

The Nature of Science: A Missing Foundation for Science Teaching and Learning

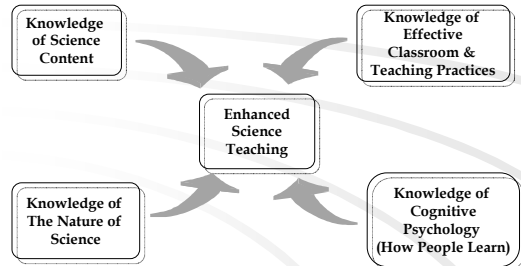
International Science Education Conference
Singapore 2006

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A Effective Synthesis for Science Instruction



What is Science?

Science is real hard. Harder than reading. We aren't allowed to have it in kindergarten.

Antonio - Kindergarten

The weatherman is science. He chooses the weather each day and writes it on the wall.

Mary Beth - Kindergarten

Science is the same old stuff. I've seen the same DVD on earthquakes four years in a row.

Joshua - Grade 4

What is Science, Really?

Science explores and addresses questions about the natural world leading to valid and reliable generalizations and explanations, using methods of investigation and producing evidence open to review by others.

W.F. McComas

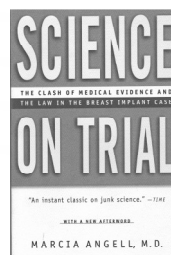
Misunderstanding Science The American Problem

	1976	1998	Change
Spiritualism	12%	52%	+40
Faith Healing	10%	45%	+35
Astrology	17%	37%	+20
UFOs	24%	30%	+6
Fortune Telling	4%	14%	+10

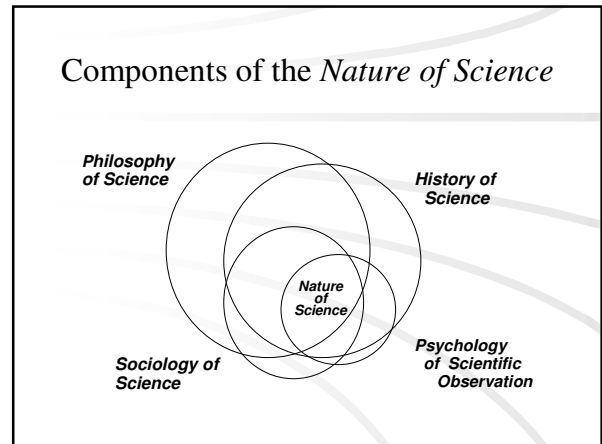
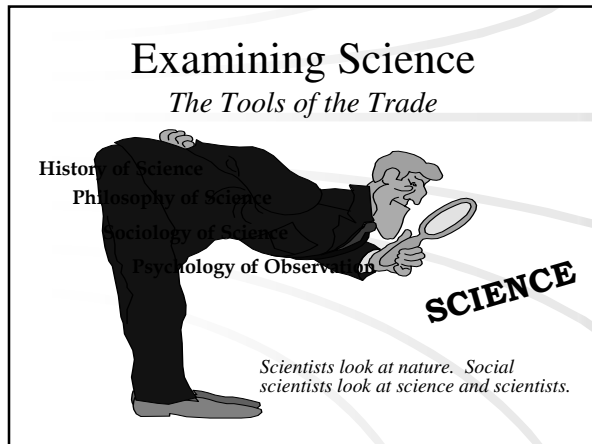
Yankelovich Monitor Survey (USA Today April 20, 1998)

The Cost of Not Knowing How Science Functions:

The Case of Breast Implants



- Cases were brought because of suspected link between silicone breast implants and auto-immune diseases like lupus
- One "expert" believed he could show an antigen-antibody effect upon exposure to silicone
- The science was not valid but juries ruled on emotion and companies unfairly lost millions of dollars!

