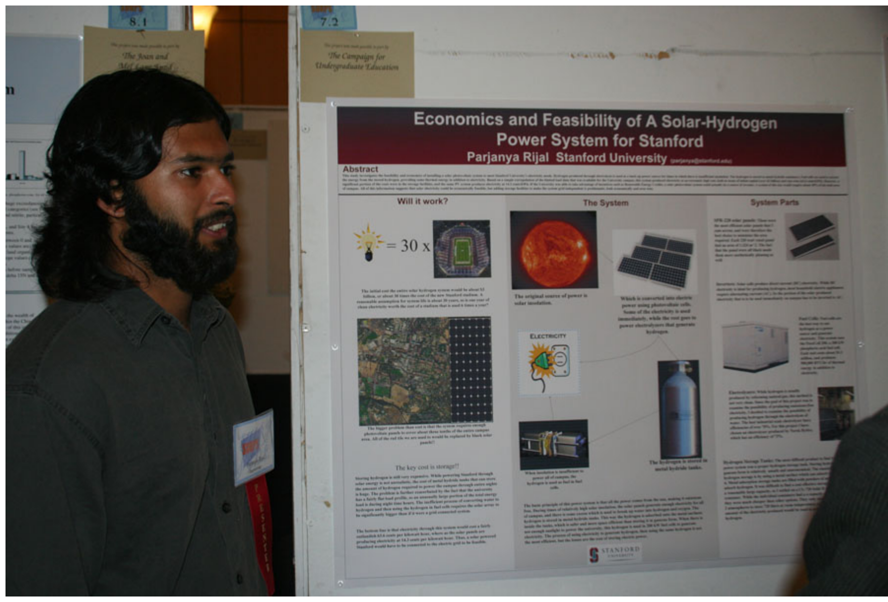
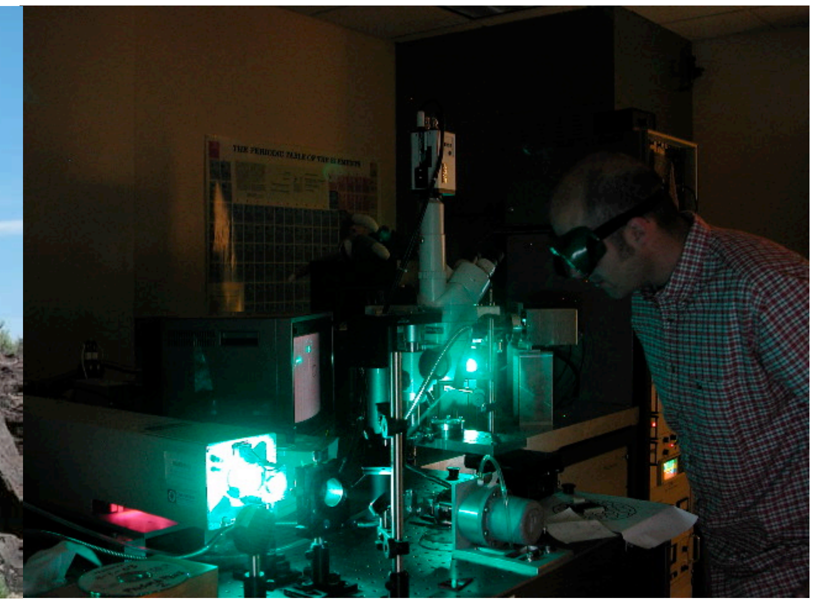
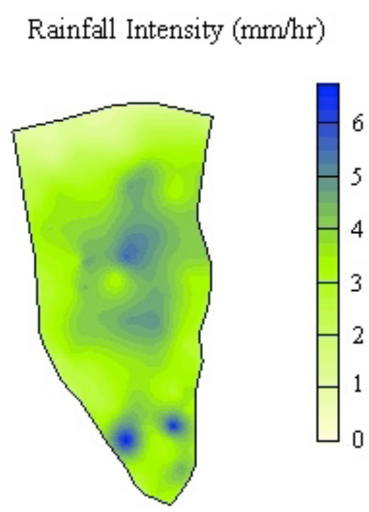
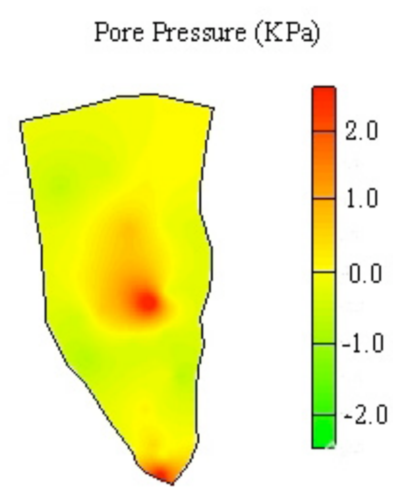


Teaching the Process of Science

Anne E. Egger
Stanford University *and* Visionlearning
2 April 2008





A little bit of background: *Science in the U.S.*

- Virtually all colleges and universities require students to take at least one science course
  ~16 million students are enrolled in college in the United States
  ~41% are enrolled in two-year colleges
  ~12% go on to major in the natural sciences
  ~50% of intended science majors switch out in the first two years

Data from the NSB 2006 Science and Engineering Indicators

A little bit of background: *Geoscience in the U.S.*

- Every year, 340,000 undergraduate students take college-level introductory geoscience courses in the United States
- 6000 students declare a major in the geosciences
  < 2% of students from introductory courses
- 2700 students graduate with a BS in the geosciences
  < 50% of declared cohort

Data from the American Geological Institute

So in our introductory courses, we have two audiences: the few who become science majors (and stay science majors) and the many that are there for the credit. Both of these audiences are absolutely critical.

A little bit of background: *Introductory courses*

- Our introductory courses are critical for recruiting majors into science disciplines
- These same courses may be the only science course that some students take
- Often have high enrollment
- Least desirable teaching assignment
- Traditionally overstuffed with content delivered in a lecture format

