Science Education for the 21st Century

Using the tools of science to teach science

and many other subjects

Carl Wieman UBC & CU

Nobel Prize

Data!!

Colorado physics & chem education research group:

W. Adams, K. Perkins, K. Gray, L. Koch, J. Barbera, S. McKagan, N. Finkelstein, S. Pollock, R. Lemaster, S. Reid, C. Malley, M. Dubson… $$ NSF, Kavli, Hewlett)

Using the tools of science to teach science

I) Why should we care about science education?

II) What does research tell us about teaching and how people learn?

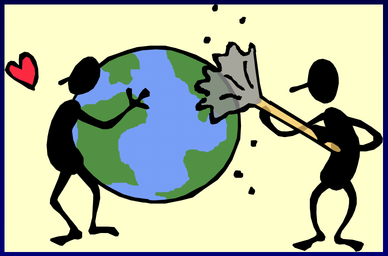
III) Some technology that can help improve learning
(if used correctly!)

IV) Institutional change (brief) --Science Education Initiatives Univ. of Brit. Columbia, and U. Col.

Changing purpose of science education

historically-- training next generation of scientists (< 1%)

- *Scientifically-literate populace--wise decisions*

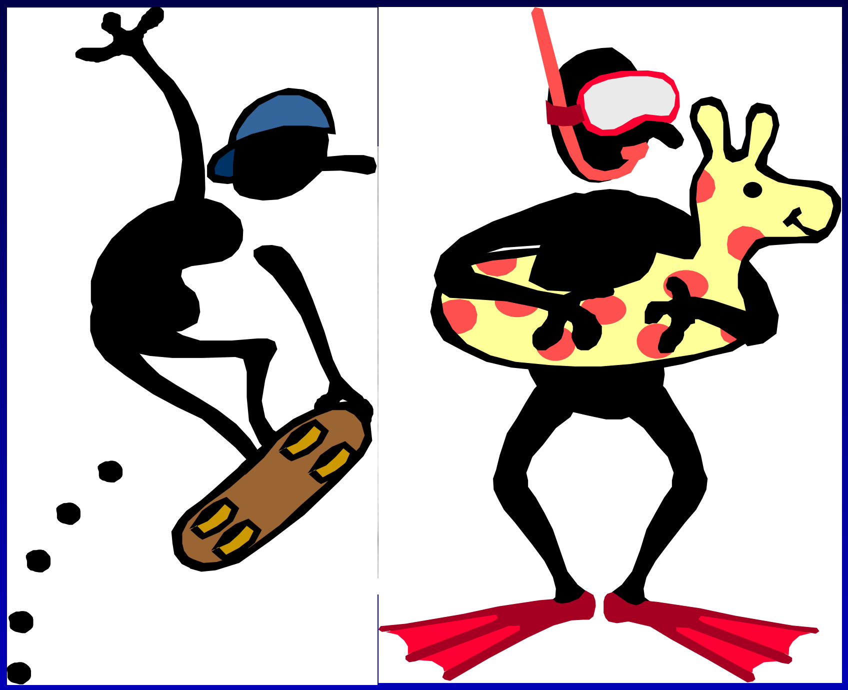


- *Workforce in modern economy.*

Need science education effective and relevant for large fraction of population!

Effective education

Transform how think--



Think about and use science like a scientist.

accomplish for most students?

possible,
if approach teaching of science like science--

- Practices based on good data & standards of evidence
- Guided by fundamental research
- Disseminate results in scholarly manner, & copy what works
- Fully utilize modern technology

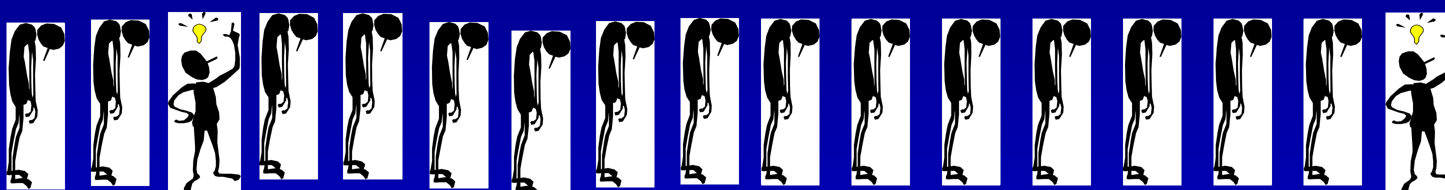
Supporting the hypothesis.....

