

Topic #2: ON SCIENCE & BEING A SCIENTIST

“The real purpose of scientific method is to make sure Nature hasn’t misled you into thinking you know something you don’t actually know.”

*~ Robert Pirsig
Zen and the Art of Motorcycle Maintenance*

OBJECTIVES FOR TODAY'S CLASS:

- Review the components of “the” formal scientific method**
- Learn how real science “in practice” involves a wide variety of approaches – especially for Global Change science**
- Hear how scientists themselves describe their science**
- Understand that science advances through constant critique of its own findings and methods**
- Have fun with quotes and cartoons about science!**

... About the reading assignment for today:

Robert Pirsig's essay from
Zen and the Art of Motorcycle Maintenance
outlines a 6-part "Formal Scientific Method":



1. statement of problem
2. hypotheses about the cause of the problem
3. experiments designed to test each hypothesis
4. predicted results of experiments
5. observed results of experiments
6. conclusions from the results of experiments

**ON SCIENTIFIC
METHOD (s?)
& the Nature of
Scientific Research**

Is there “a” single scientific method?

Many scientists regard such blanket descriptions of what they do with suspicion.

Rather than following a single scientific method, scientists use a *body of methods* particular to their work.

But first a review of the traditional outline of "the" scientific method:

- a. OBSERVATION
- b. HYPOTHESIS
- c. PREDICTION
- d. TESTING

OBSERVATION

(vs. Experiment):

Observation -- observe nature without manipulating it

Experiments -- manipulate some aspect of nature and observe the outcome

Then identify **patterns** and **regularities** in one's observational and experimental results.

What scientific methods do Global Change scientists use??

Experiments?

- The ever-changing Earth is one unrepeatable “experiment” -- We are living it!
- We can run controlled experiments on isolated parts of system, but can ALL the components of the system be part of an experiment?
- **Computer models** are the closest we come to running global change experiments . . .

Observations?

- How can the **whole Earth** be observed?
 - remote sensing from satellites



- How can change over **long periods of time** be observed?
 - paleoclimatic indicators,
“**natural archives**” (tree rings, etc.)



- Combine the above with computer models of past, present and future environments based on input from local, regional, and global observations

HYPOTHESIS

Form a HYPOTHESIS

- a “tentative guess” about how the world works
- must be able to be evaluated with available data
- often several hypotheses are formed at once
"multiple working hypotheses"
(scientists want to avoid "ruling hypothesis")

THEORY -- refers to a description of the world that covers relatively large numbers of phenomena and has met extensive observational and experimental tests.

(it is not “just” a theory or an unfounded guess)

PREDICTION AND TESTING

-- **Test** hypotheses and theories by using them to **make predictions** about how a particular system will behave . . .

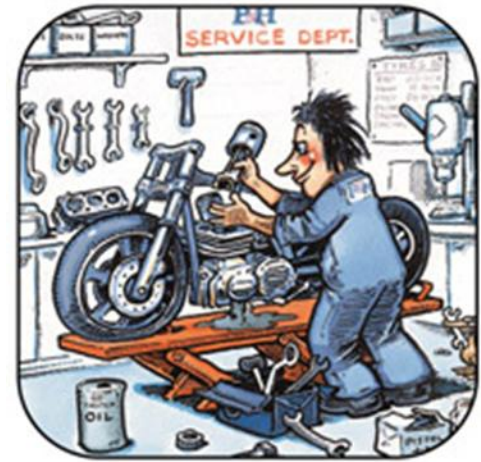
-- Then we **observe** nature to see if the system behaves as predicted.

When does a Theory become a “Law of nature?”

- when a theory or group of related theories has been tested extensively and seems to apply everywhere in the universe
- when we have had enough experience with it and have a lot of **confidence that it is true**
- we elevate the theory to a new status & **call it a law of nature**
- an overarching statement of how the universe works.

e.g. GRAVITY

Pirsig's essay also describes **two types of reasoning processes** that go into observations, hypotheses, and predictions:



Induction (inductive reasoning) =
generalizing from **individual observations**
.....to general conclusions

Deduction (deductive reasoning) =
start with **general knowledge**
(first principles or established theory)
..... and predict a specific observation.

INDUCTION:

INdividual observations →

General conclusion

DEDUCTION:

DE (“the”) big picture (theory) →

conclusion / prediction about a
specific observation

Pirsig suggests:

“ . . . in actual science, problem solving takes place by long strings of mixed **inductive and **deductive inferences** that weave back and forth between **observations** and **theory** . . . “**

**Interconnectivity
of methodological steps!**

**There is no “right” place to enter
the cycle of steps.**

More on how science “works” . . .

- **Observations & experiments must be verifiable,**
i.e. the results must be reproducible
- **Scientists must **accept** (“believe”) the results of their experiments and observations **whether or not they fit the hypothesis or preconceived notion.****
- **Science does not provide final answers . . .or ultimate truth . . .**

It attempts to produce successively more detailed and exact descriptions and models for understanding +/-or predicting the behavior of processes and phenomena in the world

How do SCIENTISTS talk about their science? . . .

