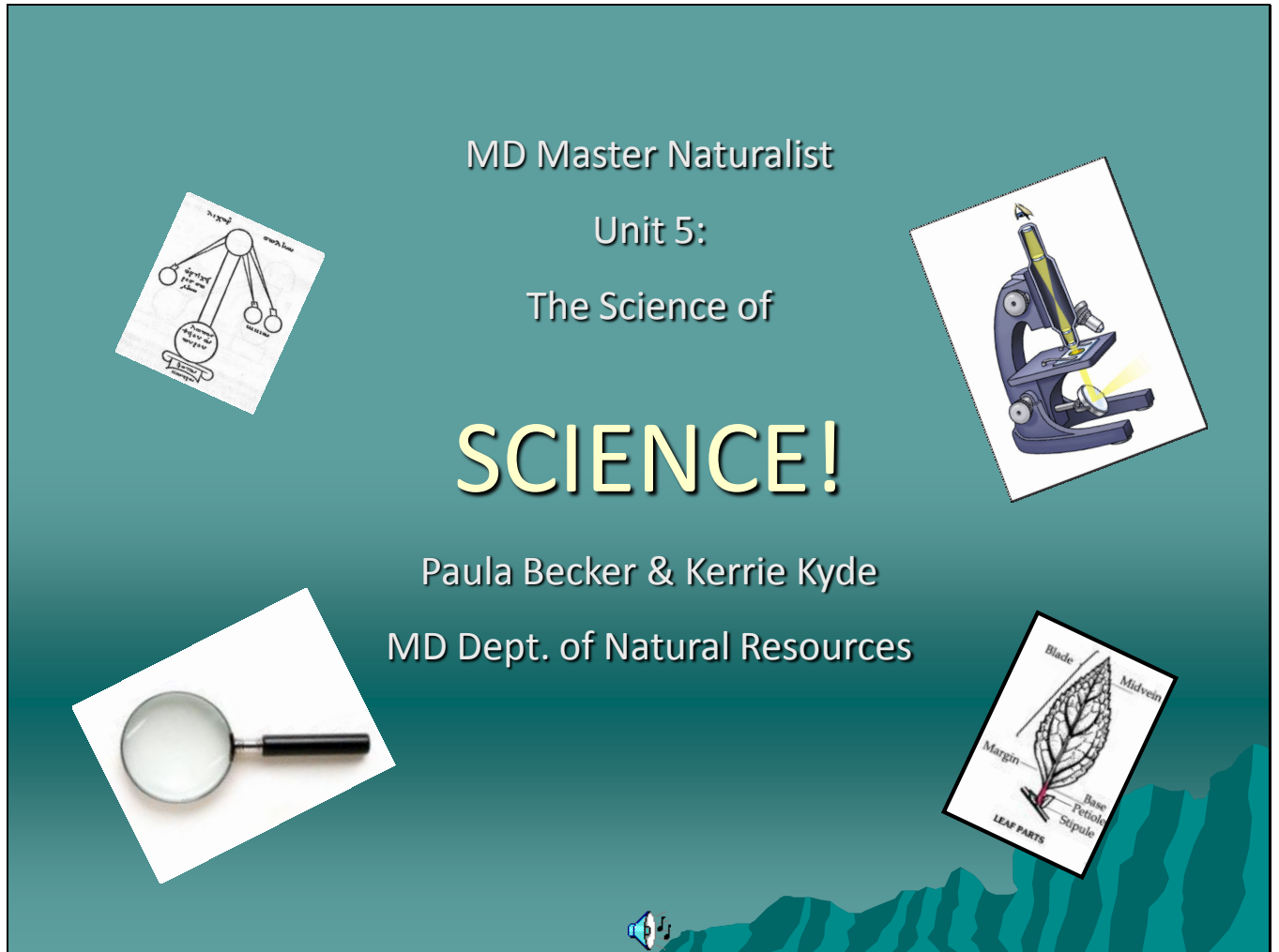


Unit 5: Science – Pre-Reading

Paula Becker

Slide 1




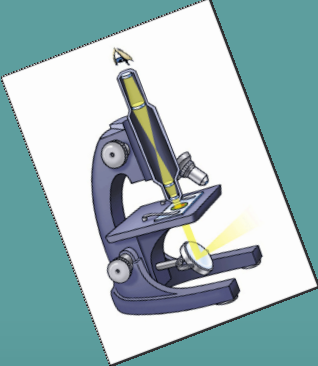
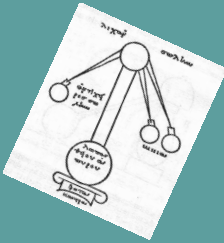


MD Master Naturalist

Unit 5:
The Science of

SCIENCE!

Paula Becker & Kerrie Kyde
MD Dept. of Natural Resources



Unit 5: Science – Pre-Reading

Paula Becker

Slide 2

What is Science?

What Science is NOT -

- concerned with the supernatural or metaphysical
- static
- unlimited
- existing in a cultural or social vacuum
- a collection of facts

“Science is built up of facts, as a house is with stones. But a collection of facts is no more a science than a heap of stones is a house.”

Jules Henri Poincaré (1854 – 1912)

Mathematician, Physicist, Philosopher


What are some things Science is NOT?

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Slide 3

Science is...



- ◆ Concerned with the natural world
- ◆ A *set* of knowledge
- ◆ A *process* of acquiring knowledge
- ◆ Evidence-based
- ◆ Testable

Science comes with a set of defined characteristics and specialized precise vocabulary.


Unit 5: Science – Pre-Reading

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Slide 4

3 Flavors of Science
(Mmmmm, Science...)

- Practical
- Theoretical
- Empirical

A three-scoop ice cream cone is centered in the lower half of the slide. The scoops are pink, vanilla, and chocolate, stacked from top to bottom on a light brown wafer cone. The background of the slide is a teal gradient with a stylized mountain range silhouette at the bottom right.

One Definition: “Our *knowledge* of the natural world and the *process* through which that knowledge is built. The process of science relies on the testing of ideas with evidence gathered from the natural world. Science as a whole cannot be precisely defined but can be broadly described by a set of key characteristics.” Understanding Science, UC Berkeley

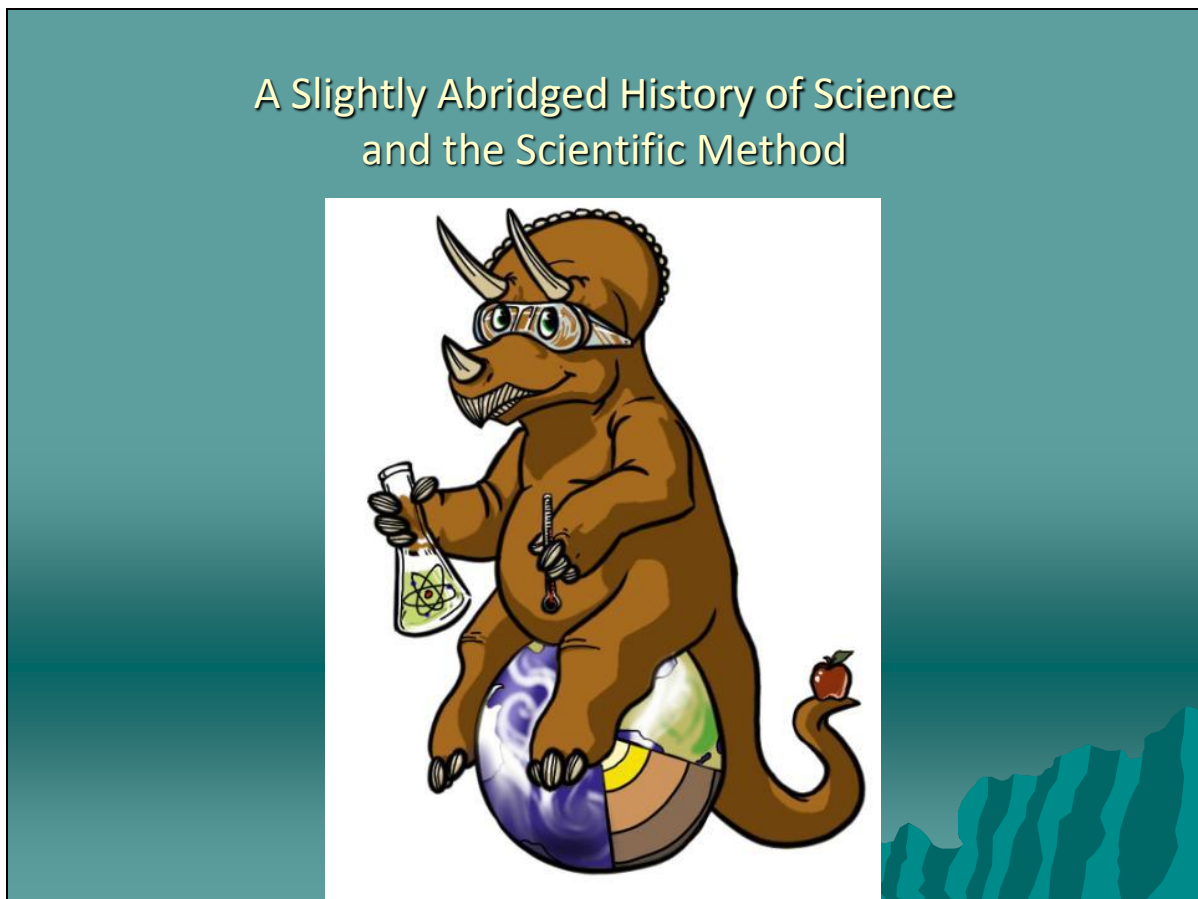
Science can be:

- Practical: knowledge put into practice, also called “applied”
- Theoretical: knowledge used in analysis, contemplation or speculation based on measurable information, as opposed to action.
- Empirical: knowledge gained from observation, experience or experimentation. May be practically used or theoretically analyzed

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Slide 5



So when did this Human construct we call science begin?

People have been wondering about their surroundings since there were people with frontal lobes advanced enough to wonder. But Science, by definition, requires some evidence of its process. So we usually date the early records to around 3500 BCE, Mesopotamia. These early people were more like mechanics and engineers. They measured the changes in seasons, noticed the placement and movement of stars, recorded flood levels of rivers, noted which plants were edible or medicinal. They even recorded their findings on stone tablets or papyrus.

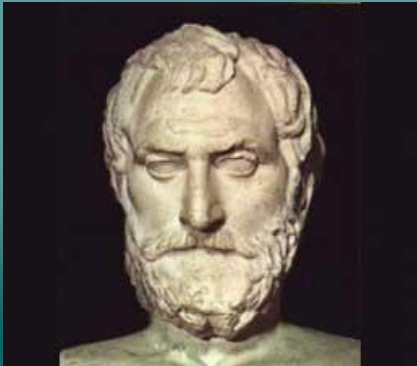
But their methods of measuring were not always standardized and they didn't have the algebra and geometry to make predictions based on trends. We wouldn't have called them Scientists (that term didn't even make it into the lexicon until the 19th century). But we may have called their children Natural Philosophers.

