

Teaching my students to think - even when they don't want to!

Edward F. Redish
University of Maryland

Some background



- ❑ I've been teaching at UMd for 40 years (starting in 1970).
- ❑ In the '80s I was involved with creating curriculum with computers.
- ❑ In '92 I gave up my research in theoretical nuclear physics and began to do research in physics education full time.

The UMd PERG & BERG:

Faculty

- Spencer Benson (Bio*)
- Janet Coffey (C&I – Bio)
- Todd Cooke (Bio)
- Andy Elby (C&I - Phys)
- Joe Redish (Phys*)

Research Faculty

- Ayush Gupta (Phys)
- Gili Marbach-Ad (Bio)

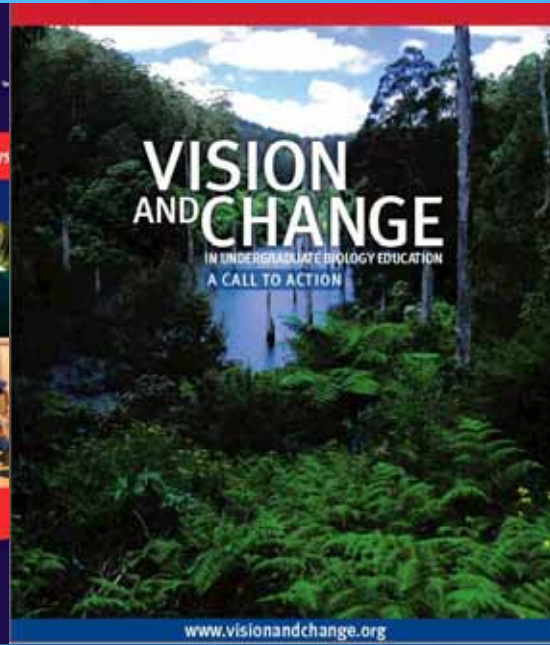
* C&I affiliate appt.

Postdoc

- Jessica Watkins (Phys)

Grad Students

- Luke Conlin (C&I)
- Brian Danielek (C&I)
- Ben Dreyfus (Phys)
- Colleen Gillespie (C&I)
- Kristi Hall (C&I)
- Mike Hull (Phys)
- Eric Kuo (Phys)
- Jen Richards (C&I)



3/29/11
UMd Teaching &
Learning Center

Why do they have to
learn to think anyway?

Learning to think

- Professionals do things quickly and automatically without thinking. Isn't that what our students should learn? Automaticity?

The changing work force

- Think about how the character of the American workforce has changed in the past 100 years.
 - 1900: Dominated by agriculture
 - 1950: Dominated by manufacturing
 - 2000: Dominated by computers/
software
 - 2050: ?

Workplace needs are changing fast

- ❑ Technology: Robots handle rote. Anything can be looked up on Wikipedia – on your cell phone!
- ❑ Changing professions: Students today will have multiple careers and need lifelong learning.
- ❑ Students need organizational skills, problem solving and other higher order skills.
- ❑ Students need to know what to look for and where. More science! (and more writing, geography, languages, ...)

Adaptive expertise

- The rapid pace of change in science implies that critical skills for scientists (and health-care workers) in the next few decades will be
 - the ability to continue to learn
 - the ability to understand the implications of new discoveries
 - the ability to integrate new tools and knowledge into their practice of science.



The Hidden Curriculum

- Typically, when we prepare our syllabi, we select what content we intend to “cover”.
- But what we really want our students to learn is more than just a set of facts: it’s a way of thinking.

Contents

CHAPTER 1 Measurement

- 1-1 Introduction
- 1-2 Basic Measurements in the Study of Motion
- 1-3 The Quest for Precision
- 1-4 The International System of Units
- 1-5 The SI Standard of Time
- 1-6 The SI Standards of Length
- 1-7 SI Standards of Mass
- 1-8 Measurement Tools for Physics Labs
- 1-9 Changing Units
- 1-10 Calculations with Uncertain Quantities

CHAPTER 2 Motion Along a Straight Line

- 2-1 Motion
- 2-2 Position and Displacement along a Line
- 2-3 Velocity and Speed
- 2-4 Describing Velocity Change
- 2-5 Constant Acceleration: A Special Case

CHAPTER 3 Forces and Motion Along a Line

- 3-1 What Causes Acceleration?
- 3-2 Newton's First Law
- 3-3 A Single Force and Acceleration Along a Line
- 3-4 Measuring Forces
- 3-5 Defining and Measuring Mass
- 3-6 Newton's Second Law for a Single Force
- 3-7 Combining Forces along a Line
- 3-8 All Forces Result From Interaction
- 3-9 Gravitational Forces and Freefall Motion
- 3-10 Newton's Third Law
- 3-11 Comments on Classical Mechanics

CHAPTER 4 Vectors

- 4-1 Introduction
- 4-2 Vector Displacements

- 4-3 Adding Vectors Graphically
- 4-4 Rectangular Vector Components
- 4-5 Unit Vectors
- 4-6 Adding Vectors Using Components
- 4-7 Multiplying and Dividing a Vector by a Scalar
- 4-8 Vectors and the Laws of Physics

CHAPTER 5 Net Force and Two-Dimensional Motion

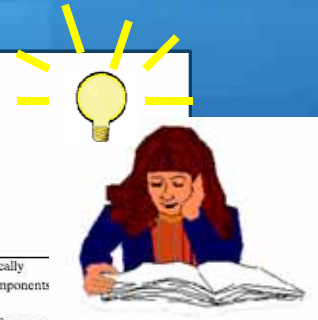
- 5-1 Introduction
- 5-2 Projectile Motion
- 5-3 Analyzing Ideal Projectile Motion
- 5-4 Displacement in Two Dimensions
- 5-5 Average and Instantaneous Velocity
- 5-6 Average and Instantaneous Acceleration
- 5-7 Uniform Circular Motion

CHAPTER 6 Identifying and Using Forces

- 6-1 Combining Everyday Forces
- 6-2 Net Force as a Vector Sum
- 6-3 Gravitational Force and Weight
- 6-4 Contact Forces
- 6-5 Drag Force and Terminal Speed
- 6-6 Applying Newton's Laws

