The Scientific Method

Unit: Laboratory & Measurement

NGSS Standards/MA Curriculum Frameworks (2016): SP1, SP2, SP6, SP7

AP® Physics 1 Learning Objectives/Essential Knowledge (2024): SP3.B, SP3.C

Mastery Objective(s): (Students will be able to…)

- Explain how the scientific method can be applied to a problem or question.

Success Criteria:

- Steps in a specific process are connected in consistent and logical ways.
- Explanation correctly uses appropriate vocabulary.

Language Objectives:

- Understand and correctly use terms relating to the scientific method, such as "peer review".

Tier 2 Vocabulary: theory, model, claim, law, peer

Summary of Concepts:

scientific method: attempting to understand concepts and make accurate predictions by systematically trying things to find out what happens.

Notes:

The scientific method is a fancy name for "figure out what happens by trying it," or "how to f— around* so you can find out".

In the middle ages, "scientists" were called "philosophers." These were church scholars who decided what was "correct" by a combination of observing the world around them and then arguing and debating with each other about the mechanisms and causes.

* The phrase is, of course, "fiddle around".

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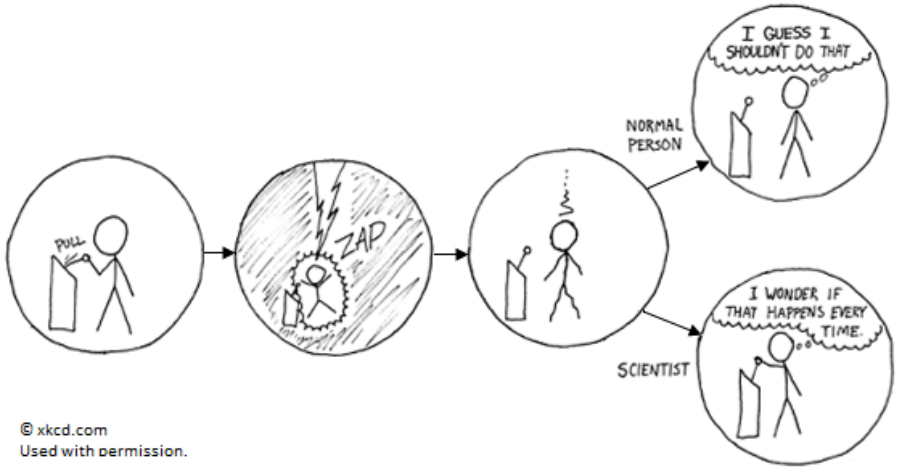
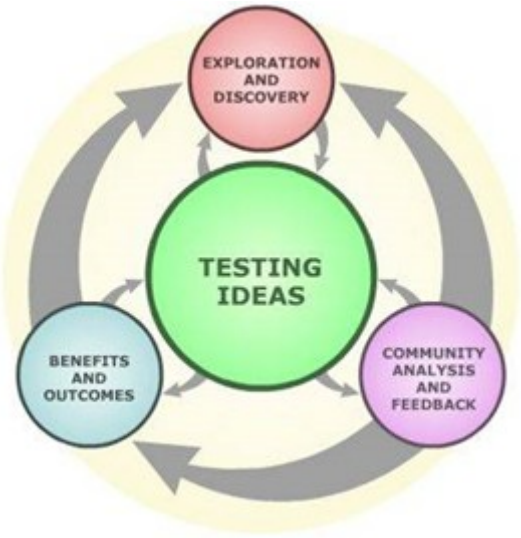
During the Renaissance, scientists like Galileo Galilei and Leonardo da Vinci started using experiments instead of argument to decide what really happens in the world.



A Mindset, Not a Recipe

The scientific method is a mindset, which basically amounts to "let nature speak". Despite what you may have been taught previously, the scientific method does not have specific "steps," and does not necessarily require a hypothesis.

