What is Science?

What is Science?

Science is a process of questioning.

Science as Inquiry

- **Biology = the Study of Life**

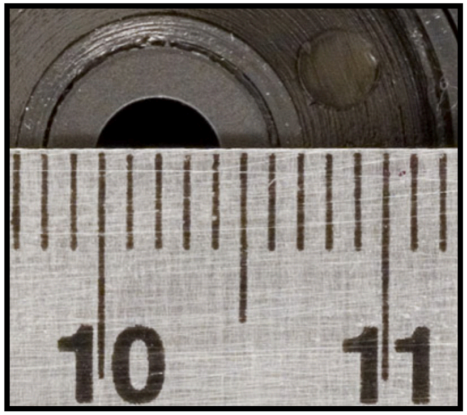
  (From the Greek *bios=life* and *logos=the study of*)

- **At the heart of science is INQUIRY**

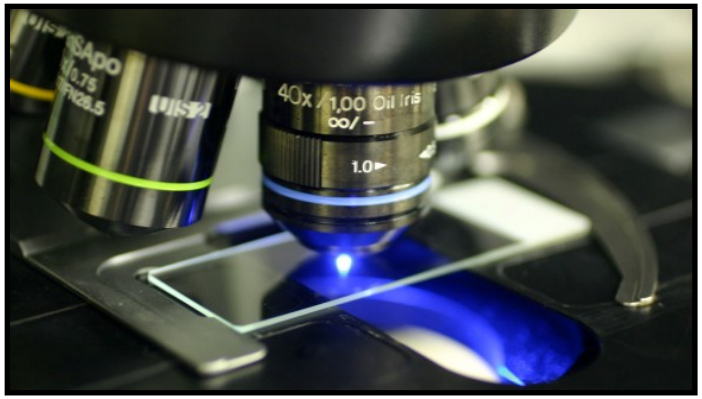
  - **Inquiry is a process of investigation, with thoughtful questions leading to a search for answers.**

Observations & Data

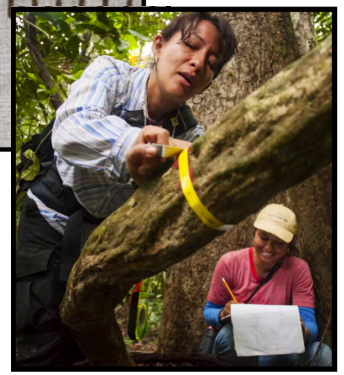
- Observations = The use of the senses to gather and record information about structures or processes.



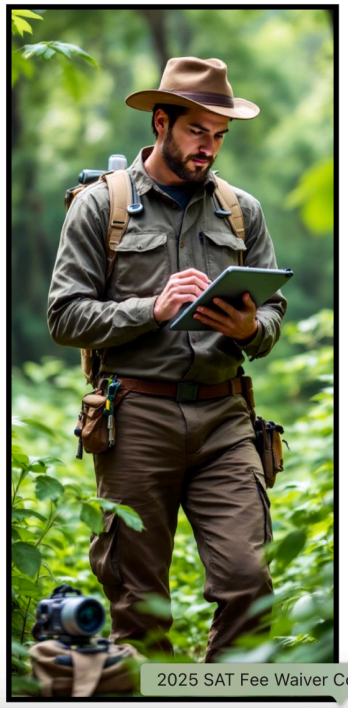
- Data = Recorded Observations
- Scientific instruments vastly increase the range of possible observations



Observations & Data



- **Quantitative Data** = Observations recorded as measurements.
  - In science, such measurements are often recorded using the Metric System.
    - **Numerical:** Depicts measurements like counts, frequencies, rates, percentages etc
      - All numerical measurements must always be reported alongside the proper **units**!



- **Qualitative Data** = Data in the form of descriptions instead of measurements.
  - **Descriptive:** Describes characteristics like texture, color, hue, behaviors etc.

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

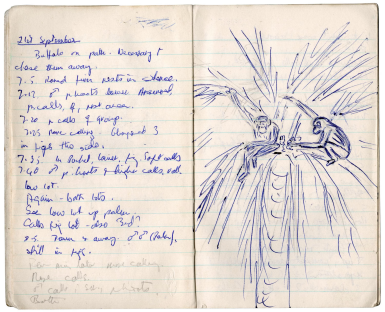
Science involves questioning in order to describe or explain.

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

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

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

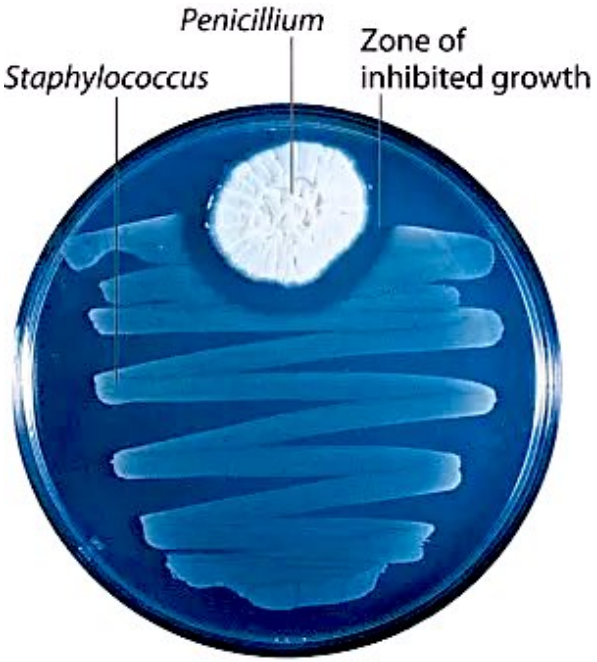
DISCOVERY SCIENCE / OBSERVATIONAL RESEARCH



