"Any sufficiently advanced technology is indistinguishable from magic."
--Arthur C. Clarke, "Profiles of The Future", 1961 (Clarke's third law)
English physicist & science fiction author (1917 – 2008)

"[Sherlock] Holmes states that he first developed his methods of deduction while an undergraduate."
--from the Wikipedia article, "Sherlock Holmes"

"By denying scientific principles, one may maintain any paradox."
--Galileo Galilei

Forming Good Hypotheses; A Little Logic

Supplementary Material for
CFB3333/PHY3333/KNW2333
Professors John Cotton and Stephen Sekula

Based on the following information on the web:
http://www.physics.smu.edu/pseudo/Induct/

The Scientific Method
A Brief Review

1) Observation of a phenomenon
2) Formulation of a hypothesis
3) Use of the hypothesis
4) Performance of experiment and reporting of the result
   - hypothesis disproven or upheld?

http://www.physics.smu.edu/pseudo

The Scientific Method
A Brief Review

1) Observation of a phenomenon
2) Formulation of a hypothesis
3) Use of the hypothesis
4) Performance of experiment and reporting of the result
   - hypothesis disproven or upheld?
5) Publish results for review and usage by peers
   - useful ideas withstand independent tests and generate new knowledge

The Purpose of the Scientific Method

To assemble an accurate, reliable, self-consistent, non-arbitrary representation of the world.

The Practice of the Scientific Method

Scientific procedures are standardized to minimize prejudice (“bias”) on the part of the scientist when testing an hypothesis.

The Practice of the Scientific Method

The Scientific Method is carried out collectively by all researchers.

An individual scientific finding can be wrong, but in the long term science is a self-correcting process (wrong ideas generate uselessness, and uselessness is weeded out of scientific practice)

The Scientific Method is an IDEAL toward which all researchers work.

The Scientific Method: What We Will Learn

- Observation of a phenomenon
  - what kind of observations?
  - how reliable are the observations?
- Formulation of an hypothesis
  - how does one begin to form a causal explanation for the phenomenon?
  - what evidence is used to generate the hypothesis?
  - how reliable is the evidence?
- Performance of experiment
  - what means are available for testing different properties or ideas?
  - how does one setup a reliable experiment?
  - how does one gather information from the experiment?

The Scientific Method: What We Will Learn (cont.)

- Publication and review of results
  - what is the venue for publication?
  - how reliable is the venue of publication?
  - is an external review performed by peers with expertise in the area of study?
  - what are the prejudices in the review and publication process?

Making Hypotheses - Induction and Deduction (with examples!)

Induction

The creative part of science:

Make a specific observation and from that state a general hypothesis (make generalizations based on specific observations)