On the white handout under
“More Science Quotes”

WHICH QUOTE DO YOU LIKE BEST?

WHICH QUOTE INTRIGUES YOU MOST?



the
symphony of science

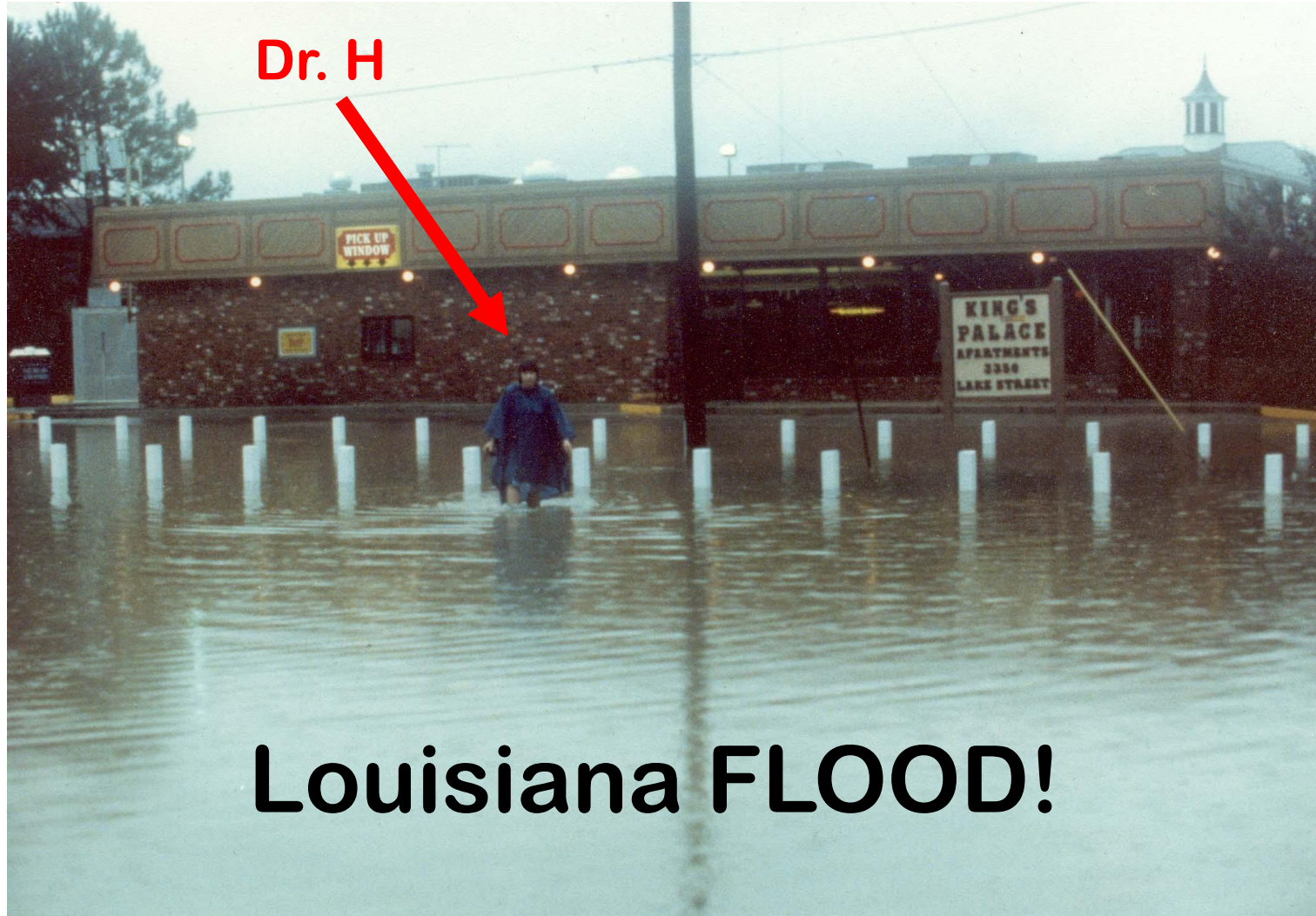
<http://www.symphonyofscience.com/>

ASSIGNMENTS FOR MONDAY & NEXT WEEK

- (1) Check off completed tasks in the D2L **CHECKLIST TOOL**
- (2) Register **your Clicker**
- (3) Access the E-Text – Complete reading of Chapter 1
- (4) Take the 2 practice **SELF TESTS & Readiness Quizzes (RQ's)**
- (5) When you've done all of the above, read the LAST chapter in the SGC E-Text titled : **ATOMS: THE NATURE OF THINGS**
Your first **GRADED RQ** will be on this chapter and due next week.

**THE PERSONAL
SIDE OF BEING A
SCIENTIST . . .**

Passionate Interest & Curiosity



Dedicated Work Effort

e.g. Field Work!

Laura →
in her field
area in New
Mexico!



Lots of hiking . . .