CHAPTER 7 Translational Momentum

- 7-1 Collisions and Explosions
- 7-2 The Translational Momentum of a Particle
- 7-3 Isolated Systems of Particles
- 7-4 Impulse and Momentum Change
- 7-5 Newton's Laws and Momentum Conservation
- 7-6 Simple Collisions and Conservation of Momentum
- 7-7 Conservation of Momentum in Two Dimensions
- 7-8 A System with Mass Exchange—A Rocket and Its Ejected Fuel



Core competencies from AAAS: Vision & Change (2011)



1. Ability to apply the process of science
2. Ability to use quantitative reasoning
3. Ability to use modeling and simulation
4. Ability to tap into the interdisciplinary nature of science
5. Ability to communicate and collaborate with other disciplines
6. Ability to understand the relationship between science and society



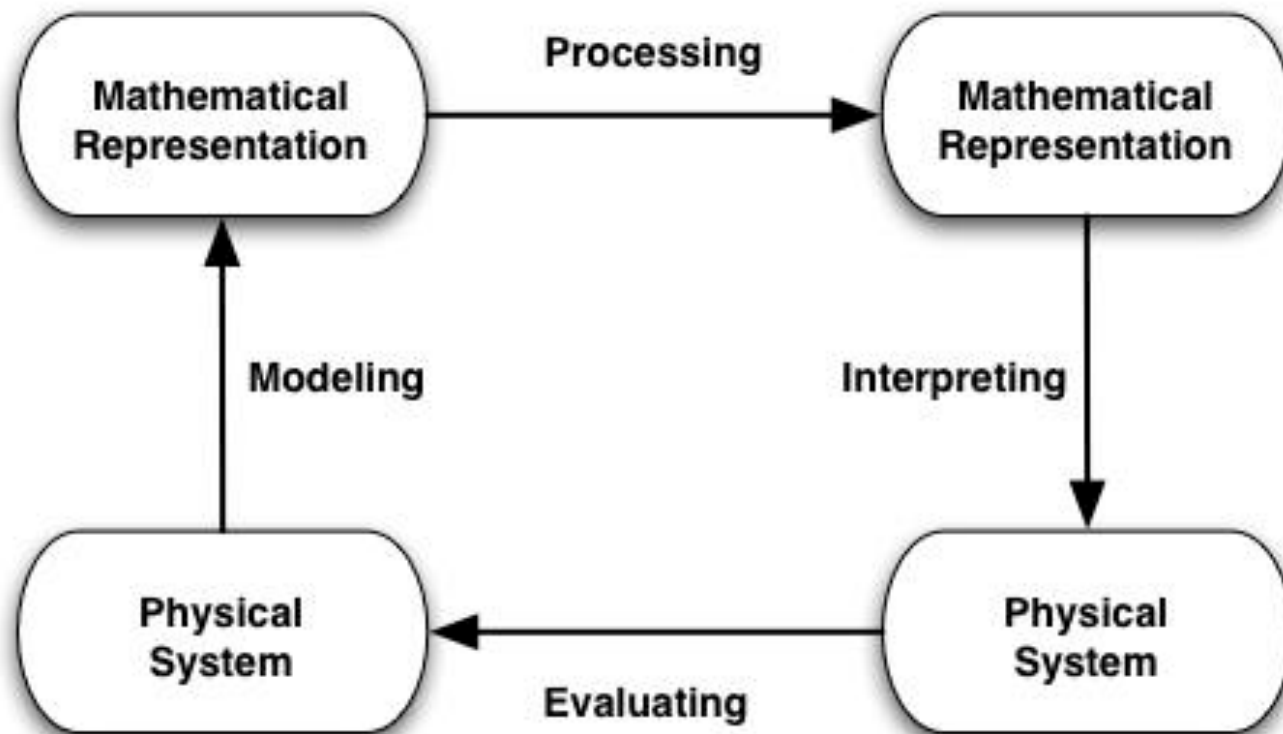
3/29/11
UMd Teaching &
Learning Center

Deconstructing our learning goals

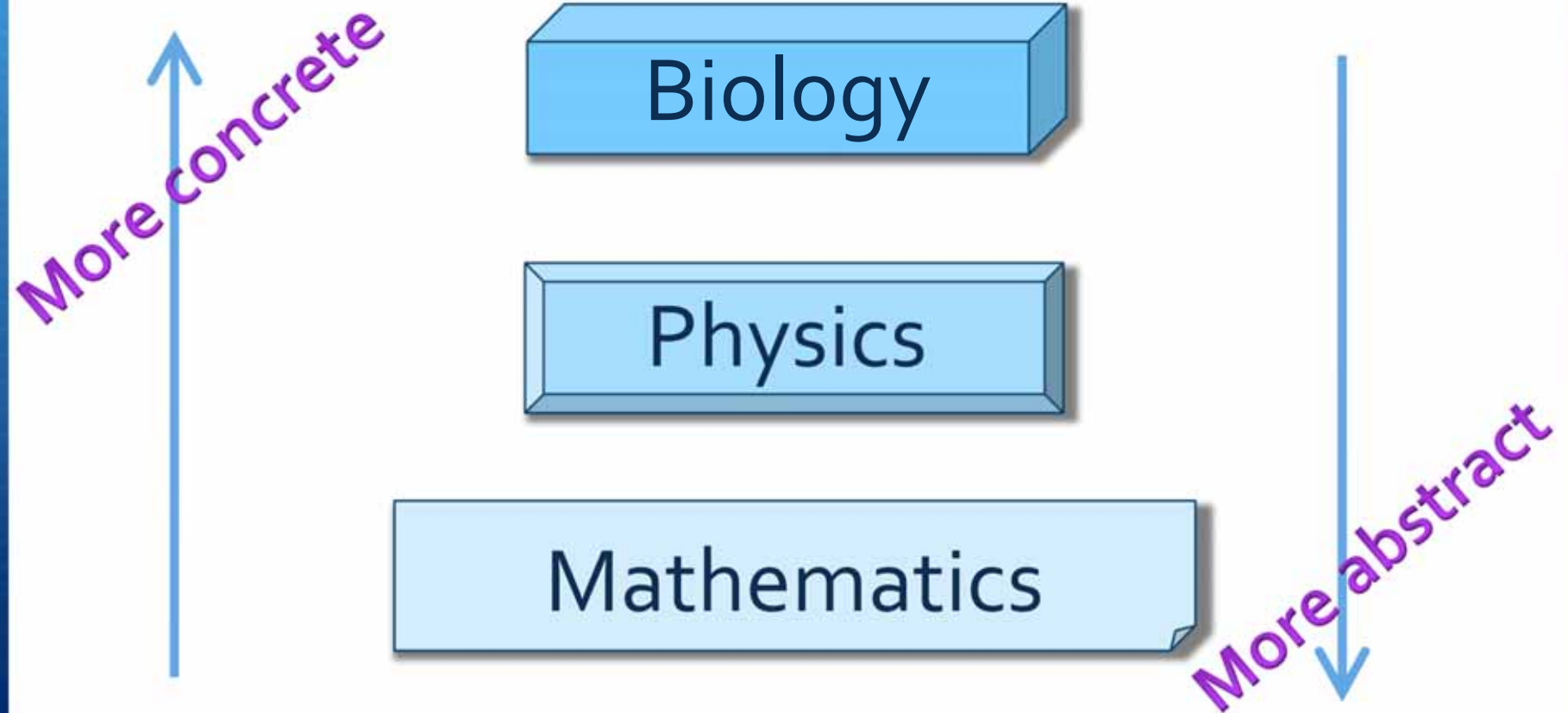
Focus on a few goals

- ❑ For a physics class, these are probably good ones to choose
- 1. Ability to use quantitative reasoning
- 2. Ability to use modeling and simulation

Scientific modeling



Physics provides value-added
for biologists as a halfway point.



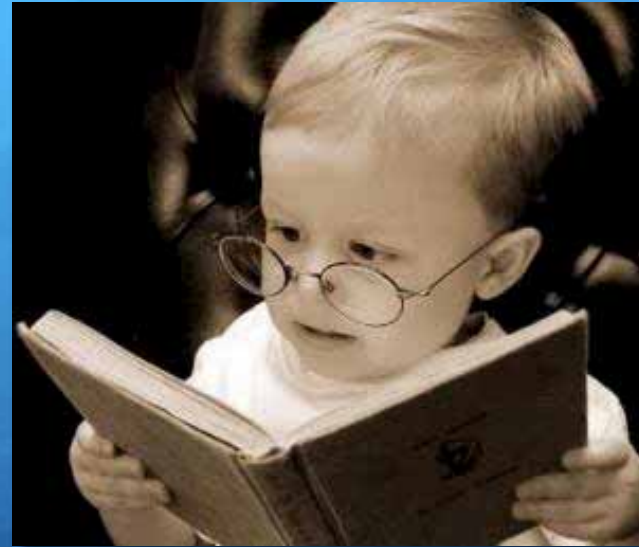
The goals we have chosen are complex and require many skills



- They need to see what they are learning as a coherent whole, not as isolated facts but a web of self-supporting parts – a “safety net”.
- They need to learn to “reason beyond simple recall” – to be able to build chains of reasoning.
- They need to evaluate the models and stories they build with “sense making” – not just familiarity but what it is that makes a story coherent and consistent with basic principles.