What does research tell us about effective science teaching? *(my enlightenment)*

How to teach science: (I *used)*

1. Think very hard about subject, get it figured out very clearly.

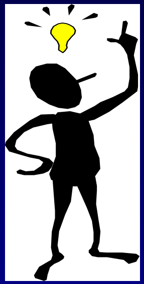
2. Explain it to students, so they will understand with same clarity.



???

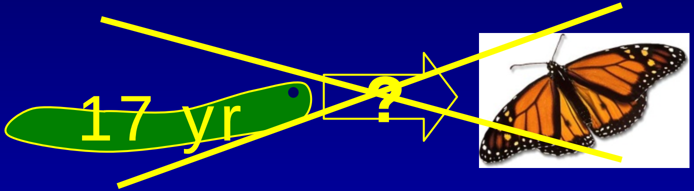
grad students

17 yrs of success in classes.
Come into lab clueless about physics?



2-4 years later $\Rightarrow$ expert physicists!

??????

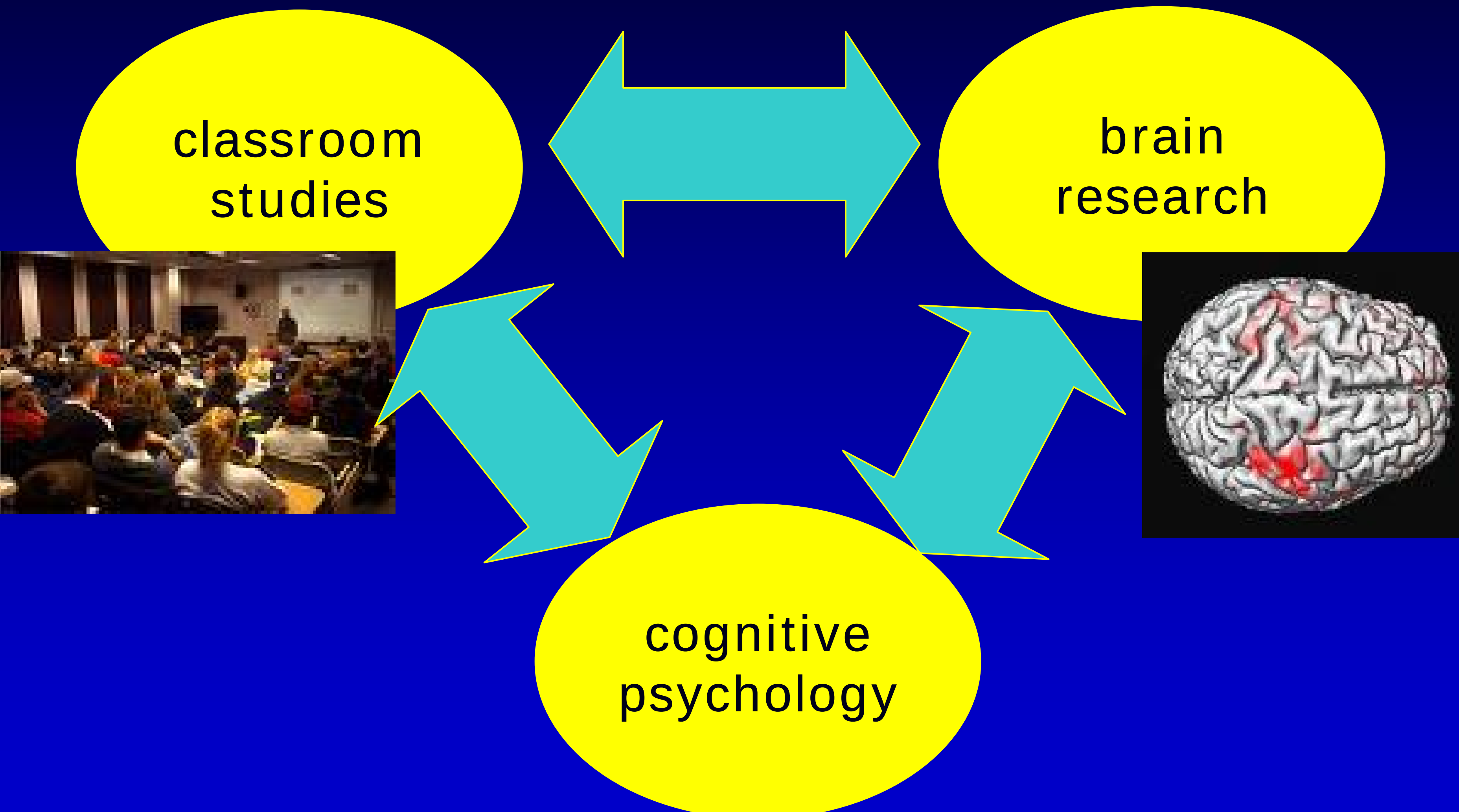


Research on how people learn, particularly science.

- above actually makes sense.

$\Rightarrow$ opportunity--how to improve learning.

Major advances past 1-2 decades
Consistent picture ⇒ Achieving learning



II. Research on teaching & learning

A. Research on traditional science teaching.

B. Cognitive psychology research-- explains results & provides principles for how to improve.

C. Research on effective teaching practices
--implementing the principles

A. Research on traditional science teaching
-lectures, textbook homework problems, exams

1. Transfer/retention of information from lecture.

2. Conceptual understanding.

3. Beliefs about physics and chemistry.

Data 1. Retention of information from lecture

I. Redish- students interviewed as came out of lecture.
"What was the lecture about?"
only vaguest generalities

II. Wieman and Perkins - test 15 minutes after told nonobvious fact in lecture.
10% remember

many other studies-- similar results

Cognitive Pysch. says is just what one expects!

a. Cognitive load-- best established, most ignored.

Mr Anderson, May I be excused?
My brain is full.

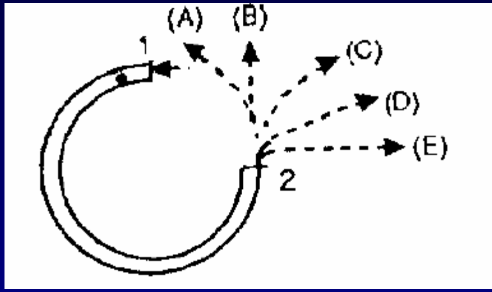
Working memory capacity **VERY LIMITED!** *(remember & process maximum 4-7 items)*