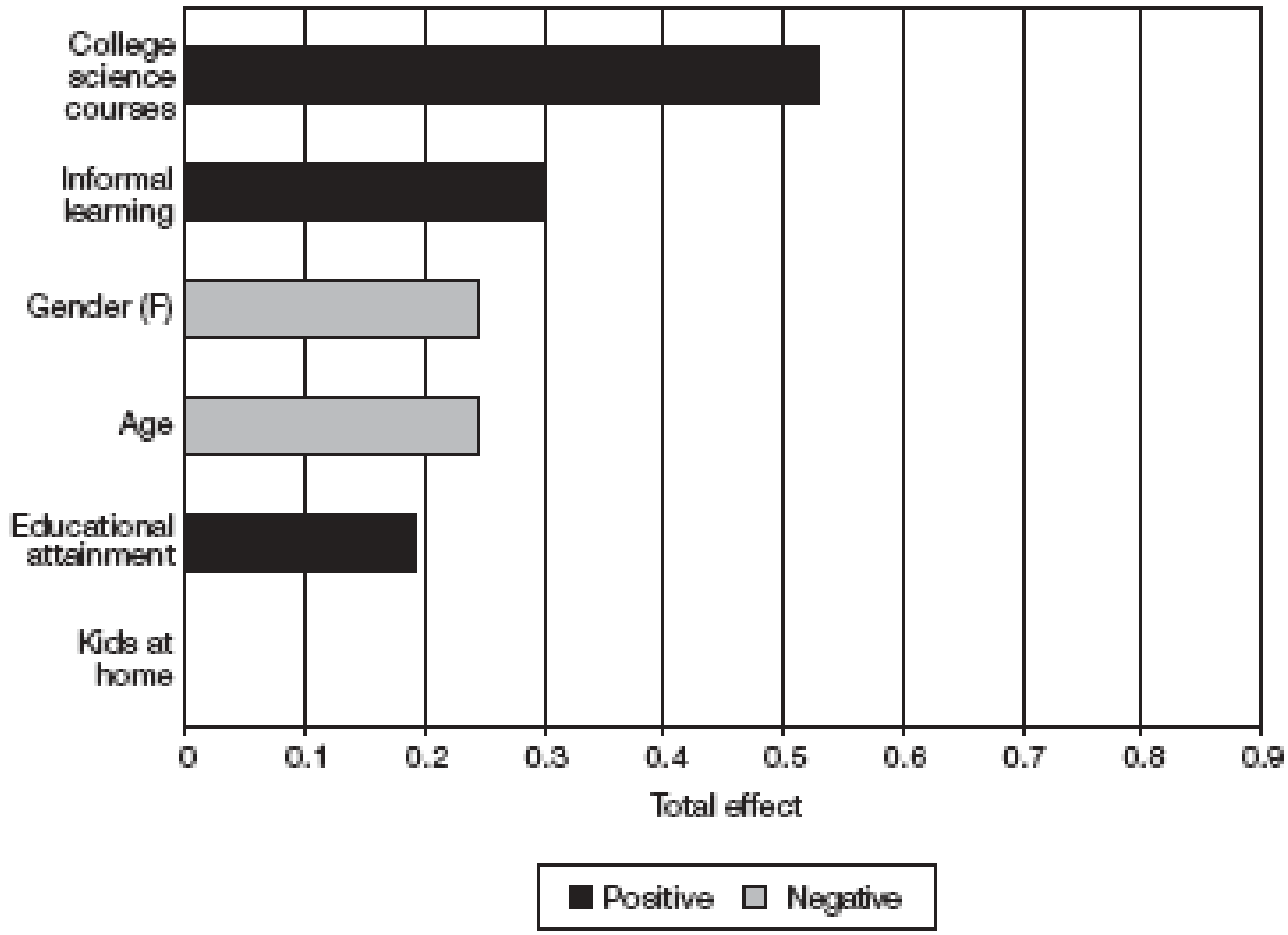


Figure 6. Total effect of selected variables on civic scientific literacy, 1999.

"... the number of college science courses is the strongest predictor of civic science literacy..."

Miller, 2004

And yet, we hear from one line of research that these are important for science literacy – and they are. So we want to use this forum to create scientifically literate citizens, and encourage them to take MORE science courses.

Are we creating scientifically literate students?

Well....

We have 16 million students taking an introductory science course – 12% go on to major in science. Are either of those groups scientifically literate after they take their course?

What is science literacy?

- An understanding of **science content** - the theories, observations, ideas, and concepts that form a body of knowledge about the natural world
- An understanding of the **process of science** - the means through which our conceptual and content knowledge was developed and continues to grow and change, and what makes it different from other ways of knowing
- An understanding of **how science is used** - how individuals and societies use science

What does the scientifically literate person look like?

They are ready for "competent **participation in a science- and technology-infused world**, not just as laboratory scientists, but as judges and lawyers, health professionals, environmental consultants, engineers, and citizens. ... scientifically literate citizen[s] critically evaluate science and scientific authority." *(McGinn and Roth, 1999)*

Notice that McGinn and Roth don't really even say anything about content – the focus is on evaluating. This is a much higher order thinking skill on Bloom's taxonomy, and one that requires a much different approach to teach.

How do we measure up?

Results of a three-question survey by the National Science Foundation in 2001 and 2004:

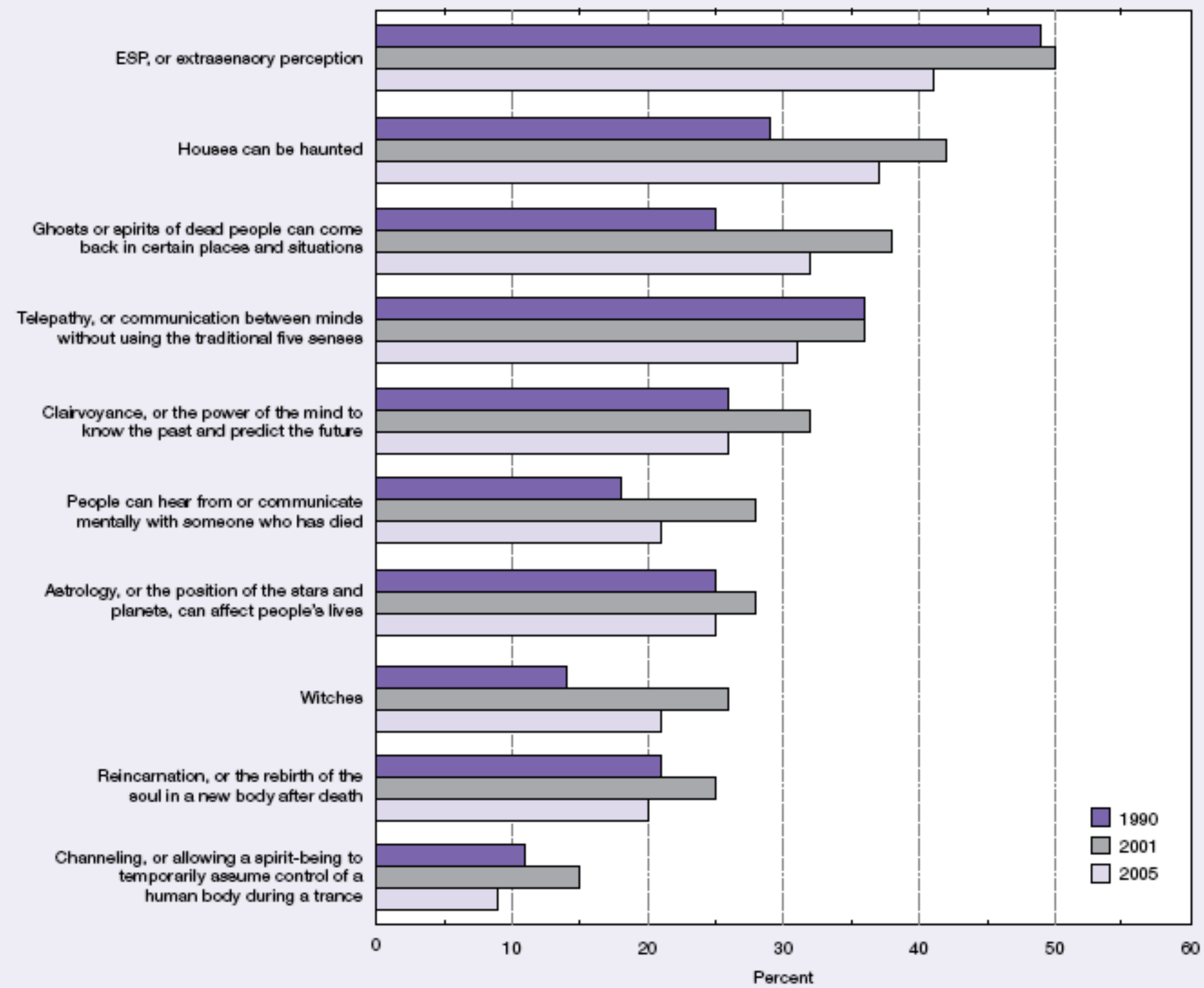
- In 2001, only 43%of Americans and 37% of Europeans could explain an experiment (46% of Americans in 2004)
- 39% of Americans could describe the nature of scientific inquiry
- In 2004, only 23% of Americans surveyed could explain what it meant to study something scientifically
- As a result, “Americans are as likely to believe in flying saucers as in evolution...” Nicholas Kristoff, NYT Op-ed, Sunday, March 29

Data from NSB Science and Engineering Indicators 2006

This is a problem!

