

The Nature of Science



Intuition leads to the flat Earth society and bloodletting; experiments lead men to the moon and microsurgery.
- Seth Mnookin

The First Vaccination

- Up through the 20th century, one of the most serious diseases of mankind was smallpox.
 - One of out every 10 children born in France and Sweden died of smallpox.
- The only known “cure” was to contract the disease and recover.
- Some inoculated themselves with fluid and pus from the sick, hoping to contract a mild case and survive.



The First Vaccination

- A British physician named Edward Jenner observed that dairymaids living in his hometown often contracted cowpox, a nonlethal disease with similar symptoms to smallpox.
- He decided to intentionally infect a young boy with cowpox, then expose him to smallpox.
 - Immunity was successfully conferred to the boy.



Edward Jenner vaccinating a child with cowpox from a dairymaid. Source: Bettman Archive / Corbis.

Eradication

- A different virus was eventually discovered for use in smallpox vaccinations.
 - Produced much milder symptoms.
- Smallpox was declared eradicated by the World Health Organization in 1980.
- The same basic technique has been used to develop vaccines for other illnesses, such as measles, tetanus, chickenpox, whooping cough, and others.



A monument dedicated to smallpox eradication at the WHO headquarters in Geneva. Source: Wikimedia.

Basic Rules of Science

- Science assumes that everything in the universe can be explained, given enough data and experimentation.
- All ideas in science are constantly being tested, evaluated, and re-considered.
 - **Hypothesis:** Testable prediction based on prior knowledge and observation.
 - Can be supported or rejected based on an experiment.
 - **Theory:** Broad explanation based on many experiments and high amounts of data.
 - Examples: Evolution, Plate Tectonics, Big Bang
- Discoveries must be **reproducible** -- designed and recorded such that the results can be repeated by other researchers.

Pseudoscience

- A far different idea is **pseudoscience**, which appears or claims to be science, but does not follow scientific principles.

Spontaneous Generation

- The theory that life arose spontaneously from non-living matter persisted from ancient times through the 19th century.
- One recipe for life called for dirty garments and husks of wheat to be added to a jar.
 - Wait 21 days, and mice appear!
- This belief was based in false science.
 - Could it be replicated consistently?
 - Were any other possible explanations tested?



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Alchemy

- The primary goal of alchemists during the middle ages was to discover a way to transform materials of little value (such as lead) to gold.
- A chemist named Hennig Brand in 1669 was studying urine, observing that it had a color similar to gold.
 - He accidentally discovered phosphorus; an element that glowed.
 - Hennig, like other alchemists, kept his discoveries secret. The study of chemistry advanced little during this time.



The Alchemist in Search of the Philosophers Stone (1771) by Joseph Wright.

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Astrology

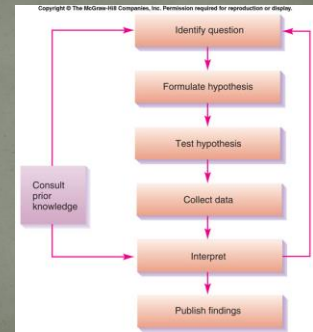
- Astrology is **another example of pseudoscience**.
- A “new” zodiac chart was created by the Minnesota Planetarium Society to reflect the change in the Earth's rotation.

Sign	Old Dates	New Dates
Capricorn	Dec. 23-Jan. 20	Jan. 9- Feb. 15
Aquarius	Jan. 21-Feb. 19	Feb. 16-Mar. 11
Pisces	Feb. 20-Mar. 20	Mar. 12-Apr. 18
Aries	Mar. 21-Apr. 20	Apr. 19-May 13
Taurus	Apr. 21-May 21	May 14-June 19
Gemini	May 22-June 21	June 20-July 20
Cancer	June 22-July 22	July 21-Aug. 9
Leo	July 23-Aug. 21	Aug. 10-Sept. 15
Virgo	Aug. 22-Sept. 23	Sept. 16-Oct. 30
Libra	Sept. 24-Oct. 23	Oct. 31-Nov. 22
Scorpio	Oct. 24-Nov. 22	Nov. 23-Nov. 29
Ophiuchus	Not a Part of the Zodiac	Nov. 30-Dec. 17
Sagittarius	Nov. 23-Dec. 22	Dec. 18-Jan. 8

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Scientific Method

- All scientific studies, regardless of complexity, follow the same series of steps, called the **scientific method**.