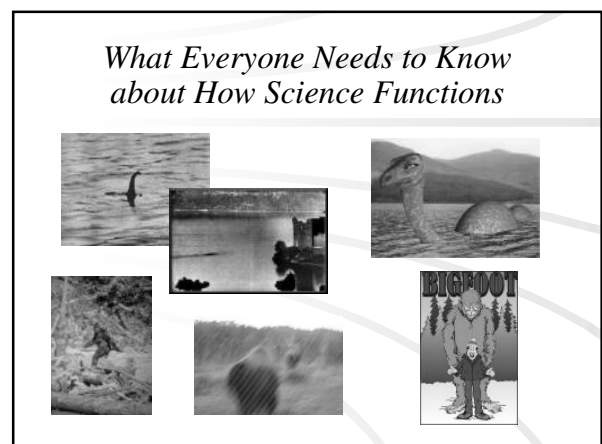


- ## Core Ideas in the Nature of Science:
- What Everyone Needs to Know*
1. Science requires empirical evidence
 2. Knowledge production in science shares many common features
 3. Scientific knowledge is tentative, but strong and self-correcting
 4. Laws and theories are related but distinct kinds of knowledge
 5. Science has a creative component
 6. Science has a subjective component
 7. There are cultural, social and political influences on science
 8. Science and technology are not the same
 9. Science and its methods cannot answer all questions

What Everyone Needs to Know about How Science Functions

Science Requires Empirical Evidence to Support Conclusions

- ## What Everyone Needs to Know about How Science Functions
- Every discovery and conclusion in science is based on data (evidence) – not just opinion -- that may be viewed and evaluated by others
 - When findings are unexpected, unbelievable or unlikely more evidence must be available



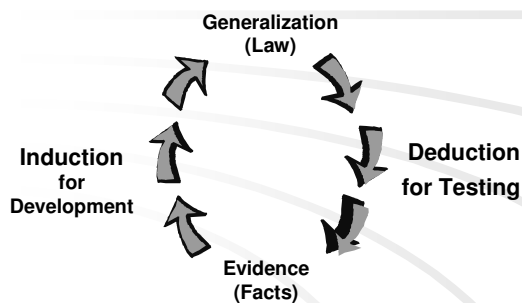
What Everyone Needs to Know about How Science Functions

Knowledge Production in Science Shares Many Common Traits

What Everyone Needs to Know about How Science Functions

- Induction and deduction (formal tools of logic) are the primary routes to knowledge in science
 - Induction is often used to form new laws and theories and
 - Deduction (hypothetico-deductivism) is often used to test those ideas

The Arch of Knowledge



Experiments are Not the Only Way to Gain Scientific Knowledge

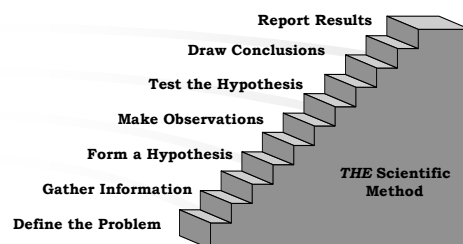
- Experiments are planned manipulations of nature to show a cause and effect relationship
- Some disciplines, such as geology and astronomy, generally lack true experimentation
- Many scientists such as Copernicus and Kepler based their discoveries on extensive observations without manipulating nature directly
- Other scientists such as Charles Darwin and Jane Goddall routinely used non-experimental qualitative approaches



What Everyone Needs to Know about How Science Functions

- Good scientists all use careful and appropriate research methods, they record and report all data, etc.
- However, there is no single shared step-by-step scientific method

There is No Single Standard and Universal Scientific Method



*What Everyone Needs to Know
about How Science Functions*

Scientific Knowledge is Tentative but Durable and Self Correcting

However, you still can't
prove anything in science

*Scientific Knowledge is Useful but You
Can't Prove Anything in Science*

- Knowledge production in science is tricky
- Gathering evidence alone is not enough to produce new knowledge
- There is a non-logical (highly creative) step that links simple facts to mature scientific ideas
- In addition, there is no way to escape the Problem of Induction

What is Induction?