How do we measure up?

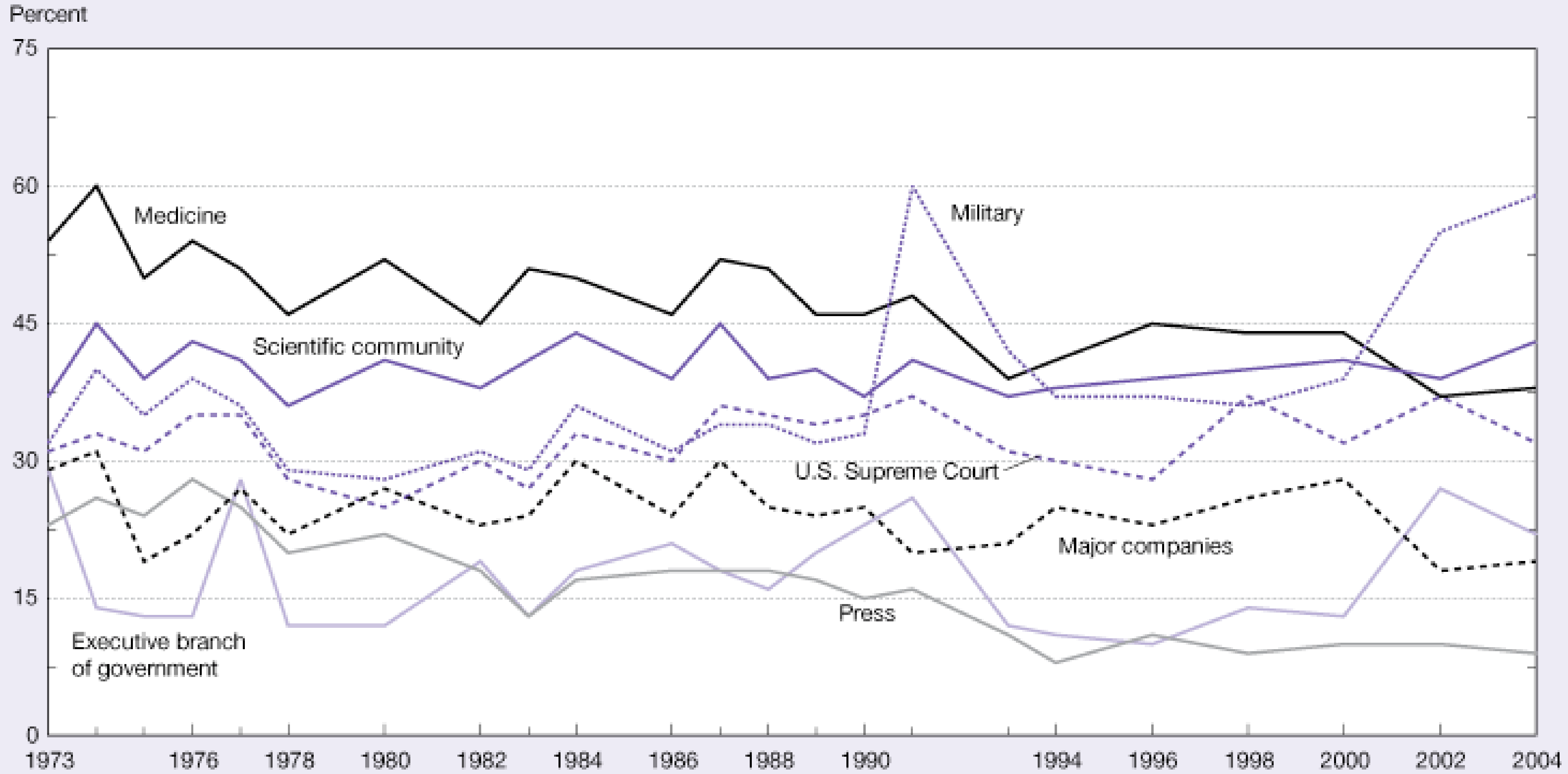
Figure 7-8
Belief in paranormal phenomena: 1990, 2001, and 2005



Confidence in science

Figure 7-19

Public expressing confidence in leadership, by institution type: 1973–2004



SOURCE: J.A. Davis, T.W. Smith, and P.V. Marsden, *General Social Survey 1972–2004 Cumulative Codebook,* University of Chicago, National Opinion Research Center (2005).

Science and Engineering Indicators 2006

Are we creating scientifically literate citizens?

- Don’t understand how science works
- High confidence in science and medicine

The New York Times
nytimes.com

March 30, 2008

OP-ED COLUMNIST

‘With a Few More Brains …’

By NICHOLAS D. KRISTOF

Unfortunately, this is a particularly lethal combination, one that prevents students from understanding why scientific knowledge is subject to debate, why scientists disagree, and how science is really a part of their lives.

Teaching to cultivate scientific literacy

- Engage students in active learning
- Get students involved in research early
- Explicitly teach the process of science

I'll focus on the last thing here, but I'll go through the first two rather quickly and then link back to them in my discussion of the process.

Teaching with active learning: *What is it?*

- The core elements of active learning are student activity and engagement in the learning process. *Prince, 2004**
- ...the primary aim of any undergraduate introductory science course—whether in biology, chemistry, physics, or earth sciences—should be to enable students to appreciate and participate in science as a special way of knowing about the world *Alberts, 2005*

Active learning is BROAD – can include lectures, and a whole variety of activities. The star is to remind me that we'll talk more about this tomorrow.

Important not just in introductory courses.