Induction

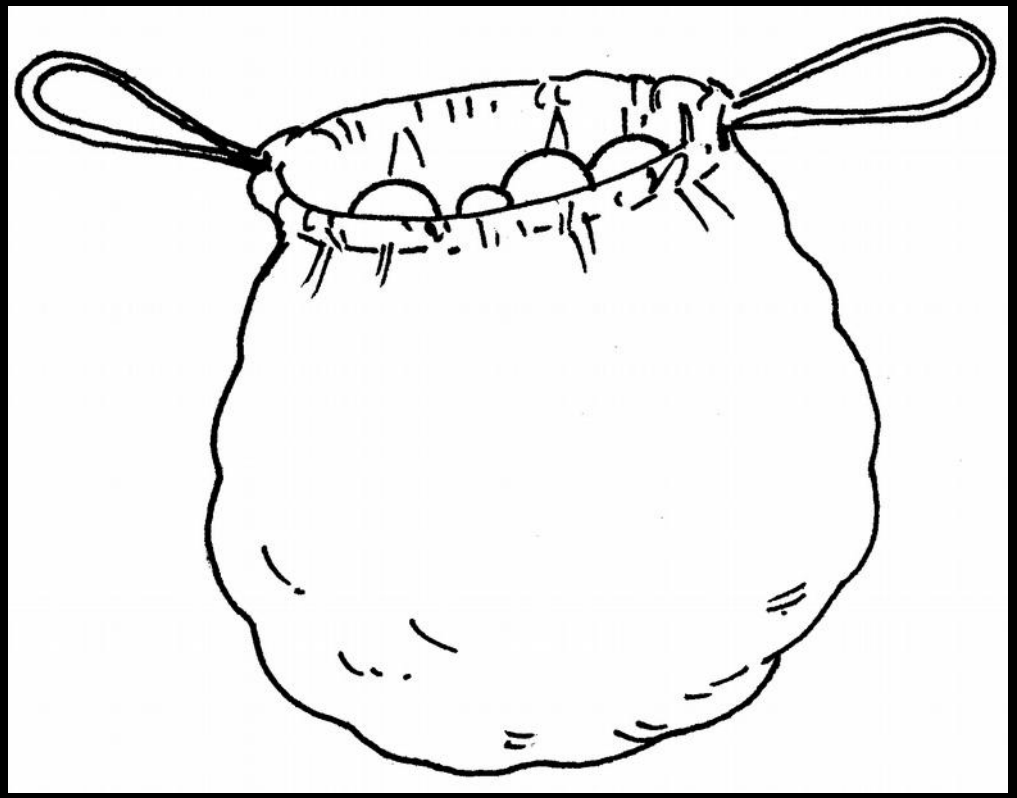
SPECIFIC ->GENERAL

Induction and Natural Science

Natural sciences (physics, chemistry, biology, etc.) are *inductive*.

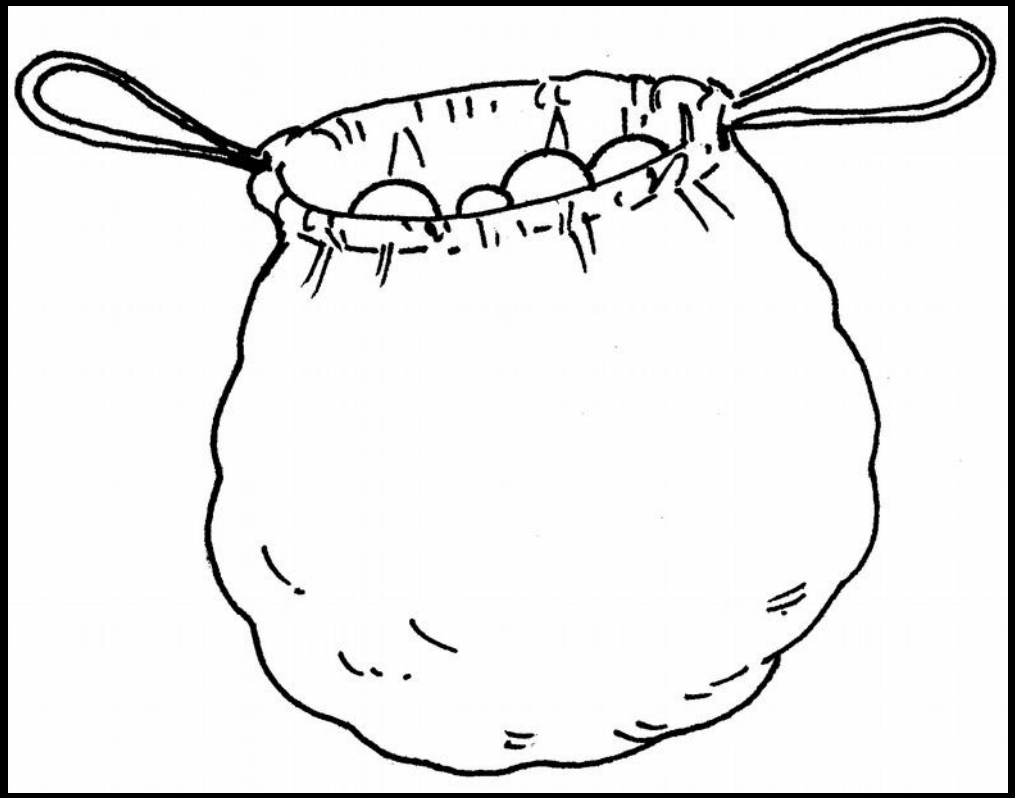
Evidence is collected. The Scientific Method is applied. Start with specific results and try to guess the general rules. Hypotheses can only be disproved, never proved. If a hypothesis withstands repeated trials by many independent researchers, then confidence grows in the hypothesis. All hypotheses are, in principle, tentative; any one could be overturned tomorrow, but very strong evidence is required to overthrow a "Law" or "Fact".