- **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 accidentally contaminated his culture of bacteria *(S. Aureus)*
  - No bacteria were growing around the mold.
  - Fleming concluded that the mould was secreting a substance that was killing the bacteria.
  - 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 antibiotic discovered - 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?"

OBSERVATION VS INFERENCE

OBSERVATION

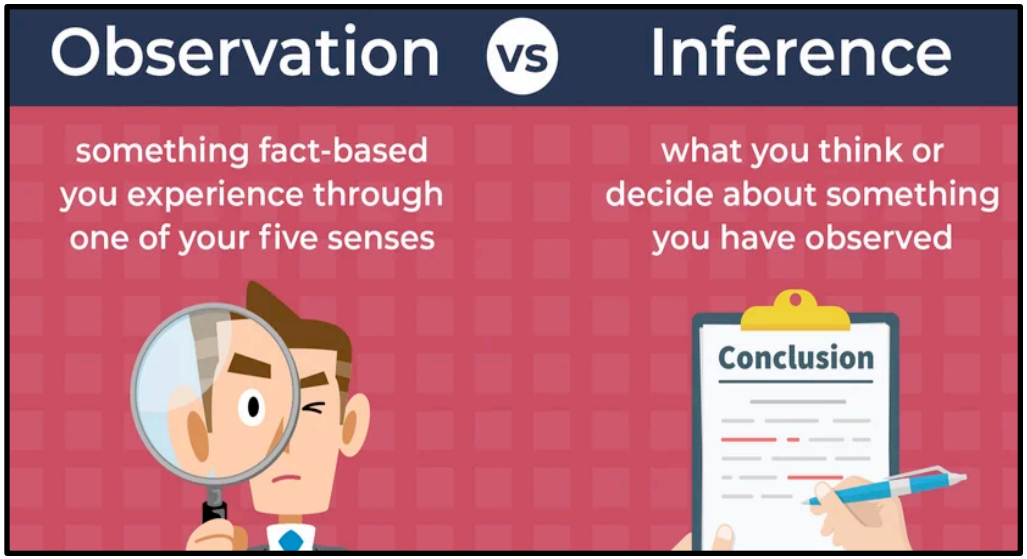
Observation refers to an act of taking note of a phenomenon that is occurring around you. This can be done by simply using your senses (touch, sight, hearing, etc.) or even complex scientific instruments. Valuable data is obtained from this approach, providing a foundation for any scientific inquiry.

INFERENCE

Inference occurs after observation, where the observed data is utilized to form a logical conclusion. Whereas observation requires data gathering, inference requires reasoning, critique, and analysis skills to interpret and explain observations that have been made. Valid inference relies on higher-order cognitive skills.

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.