Teaching with active learning: *One way to do it*

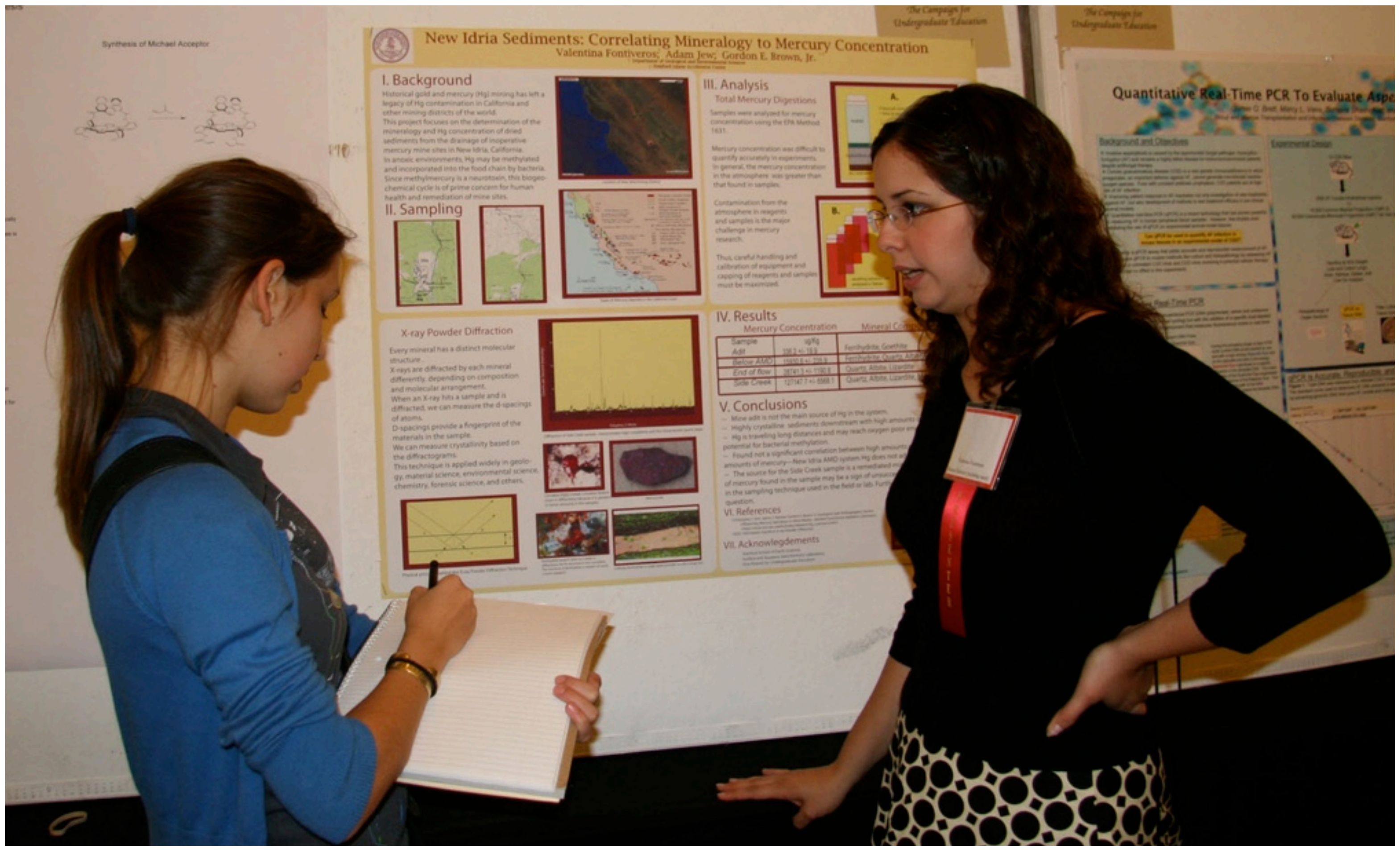
GES 1 Dynamic Earth

- Activity-based classes, integrated lecture-lab*
- No textbook (but NOT no reading)
- Shift focus from content to tools and skills
- Shift focus from regurgitation to communication

➡ *Less breadth, more depth*

The star is to remind me that I'll talk more about this tomorrow – both this individual course and how to get other faculty involved in teaching this way.

Getting involved in research early: *Integration*



- Integrated into all classes:
  GES 1: Required attendance at two research presentations

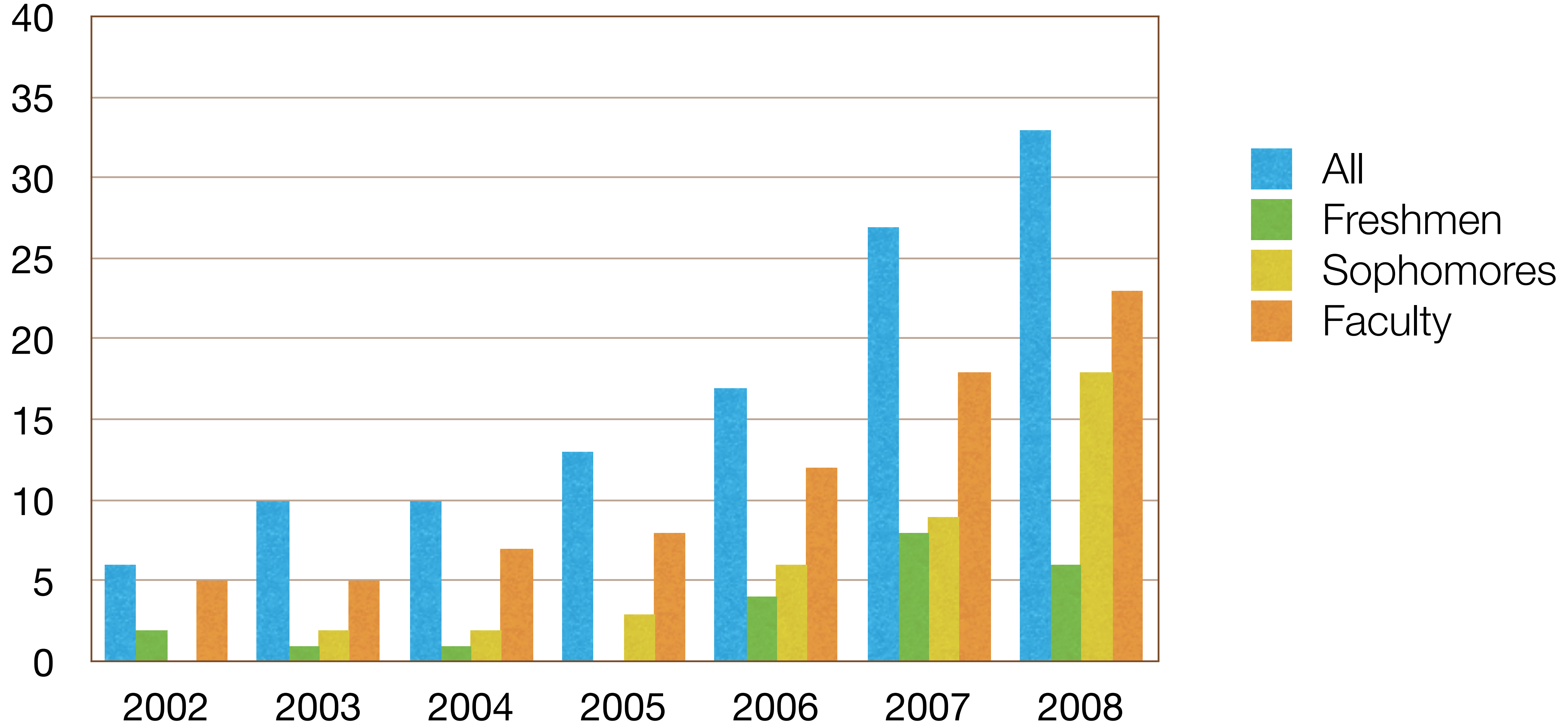
- "I plan to come back next week because I enjoy hearing about concrete examples of what I'm learning in GES 1." *Sasha E., a freshman*

The research culture is such a fundamental part of the university, and yet undergraduates are nearly completely removed from it. Just encouraging their participation and attendance at talks goes a long way.