The scientific method looks more like a web, with testing ideas (experimentation) at the center.



from the *Understanding Science* website*

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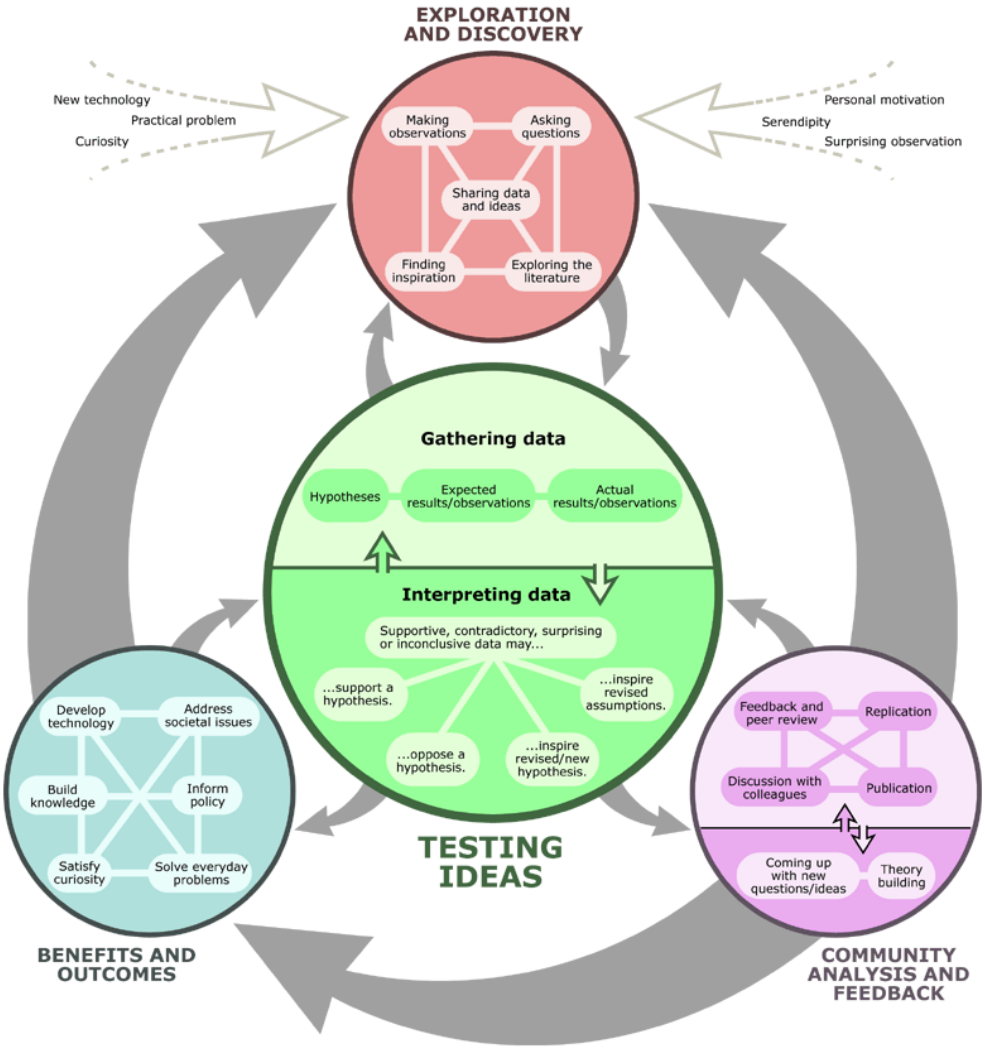
Each of the circles in the above diagram is a broad area that contains many processes:



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When scientists conclude something interesting that they think is important and want to share, they state it in the form of a ***claim***, which states that something happens, under what conditions it happens, and in some cases gives a possible explanation.

claim: a statement about something that happens, or will happen if certain conditions are met. A claim might or might not include an explanation of why or how the thing happens.

evidence: observations and experimental results that were gathered, which support the claim.

reasoning: an explanation of how the evidence supports the claim. Reasoning is usually in the form statements that logically flow from one to the next, much like a mathematical proof.

We will use the claim → evidence → reasoning mindset throughout the course.