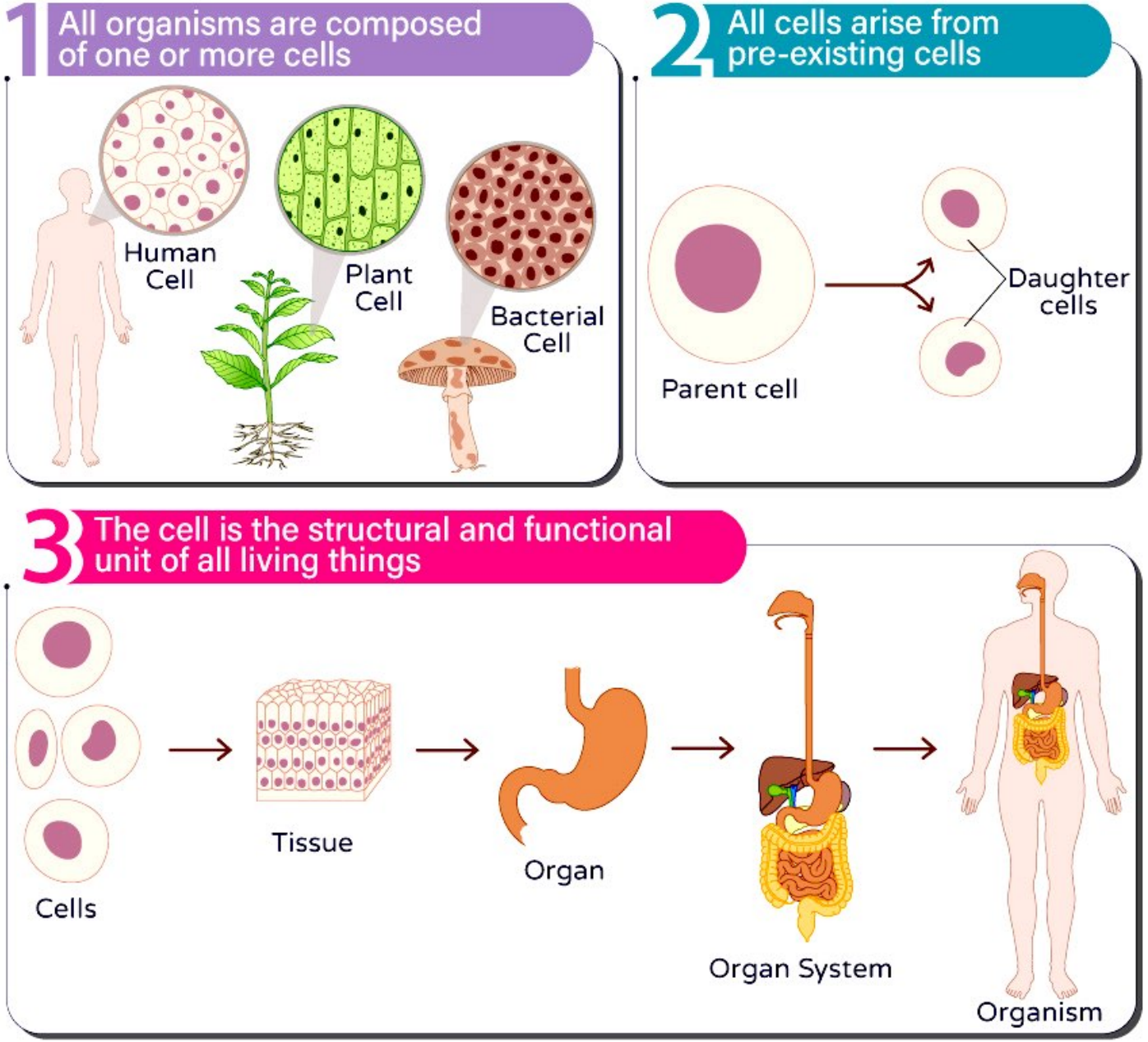
In the 1800's, scientists noticed in both plants and animals tiny units called cells.

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.

Modern Cell Theory



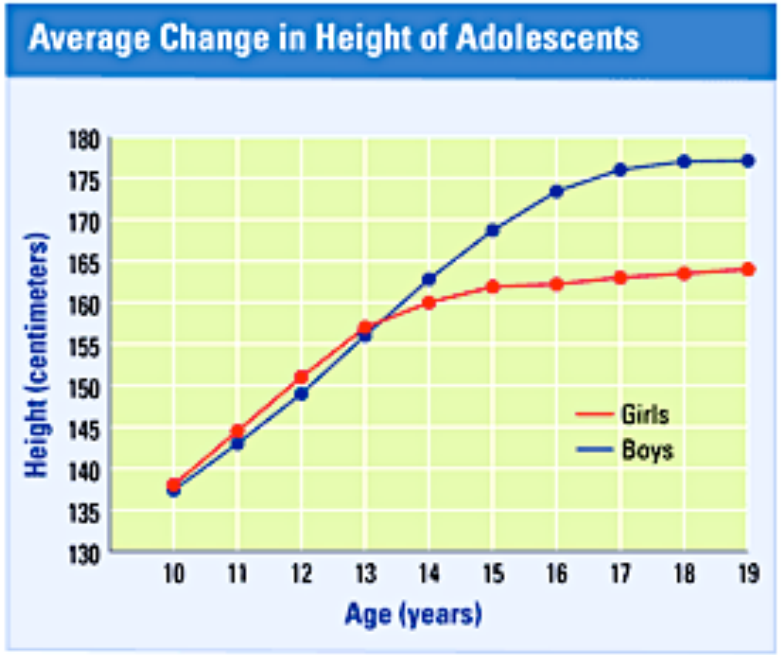
Generalizations in Discovery Science

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.

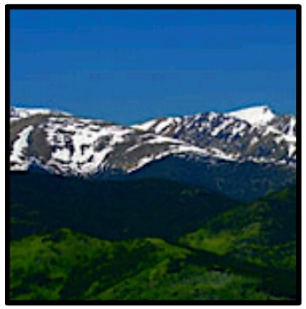
Of course, there are individual exceptions. But the generalization still holds across this very large sample of teens.



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 ex: Trees do not grow above a certain altitude in several mountain ranges. Observations of this “tree line" 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?
        - The answer would provides us with an EXPLANATION