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Slide 6

**Science Before 400 CE:
The Ancient Geeks – The Age of the Beard**



Thales of Miletus
c. 624 – c.546 BCE

“Western Philosophy begins with Thales”
Bertrand Russell

- Defined certain general principles of thought and logic
- Started investigations with a defined question (**Hypothesis**)
- First to suggest non-supernatural explanations for natural phenomena

Disclaimer: This is concerned with the historical evolution of what became known in the West as Scientific Method. It is not that Eastern civilizations didn't practice science but as Joseph Needham said in his 1954 book "Science and Civilization in China": It was not that there was not order in nature for the Chinese, but rather that it was not an order ordained by a rational personal being, and hence there was no conviction that rational personal beings would be able to spell out in their lesser earthly languages the divine code of laws which he had decreed aforetime. The Taoists, indeed, would have scorned such an idea as being too naïve for the subtlety and complexity of the universe as they intuited it."

It also may be due to:

- 1) Who was writing the histories?
- 2) The desire, or lack thereof, to share knowledge or credit
- 3) Most of the info I found on Eastern science has Asian scientific practices dating to about the same time as Greek (5-6th cent BCE), but Asians seemed less likely to pass along their findings as if they were the basis of all order and method, as the Greeks were.

The Father of Science

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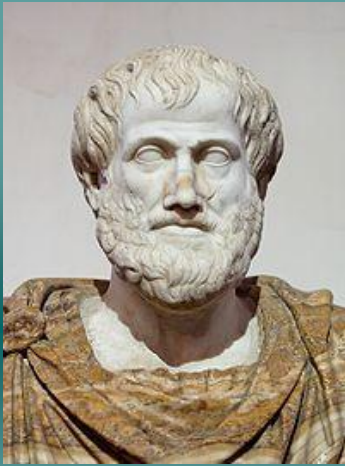
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Pre-scientific history – before the development of a standardized method

Thales – first mathematician – used geometry to calculate distances, non-supernatural explanations (earthquakes = earth floats on water, wave rocks earth)

Slide 7

Aristotle,
and his alt-rock band,
The Socratic Thinkers
384 – 322 BCE



- Relied on deductive reasoning and thought experiments
- Little empirical investigation

Scientists v. Natural Philosophers

The Socratic thinkers: Socrates, Plato, Aristotle – came up with systematic discussions of natural phenomena. Primarily deductive reasoning but some early physical investigations of anatomy, zoology, botany, mathematics. Some of Aristotle's early statements were correct: "the sun is larger than the earth". Some needed more investigation: "men have more teeth than women." Seriously?

Natural Philosophy at the time included many topics we would now call: physics, metaphysics, poetry, theatre, music. Logic, rhetoric, astronomy, politics, government, ethics, biology, morality, botany, zoology and more. Aristotle was considered "the last man to know everything there was to be known in his own time. But he was primarily an expert in logic and qualitative observation. There was little quantitative research. Mathematics of the time was not developed enough to allow for empirical analysis of questions. Aristotle thought about stuff but rarely tested it.

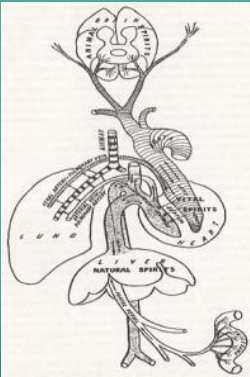
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Part of the problem was also the lack of equipment needed to measure concepts like speed, temperature, time. It wasn't until the Renaissance and the 16th century that mathematics caught up with theoretical science.

Slide 8

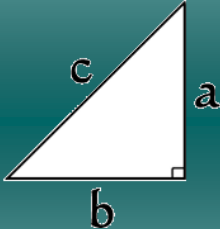
Early Mathematics, Invention and Alchemy

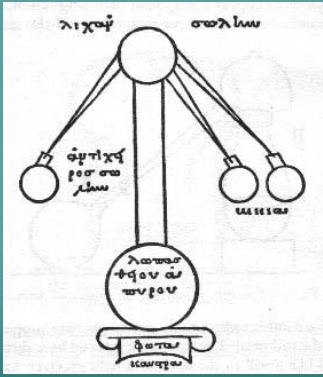


Galen's Gut

Pythagoras
Tortures School
Children For
Years to Come

$a^2 + b^2 = c^2$





Mary Gets Cookin'
in the Laboratory

So what was happening between Aristotle in the 4th cent BCE and the Renaissance?
Alchemy and Invention

This was a time for practical applications of science. Galen (2nd cent BCE) began early dissections and traced the organs of the human body, Pythagoras was developing his theorem, and a nice girl from Alexandria (maybe) was coming up with some handy gadgets for the kitchen.

Mary the Jewess, also called Maria Prophetissima, Maria Hebraea, or Miriam the Prophet was busy in the 1st cent CE (maybe) inventing devices for separating compounds by boiling point (an early still) useful for making medicines, perfumes and incenses. She also came up with a tool to

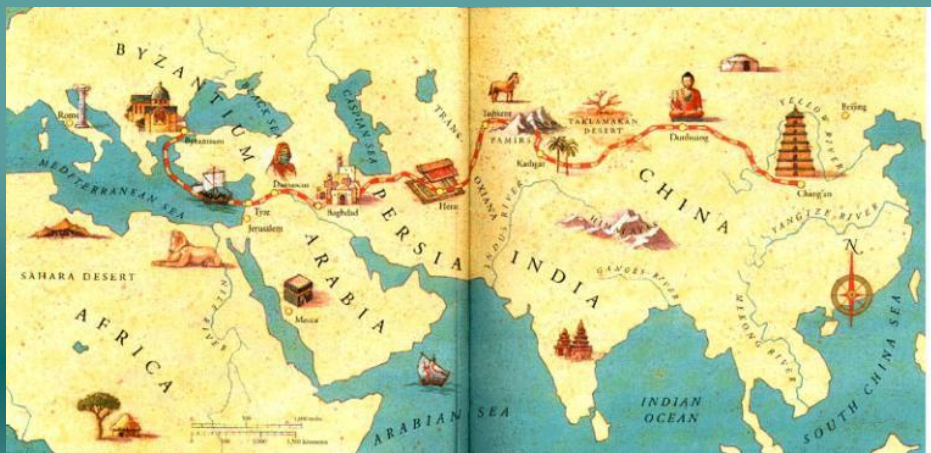
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allow compounds to boil gently and to heat to a constant temperature. Anyone who has ever used a double boiler to melt chocolate can thank the inventor of the Bain Marie.

Slide 9

The Middle Ages (5th cent. – 16th cent.): Fun, Travel, Develop a Scientific Method



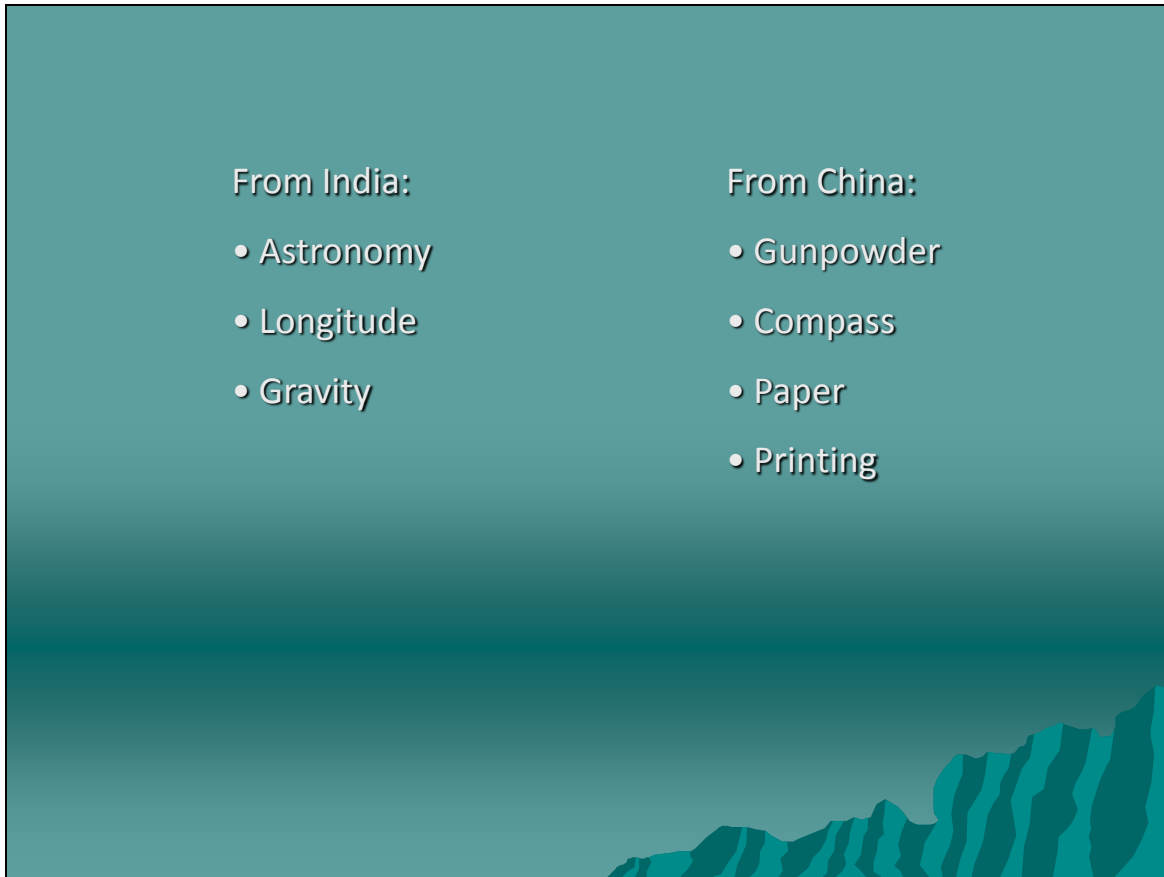
The Silk Road: 202 BCE – 1500 CE

Things were happening east of Greece (who knew there was any place east of Greece?) and with the increase in travel, both by land and by sea, these eastern inventions and concepts began to trickle west. Especially once Europe came out of its mini-ice age between 500 and 800 CE.

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Slide 10



In India, where they followed a similar heliocentric form of the solar system as the Greeks, they were calculating the circumference of the earth (which apparently is round), developing lines of longitude (crucial for sea travel), and had worked out some fairly accurate models of gravity (which weren't described in Europe until Galileo did it nearly 1000 years later).

From China came the 4 Great Inventions. So much of what comes later will build on these 4.

"Printing, gunpowder and the compass: These three have changed the whole face and state of things throughout the world; the first in literature, the second in warfare, the third in navigation; whence have followed innumerable changes, in so much that no empire, no sect, no star seems to have exerted greater power and influence in human affairs than these mechanical discoveries."
Sir Francis Bacon in Novum Organum (1620)


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Slide 11

From the Middle East:

- ◆ Algebra
- ◆ Experiment w/a Control
- ◆ Measurement



Alhazen
965 CE – 1040 CE

From the 11th century Persia and Arabia comes the Father of Optics, Abu Ali Al-Hasan ibn al Hasan ibn al Haytham, aka Alhazen. His specialties included: MATHEMATICS, PHYSICS, ASTRONOMY, ANATOMY, OPHTHALMOLOGY, ENGINEERING, and PSYCHOLOGY ETC. Often called the First Scientist, he was an Egyptian civil servant. He developed the pinhole camera. Was known for his systematic experimentation with a control group.