*Induction is the collection of
fact without bias to reach a
conclusion*

Frances Bacon (1620)

The Problem of Induction?

- It is impossible to make all relevant observations pertaining to a phenomenon
 - It is impossible to collect relevant information about the phenomenon from throughout the past and future
- There is no way to make unbiased observations of the phenomenon in question
- It is impossible to guarantee the necessary creative intuitive leap from facts to principles

The Problem of Induction

- Because of the Problem of Induction, scientific knowledge must remain tentative (in other words present scientific conclusions *could* change in the future)
- So, no knowledge in science is “sure” and final
- However, given the strength of science, it is also useful to state that a well established scientific conclusion is durable (long lasting)
- In science we must talk of substantiation *not* proof
- There is a big distinction between the way “proof” is used in common language and in subjects like math!

*What Everyone Needs to Know About
How Science Functions*

Laws and Theories are Distinct and Unique Kinds of Scientific Knowledge

*Laws and Theories are Distinct
Kinds of Scientific Knowledge*

Law: *A generalization, principle or relationship (ex. Law of Gravity)*

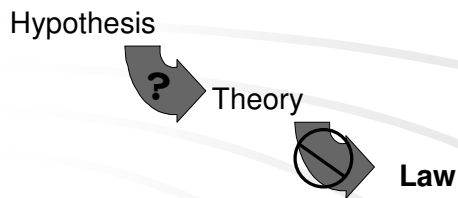
Theory: *An explanation (ex. Kinetic Molecular Theory of Matter)*

Many dictionaries fail to make this distinction and one term is frequently listed as a synonym for the other!

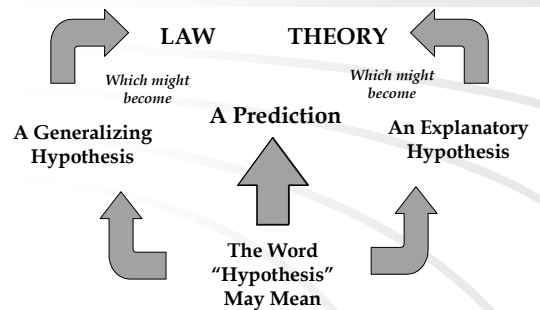
*A Hypothesis is NOT just an
“Educated Guess”*

- The term hypothesis may be defined as a . . .
- Prediction or an
 - Immature (baby) theory (best called an explanatory hypothesis) or
 - Immature law (best called a generalizing hypothesis)

*Hypotheses do Not Become
Theories Then Laws*



The Hypothesis “Family Tree”

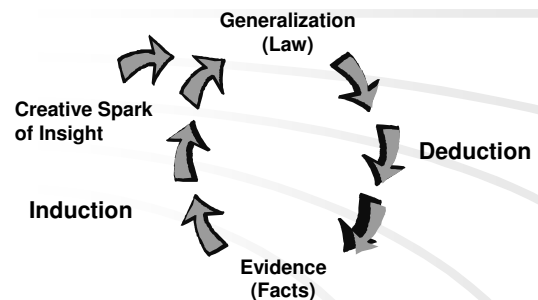


*What Everyone Needs to Know
about How Science Functions*

**Science has a
Creative Component**



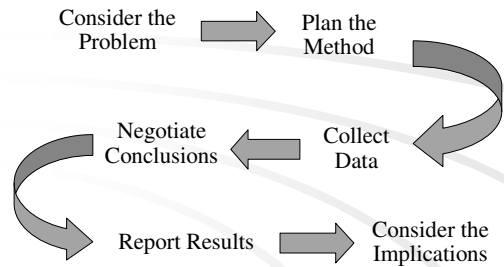
The Arch of Knowledge



Science is a Creative Endeavor

- There is creativity throughout science including in the selection of problems, the selection and application of methods of investigation
- Unfortunately, school science fails to emphasize the creative aspects of science