- They need to be able to represent the knowledge they know in a variety of forms –words, equations, graphs and diagrams – and to see the consistency among them, how they create a richer, multi-dimensional understanding of a phenomenon

What can physics do for a biologist?

- ❑ Physics makes the math real so modeling is not just a way of getting answers, but a way of integrating math into scientific thinking.
- ❑ Physics uses (hyper-) simplified touchstone examples to create a sense of understanding of principles and how they apply – stakes in the ground to which an organized web of knowledge can be attached.
- ❑ Physics is a good place to learn multi-representational translation using simple cases.
- ❑ Physics is a good place for students to learn to quantify, beginning with their everyday experience.



3/29/11
UMd Teaching &
Learning Center

What students bring into our classes – and why it matters

There are many reasons why it isn't always easy to achieve these goals.

❑ Constructivism

- We build new knowledge through manipulation and transformation of what we already know.

❑ Misconceptions

- Students often generalize their everyday knowledge – and even their knowledge from previous classes – inappropriately.

❑ Expectations

- Students think they know “how school is supposed to work.”

Physics Education Research has shown that what students bring in matters.

- Thirty years of research and thousands of papers document that students respond to intro physics with many misconceptions – some of which are extremely robust.

Some examples (often not articulated explicitly by the student)

- ❑ Motion naturally decays without any outside agency. Maintaining a velocity requires an unbalanced force.

Motion decays as the result of outside drag forces. Maintaining a velocity requires applying other forces to balance them.