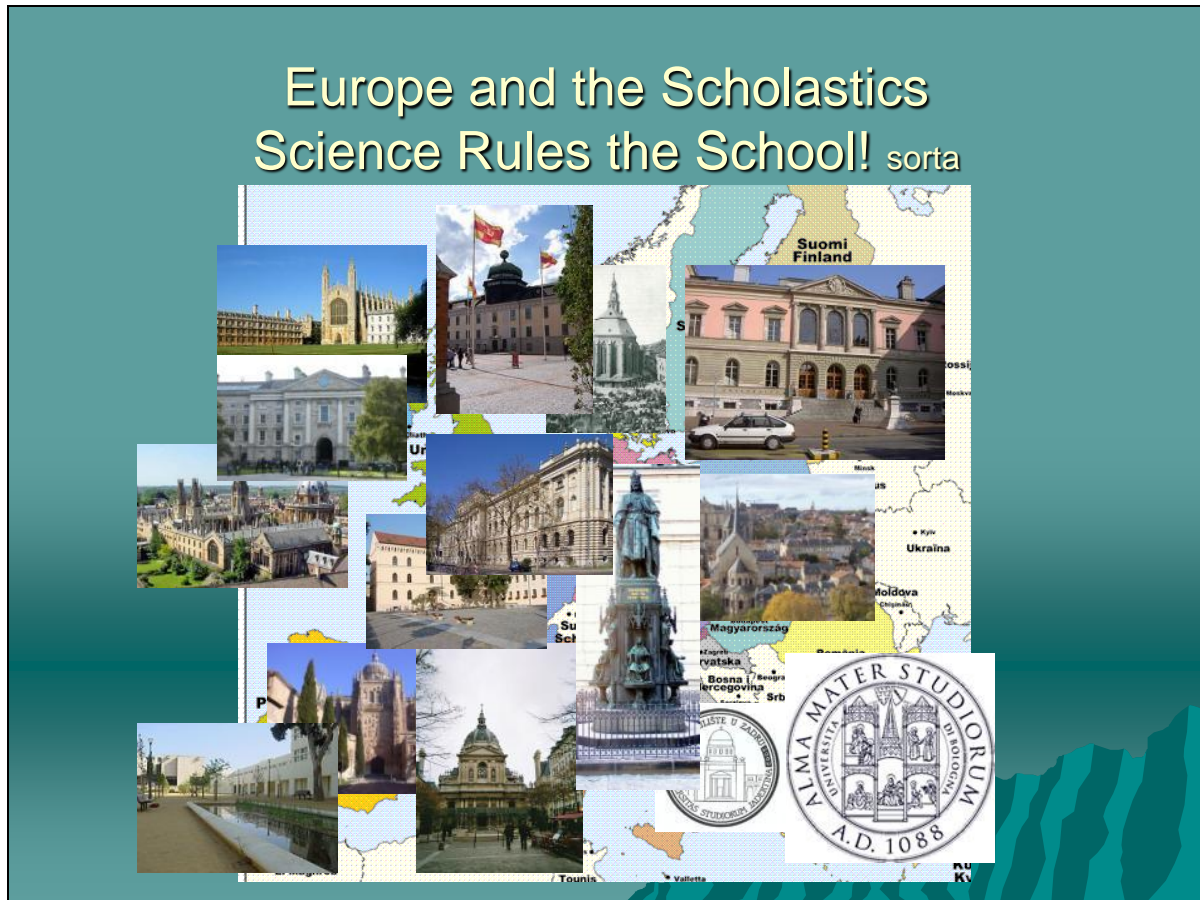
A favorite of his writings (which are numerous ~200): Influence of Melodies on the Souls of Animals – he measured the pace of camels when different music was played. Faster music = faster camel. Slower music = slower camel. No music? Surly camel. That's the control.

The knowledge of the East began to move west into Europe as people moved back and forth in large numbers, due to trade, wars and disease.

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Universities began popping up like mushrooms: 93 universities between 11th cent (Bologna) and 16th cent: University of Dublin and Marischal College Aberdeen Scotland

A scientific expansion had begun, sort of. Influenced heavily by Aristotle, university curricula of Scholasticism emphasized the reliance upon previous works and gave authority to the ancients. They emphasized deductive reasoning and observation but did not encourage new empirical investigation. More people were studying science but they weren't bringing much new thought to it. A small step backward.

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Slide 13

Religious, Cultural, and GeoPolitical Influences



Roger Bacon
c. 1213 - 1294

- Franciscan friar
- Product of the “new” university system (Oxford)
- Balked against the “tradition of authority” or Scholasticism
- Empiricist

Black Death – 1348 – 1350 CE
Fall of Constantinople – 1453 CE

Along came Roger Bacon, an early proponent of the new style. He learned Latin, Greek, and Arabic, probably Hebrew so he could read the new texts in their own languages (he didn't trust the translations). Specialized in Optics, Astronomy and Mathematics. Heavily influenced by Alhazen, he firmly believed in empirical observations and experiments.

The arrival from the East of the Black Death in Europe in 1347, especially around Italy in 1348, slowed down the expansion of science for a time (a little over 100 years). The Fall of Constantinople in 1453 released a flood of Byzantine refugees westward. And they brought as much of their libraries as they could carry.

Science was becoming more reliant on peer review. People were reading each other's works and always had something to say about it.

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This was also the time when we learn about Publish or Perish (although sometimes, depending on who was providing the funding, it was publish AND perish. See Fr. Giordano Bruno, Galileo Galilei)

Based on: *Roger Bacon and the Sciences: Commemorative Essays*. Edited by Jeremiah Hackett. 1997. Leiden, New York. 439 pp.

Bacon studied and later became a Master at Oxford, lecturing on Aristotle. There is no evidence he was ever awarded a doctorate — the title *Doctor Mirabilis* was posthumous and figurative. Sometime between 1237 and 1245, he began to lecture at the University of Paris, then the center of intellectual life in Europe. His whereabouts between 1247 and 1256 are uncertain, but about 1256 he became a Friar in the Franciscan Order. As a Franciscan Friar, Bacon no longer held a teaching post, and after 1260 his activities were further restricted by a Franciscan statute forbidding Friars from publishing books or pamphlets without specific approval.

Bacon circumvented this restriction through his acquaintance with Cardinal Guy le Gros de Foulques, who became Pope Clement IV in 1265. The new Pope issued a mandate ordering Bacon to write to him concerning the place of philosophy within theology. As a result Bacon sent the Pope his Opus Majus, which presented his views on how the philosophy of Aristotle and the new science could be incorporated into a new Theology. Besides the *Opus maius* Bacon also sent his *Opus minus*, *De multiplicatione specierum*, and, perhaps, other works on alchemy and astrology.

Pope Clement died in 1268, and sometime between 1277 and 1279, Bacon was placed under house arrest by Jerome of Ascoli, the Minister-General of the Franciscan Order. Bacon's difficulties are probably related to the Condemnations of 1277, which banned the teaching of certain philosophical doctrines, including deterministic astrology. Sometime after 1278 Bacon returned to the Franciscan House at Oxford, where he continued his studies.

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The Scientific Revolution – 1543

The Beginning of Modern Science

Began with the Publication of 2 works:

On the Workings of the Human Body – Andreas Vesalius

On the Revolutions of the Celestial Spheres – Nicolaus Copernicus

- Both results of posing a question, investigation and research using measurements
- Represented a shift from the more common Aristotelian methods of deductive reasoning to quantitative investigations

1543 - Beginning of Modern Science

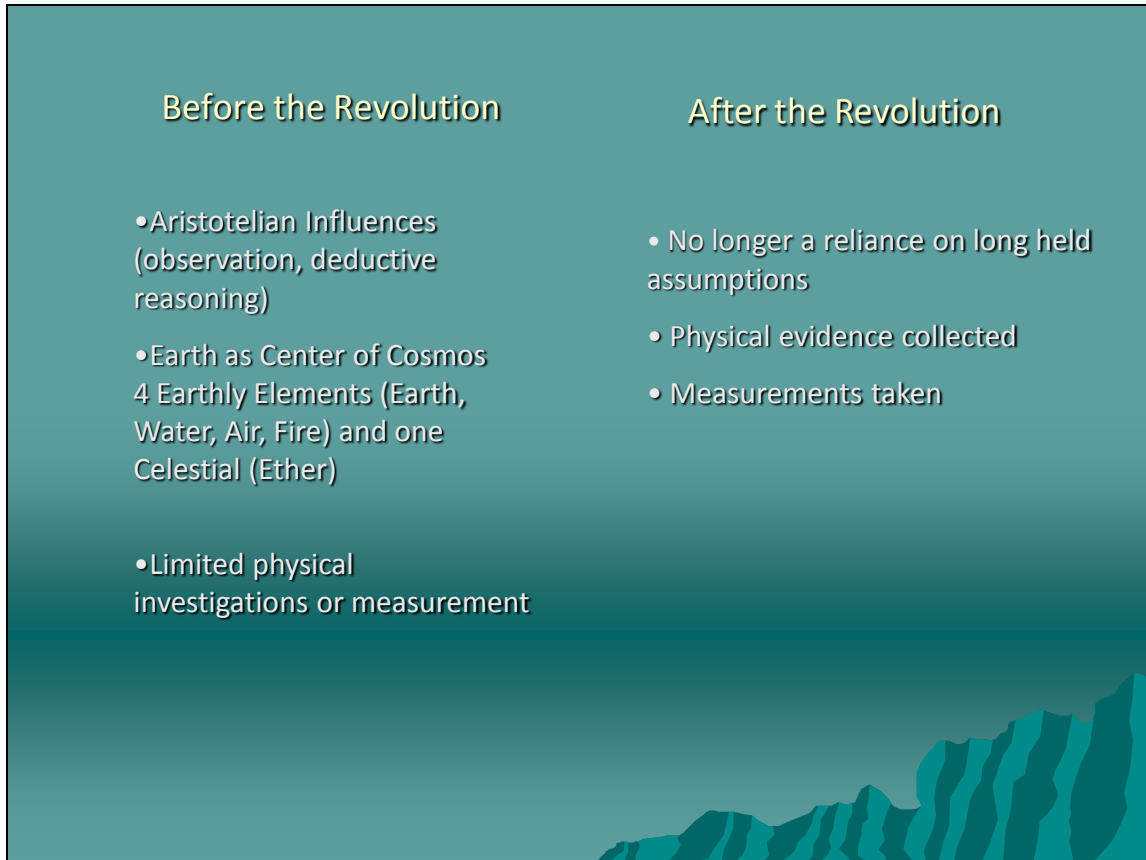
Vesalius' work went against much of Galen's texts – more dissections, study of processes

Copernicus relied heavily on the pre-crusade texts of the Middle East and Asia (not earth centric – oops)

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Slide 15



Before the Revolution	After the Revolution
<ul style="list-style-type: none">• Aristotelian Influences (observation, deductive reasoning)• Earth as Center of Cosmos 4 Earthly Elements (Earth, Water, Air, Fire) and one Celestial (Ether)• Limited physical investigations or measurement	<ul style="list-style-type: none">• No longer a reliance on long held assumptions• Physical evidence collected• Measurements taken

This was a change in the basic process of thought and it was a product of the general upheaval of the times: religious, political, cultural – which it also fed.