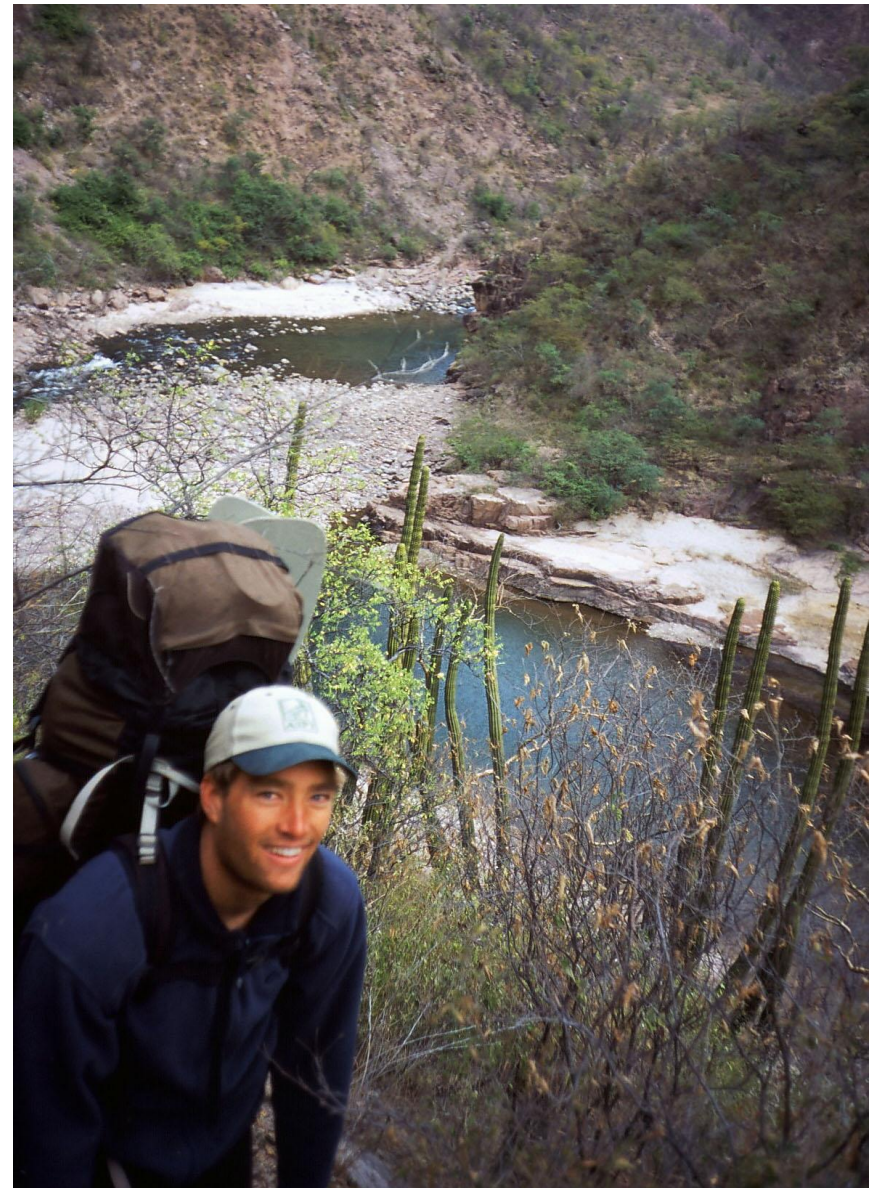
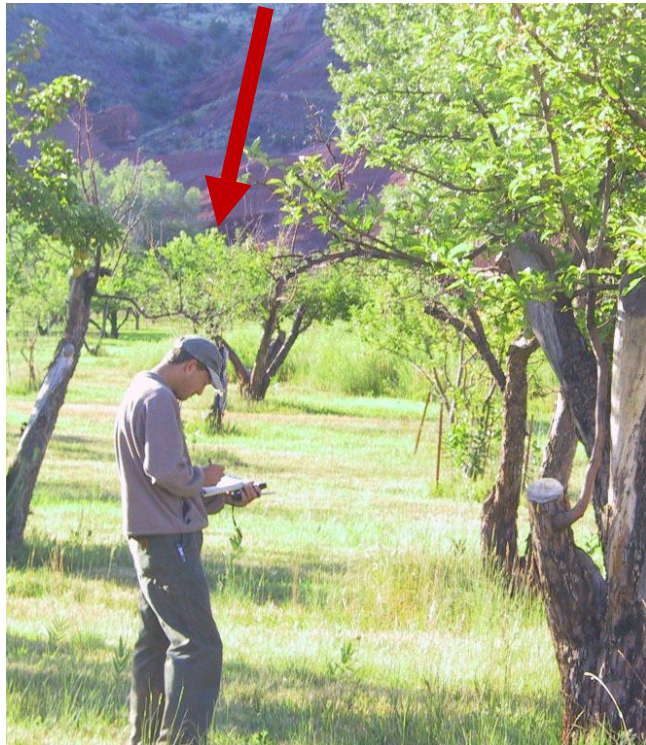
. . .more Field Work!