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

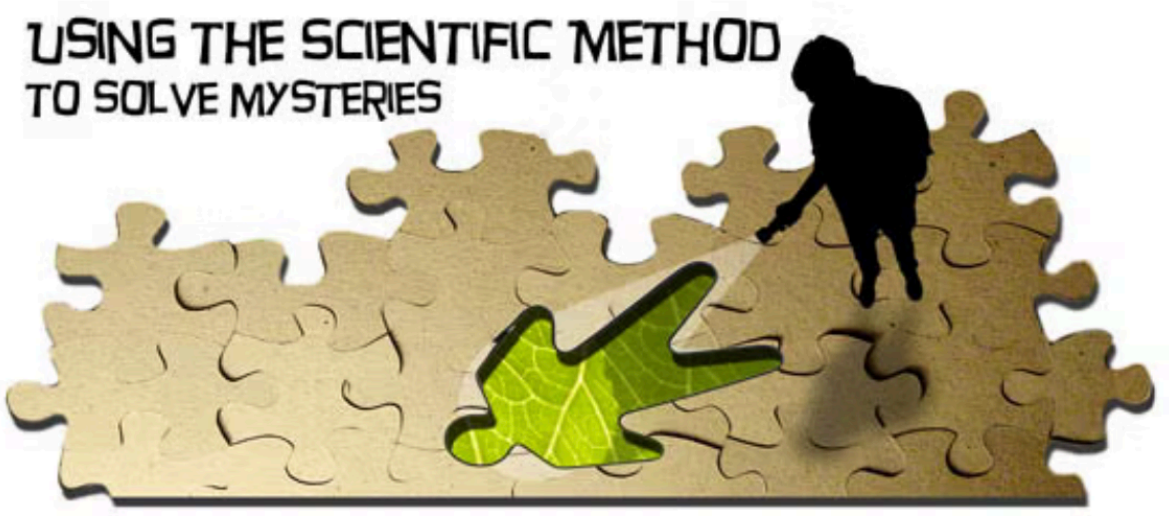
Discovering something interesting inspires us humans to seek explanations.

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

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

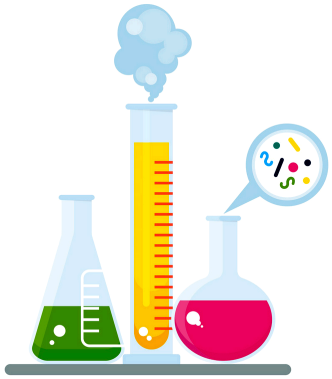
All hypothesis-based science does have in common is …

THE HYPOTHESIS



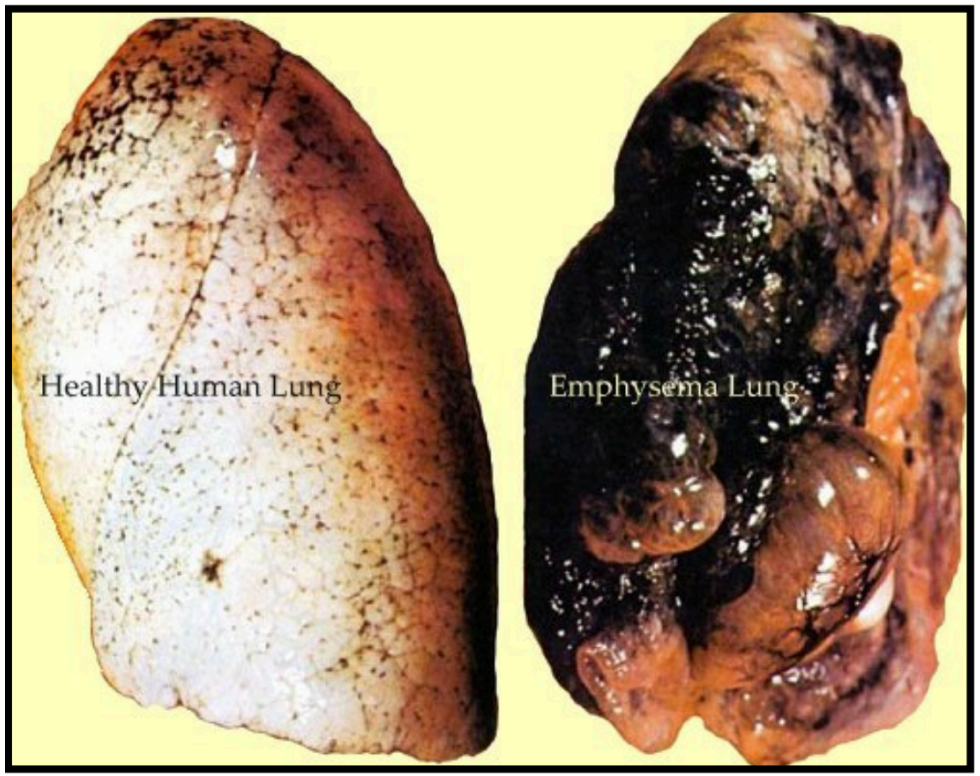
Experimental Research Involves Conducting Experiments