Example of Induction



I have a bag of marbles. I randomly draw 20 marbles from the bag. All of the marbles I draw are the same color.

Example of Induction

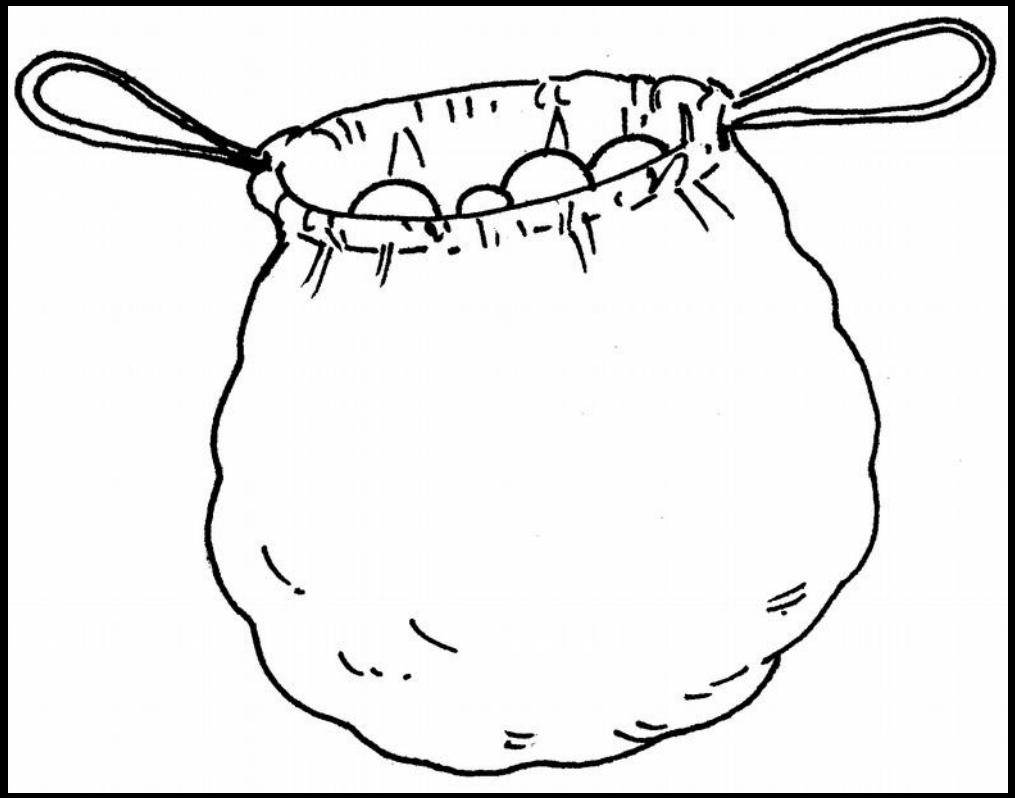


I have a bag of marbles. I randomly draw 20 marbles from the bag. All of the marbles I draw are the same color.

I can now make an inductive proposition:

HYPOTHESIS: all marbles in this bag are the same color (specifically name the color). That explains why drawing 20 at random always yielded a white marble.

Example of Induction



Further sampling is required to test the hypothesis. All it takes is one differently colored marble to overturn my hypothesis, requiring me to amend it.

NOTE: in this thought experiment, we have a rare example of a case where the hypothesis can be absolutely proven: I can dump out all the remaining marbles and see if they are all the same color!

