The Journey from Traditional Instruction to Active Learning

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THE UNIVERSITY OF NORTH CAROLINA AT CHAPEL HILL

I’m not a physics education researcher, but I play one on TV

Beginning

tracydiziere.com

…and beginning to excel

Ordinary path to professorship

"Played school" as a child

www.Masterfile.com

Typical lecture-based undergrad education

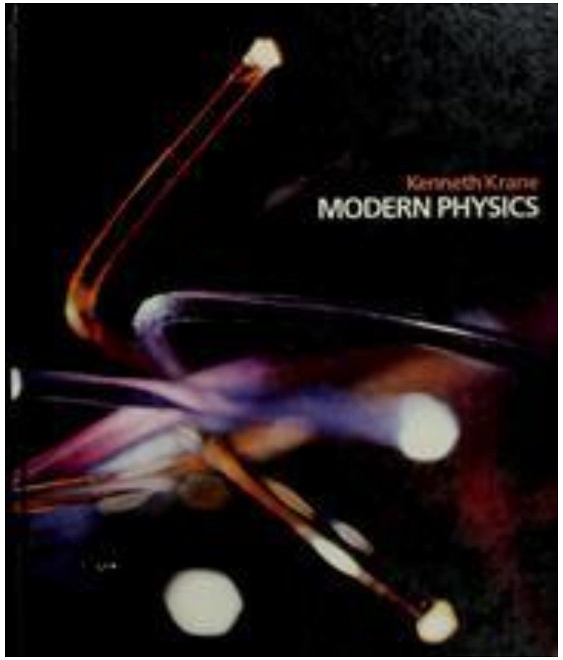
www.universitylanguage.com

One year as TA in grad school (almost no training)

After postdoc, arrived at UNC as Assistant Professor in 1984, began to establish research program

Given instruction in how to teach:

You are teaching Modern Physics. Here is the textbook. The class meets in 247 Phillips Hall.

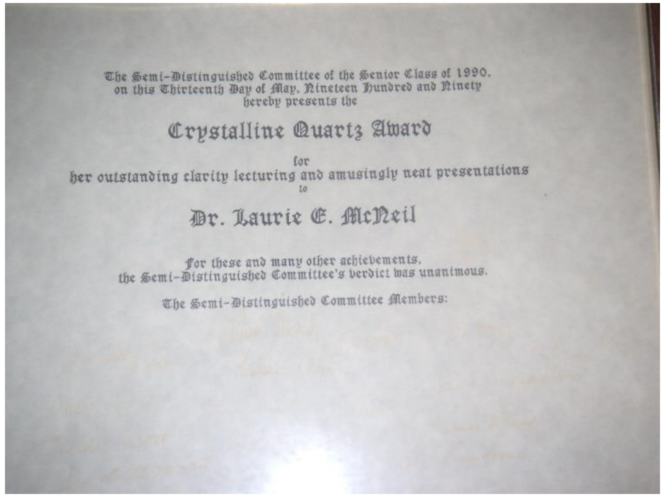


Became a “successful” teacher

DAYENU? דַּיֵּנוּ

Formal award:
Bowman and Gordon Gray Term Professorship
1996-99
“for excellence in inspirational teaching of undergraduate students”
College of Arts & Sciences

Informal award:
Crystalline Quartz Award
“for her outstanding clarity lecturing and amusingly neat presentations”
Senior physics majors, class of 1990



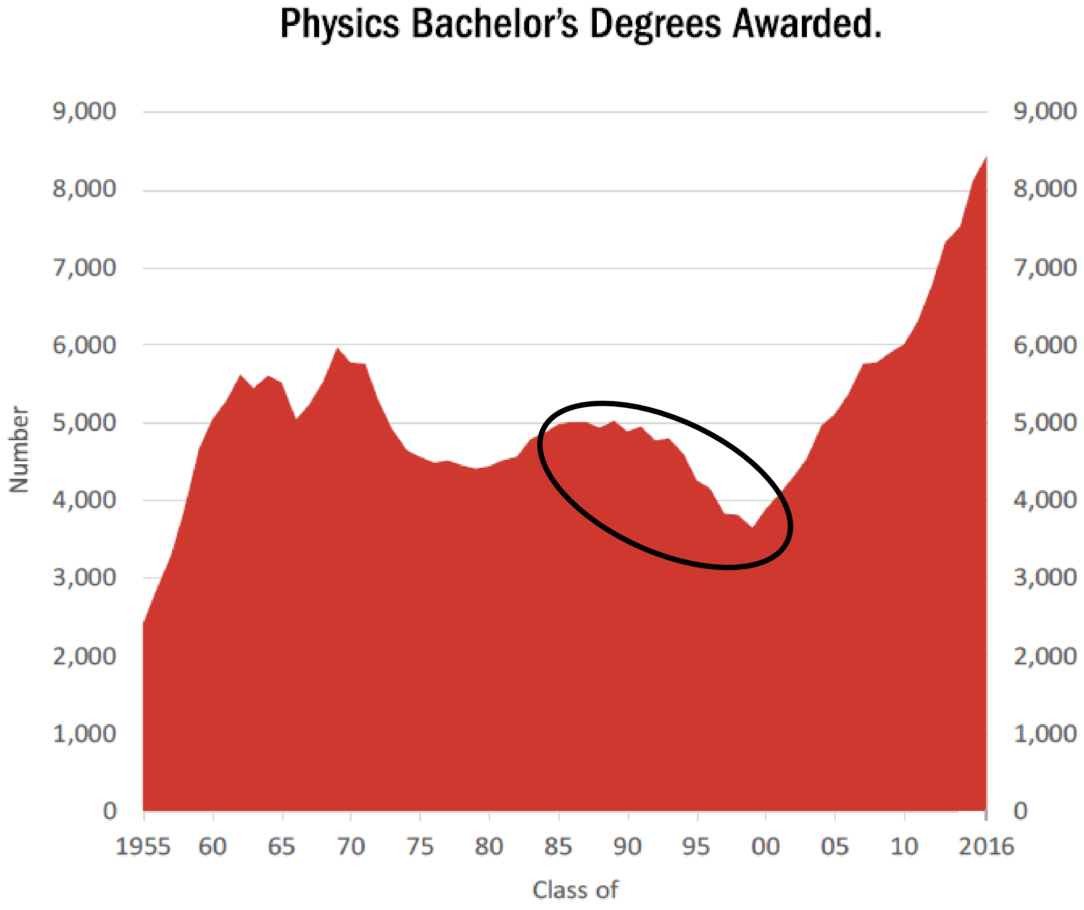
Awakening

www.approachyouractions.com

…and awakening to responsibility

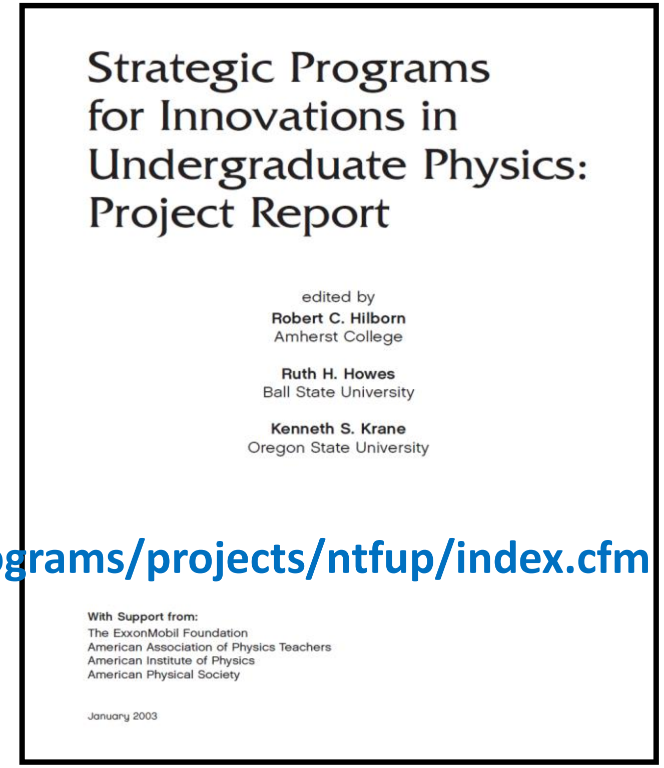
Discovering Physics Education Research

1999: National Task Force on Undergraduate Physics (NTFUP)