- **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.**



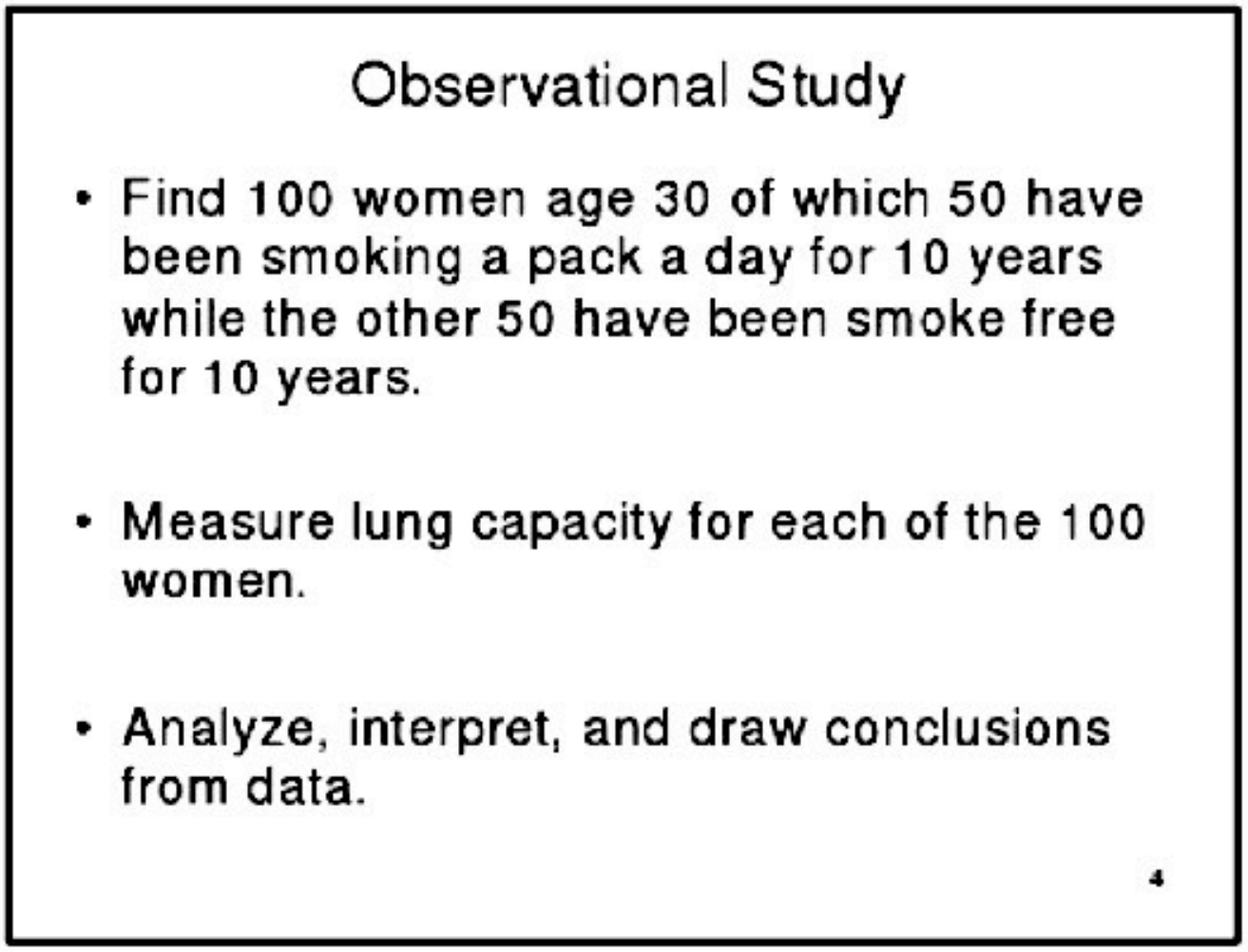
Comparing the Types of Research

- 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?