Getting involved in research early: *Highlighting*

- Low-commitment class focused on research:
  GES 3 Current Topics in the Earth and Environmental Sciences
- Different faculty lecturer every week
  - What do you do?
  - How do you do it?
  - Why do you do it?
  - How can I get involved?

Getting involved in research early: *The real deal*



School of Earth Sciences Summer Undergraduate Research Program*

Teaching the process of science: *What's the issue?*

- Despite decades of K-12 science teaching reforms, these have largely been ineffectual (*Eisenhart et al., 1996*) and most students enter college with little or no understanding of the process of science
- Our introductory courses in particular tend to focus heavily on content knowledge rather than process
- A true scientific research experience is often limited to seniors who major in science, so non-science majors may never learn the true process of science
- Even then... "One might expect students to be exposed to the real world of science through the laboratory classes that are associated with many science courses. Unfortunately, these laboratory classes generally resemble cookery lessons, and they are remembered even by scientists as unpleasant and dull." *Alberts, 2005*

Reforms have failed largely because they do not tell teachers HOW to teach the process of science, and teachers don't themselves know.

Content knowledge - 16.7 million students learn and forget the groups of the periodic table, the names of the amino acids in DNA, the formulas for minerals, what happens when you shoot a gun on a speeding train. Did they really lean science?

Teaching the process of science: *Misconceptions*

- There is one scientific method, and it involves experimentation. *most K-12 textbooks and some college ones, too*
- "Everything is science." *Moss et al., 2001 - Interviews of five US high school students in an environmental science class*
- "Technology is really good... so the computer can generate a good interpretation." *Ryder and Leach, 2000 - Paper survey of 731 science students across Europe + 19 interviews*
- Conceptual models are not an important part of data interpretation. *Ryder and Leach, 2000*
- Controversy resolves when experiments prove a theory right. *Ryder et al., 1999 - Interviews of 11 college students at Leeds involved in final year projects*
- Scientists may not work alone, but it is unclear how they interact. *Ryder et al., 1999*

WIth these kinds of misconceptions, it is no wonder that students aren't able to retain the concepts we feed them – the facts. Each of these has major implications.

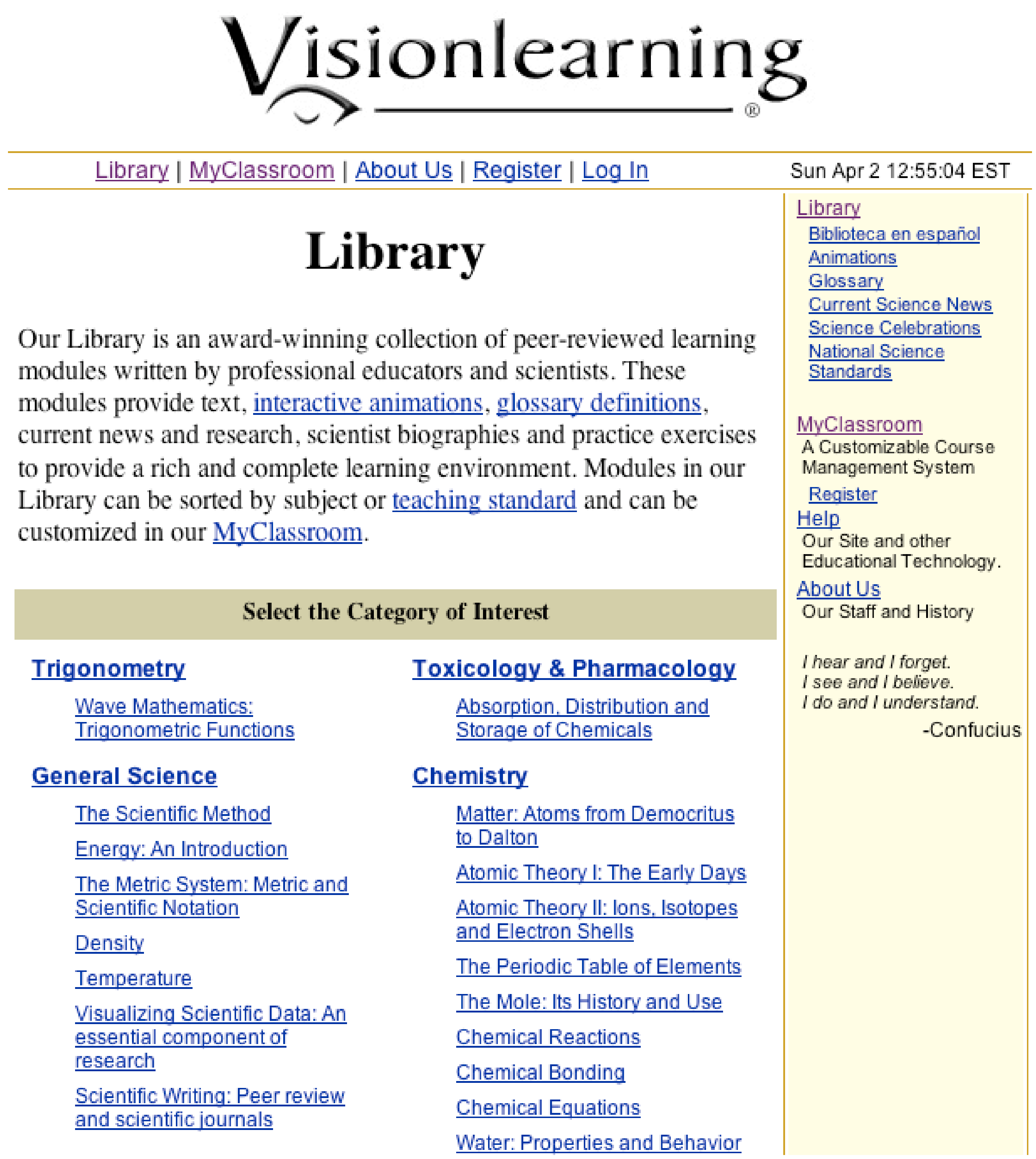
Defining teaching the process of science

- “The new scientific literacy requires increasing ability and willingness to reflect on the positive and negative ideas of science, the fallible and contingent character of science and scientists, and the heterogeneity of science and its products.” (McGinn and Roth, 1999)

- How science is a unique way of knowing - what makes it different from other ways of knowing

- How it can still be heterogeneous, involving multiple pathways, many different kinds of people, and that there is no ONE scientific method

Teaching the process of science: *New resources*



The Process of Science

Key concepts 1-6

1. Explicit teaching of the process of science facilitates understanding the knowledge of science.
2. Science is an ongoing, iterative process of investigation into the natural world as well as a body of knowledge.
3. Scientists build on the work of other scientists by collecting new data, developing and utilizing new technologies, and incorporating what is already known.
4. Science is a human endeavor that benefits from human creativity, curiosity, diversity, and diligence, while remaining subject to human fallibility and biases.
5. Science both influences and is strongly influenced by the societies and cultures in which it operates.
6. Scientists are part of the scientific community, which supports scientific progress by facilitating communication, funding research, and assuring the quality of research through peer review.