MUCH less than in typical science lecture

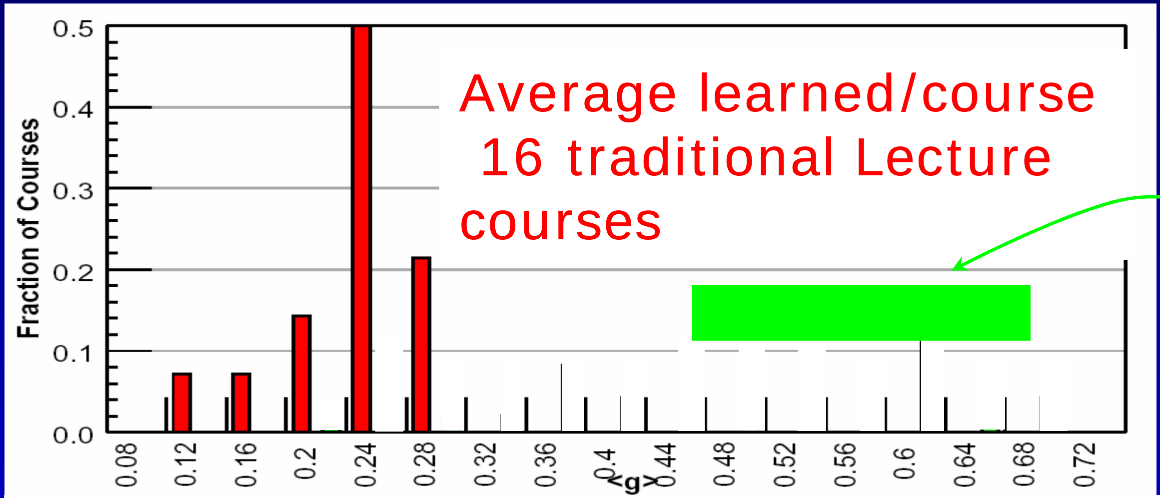
PPT slides will be available

Data 2. Conceptual understanding in traditional course.

• Force Concept Inventory- basic concepts of force and motion 1st semester physics



Ask at start and end of semester--
What % learned? (100's of courses)



Fraction of unknown basic concepts learned

improved methods

On average learn <30% of concepts did not already know.
Lecturer quality, class size, institution,...doesn't matter!
Similar data for conceptual learning in other courses.

R. Hake, "…A six-thousand-student survey…" AJP 66, 64-74 ('98).

Data 3. Beliefs about physics/chem and problem solving

Novice

Content: isolated pieces of information to be memorized.

Handed down by an authority. Unrelated to world.

Problem solving: pattern matching to memorized recipes.

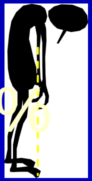
Expert

Content: coherent structure of concepts.

Describes nature, established by experiment.

Prob. Solving: Systematic concept-based strategies. Widely applicable.

~10%



% shift?

intro physics & chem courses ⇒ *more* novice

ref.s Redish et al, CU work--Adams, Perkins, MD, NF, SP, CW

*adapted from D. Hammer

II. Research on teaching & learning

A. Research on traditional science teaching.

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--implementing the principles

Connecting to cognitive psychology

Expert competence research*

Expert competence =

•factual knowledge

•**Organizational framework** ⇒ effective retrieval and use of facts

or ?

•**Ability to monitor own thinking**

("Do I understand this? How can I check?")

New ways of thinking--

Teaching factual knowledge ~~⇒~~ expert thinking

Teaching facts & processes first **inhibits** learning expert framework (D. Schwartz)

*Cambridge Handbook on Expertise and Expert Performance

Principle ⇒ people learn new ways of thinking by developing **own** understanding. Built on prior thinking.

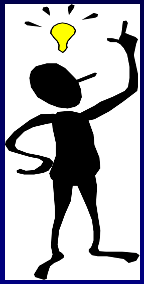
Basic biology-- have to change brain
"Understanding" all long term memory,
developed by building proteins + assembling structures

Recent research⇒ Brain development much like muscle development

Both require strenuous extended use

Effective teaching = facilitate development by motivating and engaging,
then monitoring & guiding thinking.

17 yrs of success in classes.
Come into lab clueless about physics?



2-4 years later ⇒ expert physicists!

??????

Makes sense!
Traditional science course poor at developing expert-like thinking.

Necessary cognitive processes continually happening in research lab!
(strenuous engagement + guiding feedback)

II. Research on teaching & learning

A. Research on traditional science teaching.

B. Cognitive psychology research-- explains results & provides principles for how to improve.

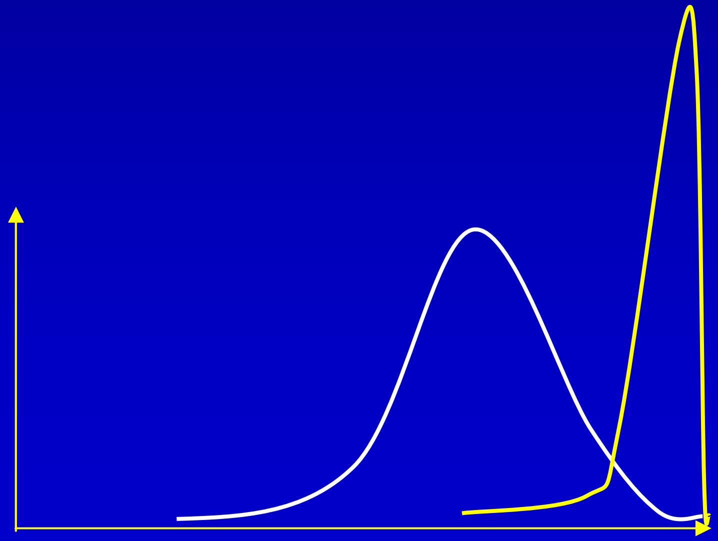
C. Research on effective teaching practices --implementing the principles in classroom