"Revitalization" of undergraduate physics programs

The *SPIN-UP* report


Strategic Programs for Innovations in Undergraduate Physics: Project Report

edited by
Robert C. Hilborn
Amherst College

Ruth H. Howes
Ball State University

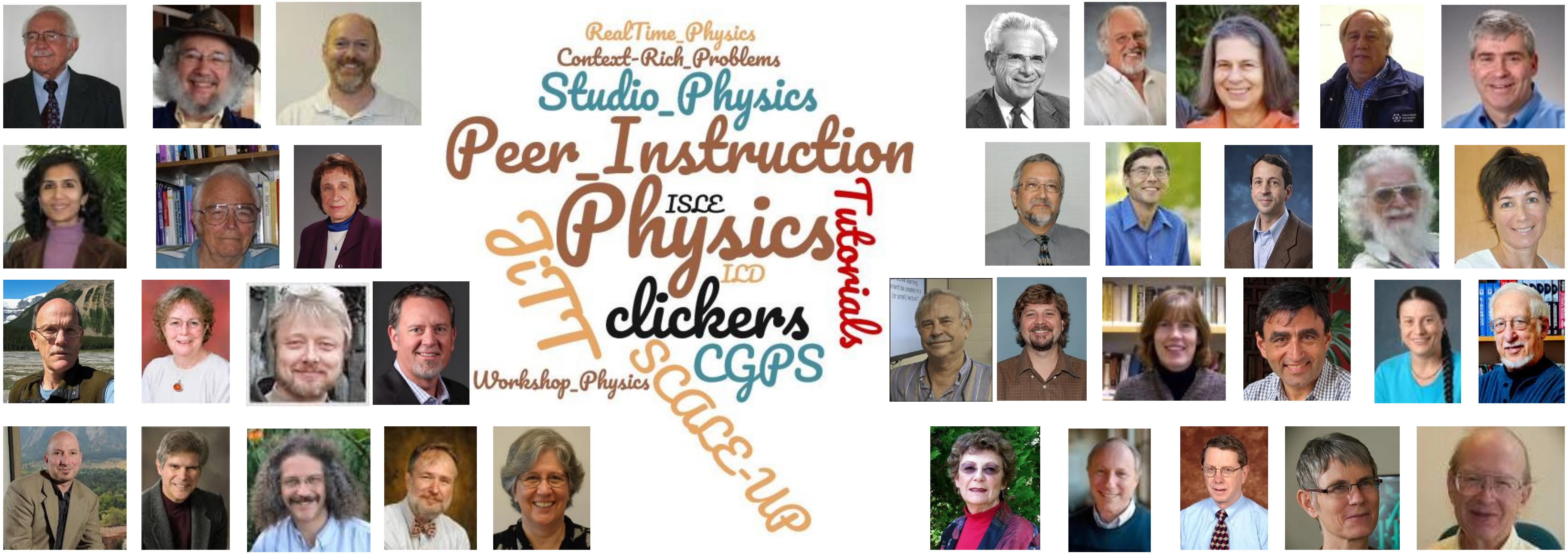
Kenneth S. Krane
Oregon State University

With Support from:
The ExxonMobil Foundation
American Association of Physics Teachers
American Institute of Physics
American Physical Society

January 2003

http://www.aapt.org/Programs/projects/ntfup/index.cfm

NTFUP brought close contact with PER specialists and their research



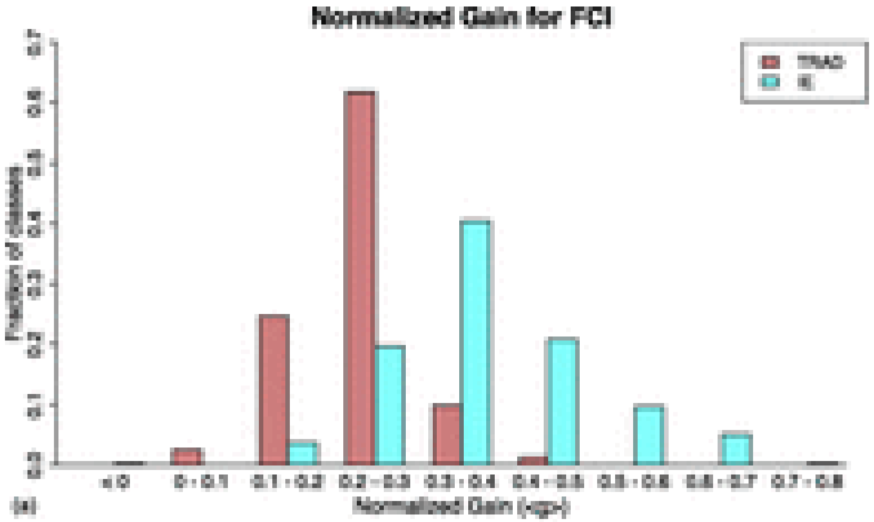
To continue to teach without using methods proven to be effective would constitute academic malpractice.