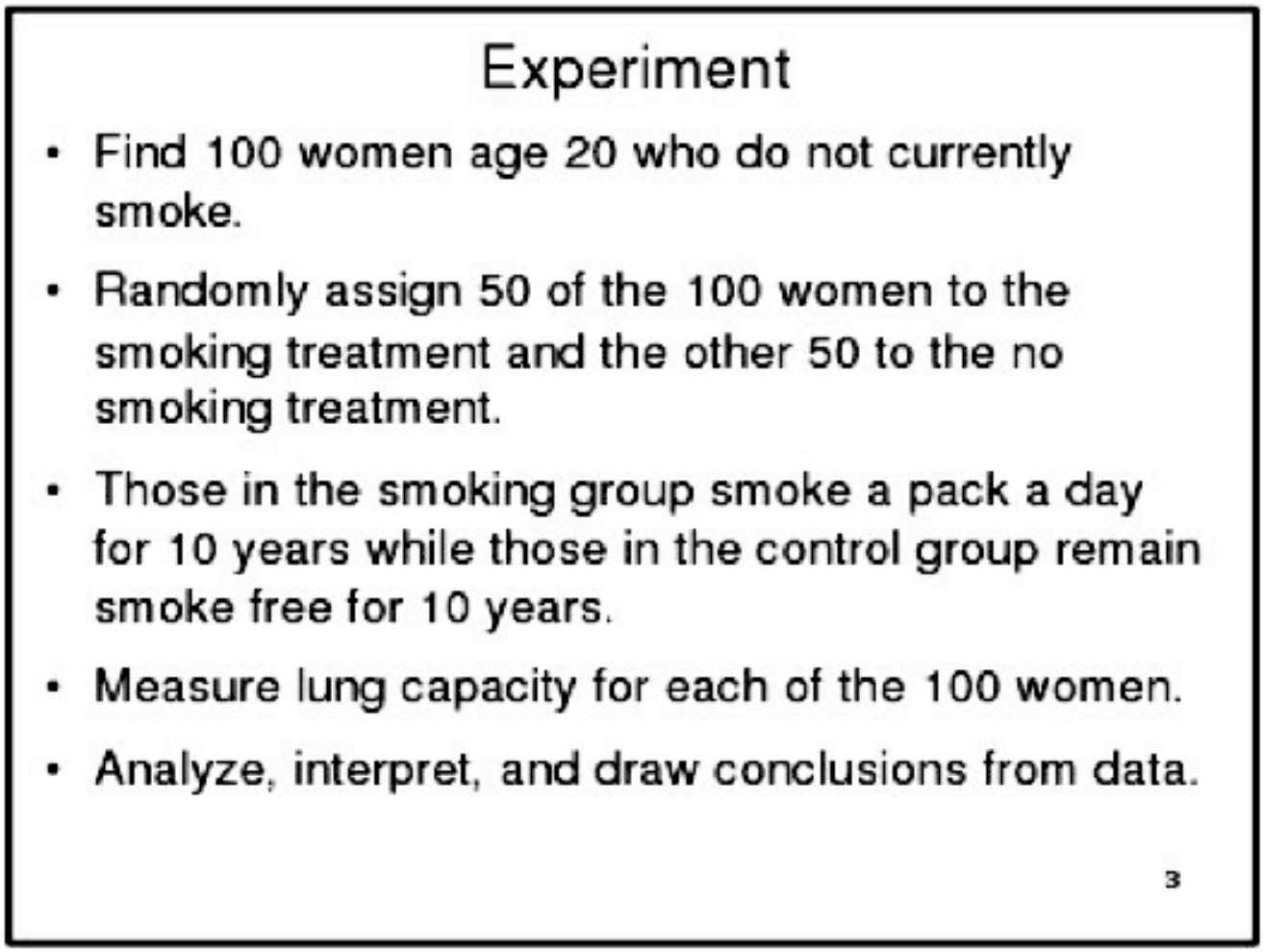
Types of Research

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



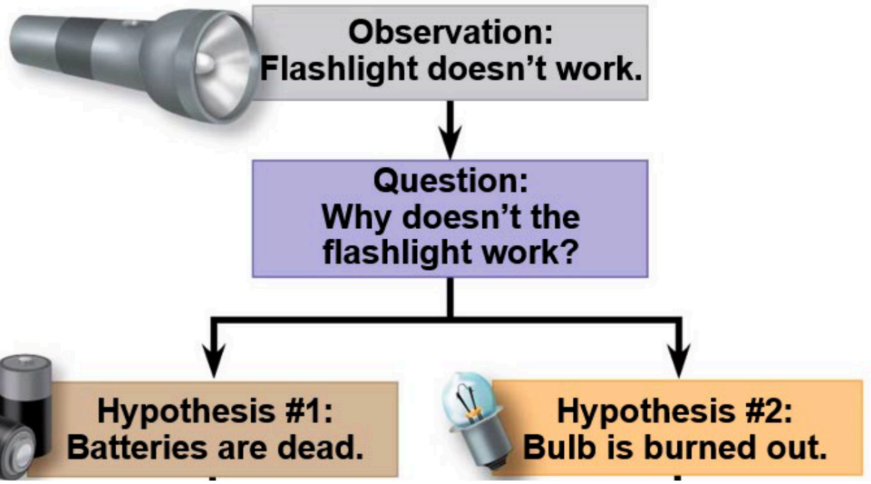
Types of Research

- **Basics of a possible Experimental Study**



Hypothesis-Based (Experimental) Science

