Ok,…picking up where we left off…Scientific Method

I want to go over the individual components of scientific method and bring them together to look at the big picture. Definitions and concepts will be explained in detail, and the link between each step will be revealed. Scientific method is the heart beat of science. It may be useful to know what's behind it.

There are many different versions that outline the process. Scientific method is fundamentally valuable. The process does not have a rigid order, but a general path to follow.

1. Observe and ask questions
2. Research
3. Formulate a falsifiable hypothesis using empirical evidence and research.
4. Test the hypothesis to see if experimental results support the hypothesis.
5. Conclude analysis
6. Share results

Observations: can be done with all five senses and/or instrumentation to gather facts and empirical evidence.

1. What is a fact?

- **Facts:** are simple basic observations that can be shown to be true. Facts do not explain relationships.
- Example: The sun is out. This is a fact. It does not describe a relationship, and it states something that can be proven simply.
- Example: the sun is out because it undergoes a series of nuclear reactions to cause light to shine on planet earth and warm the planet. This may be true, but facts do not describe relationships. This would be a series of conclusions from intensive scientific studies.

2. What is empirical evidence?
    - **Empirical evidence:** is a series of facts collected by the five senses, sometimes throughout the entire scientific process. The series of facts are used to account for events and be referred to when research is being done. Patterns can reveal themselves through empirical evidence.
    - An example could be when someone opens some lip-gloss and notices a strong smell of grapes and a week later the smell appears to be less potent.
    - An example using instrumentation could be if someone chemically analyzed the lip-gloss and a week later there is a slight decrease in a specific signal.

The facts that were collected as empirical evidence include the following sets:

Set 1: Fact 1, The lip-gloss smelt like grapes when it was opened. Fact 2, the smell appeared to be less potent a week later**.**

Set 2: Fact 1: The NMR spectra of the lip-gloss had distinct signals. Fact 2, a week later, the NMR spectra had a slight decrease in a specific signal.

With the collected facts, the empirical data shows that the grape smell appears to fade. So, the questions would be Does the smell fade? why does the smell fade? or why does the NMR signal decrease? What would…cause the smell to fade?

Research:

With the clear question "does the smell fade," A good place to start is knowing what chemical makes the lip-gloss smell like grapes. This can be done by looking at the list of ingredients on the lip-gloss container. From the ingredients list, a molecule was found that may cause the lip-gloss to smell like grapes. This can be called "compound X." The next step is to search credible sources such as peer reviewed articles and journals, scientific data bases, and text books for research that has been done on similar compounds. From the search, it was found that compounds similar to the active compound that gives the lip-gloss a grape smell evaporates over time at room temperature. So, we have two pieces of information.

1. The smell appears to fade.
2. Compounds similar to compound X evaporate over time.

Hypothesis:

A hypothesis is a critical point in the scientific process. It is where a statement is made that describes a relationship. This step should be done with an importance on clarity. Clarity can be helpful when an argument is made on whether or not the hypothesis is rejected.

The question is clear, does the smell fade? The empirical evidence showed that the smell appeared to fade. From the research gathered, we suspect that compound X may evaporate. We can link these two pieces of information together using a conjunction statement by saying the smell appears to fade and compound X may evaporate This begins to develop a relationship between the two pieces of information.

A good hypothesis should be falsifiable, meaning it has the capability to be proven wrong. A hypothesis should also predict something.

If/then or cause and effect statements can logically connect ideas into conditional relationships, and pull them out of the observation and research stage into a clear hypothesis. The empirical evidence showed the smell became less potent over time. We could say this is a consequent meaning something that follows or the effect. From research gathered, it was found that compound X may evaporate over time. We could say this is the antecedent meaning something that exists before something else or the causality. Connecting the dots using if/then statements, we could state a conditional relationship "if the compound evaporates then the smell fades." This is a true statement so long as the consequent is true and it can be proven that compound X evaporates.