Before a claim is taken seriously, the original scientist and any others who are sufficiently interested in it try everything they can think of to:

- Disprove the claim itself. (Show that the stated claim doesn't always happen as stated.)
- Cast doubt on the evidence. (Show that there were problems with how the evidence was gathered that cause it to not successfully support the claim.)
- Disprove the reasoning. (Show that the evidence does not actually support the claim, or that the evidence could just as easily support an opposing claim.

peer review: the process by which scientists scrutinize, evaluate and attempt to disprove each other's claims.

Note that scientists welcome the peer review process. If someone tries to disprove a claim, it is actually a compliment; it is more likely than not that the scientist trying to disprove a claim believes that the claim may be valid, and wants to make sure that it stands up to a higher level of scrutiny. Many scientists will go to more effort to try to disprove a claim that they believe than one that they don't.

If a claim has gained widespread support among the scientific community and can be used to predict the outcomes of experiments (and it has *never* been disproved), it could eventually become a theory or a law.

theory: a claim that has never been disproved, that gives an explanation for a set of observations, and that can be used to predict the outcomes of experiments.

model: a way of viewing a set of concepts and their relationships to one another. A model is one type of theory.

law: a claim that has never been disproved and that can be used to predict the outcomes of experiments, but that does not attempt to model or explain the observations.

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Note that the word "theory" in science has a different meaning from the word "theory" in everyday language. *In science*, a theory is:

- *has never failed* to explain a collection of related observations
- *has never failed* to successfully predict the outcomes of related experiments

For example, the theory of evolution *has never failed* to explain the process of changes in organisms that are caused by factors that affect the survivability of the species.

If a repeatable experiment contradicts a theory, and the experiment passes the peer review process, the theory is deemed to be wrong. If the theory is wrong, it must either be modified to explain the new results or discarded completely.

Theories *vs.* Natural Laws

The terms "theory" and "law" developed organically over many centuries, so any definition of either term must acknowledge that common usage, both within and outside of the scientific community, will not always be consistent with the definitions.

Nevertheless, the following rules of thumb may be useful:

A *theory* is a model that attempts to explain *why* or *how* something happens. A *law* simply describes or quantifies what happens without attempting to provide an explanation. Theories and laws can both be used to predict the outcomes of related experiments.

> For example, the *Law of Gravity* states that objects attract other objects based on their masses and distances from each other. It is a law and not a theory because the Law of Gravity does not explain *why* masses attract each other.
>
> *Atomic Theory* states that matter is made of atoms, and that those atoms are themselves made up of smaller particles. The interactions between these particles are used to explain certain properties of the substances. This is a theory because we cannot see atoms or prove that they exist. However, the model gives an explanation for *why* substances have the properties that they do.

A theory cannot become a law for the same reasons that a definition cannot become a measurement, and a postulate cannot become a theorem.

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The Language of Science

Because science is concerned with defining the limits of what we know and how confident we are that we know it, there are several words that have different meanings in science than they do in the vernacular*.

Term	Science	Vernacular*
opinion	Judgments, insights and interpretations that are grounded in expertise and based on evidence.	Subjective preferences, tastes, viewpoints.
skepticism	Judgment of a claim based solely on the strength and quality of the evidence.	Cynicism, negativity, contrarianism, denial.
consensus	Broad agreement based on an extensive body of evidence.	A popular opinion or belief within a group of people.
fact	A claim that has been extensively confirmed and is widely accepted by the scientific community. Acceptance is provisional; new evidence can disprove something previously thought to be fact.	Immutable truth.
law	An observation that something always happens and can be predicted but does not necessarily offer an explanation.	A requirement that something happens, with the threat of a penalty or punishment if the law is contradicted (broken).
theory	An explanation of a phenomenon that fits all of the evidence that has ever been observed and has high predictive power.	Speculation, hunch, guess.
model	A representation of something that helps envision or understand it.	An exact duplicate of something at a smaller scale.
uncertainty	Measured or calculated range of confidence in findings.	Not being sure.
error	Measured or calculated range of confidence in findings. (Synonym for uncertainty.)	Mistake.

* Everyday language.

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