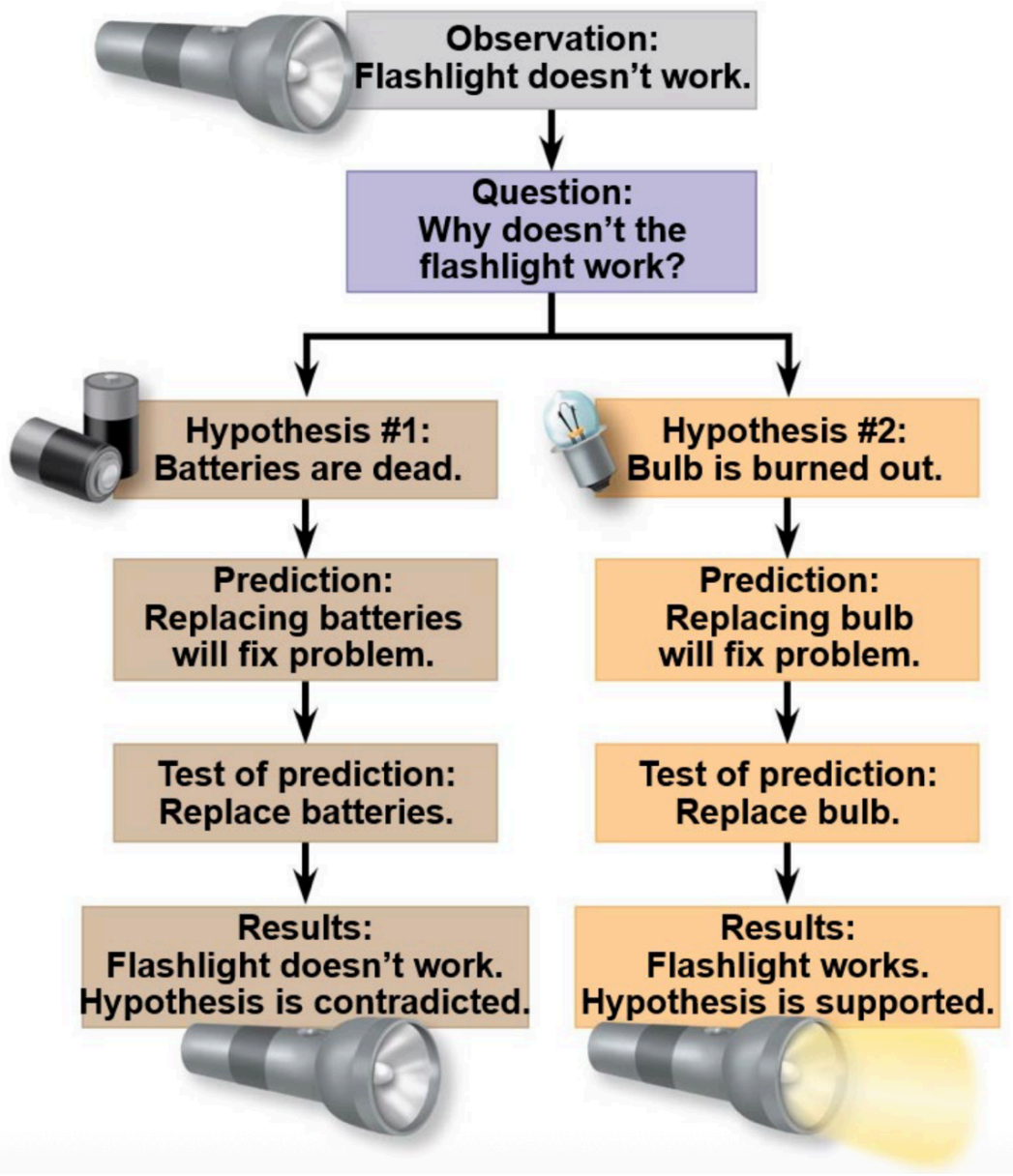
- Observations lead a scientist to ask questions about a phenomenon observed.



- 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)

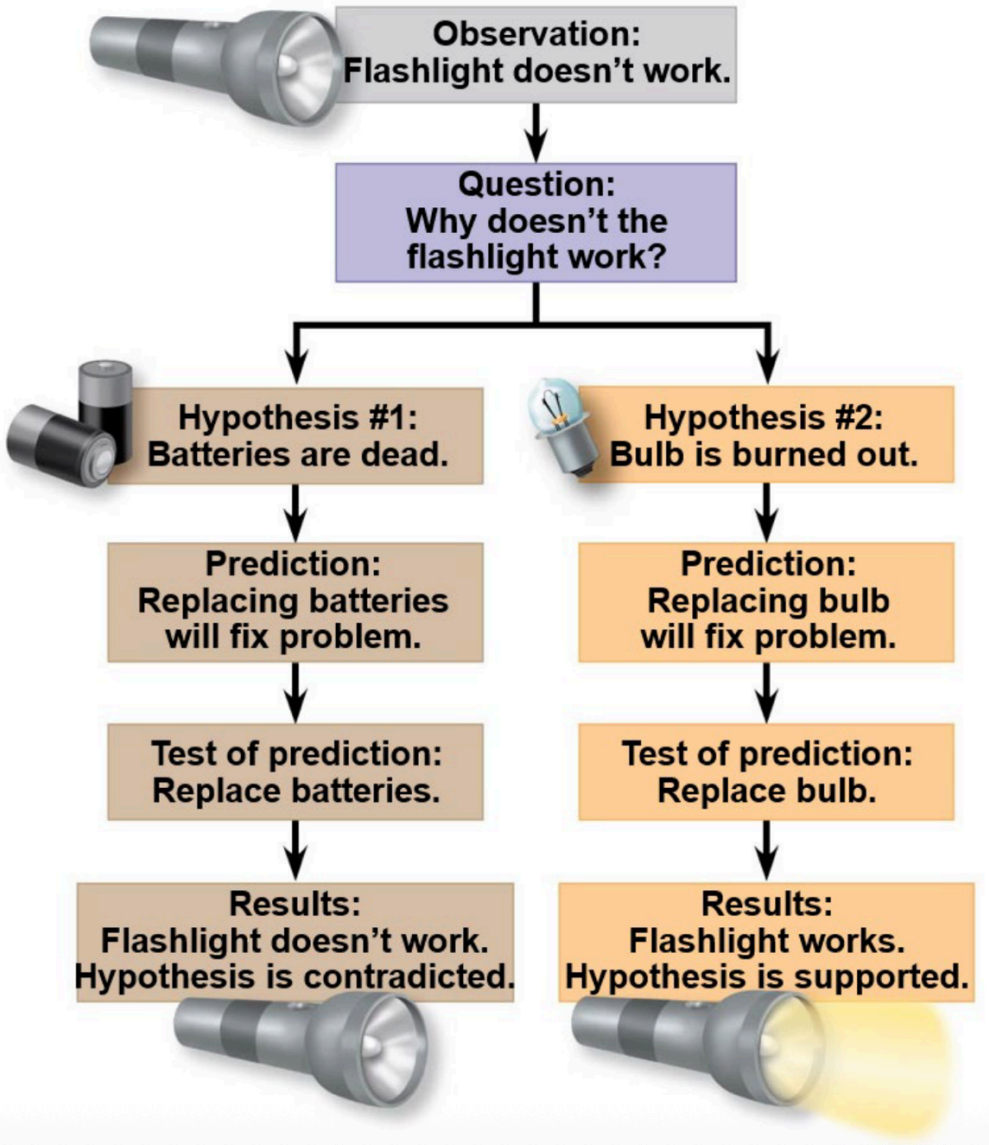
A hypothesis MUST be testable & falsifiable.