What does research say is the most effective pedagogical approach?*

⇒ **expert** individual tutor

Large impact on all students

Average for class with expert individual tutors >98% of students in class with standard instruction



* Bloom et al *Educational Researcher*, Vol. 13, pg. 4

Characteristics of expert tutors*

match principles of learning, and apply in classroom

- Motivation- why interesting, useful, worth learning,...
- Probe where students are starting from & connect.
- Get actively processing ideas, then probe and guide thinking.
  - Much of the time students are thinking and responding, not teacher telling.
  - Challenging questions that students answer, explain to each other
  - Timely specific feedback (often via questioning)
- Reflection on their learning

*Lepper and Woolverton in "Improving Academic Performance"

Engaging, monitoring, & guiding thinking.

5-300 students at a time?!

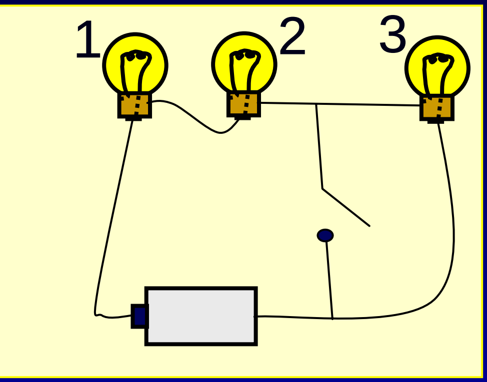
Technology that can help. *(when used properly)*

examples:

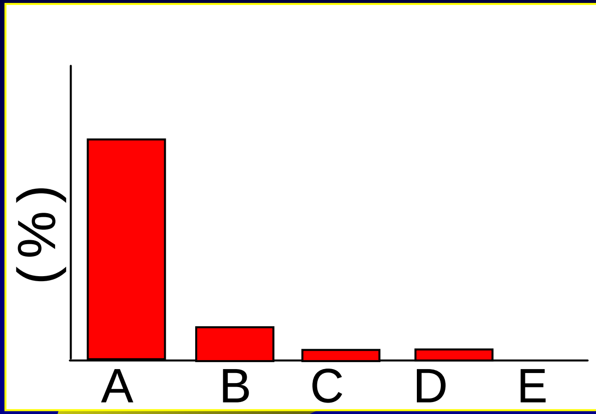
a. Interactive lecture (students discussing & answering questions) *supported by* personal response system--“clickers”