Deduction

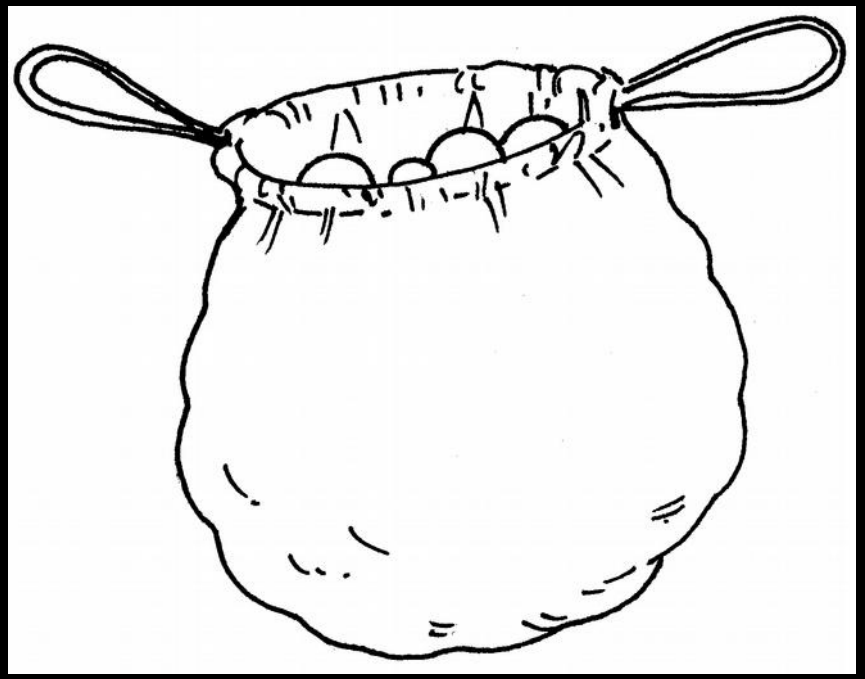
Begin with a general rule and make specific predictions

conclusions follow from a set of premises or hypotheses

Induction

GENERAL -> SPECIFIC

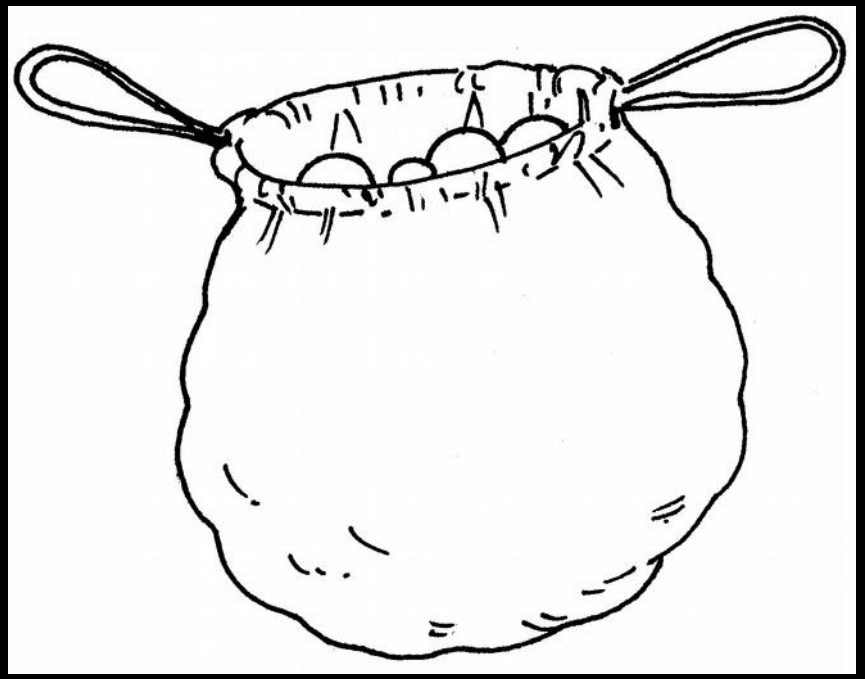
Example of Deduction #1



- We have a large bag of marbles
- *All of the marbles in the bag are white*
- I have a random sample of 20 marbles taken from the bag

Question: what can I deduce about the random 20 marbles?
(what specific claim can I make based on the original general statement?)

Example of Deduction #1



- We have a large bag of marbles
- *All of the marbles in the bag are white*
- I have a random sample of 20 marbles taken from the bag

Restating the example:

If a marble comes from this bag, it will be white.
I have a marble from this bag.
Therefore, it is white.