Scientific Method

- The first step is making an **observation**.
 - Information gathered by noticing specific details of a phenomenon.
- Dr. Edward Jenner observed that dairymaids who contracted cowpox seemed to be protected from the more deadly smallpox.



The Dairy Maid, 1650s, by Aelbert Cuyp.

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Scientific Method

- The goal is to be able to explain the observation.
- A **hypothesis**, or testable explanation, will be made based on the scientist's prior experience and research.
 - Hypotheses are preliminary explanations – they can and are often proven false.
- Dr. Jenner's hypothesis was that exposure to cowpox would grant immunity to smallpox.
- The hypothesis must be tested.

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Scientific Method

- The **experiment** tests the hypothesis under controlled conditions.
 - A controlled experiment attempts to test a **single variable**, while keeping all others constant.
 - The **experimental group** receives the variable, while the **control group** does not.
- Dr. Jenner's experiment was to inoculate the 8 year-old son of his gardener with fluid from a cowpox pustule, allow the infection to pass, then repeat with a smallpox pustule.
 - The boy (experimental group) survived 20 inoculations without succumbing to smallpox!
- The **conclusion** states whether or not the hypothesis is supported by the results of the experiment.

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Scientific Method

- The final step is **communication**, where the results are published and reviewed by others to check for errors, bias, or other issues.
- Dr. Jenner submitted his study to the Royal Society for Medicine, but was told he needed more proof.



"The Cow-Pock—or—the Wonderful Effects of the New Inoculation!—vide. the Publications of ye Anti-Vaccine Society."
- Satirical cartoon, 1802.

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Other Factors Affecting Experiments

- Accounting for every single variable in a scientific study is nearly impossible. There are many factors that can cause error.
- There is where **probability** comes in. This is the likeliness that a result occurred simply due to random chance.
 - This can be countered by increasing **sample size**, or the number of observations used in an experiment or study.
- Dr. Jenner was able to locate several other parents who were willing to volunteer their children. He even included his own 11 month-old son in the study.
- The results were finally published. Jenner called his technique vaccination after the Latin word for cow "vacca".

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- Controlled experiments aren't always possible or ideal.
- Natural experiments** are conducted in the field under normal circumstances.
 - The advantage is that these experiments take place in a more accurate, realistic environment.
 - The disadvantage is that natural phenomena are often very difficult to find.



Combating Bias

- Another significant problem in science is **bias**; the preference for an experiment to **turn out in a certain way**.
- Bias is not always intentional, but must be controlled by the experimental design.
- A **blind experiment** is conducted so the experimental subjects do not know which is the control and which is the experimental group.
 - Eliminates the "placebo effect"
- A **double-blind experiment** also **prevents the actual scientists** from knowing which is the control or experimental group.

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Scientific Fraud

- There are many examples of published studies or report that have been later found biased, flawed, or outright fraudulent.
- These are always detected, eventually, due to the **scientific method** and **peer review**.
 - The net effect is loss of time, resources, and public mistrust.
- In 1998, Dr. Andrew Wakefield published a study in the British journal *The Lancet* documenting a link between the MMR vaccine and autism in children.
 - In the following year, over a thousand articles were written about the possible link, very few by actual experts in the field.
 - Vaccine rates dropped from 92% to 85% in the U.K., with similar results in other countries.

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Autism / MMR Retraction

- Wakefield's conclusions were found out to be fraudulent and that he had manipulated the data.
- Several outbreaks of measles and mumps occurred across the world from 2002-2008.
- The United States has seen a similar effect, with vaccination rates below CDC recommendations in several schools.



According to a Time Magazine survey, 24% of adults place "some trust" in celebrities' opinions on vaccines.