The all-important recording of data in the field notebook!

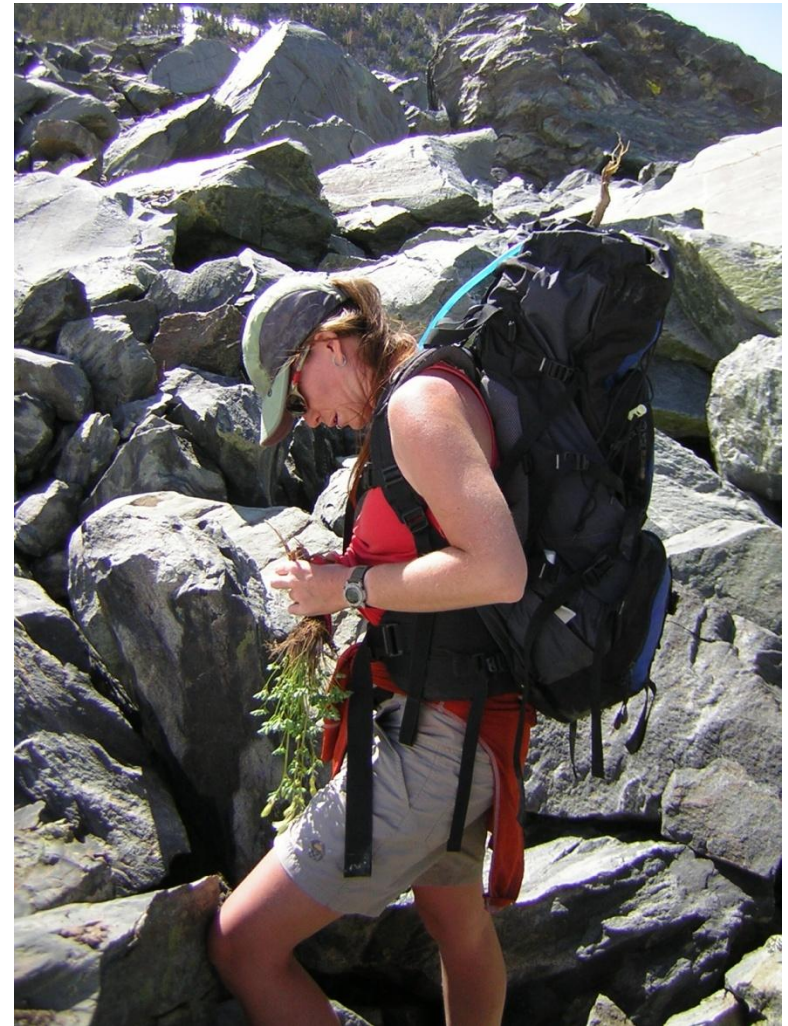
. . .more Field Work!

KANIN
in a field of
apple trees!



And even MORE
field work!

REBECCA
collecting field data



...even more Field Work!

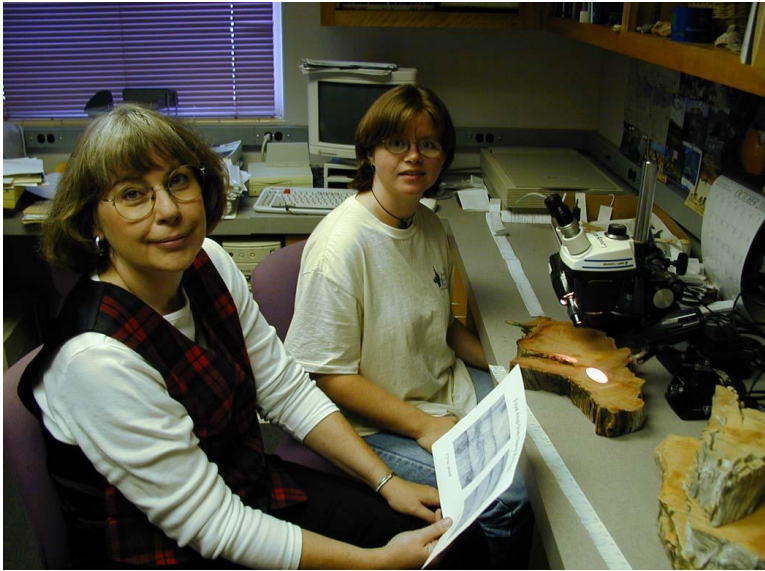
**Dedicated
Work Effort!**

**...and
(sometimes
tedious)**

LAB WORK!



Analysis, Collaboration, Discovery: Dr H's Lab



Wonder, Awe, & Contemplation of Nature



**Persistence, persistence,
persistence . . .**



Some critiques of scientific methodologies:

- **Inductive method cannot establish “certain” knowledge because the NEXT observation might change things!**
- **Deductive method might lead to FACTS and OBSERVATIONS becoming “Theory-laden”:**

i.e., We may observe *what we want to observe*, based on personally held beliefs in certain theories . . .