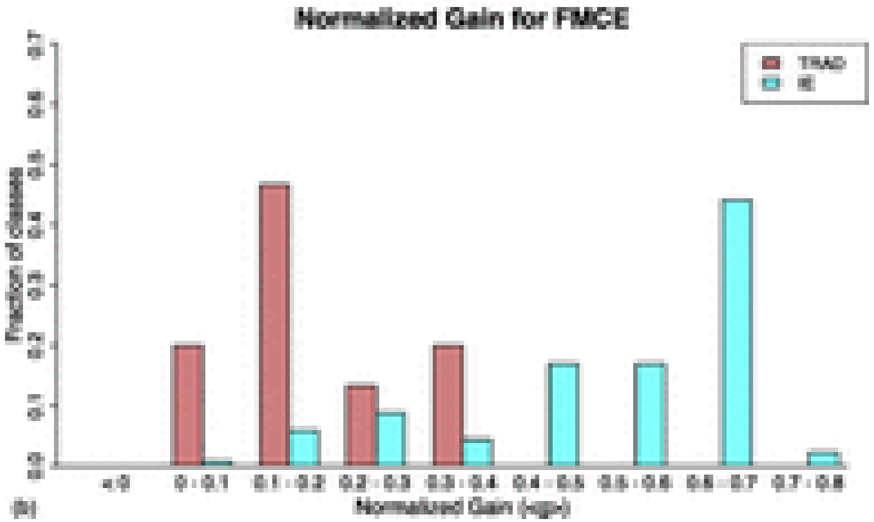
Learning

zapytaj.onet.pl/CBOSZ

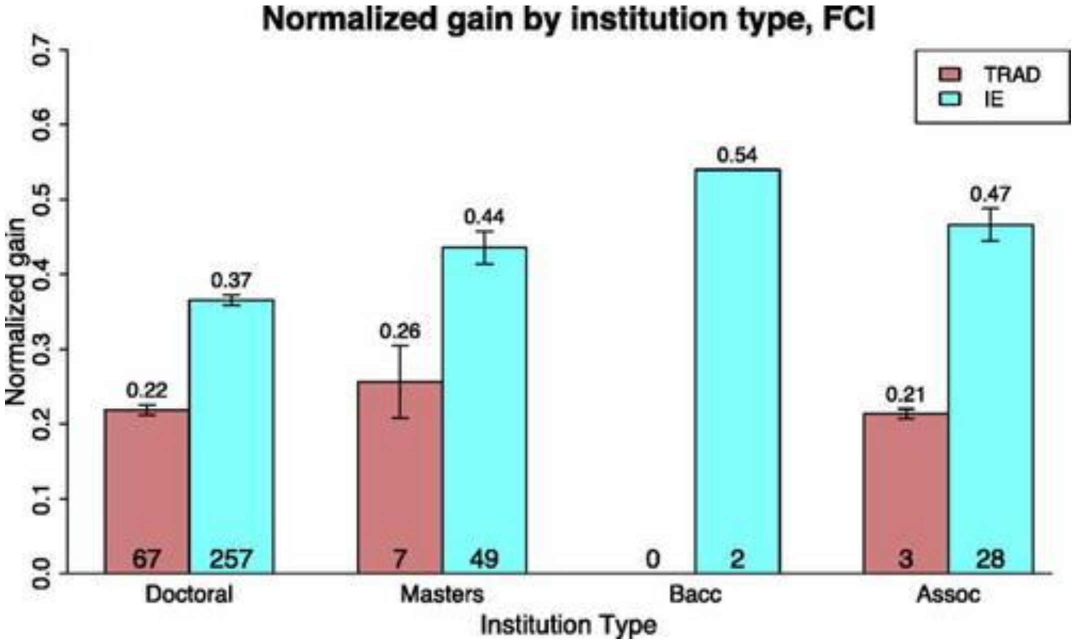
…and learning about learning

The big picture



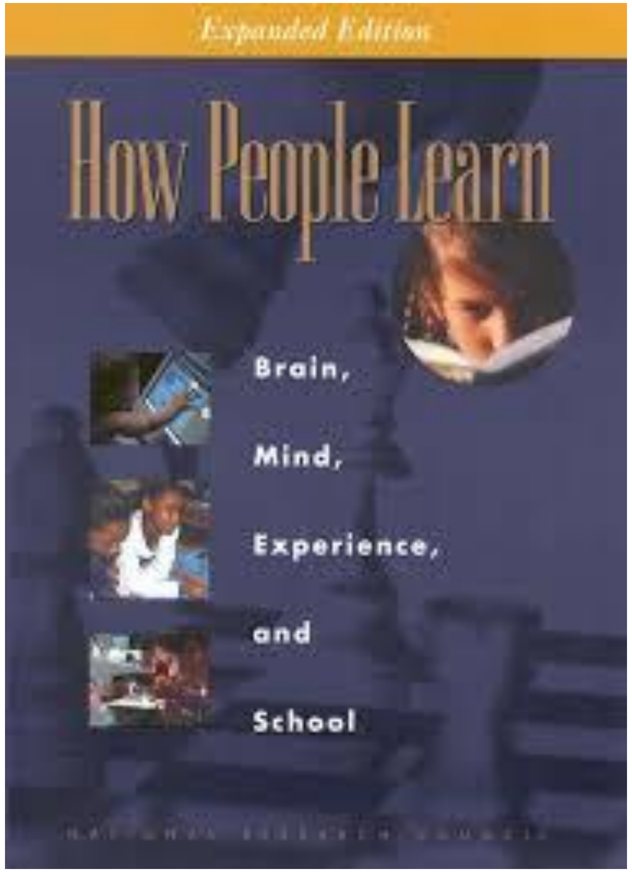


Active learning (of any kind) is more effective than traditional lecturing, regardless of class size, institution type, incoming SAT scores, etc. (45,000 students in 600 classes)



Von Korff *et al.*, *Am. J. Phys.* 84 (2016)

What the research tells us



Available for free at https://www.nap.edu

1. Teaching by telling doesn't work.
2. Algorithmic facility does not imply conceptual understanding.
3. Novice learners have preconceptions which must be specifically addressed in order to change them.
4. Scientific reasoning is not inborn.
5. The map is not the territory, and map-reading is not inborn either.
6. Understanding requires organizing knowledge in a way that facilitates application; this must be explicitly taught.

With abundant thanks to Lillian McDermott, see *Am. J. Phys.* **61**, 295 (1993)

Teaching by telling doesn't work

But I learned that way!

- No, you engaged with the material--doing homework problems, working through lecture notes, discussing with peers, questioning your comprehension, confronting difficulties and resolving them
- Even if you had learned that way, *your students are not you*. Only 5% of physics majors become physics professors, and the fraction of "younger you" in an intro physics class is even smaller.

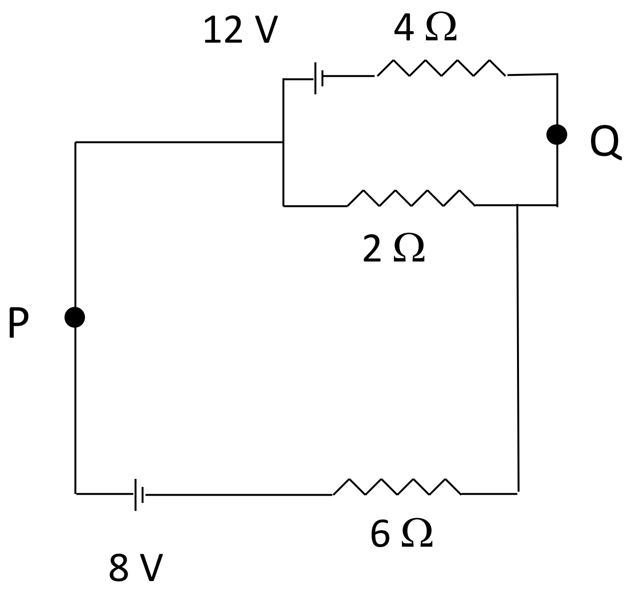
But I tell my students the correct physics, and they succeed in the course!

- Have you asked them to explain what they understand, or is the exam your only measure?
- Are they able to apply ideas in a variety of contexts? How do you know?

Algorithms ≠ understanding

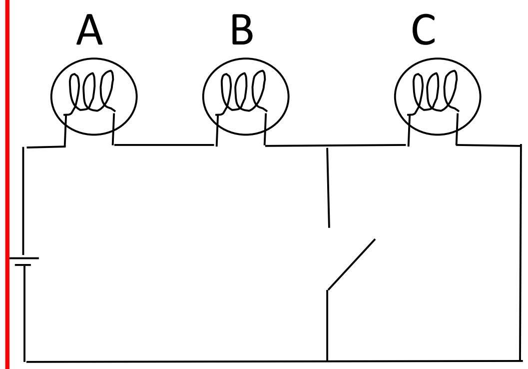
Students can learn to solve standard quantitative problems without understanding the concepts behind them.

Calculate the current in the 2-Ω resistor and the potential difference between points *P* and *Q*.



39% of students in a Harvard physics class did substantially *worse* on this question!

If the lightbulbs are identical, do the following increase, decrease, or stay the same when the switch is closed?



- Intensity of bulbs A and B
- Intensity of bulb C
- Current in circuit
- Voltage drop across each bulb

From Eric Mazur, see *Peer Instruction: A User's Manual*

Students are not blank slates

www.emergentman.com

Students have mental models about how the world works; these must be specifically addressed in order to change them.

A large truck collides head-on with a small compact car.
During the collision

A. the truck exerts a greater amount of force on the car than the car exerts on the truck.
B. the car exerts a greater amount of force on the truck than the truck exerts on the car.
C. neither exerts a force on the other, the car gets smashed simply because it gets in the way of the truck.
D. the truck exerts a force on the car but the car does not exert a force on the truck.
E. the truck exerts the same amount of force on the car as the car exerts on the truck.