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Rene Descartes (1596 – 1650 CE)
- *Discourse on the Method* (1637)
establishes the Scientific Method



Isaac Newton – (1643 – 1727 CE)
- coupled scientific theory with rigorous experimentation,
became the model for HOW science is done

(Age of Reason / Age of Enlightenment / Age of Big Hair:
17th – 19th centuries)
- A change in the basic system of thought
- Reflects the social/religious/political upheaval AND feeds it

17th Century Empiricism – The Age of Reason and its Mini-Age of Enlightenment (and big hair)

The 17th Century was roughly the start of Science the way we think of it now. It was a new set of ideas and values:

- It was the culmination of the process of detachment of philosophy from theology
- It left the Scholastic approach behind (new thought systems not originally proposed by the Academics; what was “reason”able).

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- Was not limited to scientific thought. It also permeated cultural institutions and societies
 - Critical questioning of tradition in customs, political institutions, with a strong belief in science and rationality
 - This was the era of the American Revolution, Haitian Revolution, height of the Polish-Lithuanian Commonwealth, etc.
 - Documents influenced by Enlightenment include: US Declaration of Independence, US Constitution, French Declaration of the Rights of Man and the Citizen

Science was no longer the sole domain of philosophers. The study of natural history became popular with the upper classes. Social ideas based on scientific principles began to develop. This gave birth to places to chat; there was a rise in the popularity of Coffee houses, debating societies, professional journals, salons, etc.

Science began to seep in to the public vernacular. It began to be the accepted basis for actions.

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19th and 20th Centuries – Modern Science

- A change in how science is done/funded/ received
- Professionalized (RAS, AAAS, etc)
- Institutionalized – funded primarily through universities, government grants (public funding!)
- Expansion into new fields – Geology, Quantum Physics, Ecology
- Natural Sciences (biology, zoology, botany) – refinement of techniques, increase in complexity (Hello, Carl Linnaeus)
- A return to the old ways? It's not done yet!

Darwin studied to be a geologist, trained himself as a botanist. Regarded as a scientist surely, but usually called a Naturalist. Brilliant theoretician.

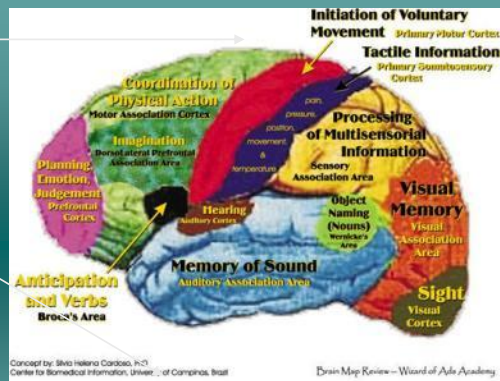
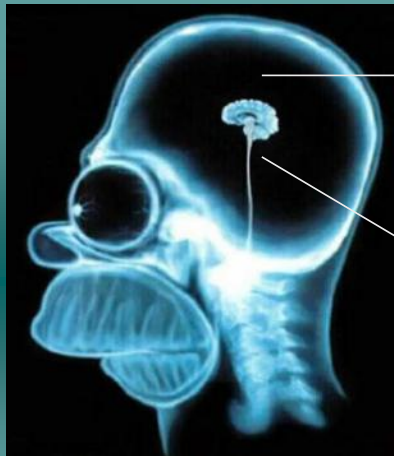
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Slide 18

Critical Thinking (Aristotle was RIGHT!)

<http://www.criticalthinking.org/>



A Definition:

Critical thinking is the art of analyzing and evaluating thinking with a view to improving it.

The Result:

A well cultivated critical thinker:

- Raises vital questions and problems, formulating them clearly and precisely;
- Gathers and assesses relevant information, using abstract ideas to interpret it effectively;
- Comes to well-reasoned conclusions and solutions, testing them against relevant criteria and standards;
- Thinks open-mindedly within alternative systems of thought, recognizing and assessing, as need be, their assumptions, implications, and practical consequences; and communicates effectively with others in figuring out solutions to complex problems.

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Critical thinking is, in short, self-directed, self-disciplined, self-monitored, and self-corrective thinking. It requires rigorous standards of excellence and mindful command of their use. It entails effective communication and problem solving abilities and a commitment to overcoming our native egocentrism and sociocentrism.

Some qualities to cultivate:

Methods of Reasoning

Recognizing Assumptions

Striving for Clarity, Accuracy, Precision, Depth, Intellectual Humility and Courage

(to name a few)

Take some time to peruse this site. It contains effective suggestions for all ages and grade levels.

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Slide 19

Why do we need this?

Recent studies show...

- “Chinese Wolfberries May Improve Vision Impairments Caused by Type II Diabetes” – Science Daily, April 2010
- “Herbal Medicines May Be Lethal, Pathologist Warns” – Yahoo News, March 2010
- “Cola Causes Bone Loss” – ABC News, Oct. 2006
- “Effects of Seltzer on Calcium Leaching from Bones Negligible” – NY Times, July 2010
- Cold Fusion, Anyone?



The slide features three images at the bottom. On the left is the logo for 'CSI: Crime Scene Investigation' with a magnifying glass. In the center is a circular portrait of a woman with short grey hair. On the right is the cover of the TV show 'Bones', featuring the two main characters.

All of these headlines were taken from various mass media outlets or public-targeted specialty sources: Washington Post, Yahoo News, and Science Daily

NPR Spring 2010, an article on a statistical cluster of cancer patients in Florida. Residents are demanding evidence of an environmental cause. Local Government is directing research but as one researcher said, “A cancer cluster is a statistical phenomenon but there is no guarantee it is caused by environmental toxins. Without thorough investigation, we don’t know if the correlation of cancer cases is causative or coincidental.”

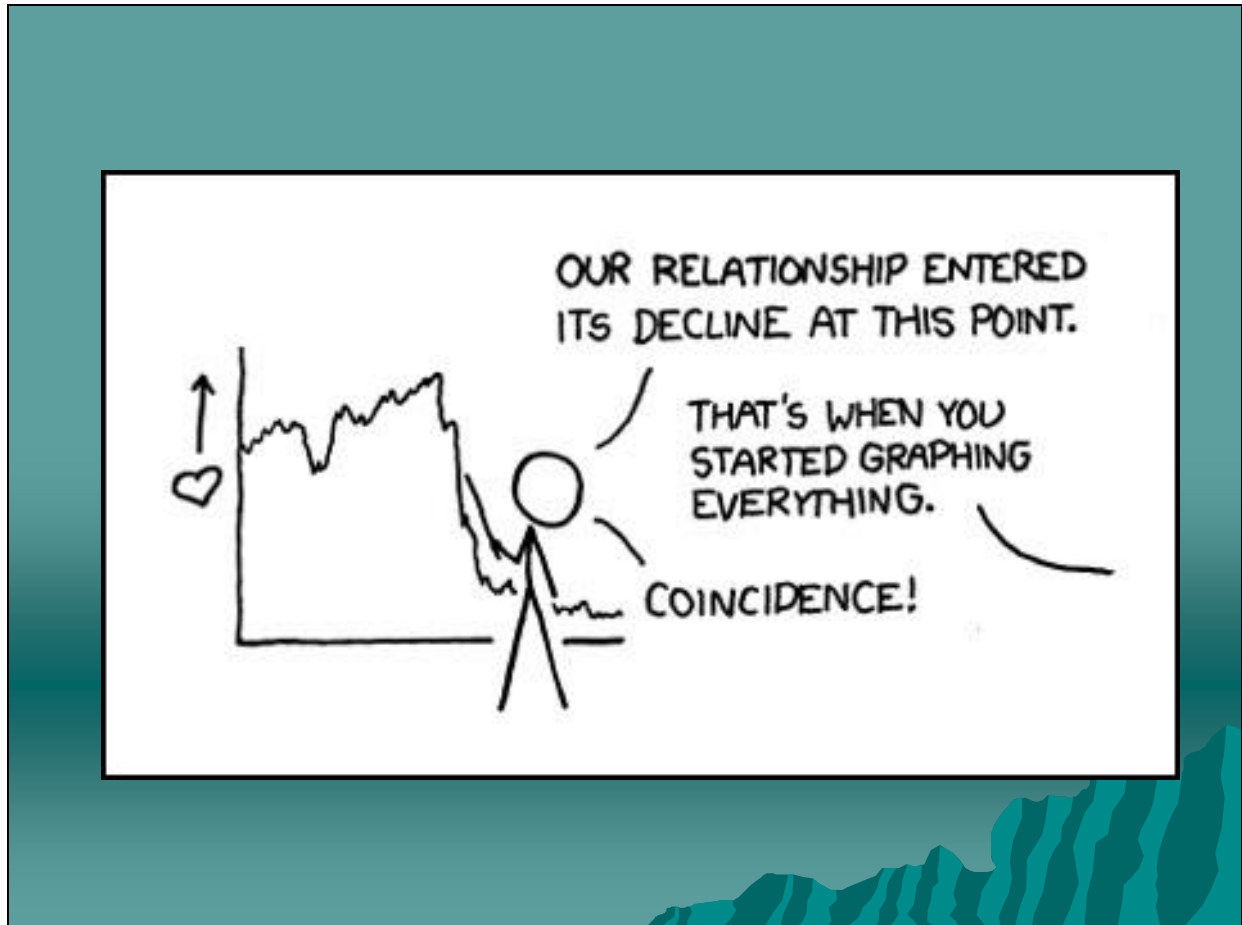
Science has seeped into the daily fabric of the general population. It is no longer isolated in the ivory (or granite) towers. But without a firm grounding in the methods of science, we could waste money and time, or risk health and the environment.

Images: Left to Right - CSI: Crime Scene Investigation, CBS – most popular drama on TV several years running. Derek Jacoby as Brother Cadfael, protagonist of series of books by Ellis Peters; a 12th cent. Monk and herbalist who solves crimes based on botanical cues. Bones, Fox TV – yet another forensic procedural. FBI cop and forensic pathologist solve crimes in the nation’s capital.