Key concepts 7-12

7. Scientists investigate a wide variety of phenomena through a variety of methods, but across all disciplines, the scientific community values the use of evidence and logic in developing arguments and open and honest communication in reporting research.
8. Scientists use multiple research methods, including experimentation, description, comparison, and modeling to explore questions about the natural world.
9. Scientists gather data from the natural world; employ a variety of techniques to analyze it, quantify uncertainty, and identify patterns and trends; and interpret that data towards developing scientific hypotheses and theories.
10. Scientific theories have held up under scrutiny and are supported by multiple lines of evidence; though they may change as new evidence and analyses come to light, they are not tenuous.
11. Debate in the scientific community is not a sign of weakness in results, but rather a valuable practice that helps strengthen scientific arguments.
12. Scientific knowledge and a scientific way of thinking can guide and inform personal and societal decision-making.

Section I: The Nature of Science

- Scientific Knowledge and Progress
- The Scientific Process

The Science Community:

  - Scientists
  - Institutions and Societies
  - Literature

Ideas in Science

  - Theories, Hypotheses, and Laws
  - Scientific Controversy
  - Science and Technology

- Science and Society

Frontispiece from Sprat's 1667 *History of the Royal Society of London*

Section II: The Practice of Science

- Scientific Research Methods
  - Experimentation
  - Description
  - Modeling
  - Comparison

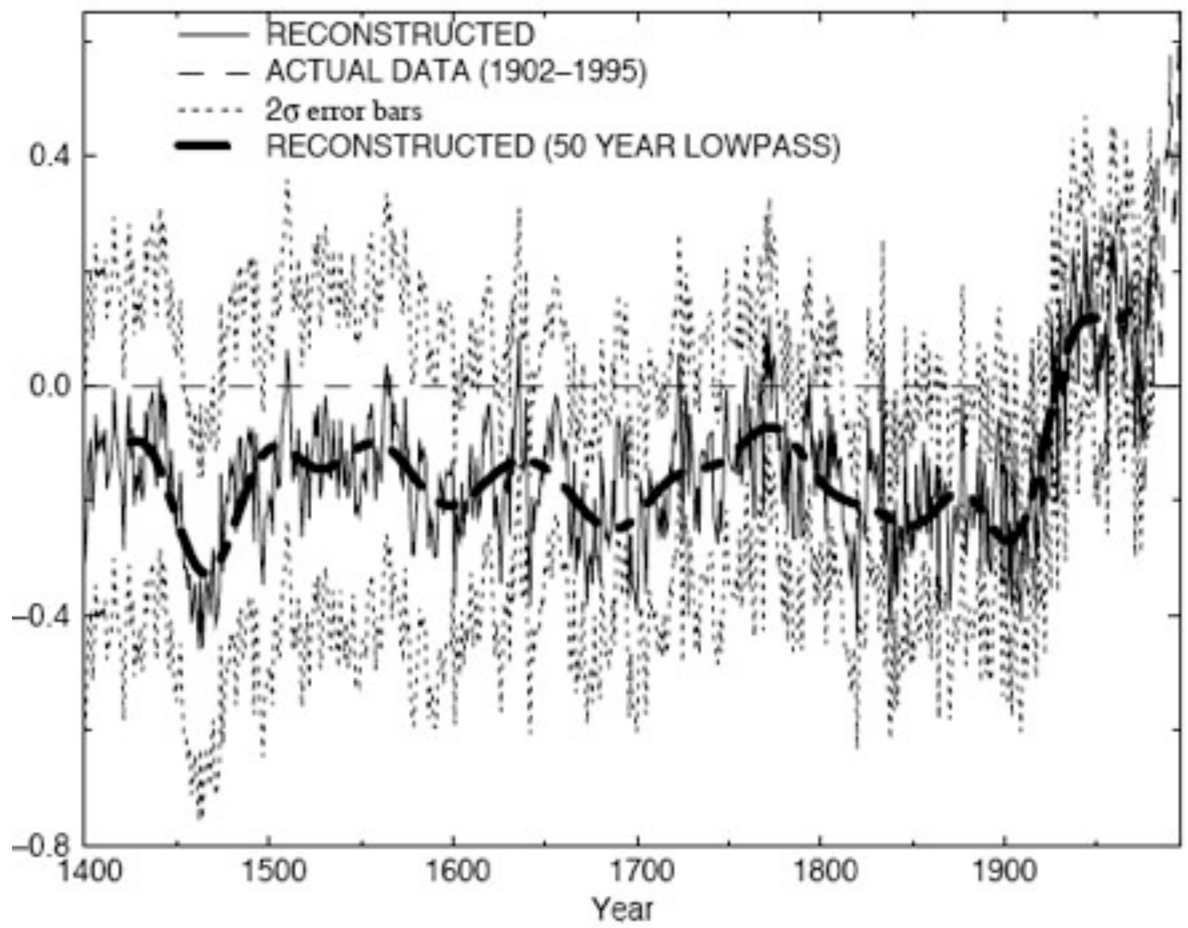
Data

  - Analysis and Interpretation
  - The Role of Statistics
  - Visualizing Data
  - Confidence and Uncertainty

Scientific Writing

  - Journal Manuscripts
  - Peer Review

- Scientific Ethics



The original "hockey stick" graph from *Mann et al., 1999*

Integrating content with process

Library Navigation

Visionlearning®

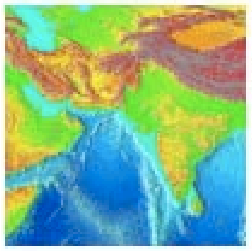


Plate Tectonics I

The Evidence for a Geologic Revolution

by: Anne E. Egger, M.A./M.S.

en español

The Himalayas are often referred to as the "roof of the world" because they host the highest peaks on earth, most famously Mount Everest at 8,848 meters above sea level. The rock that caps Mount Everest is limestone, which forms at the bottom of warm, shallow seas and is composed entirely of fossilized marine creatures-everything from plankton to clams and fish. For years, geologists struggled to explain how the hardened remains of tiny sea organisms could exist at the top of a mountain range.

Into the 1900's, many scientists believed that as the earth cooled after the Big Bang, the planet's surface contracted and wrinkled like the skin of a raisin. The 'raisin' theory implied that mountain ranges like the Himalayas were forced up by the wrinkling process. This theory assumed that all of the features on earth had formed during one cooling event and that the planet was relatively static, changing little as the cooling (and wrinkling) slowed to a halt over billions of years.

Alfred Wegener, a German geophysicist and meteorologist, was not satisfied by this explanation. His ideas drew on the widely recognized fact that Africa and South America appeared to fit together like jigsaw puzzle pieces. He collected data from the continents on both sides of the Atlantic, finding that fossils and rock types along the eastern coast of

News & Events

Earth loses its magnetism
BBC News

Plate Tectonics on Mars?
ABCNews.com

Current Science News

Experiment!

Plate Tectonics Animation
ODSN - An animated reconstruction of continental drift.

Questions?