From the FCI: Hestenes, Wells & Swackhamer, *Phys. Teacher* **30** (1992)

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Kingsport Times-News

Before instruction 75-80% of students choose A.

After traditional instruction ~65% of students still choose A!

From the FCI: Hestenes, Wells & Swackhamer, *Phys. Teacher* **30** (1992)

Scientific reasoning is not inborn.

Though children are "born scientists," scientific reasoning at the level we aspire to for our students involves multiple higher-order thinking skills.

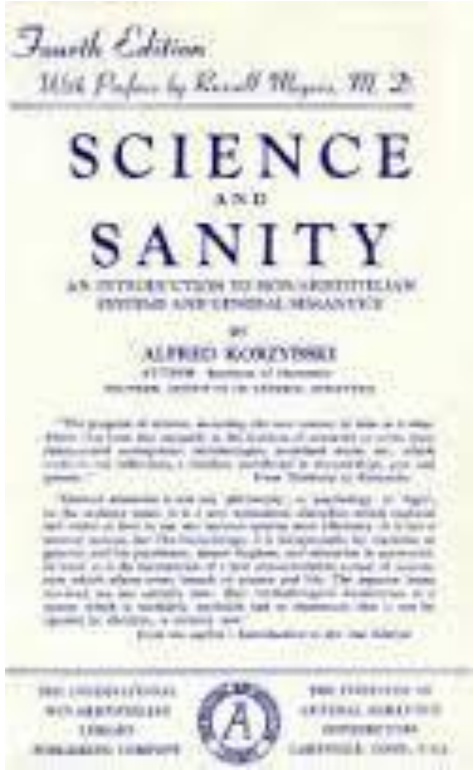
- Systematic hypothesis-testing
- Drawing conclusions based on valid evidence
- Thinking in terms of abstractions or symbols
- Thinking in terms of proportions and probabilities
- Applying quantitative analysis
- Thinking about multiple variables or dimensions at once

This does not come automatically!

The map is not the territory

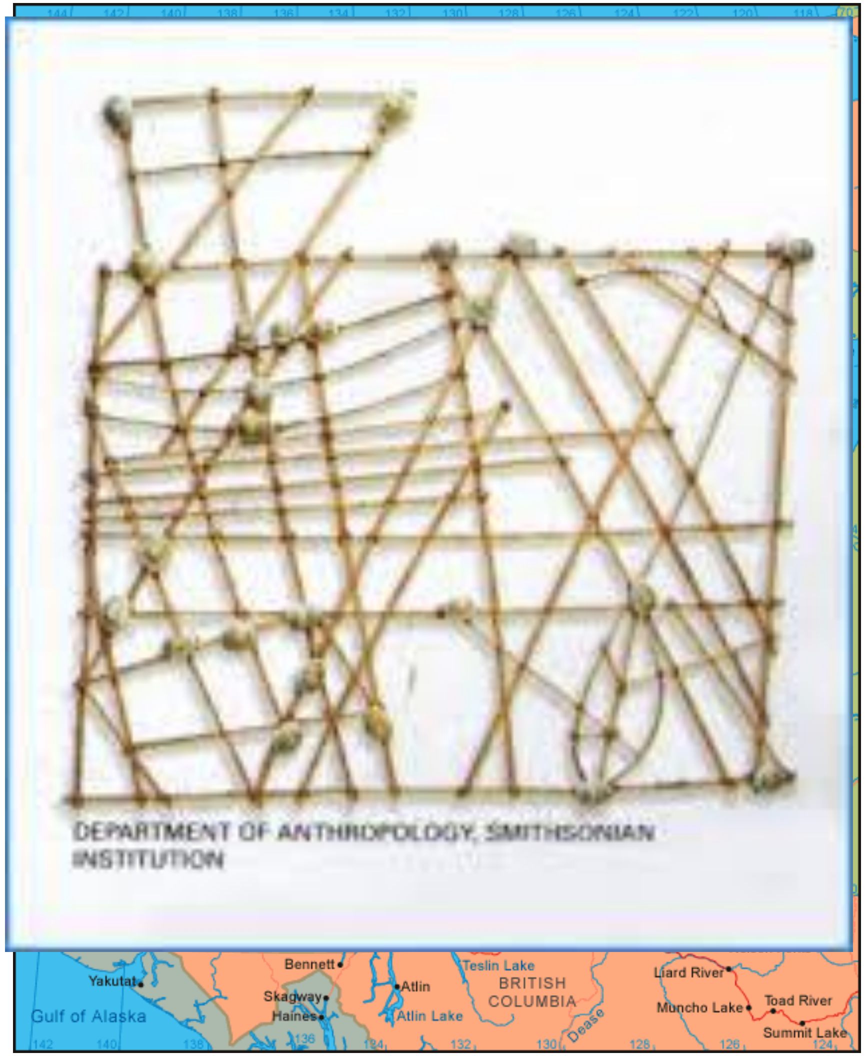
The map is not the territory, the word is not the thing it describes.