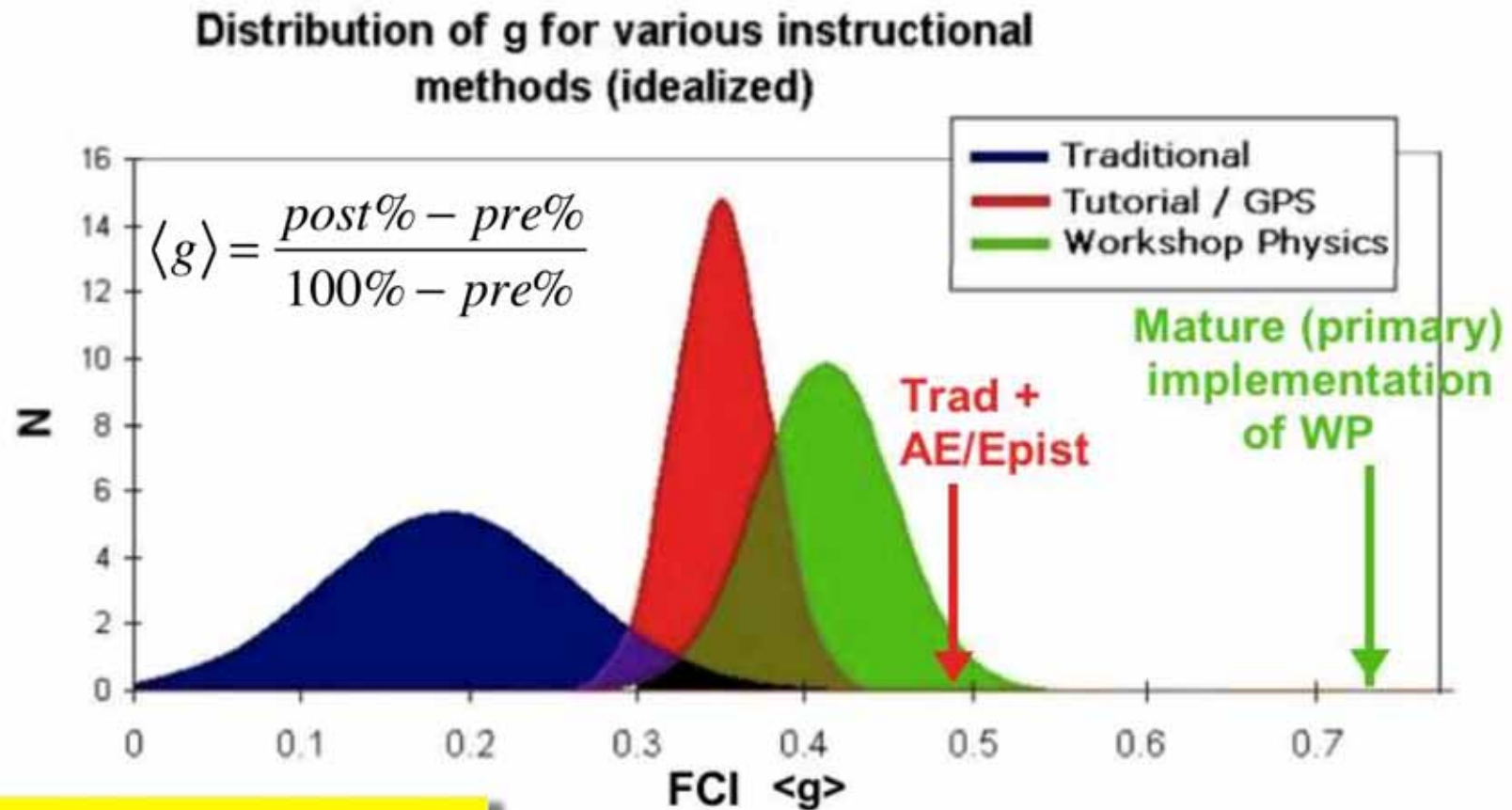
- ❑ When connected, batteries generate a constant flow of electricity that is “used up” through the circuit. (I and ΔV may not be distinguished.)

Batteries maintain a constant voltage difference across their terminals. The current delivered depends on what the battery is connected to.

Concept learning can be improved with active engagement

- A variety of instructional environments have been developed to help improve student conceptual learning in intro physics.
 - Peer Instruction (clickers)
 - Tutorials (one hour/wk guided interactive discussions)
 - Group problem solving (one hr/wk)
 - Workshop Physics (full lab-based guided inquiry with computer-assisted data acquisition and analysis)

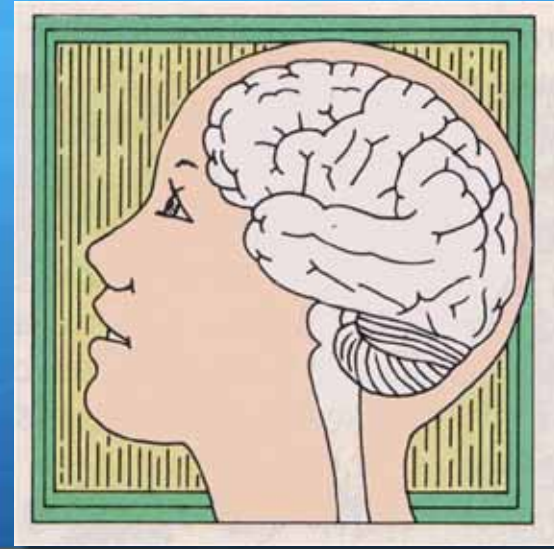
Paying attention to student knowledge building helps



From Redish & Steinberg
Physics Today. 52:1 (1999)

But there's more
than just concepts

- If we want to help our students on the path to adaptive expertise, we have to help them learn to organize and access their knowledge as well.



Some basic psychology, or: Try it in your own head

3/29/11
UMd Teaching &
Learning Center

Students bring in their knowledge of "how school works" and what their subject is about:
What is the nature of the knowledge
I am learning?
What do I have to do to learn it?
When they have this wrong, it can lead them into lots of trouble.

Experiment 1

- ❑ I will show a list of 24 words for one minute.
- ❑ Try to memorize as many as you can.

Roediger & McDermott
J. Exp. Psych. 21:4 (1995)



Thread Thimble

Bed Rest

Pin Haystack

Awake Tired

Eye Knitting

Dream Snooze

Sewing Cloth

Blanket Doze

Sharp Injection

Slumber Snore

Point Syringe

Nap Yawn

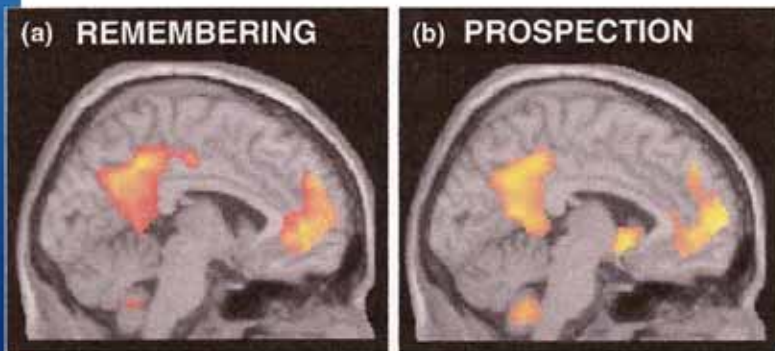
Did you have these words on your list?

1. The word “needle” was on my list – but not the word “sleep”
2. The word “sleep” was on my list – but not the word “needle”
3. Both the words “sleep” and “needle” were on my list.
4. Neither of the words “sleep” and “needle” were on my list.