Ask-a-Scientist
Argonne National Lab

Ask-a-Scientist
MAD Scientist Net

Biography

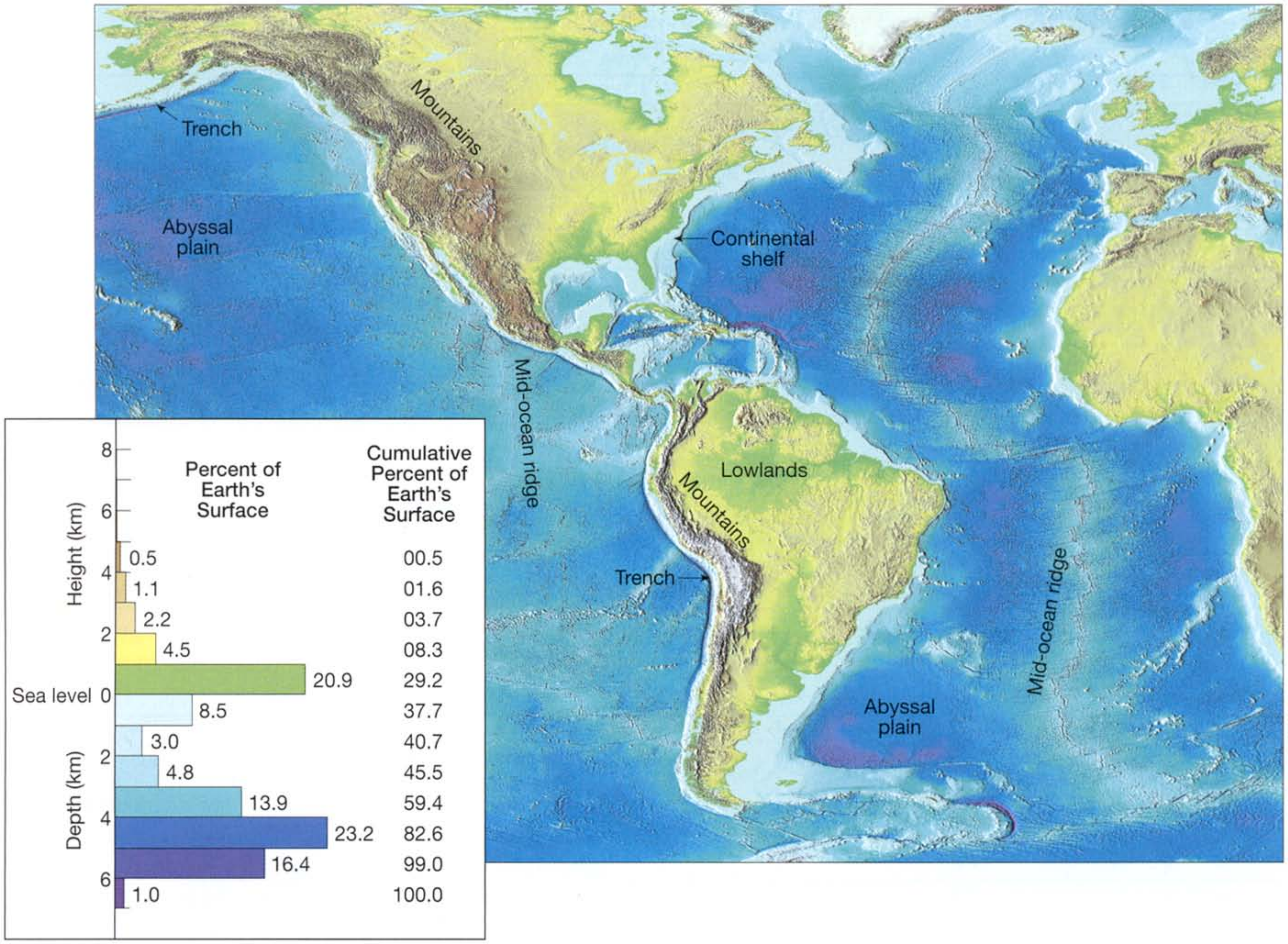
Alfred Wegener

- Plate tectonic theory + “what is a theory?”
- Specifically address misconceptions
- Historical development of knowledge
- Stories about scientists - historic to modern
- Connections to research - historic to modern

Teaching the process of science: *Being explicit*

- Active learning strategies reflect the way that science works
  BUT those reflections need to be made explicit
  - Density - isostasy - topography exercise
- Involving students in research early erases the boundary between research and education and makes the process more transparent
  BUT they need to be strongly mentored through the process
  - Research prep course for undergrads
  - Research mentoring course for grad students
- Giving students reading material on the process of science is good
  BUT it needs to be reinforced and made explicit in the classroom through connections with content and real research
  - Future research on new Visionlearning materials