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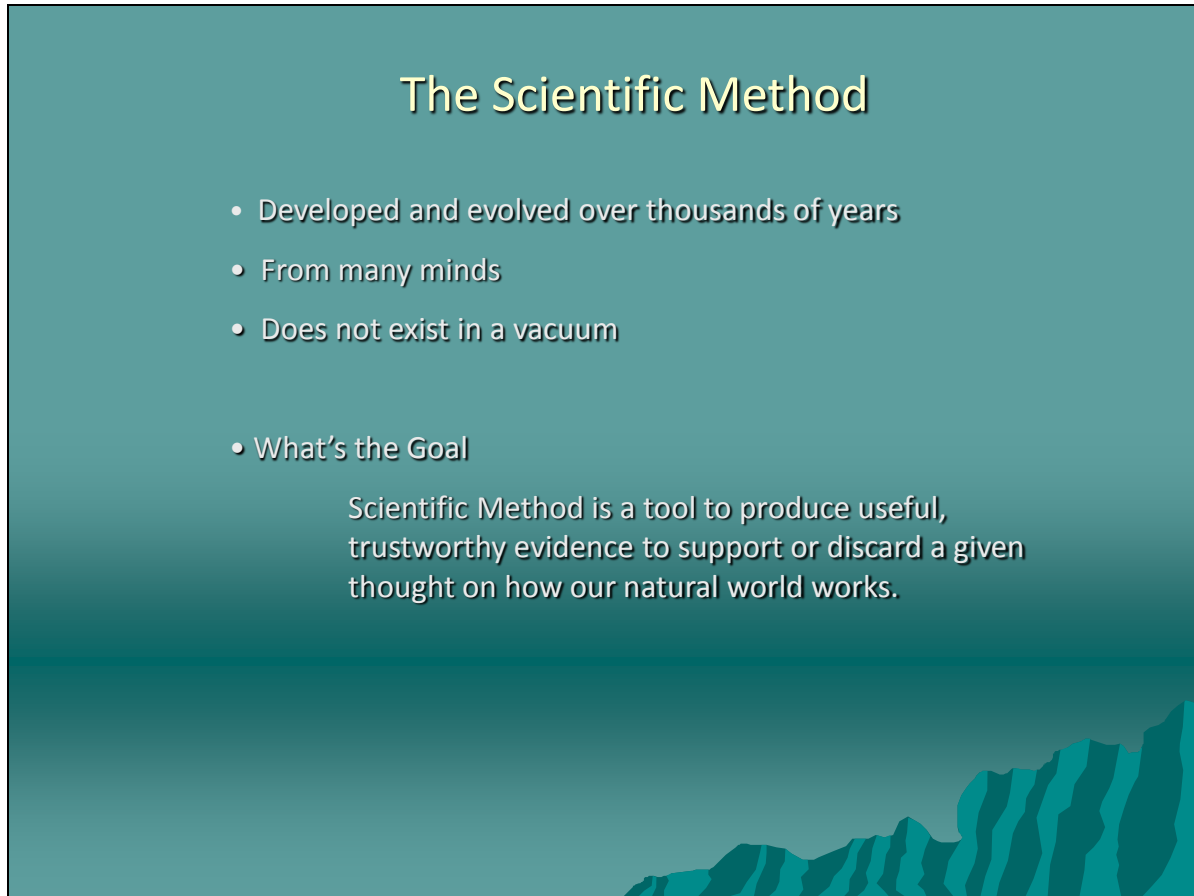


As in the Age of Enlightenment, Science pervades everything we do, whether we are aware of it or not. Popular culture, relationships, finance, sports, everything. And yet there is an appalling lack of Scientific Literacy, an understanding of how science and scientific methodology are incorporated into our thoughts. We hope to remedy that by training you all to train others.

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Slide 21



The Scientific Method

- Developed and evolved over thousands of years
- From many minds
- Does not exist in a vacuum
- What's the Goal

Scientific Method is a tool to produce useful, trustworthy evidence to support or discard a given thought on how our natural world works.

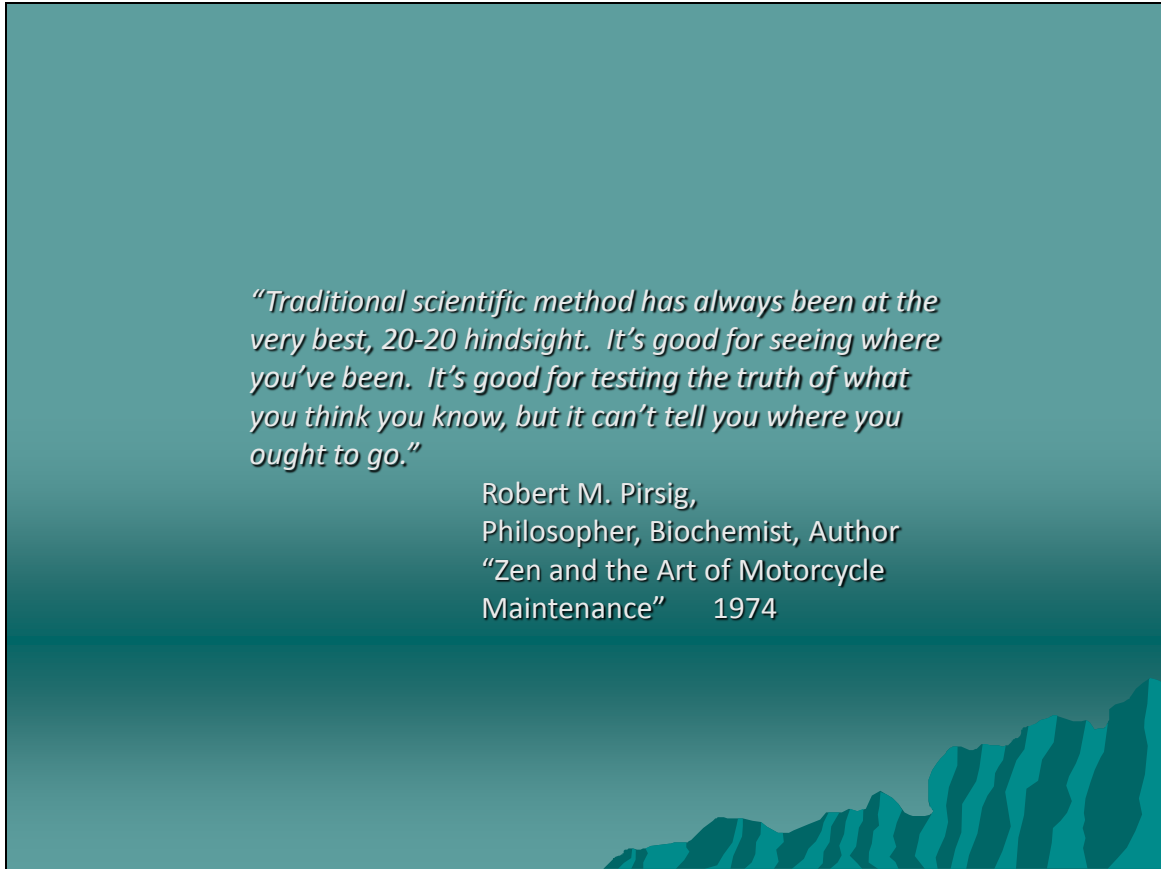
As with everything else we've discussed, the Method itself does not exist in a vacuum. Many minds, over the years have tweaked, added, teased out the finer points of how it "should" work.

The overall goal of this method is to produce useful, trustworthy evidence to support or discard a given thought on our natural world.

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The argument, refinement, and buy-in of the Method are still on-going.

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Scientific Method – the 4/5/8 Basic Steps

<i>4 -step</i>	<i>5 - step</i>
1. <i>Observation and description of a phenomenon.</i>	1. <i>Identify the question or the problem to solve.</i>
2. <i>Formulation of a hypothesis to explain the phenomena.</i>	2. <i>Research and find the facts</i>
3. <i>Use of the hypothesis to predict the existence of other phenomena, or to predict quantitatively the results of new observations.</i>	3. <i>Form a hypothesis (an educated guess)</i>
4. <i>Performance of experimental tests of the predictions.</i>	4. <i>Test your hypothesis (experiment)</i>
	5. <i>Accept or reject your hypothesis.</i>

Only 4/5/8 Basic Steps –

When I was in high school, there were 4 steps. Now, if you Google Scientific Method, you may find 5 steps or even “Science in 14 Easy Steps”.

4 steps:

1. Observation and description of a phenomenon or group of phenomena.
2. Formulation of an hypothesis to explain the phenomena.
3. Use of the hypothesis to predict the existence of other phenomena, or to predict quantitatively the results of new observations.
4. Performance of experimental tests of the predictions by several independent experimenters and properly performed experiments.

One version has it in 5 steps:

1. Identify the question or the problem to solve.
2. Research and find the facts
3. Form a hypothesis (an educated guess)
4. Test your hypothesis (experiment)

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5. Accept or reject your hypothesis.

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8 – Step

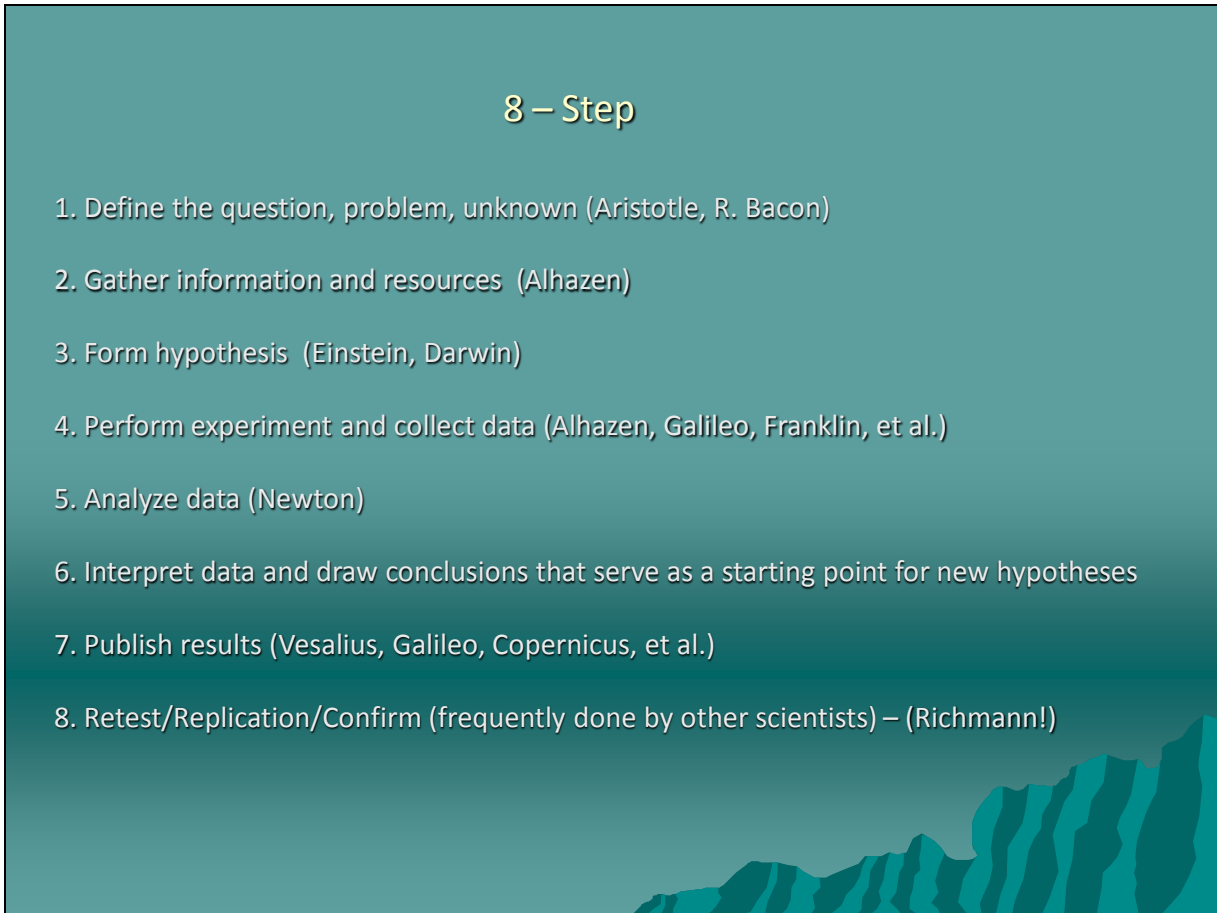
Acknowledges that:

- Scientists are part of a global community;
- Certain steps are often not separated in the mind or in practice but it is important to note the distinctions.
- Whole process may not be completed in one experiment or even one lifetime.