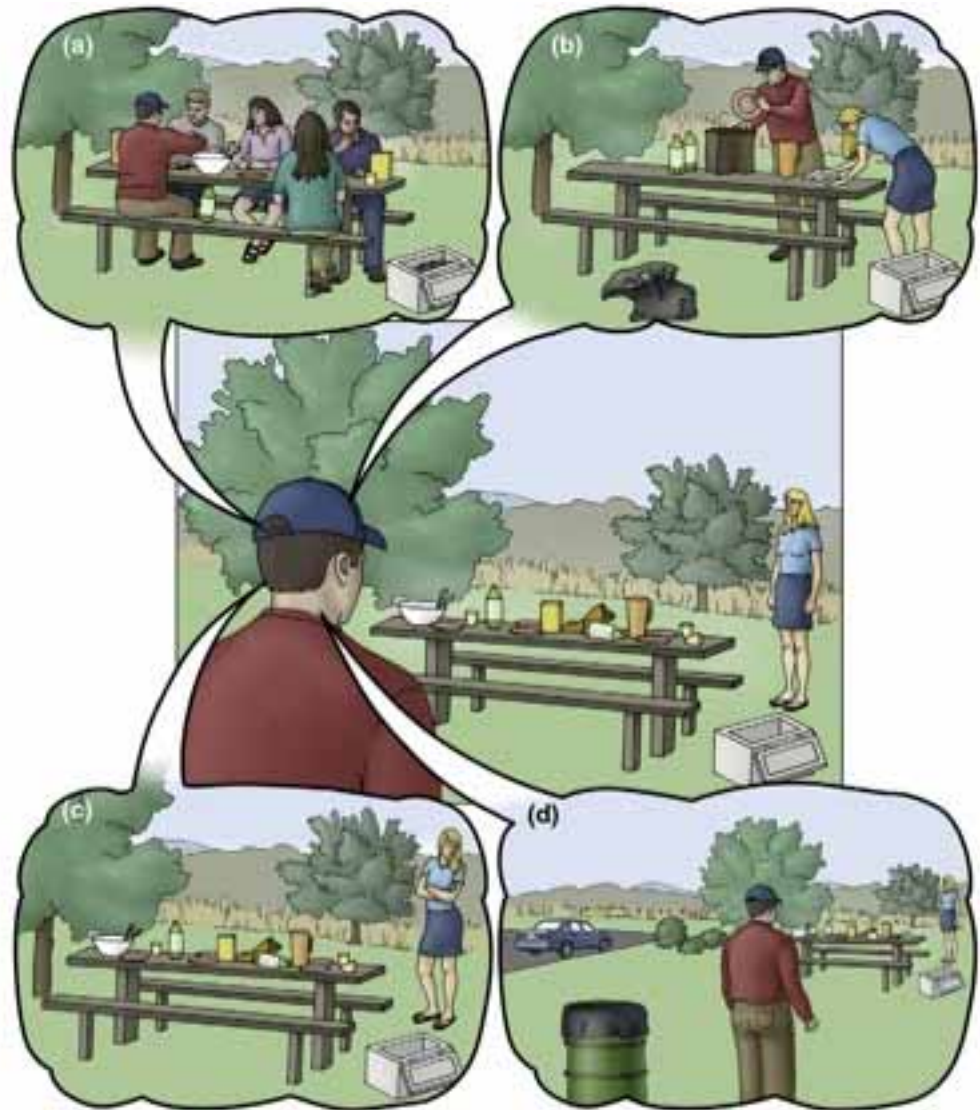


A model of memory: Predicting the Past

- (a) Recalling past events
- (b) Imagining future events
- (c) Seeing things from someone else's perspective
- (d) Navigation



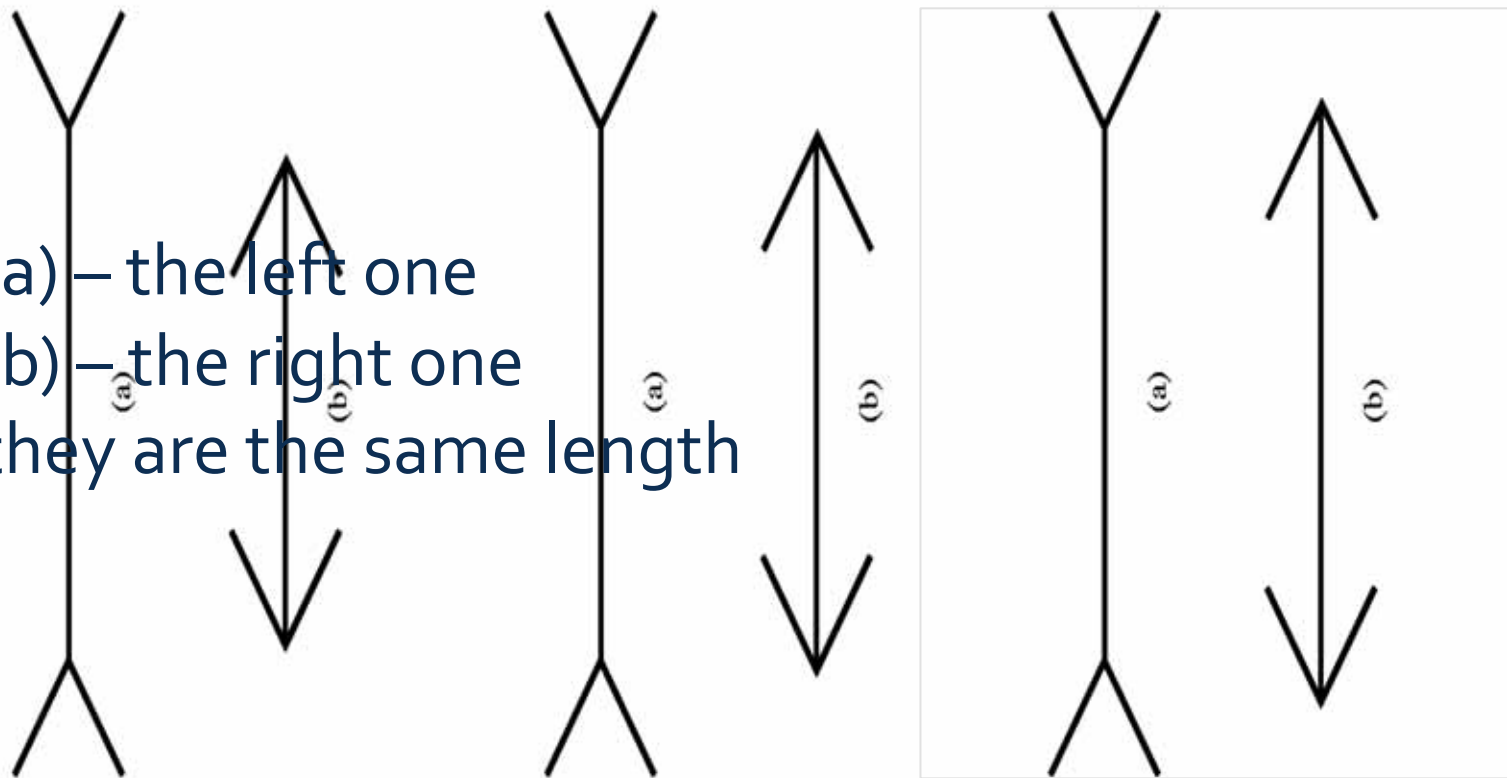
From Buckner & Carroll
Trends in Cog. Sci. 11:2 (2006)