- ✓ 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.

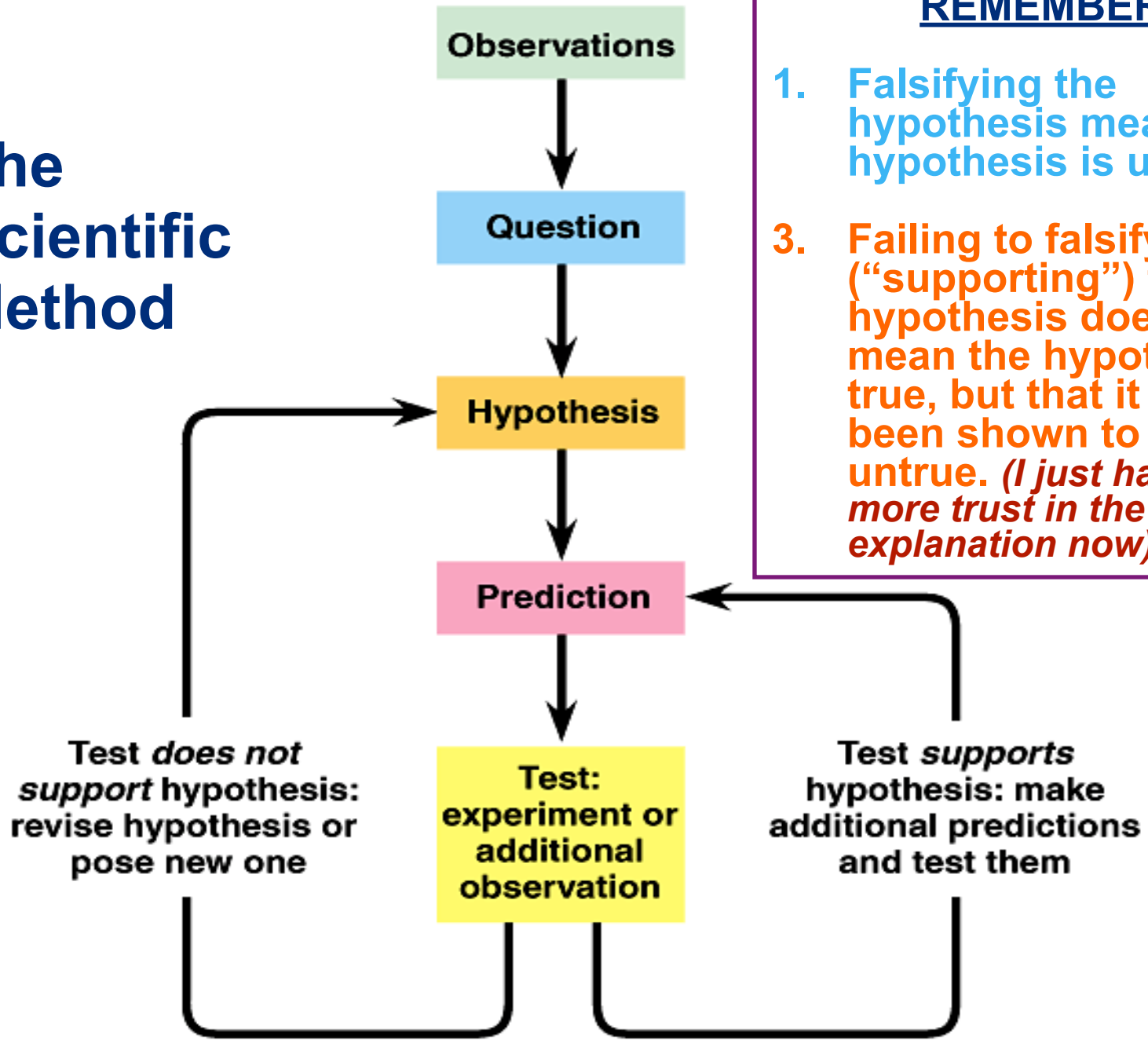


FAILURE TO FALSIFY A HYPOTHESIS DOES NOT PROVE THAT HYPOTHESIS!!!

- 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.**