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8 – Step

1. Define the question, problem, unknown (Aristotle, R. Bacon)
2. Gather information and resources (Alhazen)
3. Form hypothesis (Einstein, Darwin)
4. Perform experiment and collect data (Alhazen, Galileo, Franklin, et al.)
5. Analyze data (Newton)
6. Interpret data and draw conclusions that serve as a starting point for new hypotheses
7. Publish results (Vesalius, Galileo, Copernicus, et al.)
8. Retest/Replication/Confirm (frequently done by other scientists) – (Richmann!)

8 – Steps

1 – Questions: both Aristotle, and following his example, Roger Bacon encouraged the formal defining of the study question

2 – Gather info = Research: alHazen was an early proponent of collecting background information, doing what we would now call literature searches, figuring out what other work had been done on a given topic.

3 – Hypothesis: The hypothesis that led to Einstein's Theory of Relativity was very simple and elegant. A large part of the Theory was later proven false, as we developed the technology to explore and measure the universe, but the initial framing of the problem was very clean and uncomplicated.

Darwin's initial hypotheses concerning natural selection and evolution have almost all been proven correct – over 90% success rate.

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4 – Experiment: Alhazen and Galileo performed optics experiments. Ben Franklin is famous for the kite-and-key experiment, attempting to develop a safety system for houses to protect them from lightning. Others on both sides of the Atlantic performed similar experiments. (See below)

5 – Analyze: Isaac Newton was, among other things, a physicist, and mathematician. He viewed data through a mathematical prism. Came up with the Theory of Universal Gravity, 3 Laws of Motion. He's one of the 2 guys who developed Calculus.

6 – Interpret data and draw conclusions that serve as a starting point for new hypotheses. Publish results (Vesalius, Galileo, Copernicus, et al.)

7 – Publish: These 3 guys, and others, are known for the documents they published and, in some cases, for the trouble they got into BECAUSE of publishing.

8 – Retest: Georg Wilhelm Richmann was a German scientist living in Russia. Specialized in electricity, among other things. In 1753, in St. Petersburg, he was attempting to replicate the famous kite-n-key experiment popularized by Ben Franklin. (Really, it was an insulated rod used to quantify electricity in a storm.) He brought an engraver to capture the moment. Unfortunately, ball lightning appeared and electrocuted the man, knocked out the engraver and blew the door off its hinges. Richmann was apparently the first person in history to die while conducting electrical experiments. (From: Clarke, Ronald W. *Benjamin Franklin, A Biography*. Random House (1983))

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It's important to remember this method is not as linear as it looks. Always look back and check. Are unstated assumptions coming into play? Is there a bias? Use fresh eyes; peer review is vital for this. The iterative cycle inherent in this step-by-step methodology goes from point 3 to 6 back to 3 again. At every step along the way, peer review is vital. Get respected thinkers (not just your friends) to evaluate. Accept improvements.

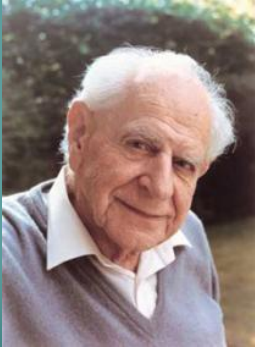
For Professional Scientists who want to publish their results, respected journals require peer review by a minimum of 2, but more usually 3, qualified scientists. These reviewers are usually not colleagues of the author(s), but they may know of one another. Scientific specialties can be a very small gene pool, sometimes.

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The Non-method Method




Karl Popper (1902 - 1994)

- Philosopher of Science
- Espoused Critical Rationalism

Paul Feyerabend (1924 – 1994)

- Philosopher of Science
- Theoretical Anarchism



While this schema outlines a typical hypothesis/testing method, it should also be noted that a number of philosophers, historians and sociologists of science (perhaps most notably Karl Popper and Paul Feyerabend – pronounced FIRE-ahbundt) claim that such descriptions of scientific method have little relation to the ways science is actually practiced, or should be practiced. They follow "methods" known as "critical rationalism" or "theoretical anarchism".

Popper rejected classical empiricism. He argued that scientific theories are abstract by nature and are truly only indirectly tested. A theory is constantly tested until eventually someone finds a circumstance in which the theory is proven false.

Feyerabend's basic concept is that scientists who follow the standard Scientific Method are limited by the rigid rules of the method. This rigidity would stifle scientific progress by limiting new research to expansions of older hypotheses.

Both of these men, and others, are considered modern leaders of the Philosophy of Science. And indeed this area is expanding in college curriculae, with Conservation Philosophy and Sociology of Scientific Knowledge So have we circled back to thinking about stuff, without empirical structure?

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What Can Go Wrong – Pseudo-Science

- 1 – Bias, Hidden Agenda
 - F. Bacon and the Doctrine of the Idols
- 2 – Assumptions (Implicit or Explicit)
 - often unconscious or Do You Really Know What You Don't Know?
- 3 – Compounding Variables
 - Are you really testing what you think you are testing?

Doctrine of the Idols, a phrase used by Sir **Francis** Bacon (1561-1626) in a written attack on the widespread acceptance of the thinking of ancient philosophers such as Aristotle (384-322 b.c.) and Plato (c. 428-347 b.c.) and the founder of modern astronomy, Copernicus (1473-1543). In his 1620 work, *Novum Organum*, Bacon vehemently argues that human progress is held back by adherence to certain concepts, which it does not question. By hanging on to these concepts, or "idols," humankind may proceed in error in its thinking and propagate that error into future thoughts.

The double edge is that in holding to notions accepted as true, we run the danger of dismissing any new notion, a tendency Bacon characterized as arrogance. A quality that goes hand in hand with arrogance is skepticism: In adhering to that which we know, we are likely to dismiss any new ideas. To combat these obstacles, Bacon advocated a method of persistent inquiry. He

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believed that humans can understand nature only by carefully observing it with the help of instruments. He went on to describe scientific experimentation as an organized endeavor that

should involve many scientists and which requires the support of leaders. Thus, Francis Bacon is credited with no less than formulating modern scientific thought. (From the Handy History Answer Book, second edition. Rebecca Ferguson. 2005. Visible Ink Press)

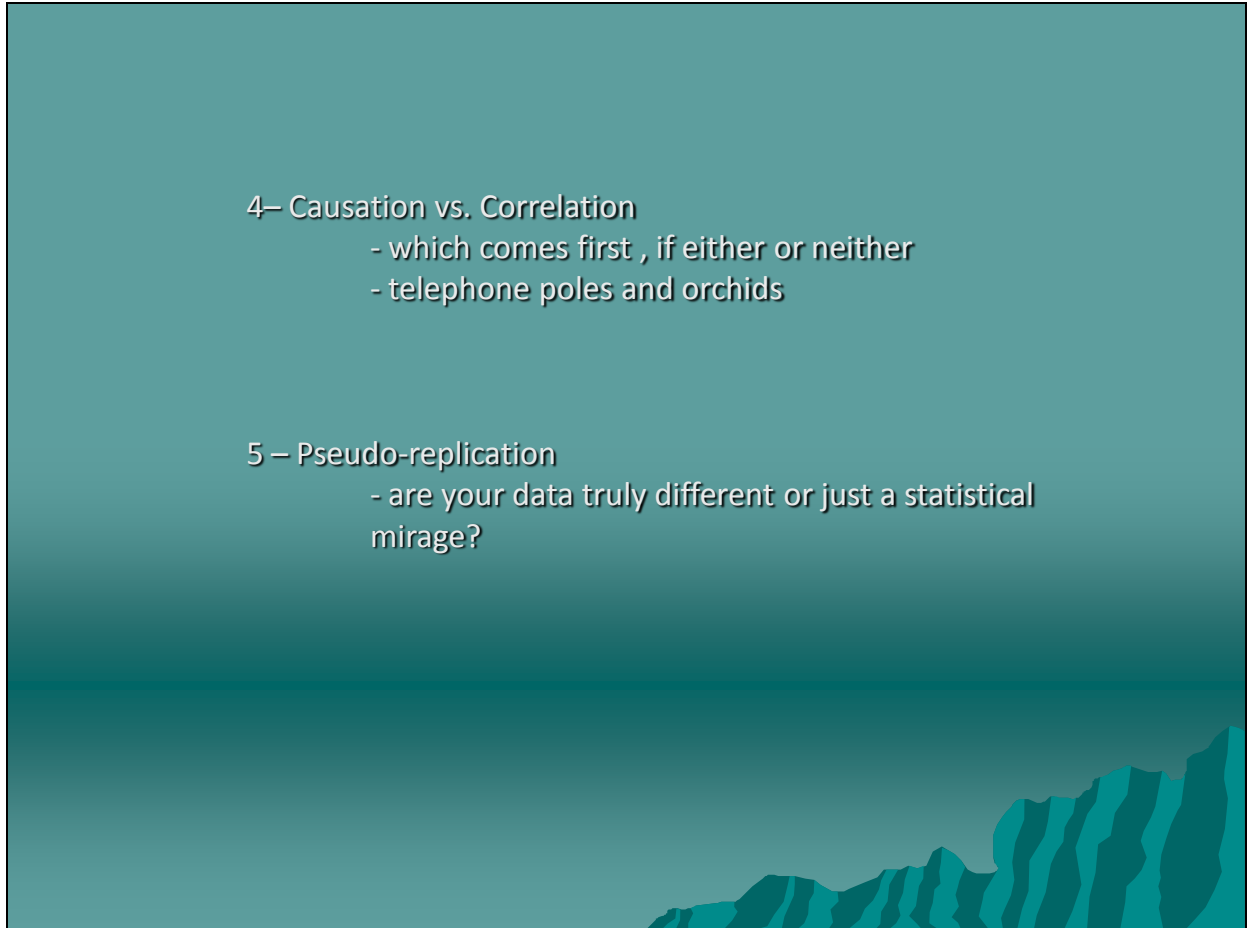
Assumptions are ok, as long as you state upfront that you are working with them. Must recognize they are there.

Compounding variables – an uncontrolled variable which may interfere with the valid outcome of a test. Example: use of pesticide – test for effectiveness on a given weed, Using one batch and run out so you mix another batch from the can in the back of the shed. What if the second batch is older? Are you testing the effectiveness of the chemical under the same circumstances? Does age have an influence on the outcome?

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Causation v. Correlation: common source of error

One can correlate the number of telephone poles in a county with the population trends of orchid populations but does that necessarily mean that the addition of telephone poles causes the changes in orchid populations?

Pseudo-Replication:

The exaggeration of the statistical significance of a set of measurements resulting from treating the data as independent observations when they are in fact part of the same data set. And therefore not independent.

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6 – Observational error

- Beliefs and expectations may affect our observations. The Flying Horse example.