. . . Or there may be certain deeply held values underlying motivation for research.

Scientists often say: “I believe such and such is happening” But what do they really mean by that??

Is it a mere “opinion?”

Belief without evidence?

Belief or confidence IN
in the evidence?

When scientists say they **“believe”** in their results, this is based on compelling scientific reasons:

(e.g., consistent observations,
converging evidence, etc.)

**“Science replaces
‘private prejudice’
with publicly
verifiable evidence.”**

- Richard Dawkins, biologist

More things to be aware of about the scientific process:

- Observations might be ignored because they don't conform with theory!
- Risk of self-deception
- Methodologies have their limits
- Theories can never be positively proven to be true, but some can be disproved by “falsifying” them (Karl Popper, philosopher of science)

Being able to FALSIFY some theories is an important step in the advancement of scientific knowledge!

(WHY? We can eliminate incorrect theories & get closer to truth)

**THE SCIENTIFIC
PROCESS
IN ACTION**

HOW DOES SCIENCE OPERATE & PROGRESS?

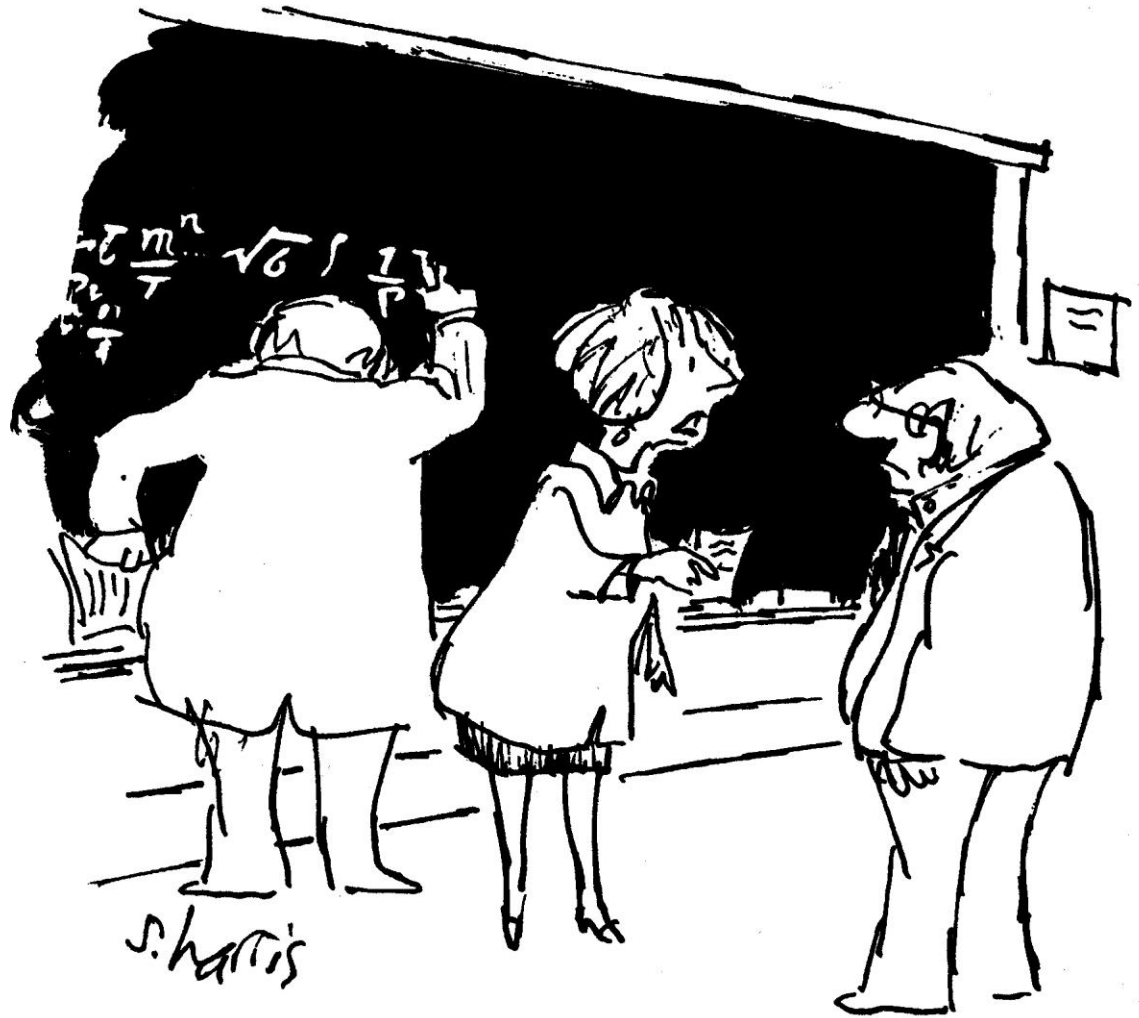
- Driven by **curiosity**
- Dedicated & **persistent research** sparked by moments of intuition & exciting **discovery**
- **Communal review of scientific results** (i.e. PEER REVIEW)
- Scientists build on previous results; it is a **cumulative process or enterprise**