Sometimes it is obvious how to clearly state a relationship, but there are some cases where relationships are ambiguous making it difficult to reveal or express in words. When the clarity of this relationship is not so apparent, two things should be considered to construct a clear statement that describes the relationship, one is premise and the other is conclusion. A premise is a proposed offer of reason to accept another claim. Words that can indicate a premise is being used are since, if, or because. A conclusion is a main point that is being asked to accept. Words that can indicate a conclusion is being made are therefore, thus, as such, as a result, and then.

Clarify, is this a proposal that is being offered as a reason to believe another claim, or is this the main point that is being asked to accept. Using the statement "if the compound evaporates then the smell fades," we can see how the statement fits into each category. The premise is "if the compound evaporates" because it is proposing a reason to believe another claim. The conclusion is "the smell fades" because it is the main point that is being asked to accept. Formats that can help to construct a valid argument are **Modus Ponens** and **Modus Tollens**.

The rules for **Modus Ponens** are that 2 premises must be made followed by a conclusion. If both premises are shown to be true, the conclusion must be true. The first premise states that if an antecedent is true than the consequent is true. The second premise states that the antecedent is in fact true. If the two premises are true the conclusion must be true. So, we have 2 premises and a conclusion. The logic is made simple and congruent.

With a Modus Ponens, we would say

"If the compound evaporates, then the smell fades."

"the compound evaporates."

"Therefore, the smell fades."

Now the hypothesis becomes compound X evaporates. If we prove this experimentally and compound X does in fact evaporate, the conclusion must be true that the smell fades. Our experimental task now is to show that compound X does in fact evaporate. This will answer the initial question "does the smell fade?" This will also give a valid argument that a conditional relationship has been found. This will give proof that the smell does fade.

This really is an intuitive statement; it is just set up in a format that is not commonly used in every-day-life.

The premise "a" is "the compound evaporates." The conclusion "b" is "the smell fades"

Plugging in the premise and conclusion into a and b reveals that any premise and any conclusion can be put in this format or syntax.

With Modus Tollens a similar format is used where there is a premise and a conclusion; however, if the conclusion is proven to not be true, then the premise cannot be true.

If the compound evaporates, **then** the smell fades.

the smell does not fade

Therefore, the compound did not evaporate.

In the hypothesis we did the following:

1. Made a conjunction statement linking the 2 pieces of information together.
2. Constructed a conditional statement describing the relationship of the 2 pieces of information.
3. Constructed a logical proof in a modus ponens format that the conclusion is true that the smell fades provided that it can be shown experimentally that compound X evaporates.

Experiment:

In the experiment, a point is made to make a clear distinction of the relationship between the cause and effect of what is being measured.

How do we do this?

To do this, all things outside of what is being measured are purposely set up where they will not interact to change or affect the experimental outcome. Terms used for things that can interact with an experiment are called variables and parameters. Some variables and parameters could be temperature, pressure, and amount of substance.

To give you an example: Some reactions are affected by the presents of oxygen, so they are done in the absence of oxygen. Likewise, some reactions are affected by the presents of water, so they are done in the absence of water. These are conditional parameters outside of what is being measured that could change the outcome.

Parameters change: Parameters are set up so they will not change and interact with the experimental outcome.

How can a parameter change effect an experiment?

The point of an experiment is to see how value "A" changes to value "B". When parameters change, they can affect value "A" so it is no longer value "A." As a result, there is no longer a relationship between value "A" and value "B." There is value "A" that has been influenced by something else that changes to give value "B." Parameters need to be locked into place, so they do not affect value "A" to give a clear relationship between "A" and "B." When parameters are locked into place, the term held constant is used.

An example of a reaction with parameters that are held constant would be the following:

An experimental sequence was carried out where the reaction times were 1 min, 5 min, and 10min. The pressure, temperature, and volume were held constant, meaning they did not change.