Jean Louis Théodore Géricault –
The Epsom Derby 1821



Eadweard Muybridge –
Photographic studies of horse
movement - 1877

Observational Error:

People observe what they expect to observe, until shown otherwise. (Ludwick Fleck, Polish Doctor and Scientist, 1896-1961)

Our beliefs will affect our observations (how we observe, what we see as important) and therefore will affect how we respond and behave. Scientific method is designed to minimize possible biases by putting the question through a standardized process.

The Flying Horse (for those of you who don't have horses to observe regularly): When the horse is in a full gallop, all four feet are off the ground. Historically and artistically, this has been displayed with the four legs fully extended.

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Jean Louis Theodore Gericault was an artist who observed but his observations were shaded by a long held belief. He was an avid horseman who ultimately died of complications from a riding accident. Horses show up in a lot of his works.

Muybridge was a photographer who measured. And, he did it to win a bet.

In 1872, former Governor of California Leland Stanford, a businessman and race-horse owner, had taken a position on a popularly-debated question of the day: whether all four of a horse's hooves left the ground at the same time during a gallop. Stanford sided with this assertion, called "unsupported transit", and took it upon himself to prove it scientifically. Stanford sought out Muybridge and hired him to settle the question.

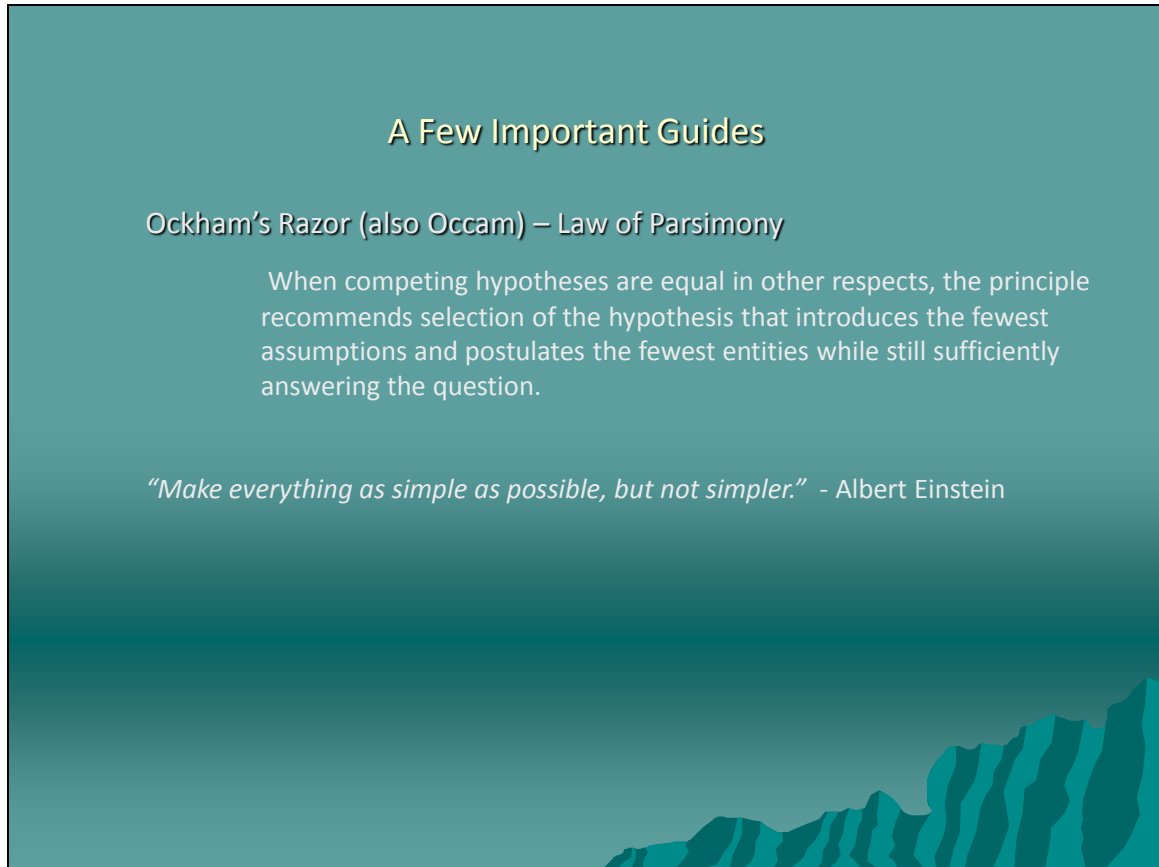
In 1877, Muybridge settled Stanford's question with a single photographic negative showing Stanford's racehorse *Occident* airborne in the midst of a gallop. This negative was lost, but it survives through woodcuts made at the time. By 1878, spurred on by Stanford to expand the experiment, Muybridge had successfully photographed a horse in fast motion. (From: Mitchell Leslie (May/June 2001). "The Man Who Stopped Time". *Stanford Magazine*.)

Maybe, they were thinking of Flying Jack Russell Terriers?

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A Few Important Guides

Occam's Razor (also Occam) – Law of Parsimony

When competing hypotheses are equal in other respects, the principle recommends selection of the hypothesis that introduces the fewest assumptions and postulates the fewest entities while still sufficiently answering the question.

"Make everything as simple as possible, but not simpler." - Albert Einstein

Attributed to 14th-century English logician, theologian and Franciscan friar, William of Ockham. Occam's Razor may be alternatively phrased as *pluralitas non est ponenda sine necessitate* ("plurality should not be posited without necessity" i.e. don't make it more complicated than it needs to be.)

In Latin, it is known as the *lex parsimoniae* (translating to the **law of parsimony, law of economy or law of succinctness**). All other things being equal, the hypothesis with the least number of assumptions and fewest number of parts while still answering the question is the best one to start with.

To quote Isaac Newton, "We are to admit no more causes of natural things than such as are both true and sufficient to explain their appearances. Therefore, to the same natural effects we must, so far as possible, assign the same causes. "

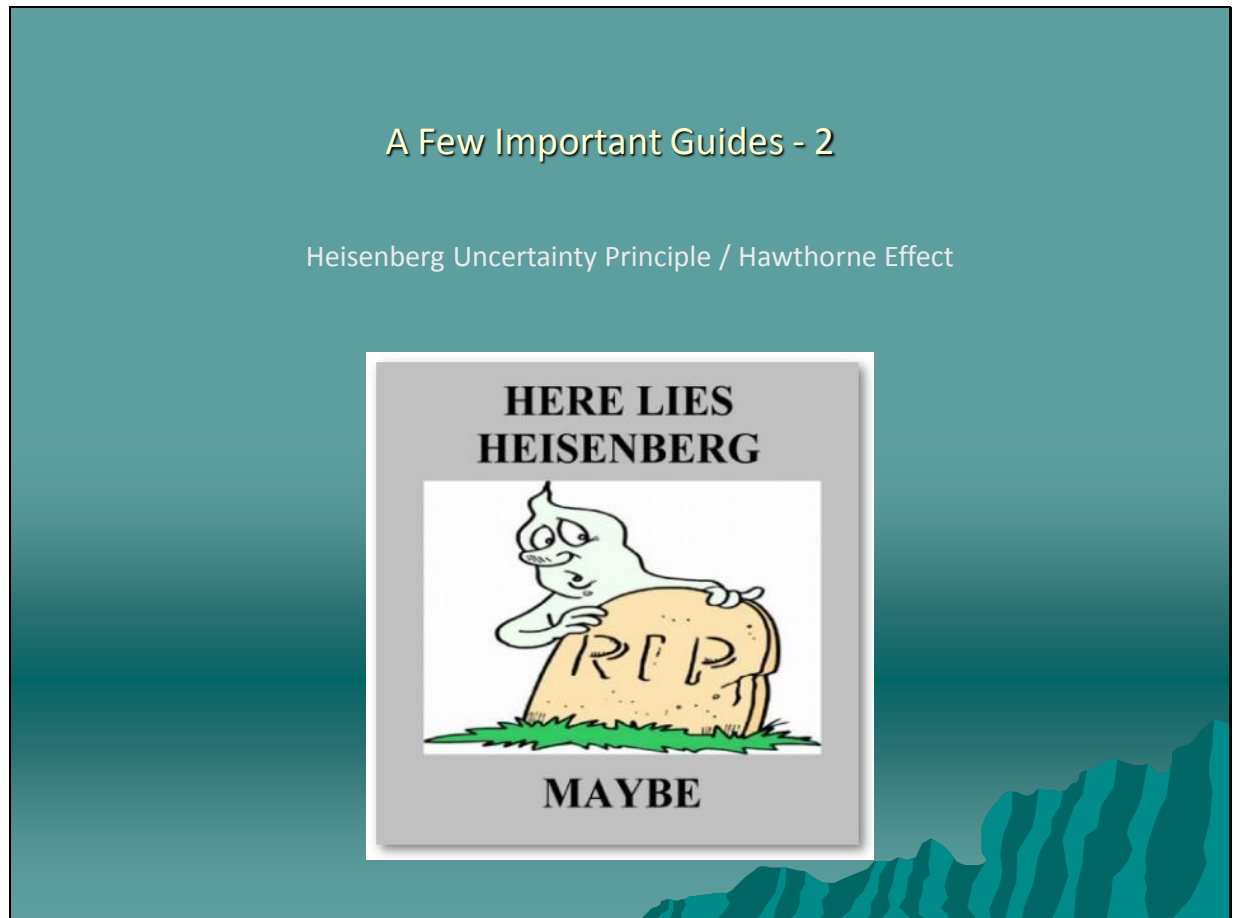
In science, Occam's razor is used as a rule of thumb or suggestion to guide scientists in the development of theoretical models. It is not a "law" to govern published reports.

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And it may win you points on Big Bang Theory Trivial Pursuit.

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A maxim from quantum physics, The Heisenberg Uncertainty Principle originally addressed pairs of physical properties, like speed and location of a particle. According to Heisenberg its meaning is that it is impossible to determine simultaneously both the position and velocity of an electron or any other particle with any great degree of accuracy or certainty. The more certain you know one property, the less precisely the other can be known.

More simply, the act of observation or measurement has an effect on that which is being observed or measured. Thus, it is also called the Observer Effect.

Other areas of science have their corollaries to the Principle. In sociology, there is a famous incident known from the Hawthorne Works factory (a subsidiary of Western Electric).

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The term was coined in 1955 by Henry A. Landsberger when analyzing older experiments from 1924-1932 at the Hawthorne Works (a Western Electric factory outside Chicago). Hawthorne Works had commissioned a study to see if its workers would become more productive in higher or lower levels of light. The workers' productivity seemed to improve when changes were made and slumped when the study was concluded. It was suggested that the productivity gain was due to the motivational effect of the interest being shown in them.

Although illumination research of workplace lighting formed the basis of the Hawthorne effect, other changes such as maintaining clean work stations, clearing floors of obstacles, and even relocating workstations resulted in increased productivity for short periods. Thus the term is used to identify any type of short-lived increase in productivity.

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A Few Important Guides - 3

The Opossum Conundrum – Part I



Who knows about opossum reproduction, from a mechanics perspective?

The opossum is a mammal, and a marsupial. Which category wins out during breeding? The answer was unknown until recently, scientifically speaking.

Through the 19th century and well into the 20th, no one had observed ‘possums mating.

Speculation abounded. What was seen was that:

- Male ‘possums have a bifurcate, or forked, penis; and
- The young emerged from the pouch, fully formed.