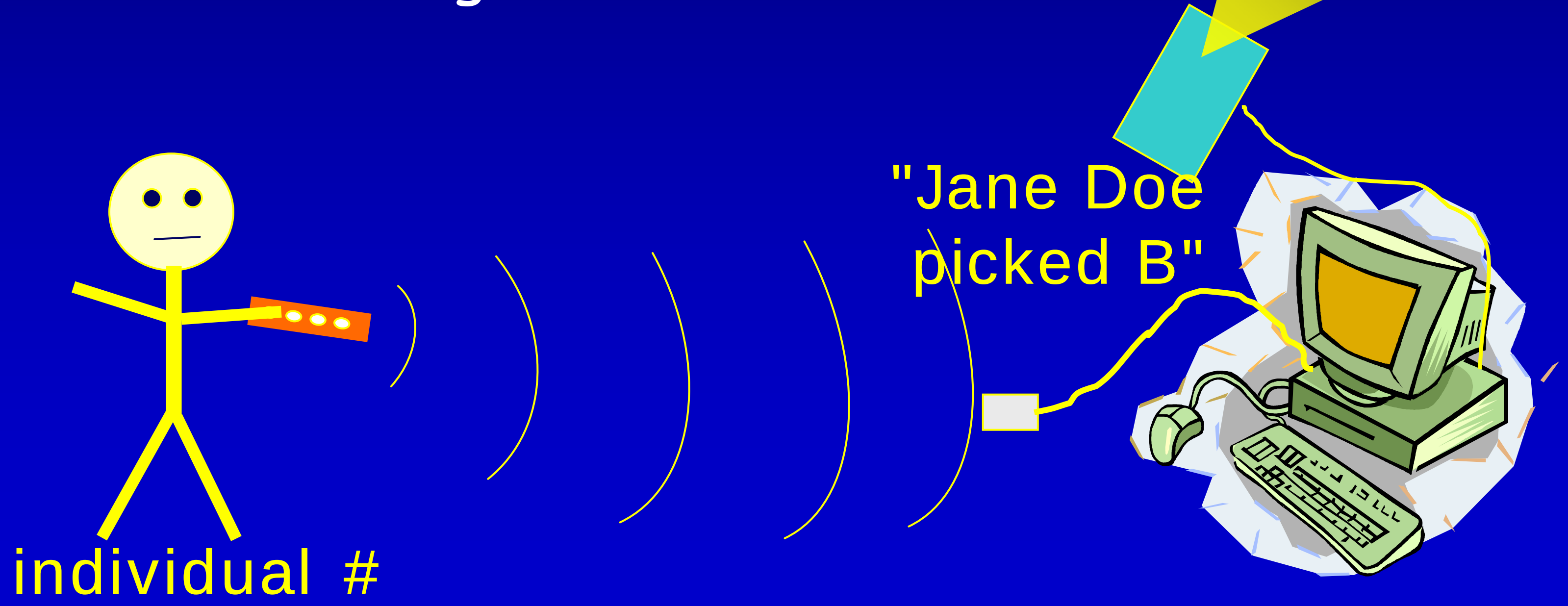
b. interactive simulations

a. concept questions & “Clickers”--



When switch is closed, bulb 2 will
a. stay same brightness,
b. get brighter
c. get dimmer,
d. go out.





clickers*--

Not automatically helpful--

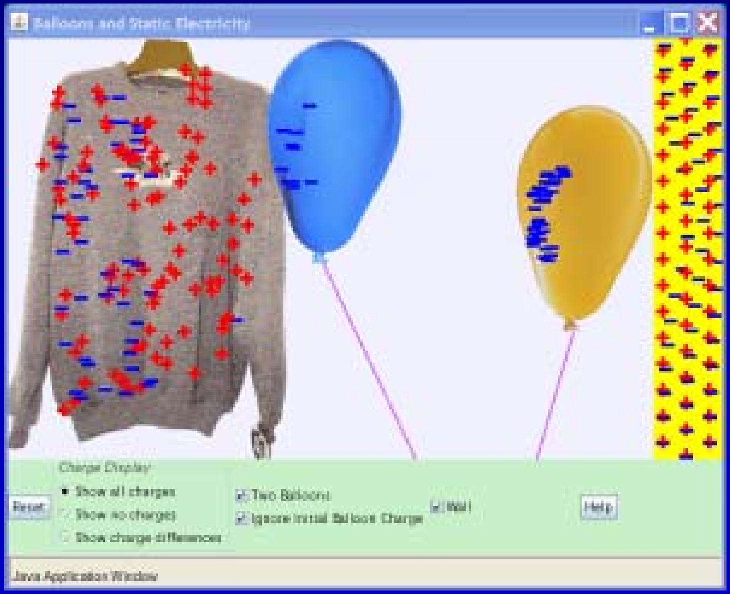
Used/perceived as expensive attendance and testing device⇒ little benefit, student resentment.