Another example of how a parameter change could affect an experiment would be if we wanted to know what reaction was the fastest compound a and x, compound b and x, or compound c and x, and the reaction with x is sensitive to temperature. If compounds a, b, and c react with x at different temperatures, it would be hard to determine reaction speed because temperature can greatly affect reaction speed. However, if all three experiments were done at temperatures that

were held constant, then the experiment would be meaningful and show some information about how fast a, b, and c react with x.

Another good practice is making only slight changes. Slight changes should be made between experiments. This can decrease the amount of questions there are between the cause and effect with each experiment.

To conduct a meaningful experiment, the experiment should have what is being measured isolated from influences outside of what is being measured, parameters should be held constant when they are not involved in what is being measured, and only slight adjustments should be made with each experiment.

- **Lip gloss:**
- How could we set up an experiment with our hypothesis that the smell fades because compound X evaporates?
- We suspected that the good smelling chemicals evaporated. How can a quantitative measurement be recorded when the compound evaporates? When something evaporates, the liquid volume will decrease and the weight will decrease. So, we isolate compound X and put 1 mL in a 10mL graduated cylinder to see if the volume decreases. If we want an additional way to measure the evaporation, we can put the graduated cylinder on a scale and record the initial and final weight. This gives 2 ways to measure one experimental parameter. How long should we do the experiment? The lip-gloss was noticeably less potent after 1 week, so compound X could simulate this by being left out to evaporate for one week.
- **data analysis and conclusion:** When the data is analyzed from the experimental results, it will either support the hypothesis and the hypothesis will not be rejected, or it will not support the hypothesis and the hypothesis will be rejected. A conclusion is then made based on whether the experimental data supports the hypothesis. Compound X evaporated and the smell faded. The experiment supported the hypothesis, so the hypothesis was not rejected. It was concluded that the reasons offered for the conditional relationship between compound X evaporating and the smell fading was accepted. The smell faded because compound X evaporated.
- **The final step is to share your study** to the world for brutal scrutiny by others. Brace yourself for impact. As scientist, the work that is done will be criticized. Sometimes this is delivered in a warm spirit, and sometimes it is not. I would not waste time on taking it personal. What is important is using the information that is given to make improvements.

  Summery:

- So, looking at the steps we went over, we started with observations and questions. Once we had a clear question, we did some research to get information about the questions. From the research information and observations, a hypothesis was developed using if-then statements. Modus Ponens and Modus Tollens helped to clarify a valid argument.

An experiment was constructed to test the hypothesis. The data was analyzed, and it was concluded that the experimental results supported the hypothesis. The experiment was then shared.

- This process chips away any possible doubt or error.
- If you think of the line on the zero mark at the y axis as being 100% true, and the x axis as the body of evidence that has not been rejected, the increasing body of evidence gets infinitesimally closer and closer to the truth as the body of evidence increases. At some point the scientific community determines that a law or theory can be developed.
- Laws and theories are similar, but they are not the same. One does not get promoted into the other. Much like a rook cannot develop into a knight. A rook is a rook, and a knight is a knight.
- **Scientific Laws describe what happens.** A scientific law does NOT explain why something happens.
- Example 1: If two bodies move away from each other, the force of gravity decreases. This describes what will happen, not why.
- **Scientific Theory: describes how or why something happens.**
- For example, the theory of relativity explains why…light bends around massive objects.

Ok, so theories and laws are not the same and they do not get promoted into each other.

What are the similarities?

Laws and theories are very respected in the scientific community. They both have

1. **Repeatability:** the relationships are tested over and over with the same results.
2. **Revisability:** laws and theories can be modified or tweaked as new information comes in.
3. **Predictability:** Laws and Theories have predictive power.
4. **Fundamental truths of nature:** Laws and theories are held to be fundamental truths of nature until farther studies can prove them wrong.
5. **Starting points for research:** Laws and theories often serve as starting points for research. They can be thought of as the foundation points of science like pillars holding up an enormous building.

So, each time a study is done through the scientific method, a body of evidence is developed. With the increasing body of evidence, the truth of a given phenomenon reveals itself more clearly.

Check point 19