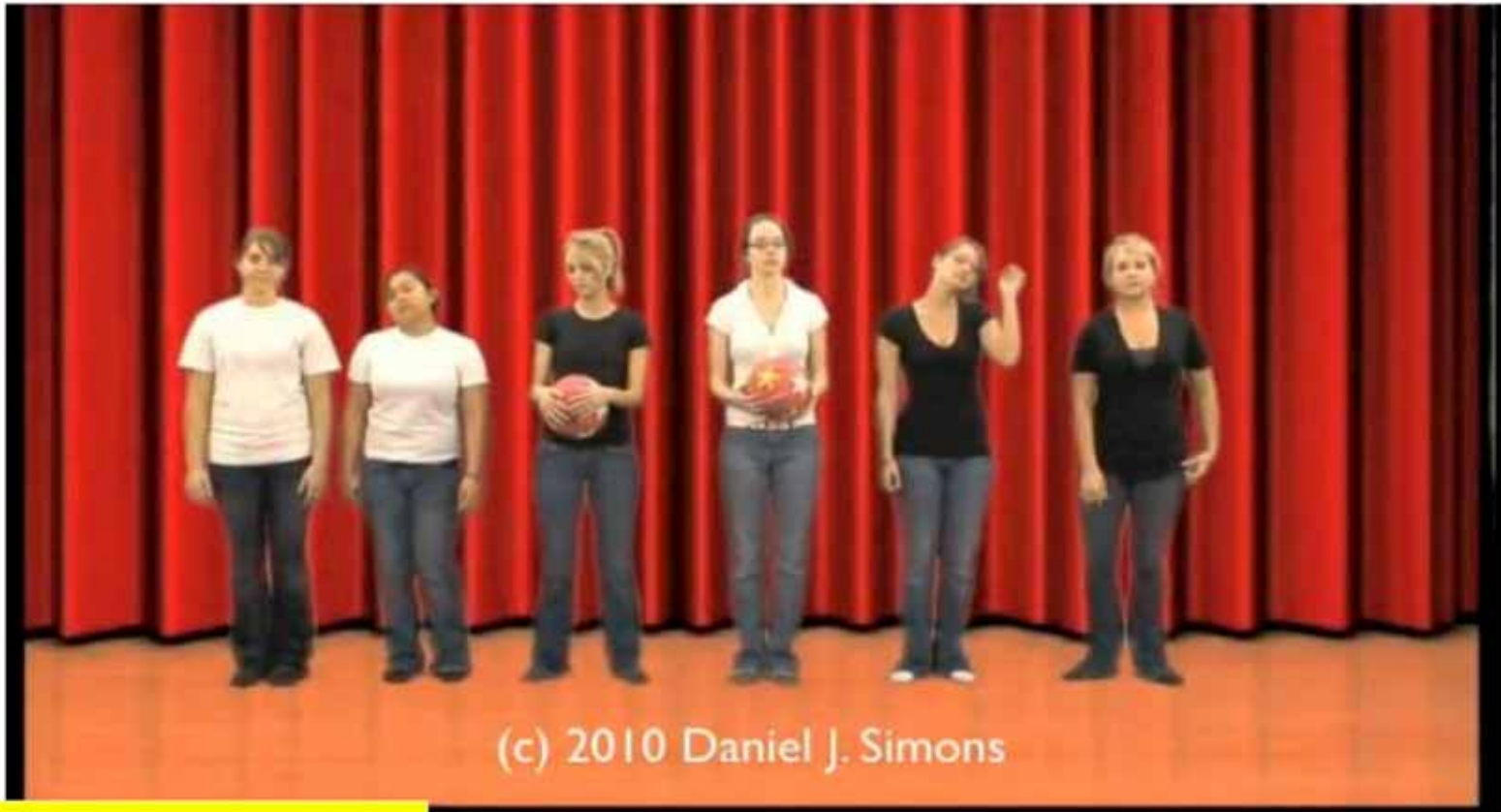
Expt. 2: Which line is longer? (Ignore the arrowheads)



1. (a) – the left one
2. (b) – the right one
3. they are the same length



Experiment 3: Count the passes



Simons & Chabris
Perception. 28:9 (1999)

8/29/11

Implications

- ❑ Memory is reconstructive. Direct one-step recall is not always right. Students need to learn to build a web of knowledge.
- ❑ Students may not expect that they need to do this, based on previous experience with school (and science classes).
- ❑ Inappropriate expectations can lead our students to “miss the gorilla in the classroom” and ignore our explicit claims that we want them to think.