A Scientific Investigation Model



What Everyone Needs to Know about How Science Functions

Science has a Subjective Component

Science has a Subjective Component

- We all observe the world with our own biases and prior conceptions
 - This is called “theory-laden” observation
- Scientists do this too
- Much of the time this bias is an advantage because it helps scientists sift quickly through useless data (observations)
- However, sometimes prior conceptions block our ability to “see” something interesting

What Everyone Needs to Know about How Science Functions

There are Social, Cultural and Political Influences on Science

Science has Cultural, Social and Political Components

- The work that is done in science in a particular nation is likely related to the interests and priorities of that nation
 - Consider the current stem cell debate in the U.S.
- Funding and national (cultural) priorities play large roles in the direction taken in scientific research
- Science itself is a highly social endeavor
- Science is done in groups and final knowledge is negotiated in groups



Science has a Social Component

The negotiation and validation of knowledge make science a highly social activity

In the end, truth "is whatever scientists say it is when they come to the end of their labors."

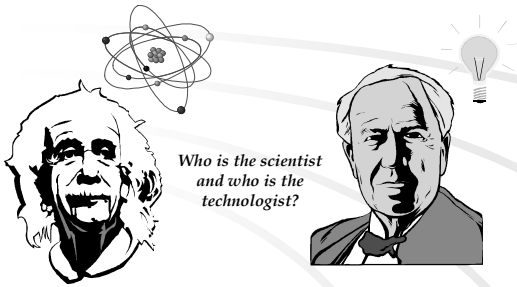
Charles S. Peirce

Horgan, J. (1996). *The End of Science*. New York: Broadway Books (p. 33)

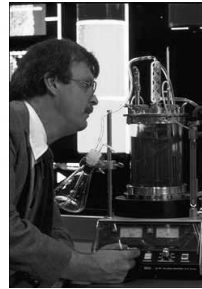
What Everyone Needs to Know about How Science Functions

Science and Technology Impact Each Other, but they are Not the Same

Science and Technology are Not the Same



Science and Technology are Not the Same



Pure science generates new knowledge for the sake of knowledge alone

Science and Technology are Not the Same



Technology makes use of scientific knowledge to achieve a specific purpose

Science and Technology are Not the Same



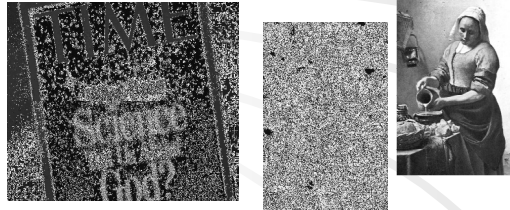
Of course, in the real world, science and technology interact and impact each other regularly

*What Everyone Needs to Know
about How Science Functions*

Science and its Methods *Cannot* Answer All Questions

Science Can Not Answer all Questions

Questions of aesthetics, morality, ethics, and religion cannot be addressed by science



Science Can Answer all Questions

- Many who are religious think that their knowledge base is more secure, useful and comprehensive than that of science
- Many in the science community think that their knowledge base is more secure, useful and comprehensive than that of religion
 - This view is called scientism
- In the final analysis, many believe that we need both science and religion

Science Can Answer all Questions

Religion and science are not in conflict if each is properly applied -- they answer different kinds of questions.

Potential friction can be reduced by knowing what kinds of questions are appropriate to ask of which authority.

Conclusions and Recommendations

- The nature of science is one of the most important *content* elements in any science course
- The nature of science provides a view to the epistemology of the discipline and is interesting and engaging for students because it shows science to be a vital and dynamic pursuit of knowledge
- The nature of science is as important as any other science facts and principles, yet it rarely appears as a specific element in the curriculum
- We must all work to change that situation!

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