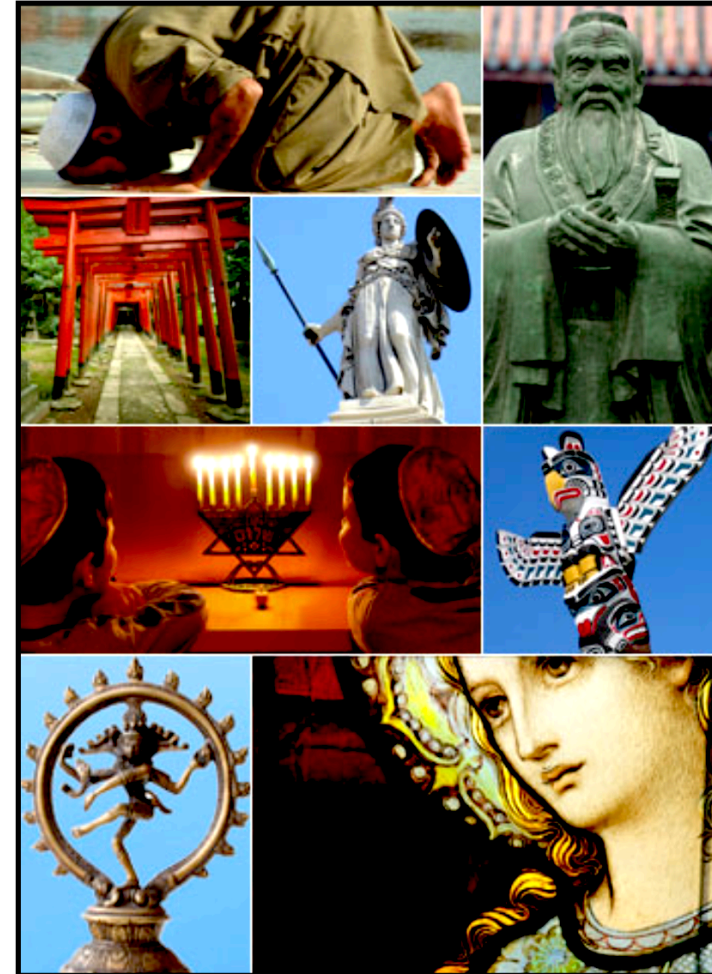


- For example, science can neither verify or disprove that supernatural forces cause phenomenon witnessed in nature.
 - Supernatural explanations of natural events are simply outside the bounds of science.
- For example, science cannot determine which ethical stance is good or bad
 - Science is not useful 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 are **NOT** true. (*What experiment could ever be done to falsify the existence of unicorns?*)



**ANY
QUESTIONS?**