- **Open but skeptical mind; theories may be falsified but never verified**
- **Human error, plagiarism, and fraud** will get weeded out over time
- **Conflicts of interest**, (e.g. who's funding the research?), **ethics**, & **human values** play an important role in “objective” science (self-awareness needed!)
- **Collaborative efforts** (Team work!) essential as body of knowledge gets more complex

- **Wonder, awe, joy & mystery** are at the source of scientists' love for their work



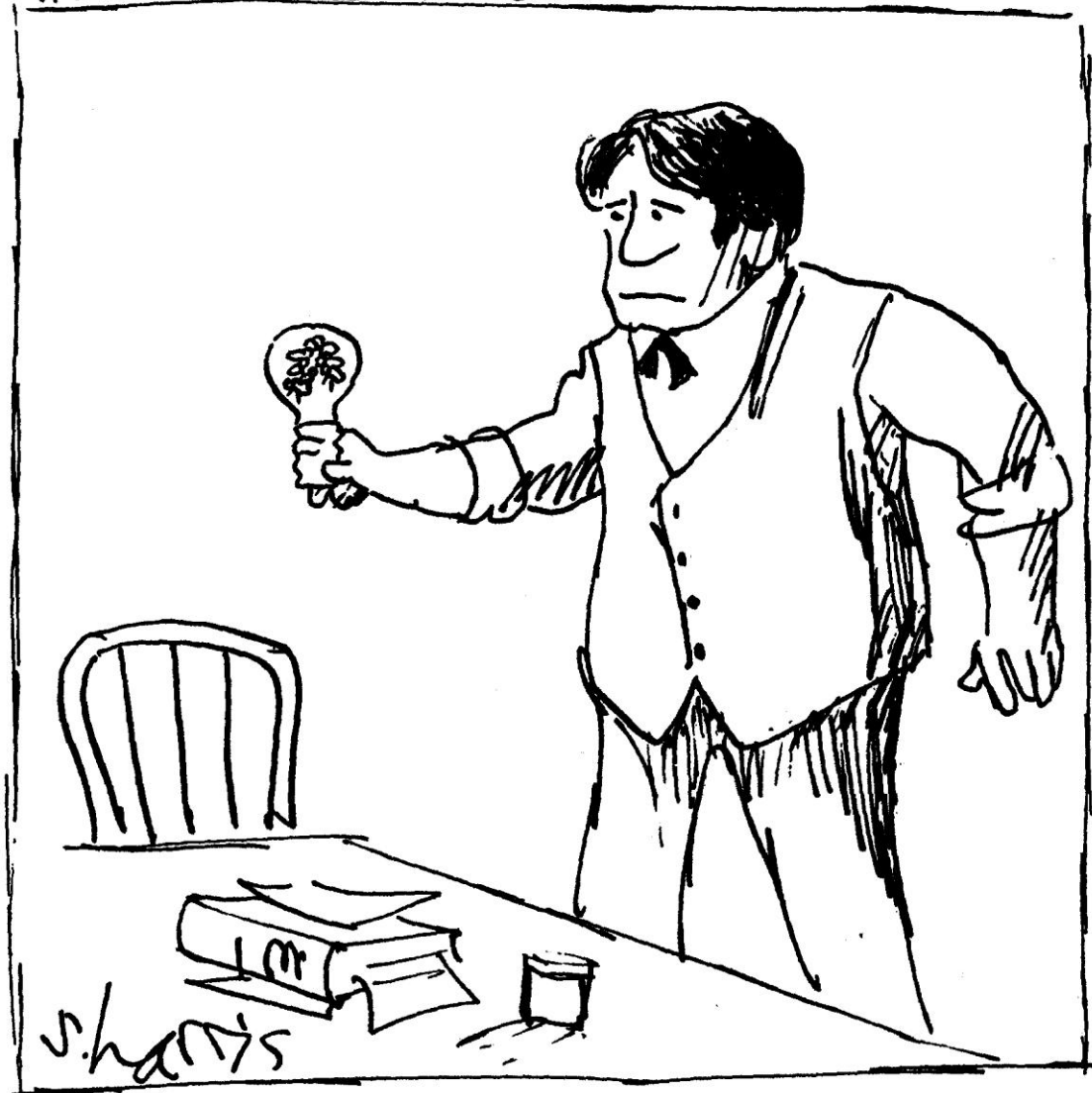
What aspect of science just discussed is depicted humorously by this cartoon?



"WE COLLABORATE. I'M AN EXPERT, BUT NOT AN AUTHORITY, AND DR. GELPIS IS AN AUTHORITY, BUT NOT AN EXPERT."

YOUNG THOMAS EDISON TRIED TO PASS OFF A
CONTAINER FILLED WITH FIREFLIES AS AN
INCANDESCENT BULB

And this?



And lastly,
what about
this one?



"COMRADE — THE COMMISSAR OF MATHEMATICS
WANTS IT TO EQUAL 29.86."