Alfred Korzybski

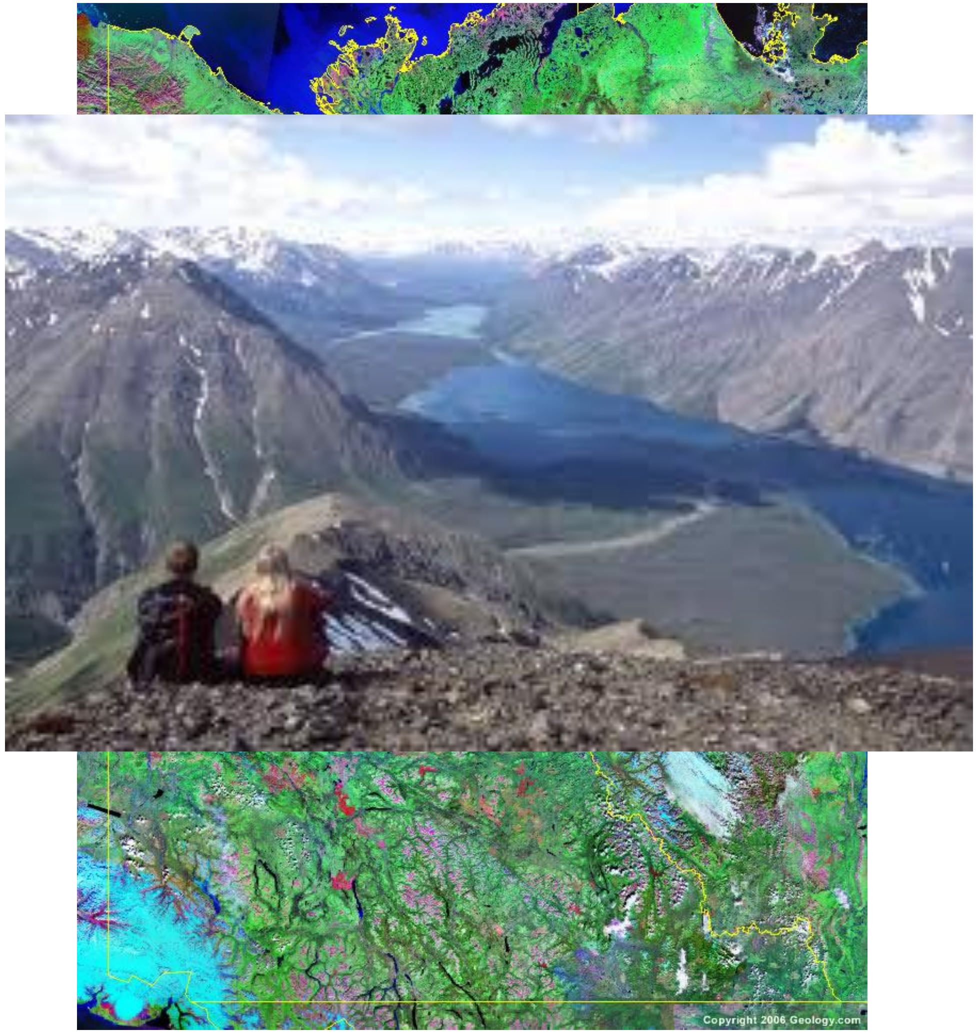


The map is not the territory

Map



Territory



The map is not the territory

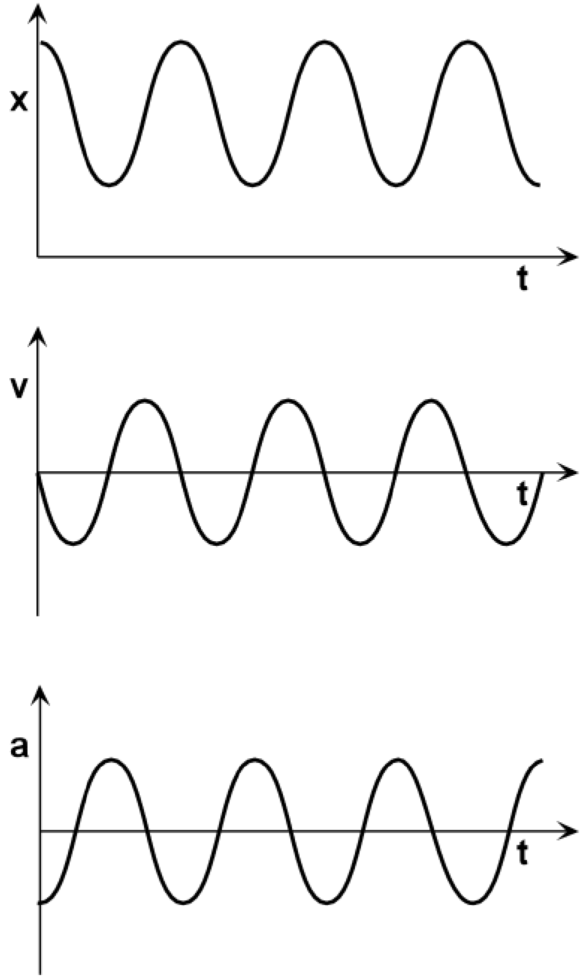
Map-reading isn't inborn either

Map

$$\vec{F} = -k\vec{x}$$

$$m\frac{d^2\vec{x}}{dt^2} = -k\vec{x}$$

Map



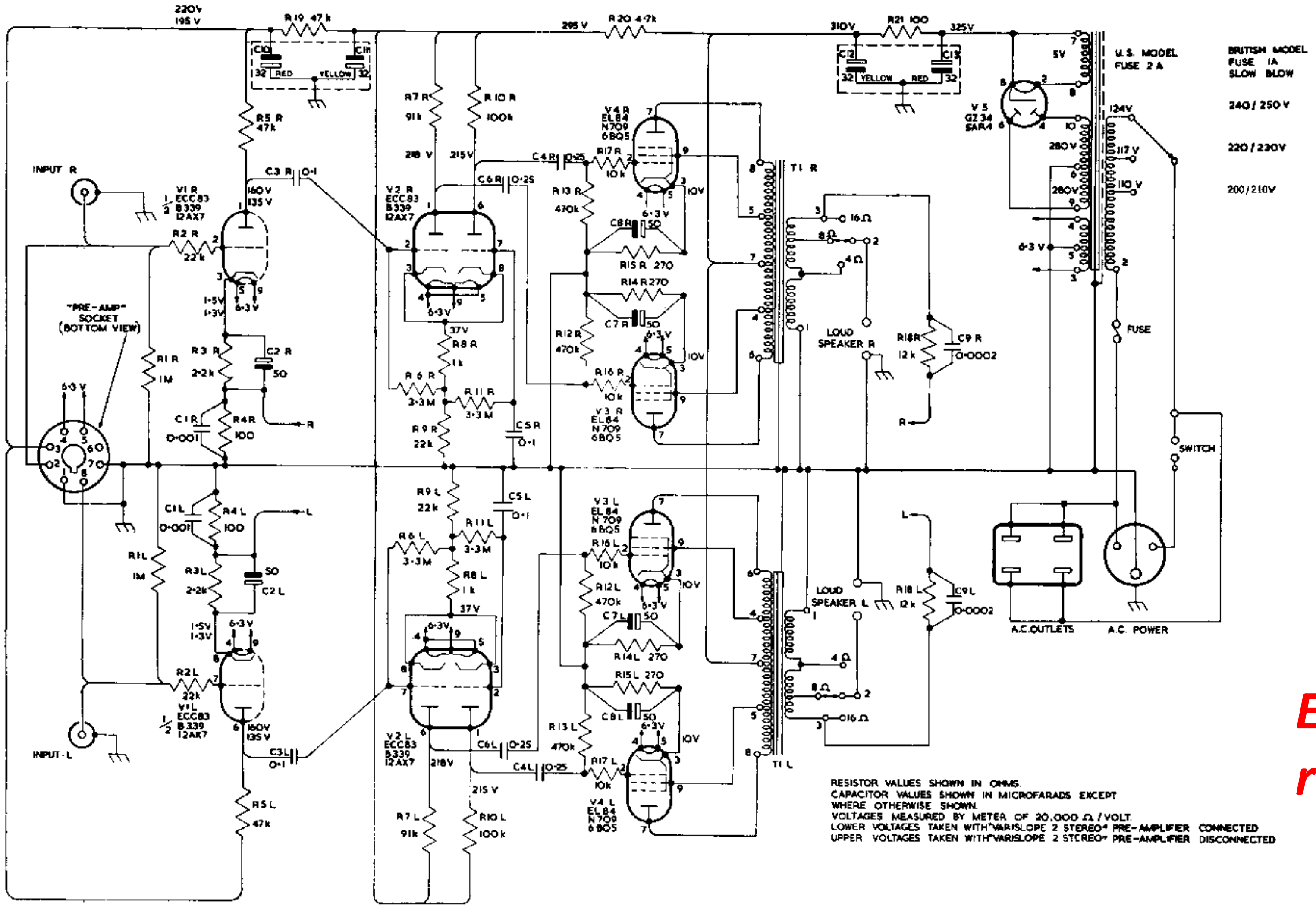
Territory

Knowledge organization is not automatic

Facts (and equations) are not knowledge--understanding requires *organizing* knowledge in coherent way.