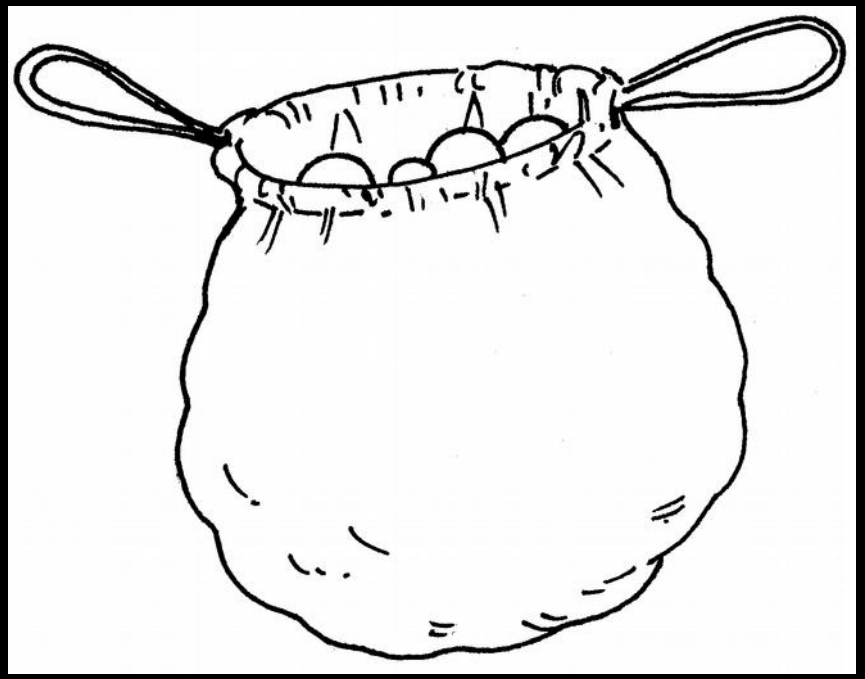
Example of Deduction #1

This kind of reasoning is called “modus ponens,” from Latin and meaning “the way that affirms by affirming.”

In a logical form, *modus ponens* can be framed as:

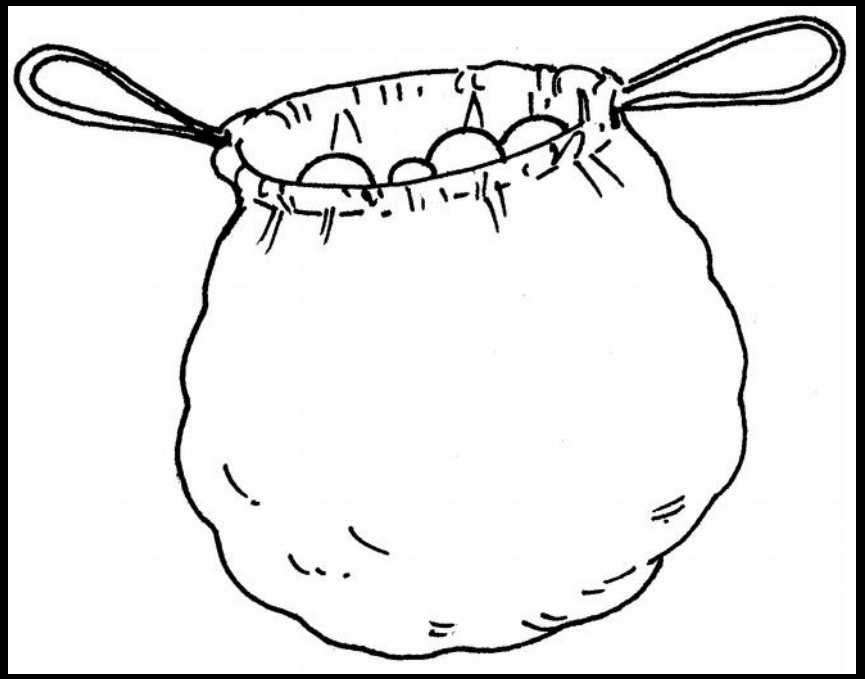
If P, then Q
P
Therefore, Q

Example of Deduction #2



- We have a large bag of marbles
- All of the marbles in the bag are white
- I have a random sample of 20 marbles (I don't know if they are from the bag or not) that are multi-colored

Example of Deduction #2



- We have a large bag of marbles
- *All of the marbles in the bag are white*
- I have a random sample of 20 marbles (I don't know if they are from the bag or not) that are multi-colored

Restating the example:

If a marble comes from this bag, it will be white.
I have a marble that is not white.
Therefore, it is not from this bag.