IN-CLASS ACTIVITY

“Think-Pair-Share” Exercise on:

**CARTOONS & QUOTES
ABOUT & BY SCIENTISTS**

Form a “MINI-Team” of 2 – 3 people & **INTRODUCE YOURSELF** while the stapled green handout is being distributed (one for every team)



**WE RE-USE & RECYCLE – PLEASE DO NOT WRITE
ON THIS HANDOUT SO WE CAN COLLECT IT
AND RE-USE IT AGAIN**

We’ll do PART A (see the cartoons on pp 2-3)

CARTOON A



CARTOON B



"IT'S OUR NEW ASSEMBLY LINE. WHEN THE PERSON AT THE END OF THE LINE HAS AN IDEA, HE PUTS IT ON THE CONVEYOR BELT, AND AS IT PASSES EACH OF US, WE MULL IT OVER AND TRY TO ADD TO IT."

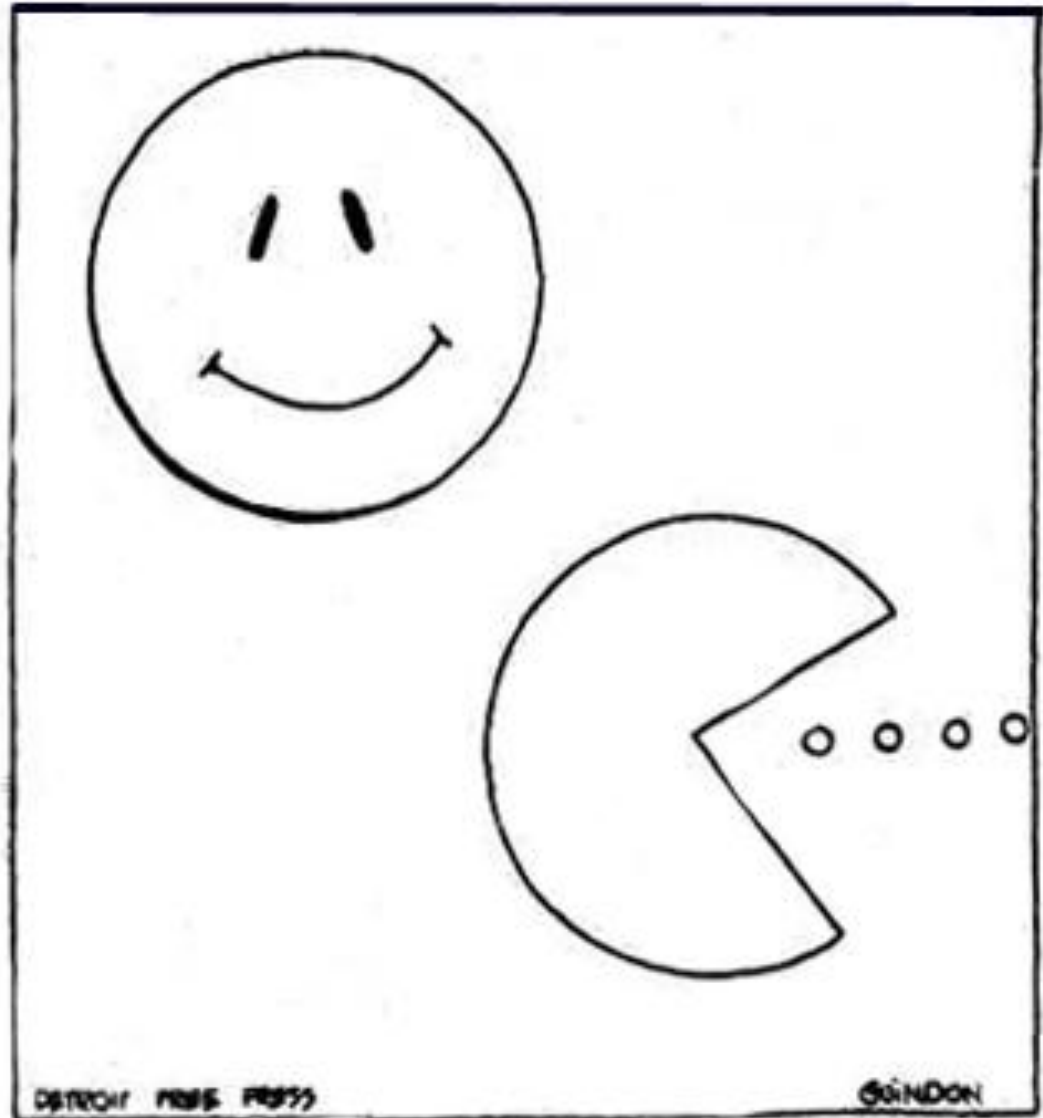
CARTOON C



CARTOON D



CARTOON E



In the year 2074, A.D., a curator at the Museum of Modern Art in New York will conclude that the happy face and Pac-Man were done by the same artist.