Gisela Kassoy

Knowledge organization is not automatic



CIRCUIT DIAGRAM

Expert (but not novice) electronics technicians reproduced large portions of diagram after exposure of a few seconds

Experts organized diagram into "chunks," e.g. "amplifier," "filter"

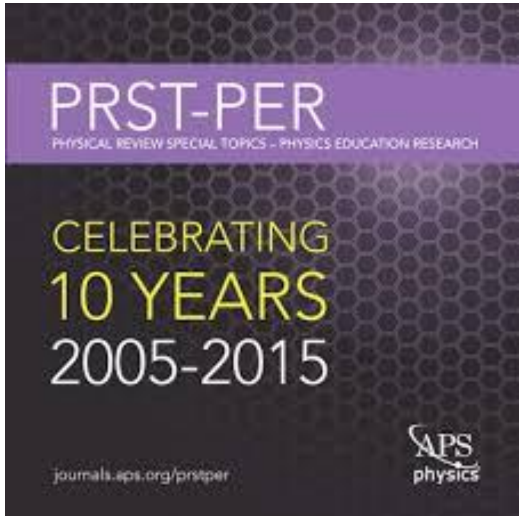
Experts could not reproduce a random collection of elements

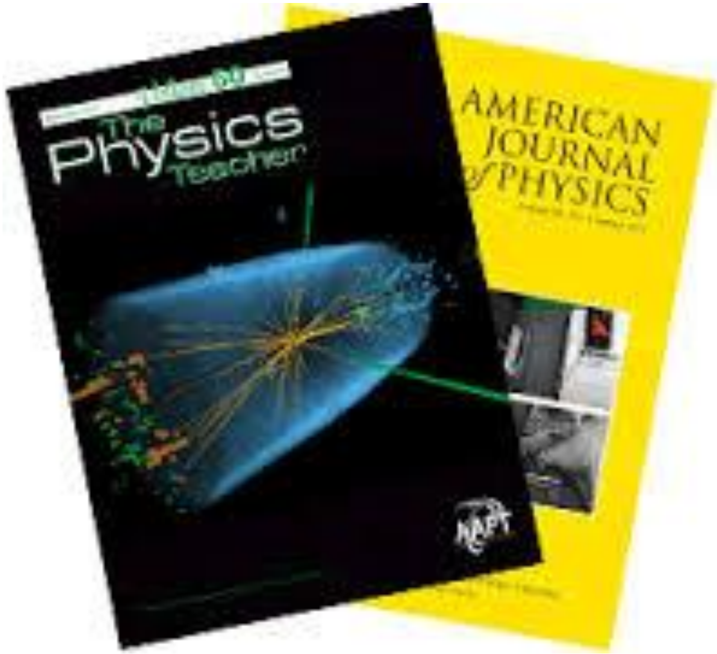
Egan & Schwartz, *Memory & Cognition* **7** (1979)

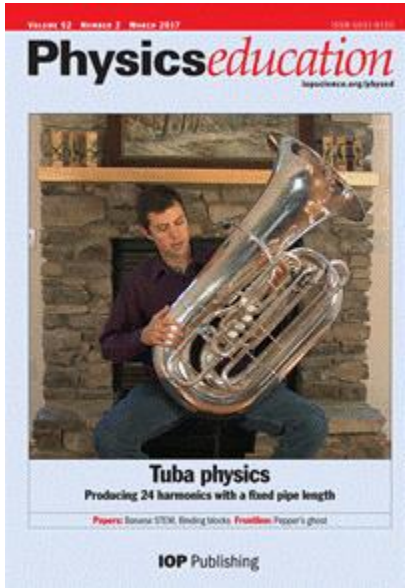
What else PER gives us

Content knowledge is not enough—we also need ***pedagogical content knowledge***

- Student difficulties
- Student mental models
- Effective instructional strategies for a particular concept
- Assessment methods

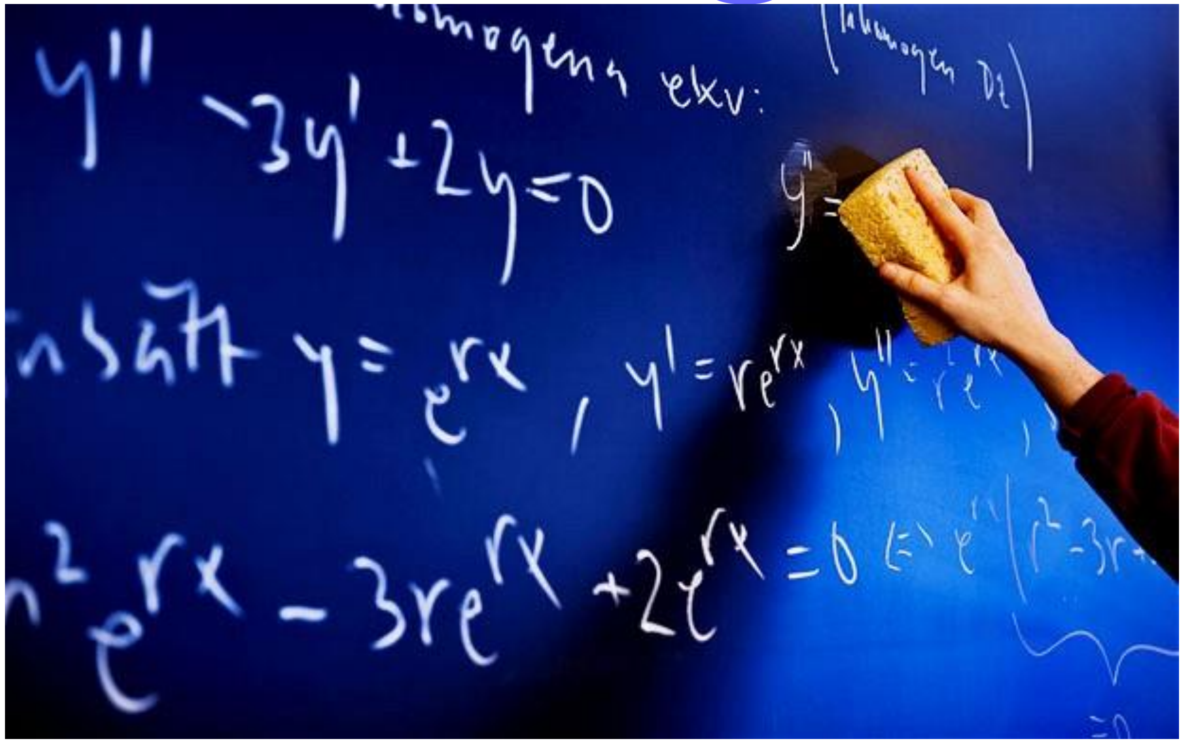






Excellent book from the Research Corp!

Doing



…and doing better

Evidence-based practices I have adopted (so far)

- **Peer instruction (TPS)**
  - Frequent application of concepts (retrieval practice)
  - Immediate feedback (do they get it?)
  - Resets attention span
- **JiTT**
  - Knowledge transfer before knowledge use
  - Advance warning of what students struggle with
  - Students feel their concerns are heard
- **Tutorials**
  - Scaffolding for guided reasoning
  - Address preconceptions explicitly
- **PhET**
  - Explore dependence on parameters

Evidence-based practices I have adopted (so far)

- **Cooperative group problem-solving (Minnesota model)**
  - Groups can solve more complex problems than individuals can
  - Context-rich: estimation, assumptions, sense-making
- **Design from learning goals**
  - What do I want the students to be able to do?
  - What class activities will lead to my desired outcomes?
  - How will I tell if I have succeeded?
- **Studio physics**
  - Most class time spent working in small groups to apply concepts
  - "All of us are smarter than any of us"
  - "Whenever we don't understand, we explain to each other"

Backwards design

- **Begin with learning goals**
  - "After instruction, students should be able to…"
  - Active verbs: *identify, construct, sketch, solve, distinguish, calculate, compare, determine, …*
  - "Understand": how will you tell that they are not just performing an algorithm?
- **Select class activities that will require students to apply knowledge step-by-step**
- **Assess *specific* goals**
  - Formative: retrieval practice
  - Summative: have they achieved what you hoped, i.e. did the activity work?

Studio physics

- **Lecturing reduced or eliminated**
  - Reading assignment before class, with quiz (*JiTT*)
  - Instructor(s) is “guide on the side” rather than “sage on the stage”
  - All (or most) class time devoted to small group work
    - Experiments (often mini-)
    - Tutorials
    - Cooperative group problem solving
    - “Lightning round” for applications of math skills
    - Manipulate simulations
- **Multiple types of activities within a single class period**
- **Activities provide “scaffolding” to guide concept development**
- **Specific learning goals addressed**

Studio physics cont.