No one ever saw ‘possums copulating. (This was before YouTube.) Naturally, it was believed that, since the only place on the female that had 2 corresponding holes of the right size was her nose, the male ejaculated into the female’s nostrils. She then sneezed the sperm into her

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Pouch, where eggs were fertilized and developed. Sounds reasonable, given the facts at hand.

In the mid-1800s, 2 documents were published in professional journals debunking this myth.

One paper was published by a German scientist in a German publication (not well read in the US, where the North American ‘possum was the subject of the study). The other paper was by an American doctor and published in a small but well-respected medical journal. Not widely read outside of a limited group of medical doctors interested in marsupial reproduction (small esoteric chat rooms, even back then). So the general population still believed the nostril thing.

In 1922, another American researcher, noting the lack of trustworthy information on possum breeding, published another report, clarifying that possums, in fact, copulate using the same method as just about every other mammal out there. The male uses one “tine” or the other, not both. No nostrils are involved for anything other than breathing. Fertilized and partially developed young emerge from the female’s vagina and crawl up her belly to the pouch. In the pouch, they each attach to a teat which then swells so that the baby cannot let go until it has grown large enough, at which time they emerge from the pouch. Simple.

This researcher notes in his opening paragraph that the still-held view, especially in rural towns, involves the nose transfer method. This folk-lore was still prevalent through the 1950’s in many parts of the country. Enough so that it was mentioned in a 1980’s college level mammalogy course as the previously held prevailing view.

So what are the issues here? Lack of complete observation and empirical data, lack of accessibility to the latest information, human educational trends, uncooperative study subjects.

We think we’ve got it right, now...



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The Method and Modern Dilemmas

The Opossum Conundrum – Part II



Or maybe not...

20 Sept. 2010 NPR, Morning Edition

Text:

Good morning. I'm Linda Wertheimer.

Forget bedbugs. Brooklyn has a larger pest: opossums. The New York Post reports that three years ago, the city tried to curb its rat problem by setting opossums free in local parks. The idea: opossums would eat rats, and when that food supply was gone, die off. Today, the nocturnal critters with twitchy pink noses are still around. They rejected rats. They eat garbage and climb fruit trees. And the rats are OK, too.

It's MORNING EDITION.

What did they do wrong? What part of the Method did they skip? It's ok to be informal with the Method (you don't have to write each step down)

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Identify problem – check: Too many Rats in Brooklyn

Form Hypothesis – check: Opossums will eat Rats

Test Hypothesis / Experiment – check: Dump ‘possums in Brooklyn

Analyze Results – check: ‘possums not eating rats, bummer

Report results – check: we just heard it from the radio

What’s missing? BACKGROUND RESEARCH – Apparently, no-one at the Brooklyn Dept. of Public Works knows that possums are omnivores. Really, they are easy-vores – whatever is easiest to get is dinner. Why eat a rat that you have to chase, possibly getting bitten in response, when you can eat fresh fruit and day old donuts out of the dumpster behind the coffee shop?

In this example it is funny (unless you live in Brooklyn). But this is a common response to pests, be they animal or vegetable or something in-between. Throw something, anything at it and make it go away. But there are ramifications to any response, be it chemical or biological or mechanical. Any time we want to use biological controls for pests, for instance the Galerucella beetles to eat purple loosestrife or predatory wasps to kill brown marmorated stinkbugs; we need to consider the possibility that we are substituting one uncontrollable problem for another. Chemical response can effect water or air quality. Mechanical response is labor intensive and may require additional remediation or clean-up.

Just something to keep in mind.

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Broad Types of Ecological Sampling



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Why do we sample a population?

- measuring an entire population is often not possible, or expensive, or unnecessary

What do you call a “sample” that includes the entire population? (Hint: you just filled one out for 2010) -

A Census

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Factors in Choosing a Sampling Technique

- Experiments in the field will be subject to the vagaries of weather, microchanges in the habitat, wandering predators, nature beyond your control
- Are your sites selected at random or are they stratified? Are you allowing for a bias in site selection?
- What kind of time do you have to complete your experiment? Equipment/labor? Will your observations be qualitative or quantitative?
- Size matters!

Sample size (n) matters: you can form a theory based on data collected from a small sample size but it is likely it cannot be applied to a larger group. So your theory will be easily discarded. Often a minimum sample size of 50 is recommended.

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Sampling Techniques:

1) Transect – a walk in the woods (or whatever ecosystem you choose)

- Can be horizontal or vertical
- Analyse data through space
- May also have a temporal component (collect at the same sites over time)

2) Case study – follows data point (often 1) over a long period of time

- Allows for observations of many details not often available in large samples
- Limited sample size means the results can only be applied restrictively



Transect –

Part of what the field exercise is. Horizontal – ex.: follow a line through the study area, collect data at set points. Vertical – ex: survey up a tree, recording animals that use different parts or elevations of the tree. Hybrid: up a steep slope. Elevation matters, slope degree matters, aspect matters.

Case Study Example: This eagle is a juvenile that was rescued from a mud pit in Southern Maryland. He was cleaned up and fitted with a transmitter. His location was recorded every week for a breeding and wintering season, until the transmitters fell off. The eagle and 4 of his buddies were tracked moving around the Chesapeake Bay but staying in well defined neighborhoods. They visited the same sites on a regular basis. This is info which might be extrapolated to young male bald eagles of the Chesapeake Bay area. It would not be applicable to mature birds, or females or birds in other locations, UNLESS similar case studies of these other groups corroborated the behavior.

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3) Plots – limited spatial size (10m square v. 3 m circle v. 1 m cylinder)

- May stratify or unstratify, depending on the occurrence of subpopulations
- Limited site size allows for more complete sampling within the plot
- Permanent or temporary

4) Visual observation

- Can be manned or unmanned (video on motion sensor)
- Hawthorne effect?



The image shows a black bear in a forest setting, surrounded by trees and grass. The bear is positioned in the middle ground, facing right. The forest floor is covered with green grass and some fallen leaves. The trees are thin and vertical, suggesting a deciduous forest. At the bottom of the image, there is a black banner with the white text 'USGS Northern Divide Bear Project' and a small USGS logo on the left.

Stratified Sampling –

- A sample derived by dividing the population into a number of non-overlapping classes or categories from which cases are selected at.
- used when the sample population has different sub-populations or descriptive characteristics. The researcher randomly samples within each sub-population.

The data collected are not random within the population because the decision was made to ensure all sub-populations are represented. But the samples are random within the sub-populations.

VS. Unstratified sampling – samples are selected at random from the overall population. If your population has sub-groups, you are not guaranteed each subgroup will be represented in the findings.

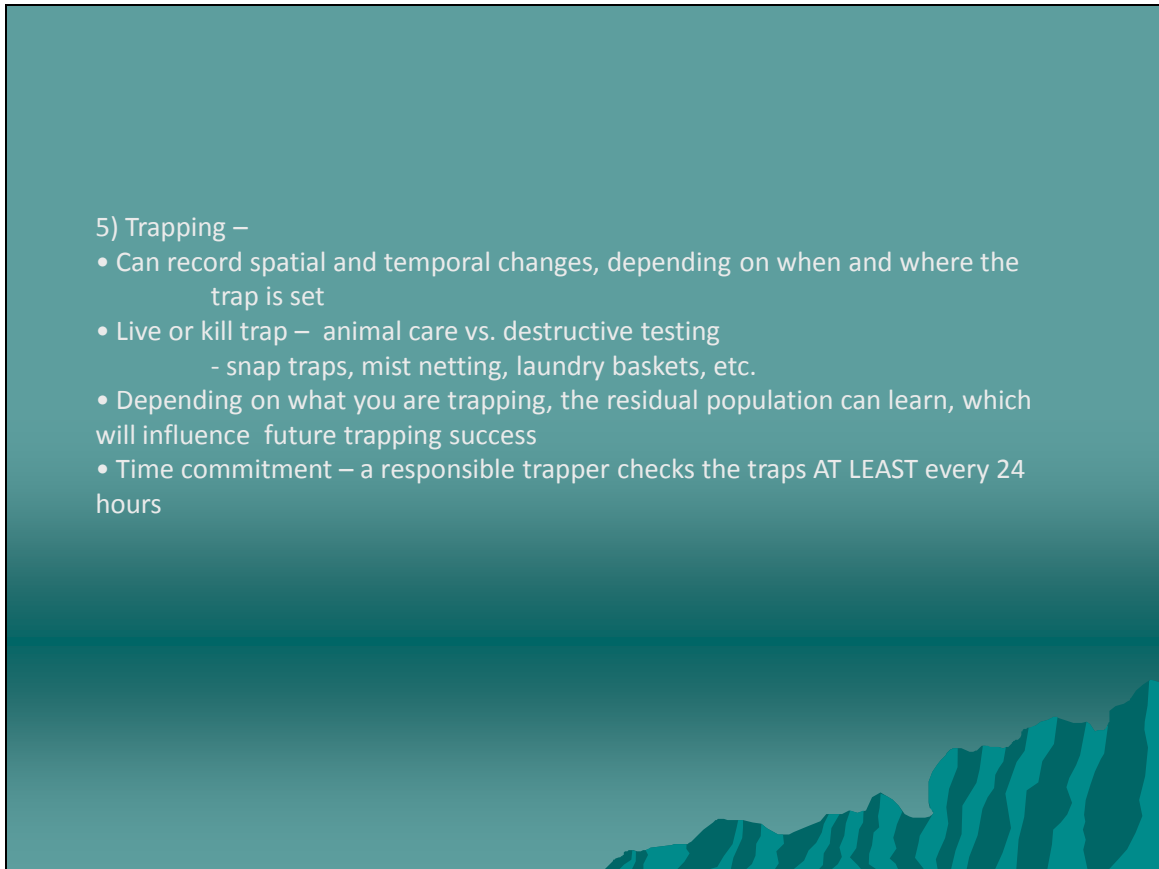
Visual Observation – - remember, an observer's biases or expectations may affect the results. Who knows the Gorilla and Ball Passing video? Google it and try it.

- Also, with the observer's presence change the outcome?

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5) Trapping –

- Can record spatial and temporal changes, depending on when and where the trap is set
- Live or kill trap – animal care vs. destructive testing
 - snap traps, mist netting, laundry baskets, etc.
- Depending on what you are trapping, the residual population can learn, which will influence future trapping success
- Time commitment – a responsible trapper checks the traps AT LEAST every 24 hours

Trapping:

Questions to ask:

If I use a live trap for animals, am I prepared (time, labor, equipment, and permit) to deal with animal care (you want to **KEEP** them alive)?

If I use kill traps, and have a permit to do so, will the destructive testing affect the health of the ecosystem or dangerously reduce the population of the animal being studied?

Types of traps: snap traps (like for mice), mist netting for birds or bats, sticky card for insects, pitfall traps for crawling things, laundry baskets for leaves

(A researcher in Baltimore County wanted to know the amount and rate of leaf fall in a given forest. He placed laundry baskets, upright, to catch what fell from the forest. This precluded anything being blown in – except in high wind events. And he could empty the baskets easily to start recording again. Low tech, inexpensive, didn't need a permit. (Just looked like gnomes were doing their laundry in the woods.)