CARTOON F



CARTOON G



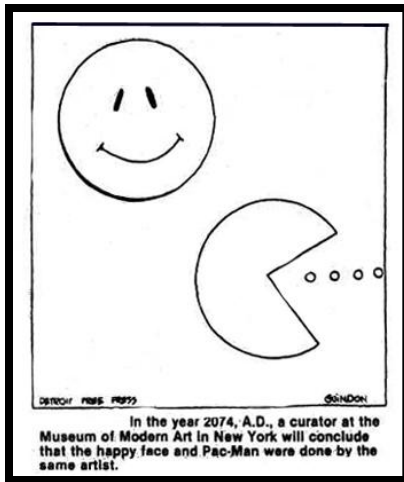
"IT STARTED WITH A SIMPLE CASE OF
PEER-REVIEW."

DIRECTIONS FOR CLASS ACTIVITY – PART A:

1. **THINK: PART A** First, look over the cartoons and decide on the one phrase that best expresses an **aspect of SCIENCE** that the cartoon is “spoofing”.
2. **PAIR:** Pair up with your Mini-Team.
3. **SHARE:** Share & discuss your ideas & answers with each other and discuss your reasoning.
4. Come to a consensus and **WRITE YOUR ANSWERS ON YOUR OWN WHITE HANDOUT** (NOT the green handout!) The correct answers will be revealed in several minutes.

See how well can you do !!!

When you finish Part A, **continue with Part B** until other teams finish

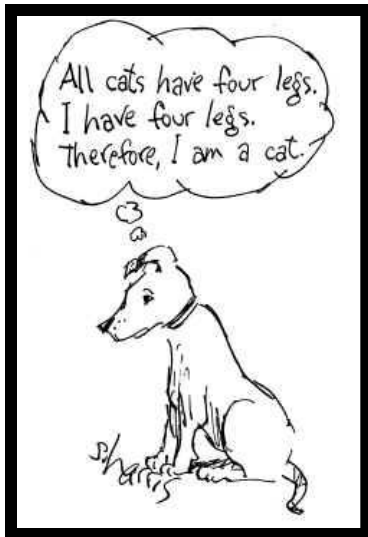


E **INDUCTIVE REASONING**

Inductive reasoning reasons from the "I**N**dividual to the general" -- in other words, a general statement or conclusion is made based on one or more individual observations.

In this cartoon, the curator is making an unfounded conclusion (or generalization) that the same artist created both the happy face and Pac-Man.

The cartoon illustrates one of the dangers of inductive reasoning (making unfounded conclusions from too little evidence) in a humorous way.



D

DEDUCTIVE REASONING

Deductive reasoning reasons from "DE" (the whole thing (the general) to an individual situation"

-- in other words, a general theory, law, or statement is assumed and then conclusions are drawn about individual things based on the general theory.

Deductive reasoning also has dangers, as illustrated in the cartoon where the dog erroneously deduces he is a cat based on the correct theory that all cats have four legs.



F **EVER-CHANGING NATURE OF SCIENTIFIC KNOWLEDGE**

Cartoon F is the best answer for this phrase.

It illustrates that no discovery should be considered "final" in science -- something new may always turn up to change what we know.

(Cartoon B is another possible choice, but B is better described by one of the other phrases)



C PREDICTION & TESTING

Cartoon C illustrates (in a humorous way) how prediction and testing go hand in hand.

Sometimes the most important scientific discoveries take place in experiments when we do NOT get the results that are predicted.



A **CONFLICT OF INTEREST**

Cartoon A best illustrates the concept of "conflict of interest," which arises when a scientist may have funding from a specific source, or have a strong personal interest in a specific scientific outcome, that may influence his or her objectivity in conducting research or drawing conclusions.

"Conflict of interest" usually is an internal conflict within a scientist or scientific research group -- not an external "battle" among scientists (as depicted in Cartoon G).



G REVIEW OF SCIENTIFIC RESULTS BY COLLEAGUES

Cartoon G depicts the process of **PEER REVIEW** in a humorous and unflattering way. Peer review is a careful evaluation of one's results, publications, etc. by one's colleagues.

The review is designed to determine if the research is valid and a significant contribution to science.

Note that the peer review process is a normal and beneficial part of the scientific process.

It does not usually end up in a fist fight as depicted in the cartoon!

and the last cartoon

B

_____ **SCIENCE IS A CUMULATIVE ENTERPRISE (i.e. process)**



Cartoon B best illustrates the idea that science is a cumulative process.

Science progresses by new pieces of information that are added to pre-existing knowledge.

Although Cartoon F also expresses the concept of new knowledge being progressively discovered by individuals, the "conveyor belt" image of several scientists adding to an idea one after the other in a cooperative venture is a slightly better representation of the "cumulative enterprise" concept.

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- Hear how scientists themselves describe their science**
- Understand that science advances through constant critique of its own findings and methods**
- Have fun with quotes and cartoons about science!**

NOW COMPLETE PART B on your own!

**WE'LL WRAP UP THE SCIENCE
DISCUSSION ON MONDAY**

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