Facilitated by rooms designed for group work

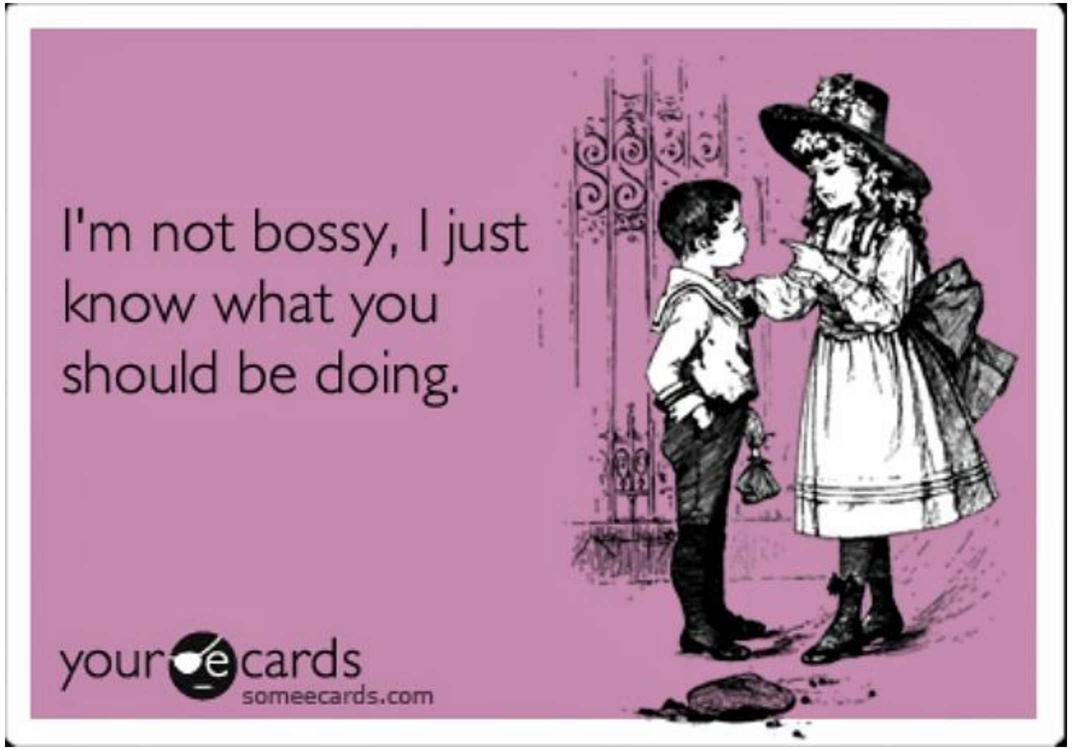
Pittsburgh

FSU

MIT

Can be done in traditional lab spaces

Doing more



…and doing more for more students

Stepping forward

So I have transformed my own teaching. Now what?

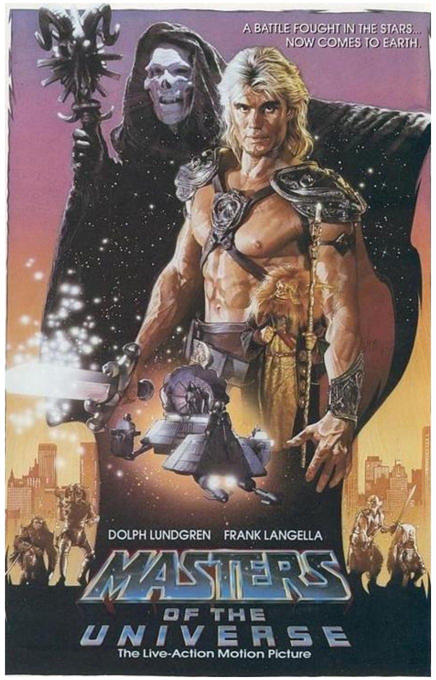
- Senior member of department (20+ years)
- Asked to take on leadership role (Department Chair)
- Opportunity to improve teaching across department
- Began with introductory courses (largest enrollment)
- NSF funding available
- Needed to persuade colleagues: opportunity for leadership development!

"The kid's good."

Getting my colleagues on board

Goals:

- All introductory physics courses to be taught using research-validated interactive engagement methods
- Common experience and expectations for all students in each course
- Teamwork to reduce duplication of effort
- Improved learning outcomes



What we have now: Lecture/Studio model

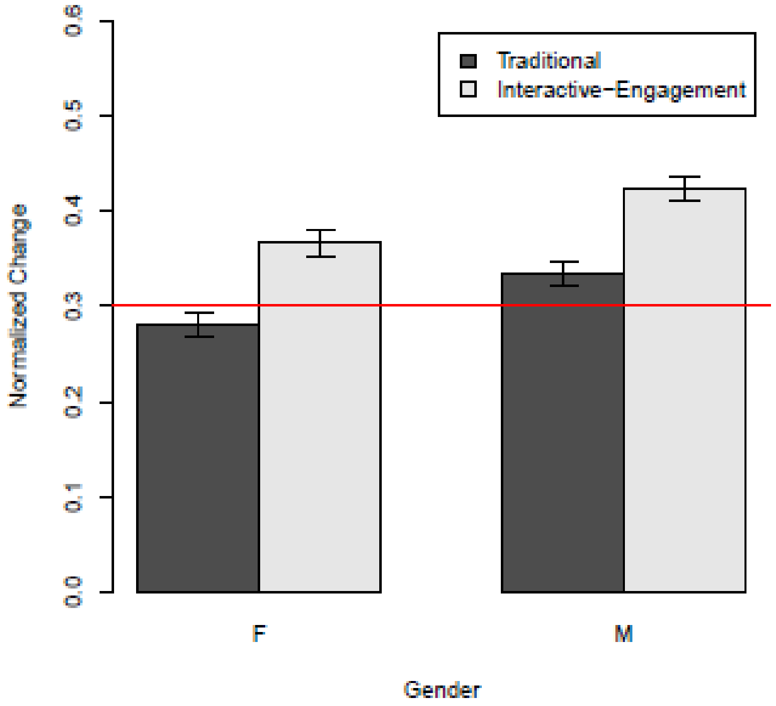
Weekly cycle:

- Reading assignment with quiz, including "what was confusing?" (*JiTT*)
- Class meetings (two sets each week)
    - Interactive lecture (all students) (*Peer Instruction*)
    - Studio session (multiple sections, 1 instructor per 30 students) (*Tutorials, Cooperative Group Problem Solving,* lab experiments)
- End-of-chapter HW (web-based, autograded)

Exams include conceptual and quantitative questions

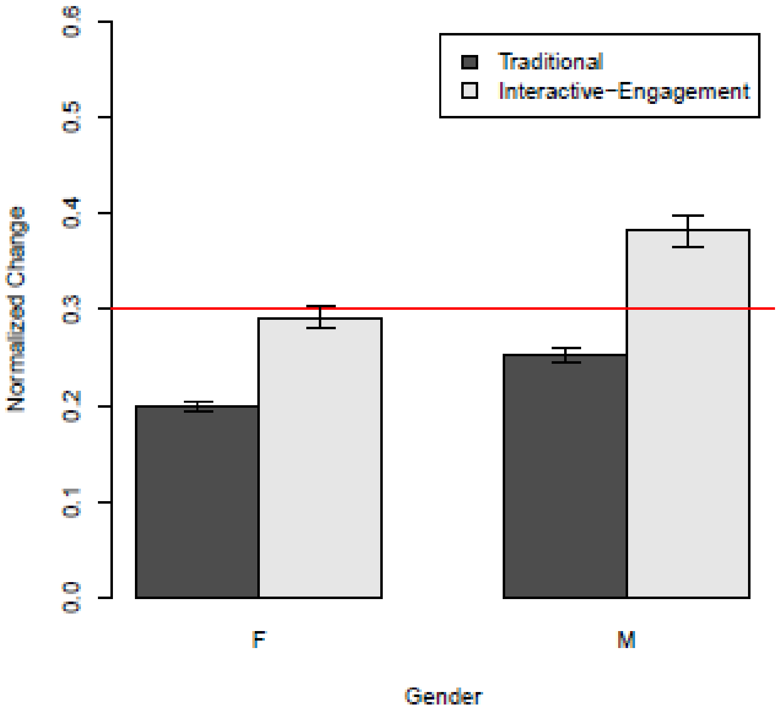
Sequences for physical science majors (IPPS) and life science majors (IPLS) taught this way