Example of Deduction #2

This kind of reasoning is called "modus tollens," from Latin and meaning "the way that denies by denying."

In a logical form, *modus tolens* can be framed as:

If P, then Q
not Q
Therefore, not P

Class Poll

Classify the following statement: *All cars have wheels. This object has wheels. Therefore, it is a car.*

A) Modus Ponens: the way that affirms by affirming.
B) Modus Tolens: the way that denies by denying.
C) Neither: this is a logically inconsistent statement.

http://www.physics.smu.edu/pseudo

This has wheels, but it is not a car!

Incorrect ways of arguing

- If P then Q. Not P. Therefore, not Q.
  - example: if it is a car, it has wheels. It is not a car. Therefore, it does not have wheels.
- If P then Q. Q. Therefore P.
  - example: if it is a car, it has wheels. It has wheels. Therefore, it is a car.

Class Poll

Classify the following statement: *If blue is bleet, it will rain on Tuesday. It did not rain on Tuesday. Therefore, blue is not bleet.*

A) Modus Ponens:
if P then Q, P. Therefore Q.
B) Modus Tolens:
if P then Q. Not Q, Therefore, not P.
C) Neither:
this is a logically inconsistent statement.

Class Poll

Classify the following statement: *If blue is bleet, it will rain on Tuesday. It did not rain on Tuesday. Therefore, blue is not bleet.*

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C) Neither:
this is a logically inconsistent statement.

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DIFFERENT WAYS OF ARGUING

Aristotelian Method

(Aristotle: 384-322 B.C.)

Argument by authority: here is the way I see it, everybody listen!

Some things he said seem reasonable:

All Earthly objects tend to rest -- their natural state.
All celestial objects remain in circular motion forever.

But other things he said make no sense today:

"Males have more teeth than females in the case of men, sheep, goats, and swine; ..."
Aristotle online -- The History of Animals 350 BCE

Heavier objects fall faster than light ones, in proportion to their weight.

How about an experiment to test these arguments? Do they pass a self-consistency test?

If your theory is not self-consistent, or your theory disagrees with careful experiments, then your theory is wrong. It doesn't matter how beautiful the theory is; it's wrong.

Galilean Method

(Galileo Galilei: 1564-1642)

Argument by evidence: experiment is the only way to gather objective evidence, upon which argument should be based.

He greatly improved the telescope. He profited by selling his telescopes and designs to merchants. Thanks to his profits and the support of a wealthy patron, he was free to pursue fundamental research (research for the sake of learning). He was the first to observe moons orbiting Jupiter, to see the phases of Venus, to realize that the moon had mountains and craters, and to see sunspots.

Based on these observations, he argued that the Earth cannot be at the center of the cosmos; rather, the Earth and other bodies orbited the Sun.

Galilean Method

(Galileo Galilei: 1564-1642)

Argument by evidence: experiment is the only way to gather objective evidence, upon which argument should be based.

Galileo's conclusion contradicted the widely held belief, based on "common sense" and Biblical scholarship, that the Earth was the center of the cosmos. For his arguments, and his publications, he was brought before the Inquisition and forced (on penalty of death) to recant his "opinion" and affirm the word of the Bible. He was placed under house arrest for the remainder of his life. Ironically, while under house arrest he revisited some old work he had abandoned and began to write down the laws of motion. These were formalized by Sir Isaac Newton, who was born in the same year Galileo died.

Galileo's major publication, containing all his data and arguments, was entitled "Dialogue on the Two Chief Systems of the World." It was formally removed from the Vatican's banned books list in 1835. Pope John Paul II apologized for the "Galileo affair" in 1992, referring to it as a "tragic mutual incomprehension."

http://www.physics.smu.edu/pseudo

Apollo 15 Mission (1971): http://www.youtube.com/watch?v=5C5_dOEyAfk