3/29/11
UMd Teaching &
Learning Center

Expectations, Framing, and Epistemology

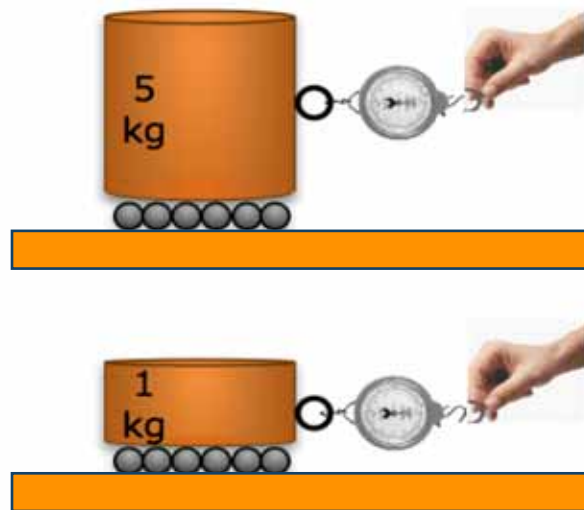
Example:

- A simple bit of physics

The prof drops two metal spheres, one of 1 kg, the other of 5 kg. They hit the ground at (almost) exactly the same time. The force of gravity on the 5 kg weight is:



1. Greater than the force on the 1 kg weight
2. Less than the force on the 1 kg weight
3. The same as the force on the 1 kg weight.
4. There is not enough information to tell.



You are pulling two weights along a table with equal force. Which one would speed up faster?



1. The 1 kg weight
2. The 5 kg weight
3. They would speed up the same way.
4. There is not enough information to tell.

Implication:

- ❑ Students often exhibit “one step thinking” and don’t call on knowledge they perfectly well know when that knowledge would be appropriate.
- ❑ Getting them to change their approach may not be easy.

Student expectations matter!

- ❑ “Just tell me what you want me to know and I’ll give it back to you on a test.”
- ❑ “There’s so much material on a science test that there’s no time to think. You just have to memorize as much as you can.”

Does it happen? Some data

□ Student responses to expectations survey items deteriorated as a result of one semester of physics.

- + In this course, I do not expect to understand equations in an intuitive sense; they just have to be taken as givens.
- + The most crucial thing in solving a physics problem is finding the right equation to use.
- + Understanding physics basically means being able to recall something you've read or been shown.
- + A significant problem in this course is being able to memorize all the information I need to know.

**Redish, Saul, & Steinberg,
Am. J. Phys. 66:3 (1998)**

Student expectations affect what they choose to do in class.

- Here are some quotes from interviews we have done with students taking BSCI 207 (Organismal Biology)

- And I'm just studying the wrong way. I realized too far into the last unit that basically I was studying straight out of the book, working on memorization, which is how I studied for organic chemistry. But that's not the way to go about biology... And that's another thing that wasn't made clear to me, I think it might have been the high school to college transition, but it was not made clear to me that the textbook should not be used as the main material, that the lecture notes are what's important. Because in high school, basically the course is taught straight out of the book, and you can pretty much be safe if you just read the book ahead of time...

S: I don't like to think of biology in terms of numbers and variables. I feel like that's what physics and calculus is for. So, I mean, come time for the exam, obviously I'm gonna look at those equations and figure them out and memorize them, but I just really don't like them. ...it's basically a way to put it, put the concept into words. I think that's what the only function of the equations are. It's just to help you write it down. ... I think that biology is just-- it's supposed to be tangible, perceivable, and to put that in terms of letters and variables is just very unappealing to me.

- ❑ **I:** Were any of [the group activities] particularly helpful for you?
- ❑ **S:** Ok, well, the wooden horse demonstration?... The little one and the big one ... I mean, visually I knew that it doesn't work when you make little things big, but I never had anyone explain to me that there's a mathematical relationship between that, and that was really helpful to just my general understanding of the world. It was, like, mindboggling.
- ❑ **I:** Could you explain it to me now?
- ❑ **S:** So if you had a one-unit increase in mass-- or, in volume, the mass would increase by another power of that one unit, so it's just really disproportionate, and that's why certain organisms only-- can only be so big, because then that makes more work for internal transport, gas exchange, and stuff like that ...It was really, like, it blew my mind.

“You may know everything, but when I see how [the professor] words a question you have to be able to fit that mold and give him what he wants to hear. ‘Cause there'll be a question where you know you can give him an entire answer and it's wrong because of missing one word that he circled on the key. ”

In a later part of the interview, he says

“I'm not a big fan of regrades. I don't like bothering the professors about it so I didn't even look at the test after I got it back....I'll look at the keys, but...if I got it right it's going to be the same thing on the key. If I got it wrong there's no point in studying it.”

Key concepts for discussing expectations

□ Framing –

- The process of “choosing” a set of data in your environment to selectively pay attention to – equivalent to deciding that everything else can be safely ignored.

□ Epistemology –

- Knowledge about knowledge:
What is the nature of the knowledge I am going to learn in this class and what is it that I need to do to learn it?



3/29/11
UMd Teaching &
Learning Center

Going Beyond Content: Teaching Thinking

So what can we do to help?

- Teaching is leading students into a situation in which they can only escape by thinking"

*Tag line on
Spencer Benson's emails*

Recall some specific thinking goals

- ❑ Integrating (blending) the physical situation with the math.
- ❑ Getting beyond one-step recall – sense-making and looking for coherence.
- ❑ Using interlocking multiple representations.

What I have seen

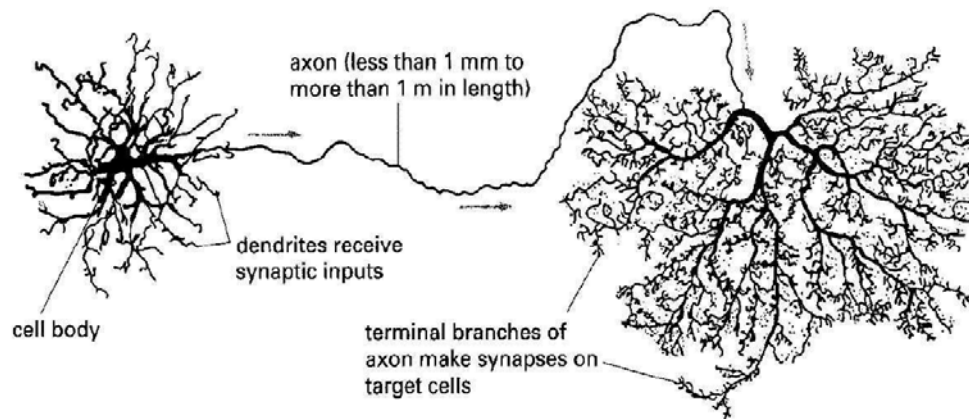
- ❑ Students will use equations as manipulatives (processing) without making the physical blend that creates meaning – at every level, from the simplest to the most complex.
- ❑ Students will give up if they can't see their way to an immediate answer.
- ❑ Students will use multiple representations as independent answers for the purpose of satisfying an instructor's request without seeing their value as tools for consistency checks.