What we have now: Lecture/Studio model



IPPS

FCI and CSEM pre/post learning change



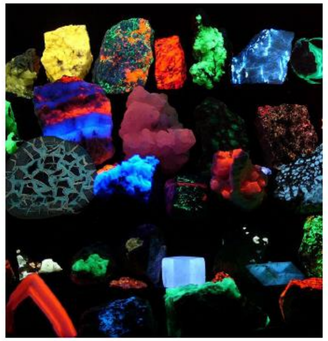
IPLS

Learning gains on concept inventories are now significantly higher, with no loss of problem-solving ability!

David Guynn M.S. thesis

Studio activities for IPLS

Absorption and Fluorescence



Introduction

The energy in a molecule is *quantized*, meaning it can only have certain discrete values and not any values in between. Thus a molecule can only absorb and emit energy in amounts equal to the difference in energy between two allowed states. Since the energy of a photon (in electron volts) is related to its wavelength (in nanometers) by $E = hc/\lambda$ (where h = Planck's constant and c = speed of light and hc = 1240 eVnm), this means that a molecule will only be able to absorb specific wavelengths of light. The color we perceive in a material (biological or otherwise) is determined by the wavelengths of light that it absorbs (and the wavelengths it does *not* absorb). Specific biomolecules absorb specific wavelengths of light, resulting in a variety of biological effects from photosynthesis to concealment.

Learning Goals

At the end of this activity, you should be able to…

- Relate the perceived color of an object to its absorption spectrum.
- Explain why the emission wavelength is larger than the absorption wavelength in a fluorescence process (Stokes shift).
- Using the transmission spectrum of the eye lens and the absorption spectra of the visual pigments, determine the range of wavelengths that an organism can perceive.
- Relate absorption and emission wavelengths to differences in energies of quantum states.

Newton's Laws: Jumping Grasshoppers 2

Introduction

This activity is a follow-up to Grasshoppers 1, and expands upon that activity in two ways. First, while Grasshoppers 1 explored the forces on a grasshopper during a *single* jump, today's activity will compare key dynamical features such as mass, maximum force, and maximum jump distance across *multiple* jumps. Second, while in Grasshoppers 1 we assumed that the grasshopper jumped straight upward, in today's activity we will explore a grasshopper jump in two dimensions, allowing us to draw conclusions about jump distances.

Learning Goals

After completing this studio, you should be able to…

- Analyze the motion of connected objects.
- Apply Newton's laws to reason about the changes in the maximum jump distance of a grasshopper.

A. Exploration 1: Deducing position from velocity, and taking a graphical perspective

First, some unfinished business from Grasshoppers 1, we will use numerical integration again, this time to find the position of the grasshopper from its velocity.

1. Complete the blanks in the following sentences:
   a. $v(t)$ is the __(1)__ of $a(t)$, so to get $v(t)$ we need to look at the __(2)__ of the $a(t)$ graph.
   b. $y(t)$ is the __(3)__ of $v(t)$, so to get $y(t)$ we need to look at the __(4)__ of the $v(t)$ graph.

Fluid Dynamics III: Reynolds Number

Introduction

The motion of an object in a fluid is controlled by its *Reynolds number*, a dimensionless quantity that is the ratio of the inertial forces acting on the object to the drag forces it experiences. For a sphere of diameter d moving at speed v the Reynolds number can be expressed as:

$$Re = \rho dv/\eta$$

where ρ is the density of the fluid and η is its viscosity (sometimes called its *dynamic viscosity*).

Learning goals

After completing this activity, you should be able to…

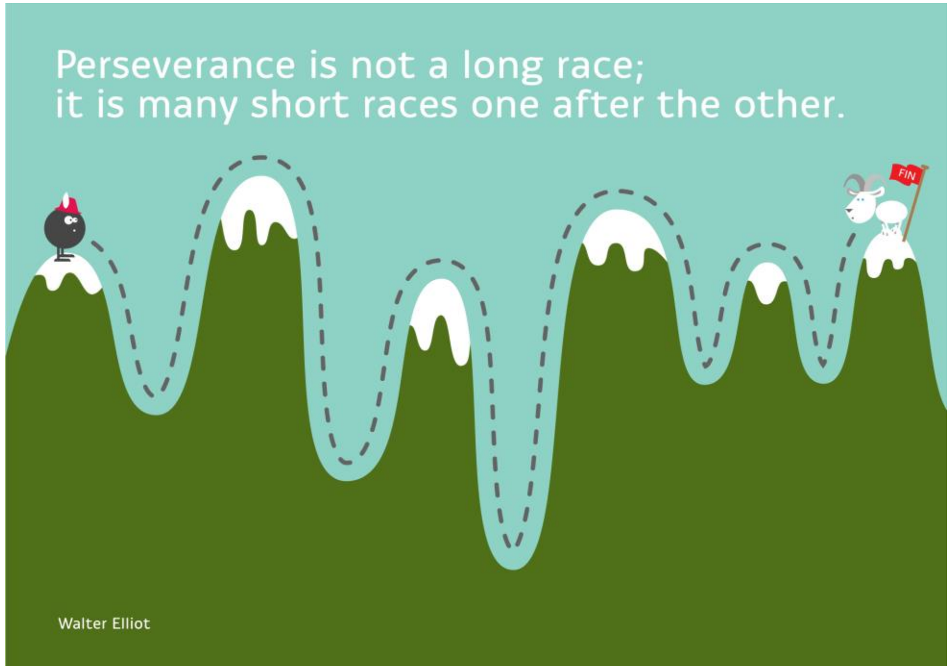
- Calculate the Reynolds number for a particular fluid and flow speed, using parameters provided.
- Use the Reynolds number in a particular situation of fluid and flow speed to determine whether inertial or drag forces dominate.
- Specify and calculate the forces on a sphere moving in a fluid, including the drag force.
- Use Newton's laws and the drag force to determine the terminal speed of a sphere falling in a fluid.
- Apply dynamic scaling to determine appropriate values of size, speed and viscosity for a scale model.
- Describe the motion of an organisms in a fluid under conditions of very low Reynolds number.

Smith *et al.* *AJP* **86**, 862 (2018)

http://paer.unc.edu/projects/ipls/

Guidance for your journey

- Your students are like everybody else's students
- Try one or two things at first
- Remember that effort can be painful (for you and your students)
- Persevere—it will be better the second time (and the third)



www.ordnancesurvey.co.uk

Guidance for your journey

- Don't reinvent the wheel

James Steidl

…or the flat tire

Laura Tiger

Guidance for your journey

- Steal from the best
- Implement methods *in their totality*
- Novel isn't always better

photo by ROMULO YANES

Johnsonville.com

https://static1.squarespace.com

L'envoi

Teach like a scientist--you owe it to your students and to your own professionalism.

Do your "very goodest"--carry out your teaching duties as effectively as your circumstances allow—and they allow a lot more than you may think.

One must learn by doing the thing; though you think you know it, you have no certainty until you try.

Sophocles (Women of Trachis)

www.diocese-st-hyacinthe.qc.ca