Example activity:
Density, Isostasy, and Topography



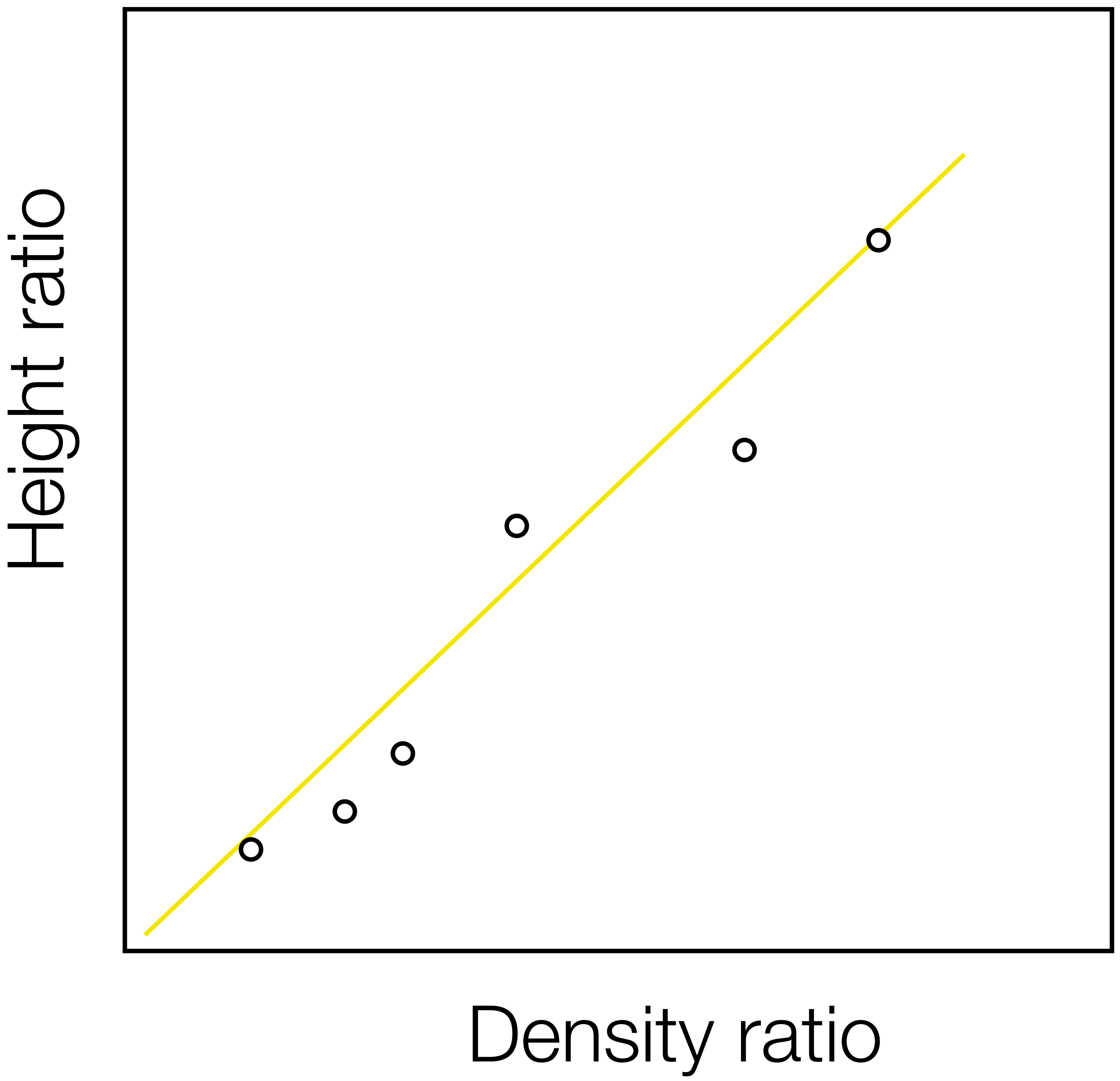
Define the question

Activities are things your students might do now in labs, but there are advantages to doing them as a class.

Students work largely in groups during class - here they are collecting data

Sharing data- one of the big advantages about doing in big class

Wood block measurements



Plot data and derive equations

Led to several teachable moments - why we use equations to simplify our observations

Follow-up questions

- Using your equation, calculate the thickness of the crust in the Andes, assuming they are made largely of granite and have an average elevation of 5 km above sea level.

- Based on what you now know about crustal thickness and isostasy, sketch what you would expect the crust to look like in an east-west cross-section across South America. Include approximate crustal thicknesses.

Follow-up readings

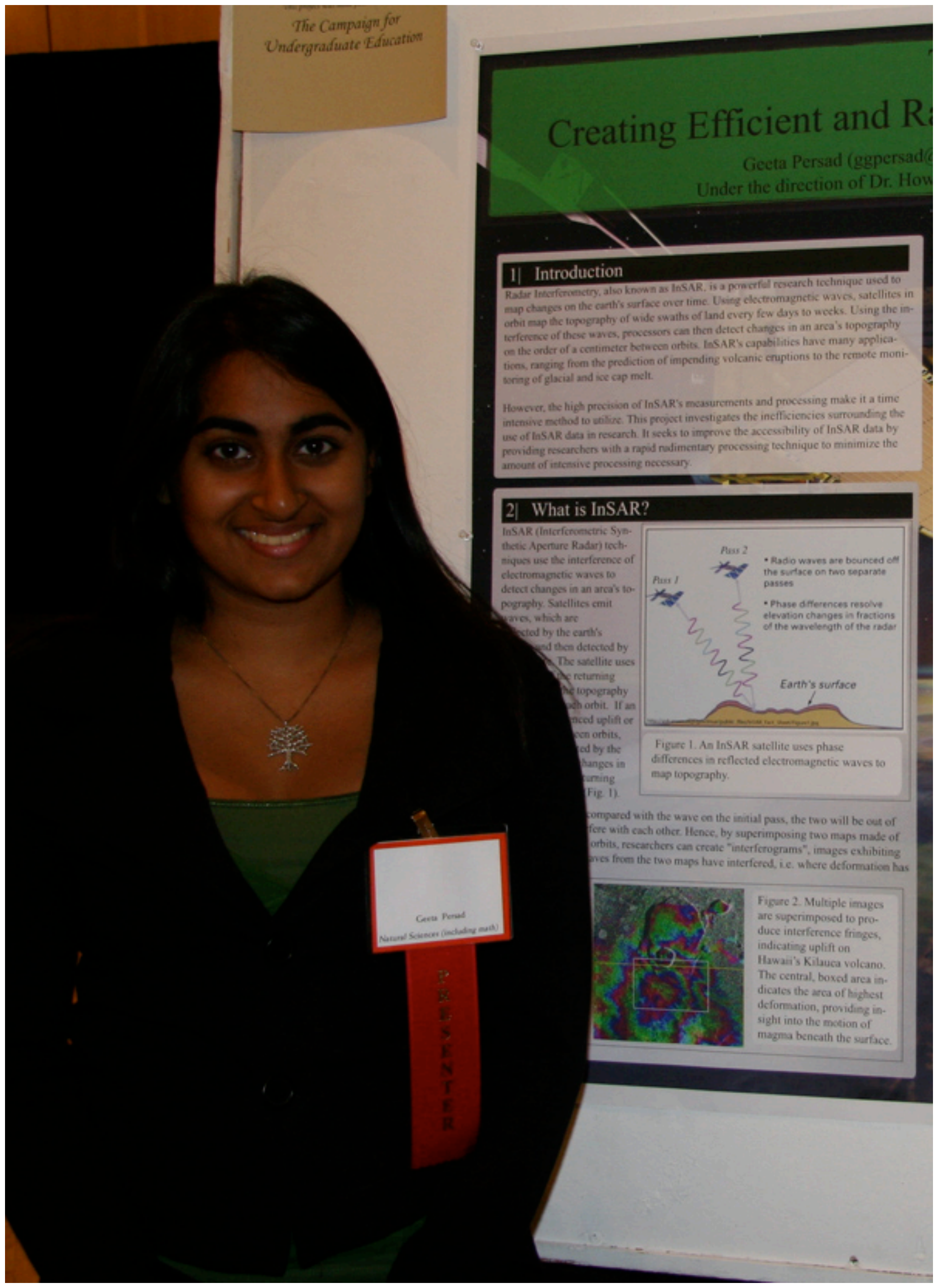
Good feedback from this! Students are engaged, and ask great questions, and then do the reading because it follows up the activity and gives them more details. They see the connections between concepts and we are able to build on concepts throughout the semester, rather than give this smattering of topics throughout.

In section, they clear up any misconceptions, and anything persistent, I have time to address in class the next day.

However…

Mentoring classes: *Being explicit*

- For undergrads
  - Writing proposals
  - Doing background reading
  - Communicating with your advisor
- For grads - new course this year
  - Designing an appropriate project
  - Ethics and safety
  - Communicating with your advisee



The future of science teaching

If research universities marshal their collective will to reform science education, the impact could be far-reaching. We will send non-science majors into society knowing how to ask and answer scientific questions and be capable of confronting issues that require analytical and scientific thinking. Our introductory courses will encourage more students to become scientists. Our science majors will engage in the process of science throughout their college years and will retain and apply the facts and concepts needed to be practicing scientists. Our faculty will be experimentalists in their teaching, bringing the rigor of the research lab to their classrooms and developing as teachers throughout their careers. Classrooms will be redesigned to encourage dialogue among students, and they will be filled with collaborating students and teachers. Students will see the allure of science and feel the thrill of discovery, and a greater diversity of intellects will be attracted to careers in science. The benefits will be an invigorated research enterprise fueled by a scientifically literate society.

Handelsman et al., Scientific Teaching, 2001

You are already here - this is good. You are part of the solution.