Deal with it!

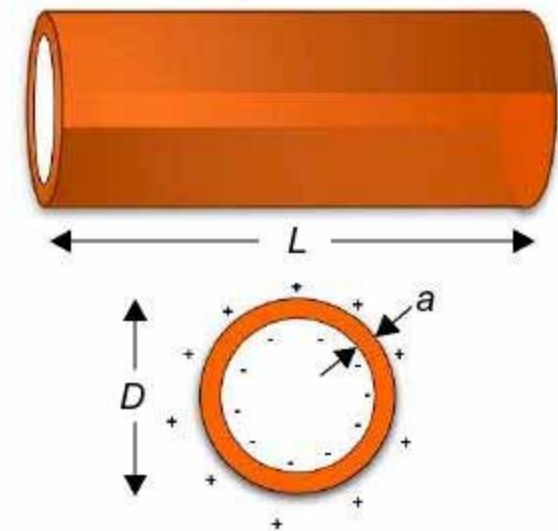
- ❑ This is the set of expectations students bring in to our classes.
- ❑ If we don't change the way we teach them, they will simply carry these "failures to think" on to the next level.
- ❑ Let's consider an example in some detail.

Deconstructing an example: Electric pulse on a nerve axon

- An axon can be modeled as a cylindrical capacitor that is maintained at a voltage difference of ~ 70 mV.



- A signal on the axon is a local depolarization of a ring. This depolarization is what moves down the axon.



Understanding transverse waves: a pulse on a spring

- ❑ The pulse on the axon is transverse.
- ❑ Modeling transverse waves mathematically is complicated.
- ❑ There are two independent variables (x and t) and they have to be interplayed carefully.

Reverse engineering this knowledge

- What do you need to know?
 - What it means for a wave to be transverse (propagation of pattern vs. matter)
 - How to make sense of equations with two independent variables
 - How to think about equations physically

Transverse motion

- Students are continually confused about the difference between the motion of the matter (here, the motion of the charge) and the motion of the pattern.
- We do an exercise in class in which the students do the wave – allowing us to refer back to motions in which they have a kinesthetic experience.



Making sense of the equations

- As the driver moves through one period (in a time T) the leading edge moves a distance $v_0 T$. Therefore

$$\Delta x = v_0 \Delta t$$

$$\lambda = v_0 T$$

$$\lambda = \frac{v_0}{f}$$

$$\lambda f = v_0$$



Students get confused about two variable equations

- There are many ways to write an equation for a sinusoidal propagating wave:

$$y(x,t) = A \sin(kx - \omega t)$$

$$y(x,t) = A \sin k(x - v_0 t)$$

$$y(x,t) = A \sin \left[2\pi \left(\frac{x}{\lambda} - \frac{t}{T} \right) \right]$$

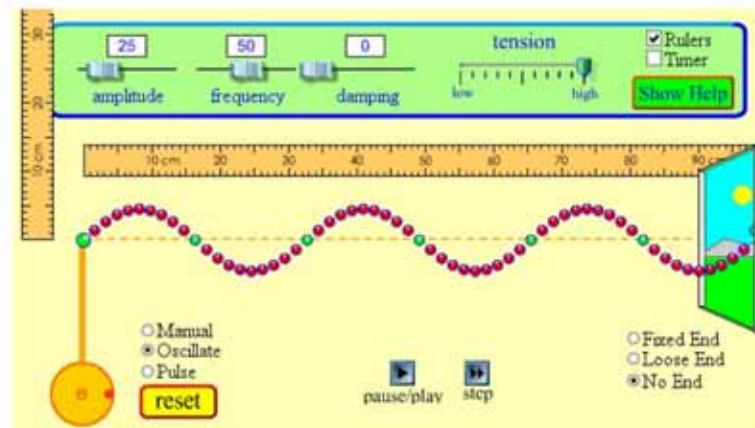
- When asked to come up with such an equation, a significant number of students will come up with bizarre results that show they are not interpreting the symbols as representing anything physical.

$$x = A \cos(\omega_0 t)$$

$$x = A \sin(kx - \omega t)$$

Demanding they think about the physics: An exam problem

- A screen from a program simulating the motion of a transverse wave on a spring is shown at the right. When the play button is pressed, the wave pattern shown in the wave begins to move to the right.
- What is the equation for the position of the green bead attached to the yellow rod?



- A. $y(t) = \sin(\omega_0 t)$
- B. $y(t) = (5 \text{ cm})\sin(\omega_0 t)$
- C. $y(t) = (25 \text{ cm})\sin(\omega_0 t)$
- D. $y(t) = -(5 \text{ cm})\sin(\omega_0 t)$
- E. Something else.

The are many pedagogical tools for making them think

- ❑ Paired clicker problems (showing the problem of 1-step thinking)
- ❑ Research-based guided worksheets (coherence)
- ❑ Homework and exam problems (blending physical and mathematical thinking)
- ❑ Estimation problems (quantifying experience)
- ❑ Multi-representation translation problems (stressing consistency and cross-checks)

Results are good

- Documented in many ways
 - Behavior on exams
 - Pre-post testing
 - Expectations survey
 - Testimonials and anecdotes

The takeaway message

- If we want to teach general skills and scientific thinking we need to
 - Pay attention to students' epistemological expectations and misconceptions.
 - Deconstruct our own understanding both of the content and the skills.