Used/perceived to enhance engagement, communication, and learning ⇒ transformative

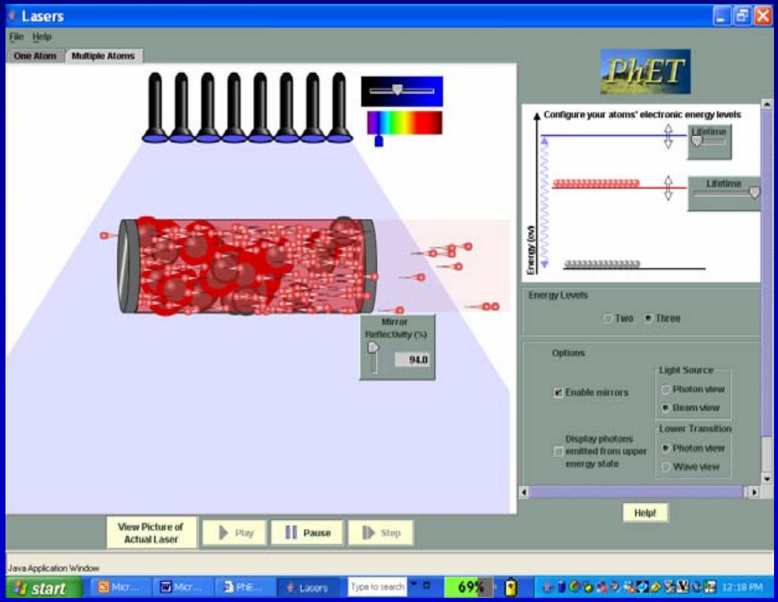
•challenging questions
•student-student discussion ("peer instruction") & responses
•follow up instructor discussion- timely specific feedback
•minimal but nonzero grade impact

*An instructor's guide to the effective use of personal response systems ("clickers") in teaching-- www.cwsei.ubc.ca

Highly Interactive educational simulations--
phet.colorado.edu   70 simulations physics & chem
FREE, Run through regular browser
Highly effective when based on/incorporates research on learning.



balloons and sweater



laser

Perfect Classroom not enough!
(time required to develop long term memory)

Build further with extended practice to develop expert-thinking & skills.

$\Rightarrow$ **homework**- authentic problems, useful feedback

Some Data:
Results when develop/copy research-based pedagogy

- Retention of information from lecture

  10% after 15 minutes ⇒ >90 % after 2 days

- Conceptual understanding gain

  15-25% ⇒ 50-70%

- Beliefs about physics and problem solving, interest

  5-10% drop ⇒ small improvement *(just starting)*

IV. Institutional change --
"from bloodletting to antibiotics"

Widespread improvement in science education
Changing educational culture in major research university science departments

UBC CW Science Education Initiative and U. Col. SEI

- Departmental level

$\Rightarrow$ **scientific approach to teaching, all undergrad courses = *goals, measures, tested best practices***

All materials, assessment tools, etc to be available on web

Summary:

Need new, more effective approach to science ed.

Tremendous opportunity for improvement

⇒ Approach teaching like we do science

and teaching is more fun!

Good Refs.:

NAS Press "How people learn"

Redish, "Teaching Physics" (Phys. Ed. Res.)

Handelsman, et al. "Scientific Teaching"

Wieman, (~ this talk) Change Magazine-Oct. 07 at *www.carnegiefoundation.org/change/*

CLASS belief survey: CLASS.colorado.edu

phet simulations: phet.colorado.edu

What expert tutors do matches research from very different contexts

- cognitive psychologists-- activities/motivation required for expert mastery

- educational pysch. --how people learn, activities most effective for learning.

- science education-- effective classroom practices

e.g. A. Ericsson et. al., Cambridge Handbook on Expertise...
Bransford et al, How People Learn,- NAS Press
Redish- Teaching Physics, Handlesman- Scientific Teaching
K. Perkins, S. Pollock, et al, PR ST-PER, ...

Characteristics of expert tutors*

(Which can be duplicated in classroom?)

Motivation major focus (context, pique curiosity,...)
Never praise person-- limited praise, all for process

Understands what students do and do not know.
$\Rightarrow$ timely, specific, interactive feedback

Almost never tell students anything-- pose questions.

Mostly students answering questions and explaining.

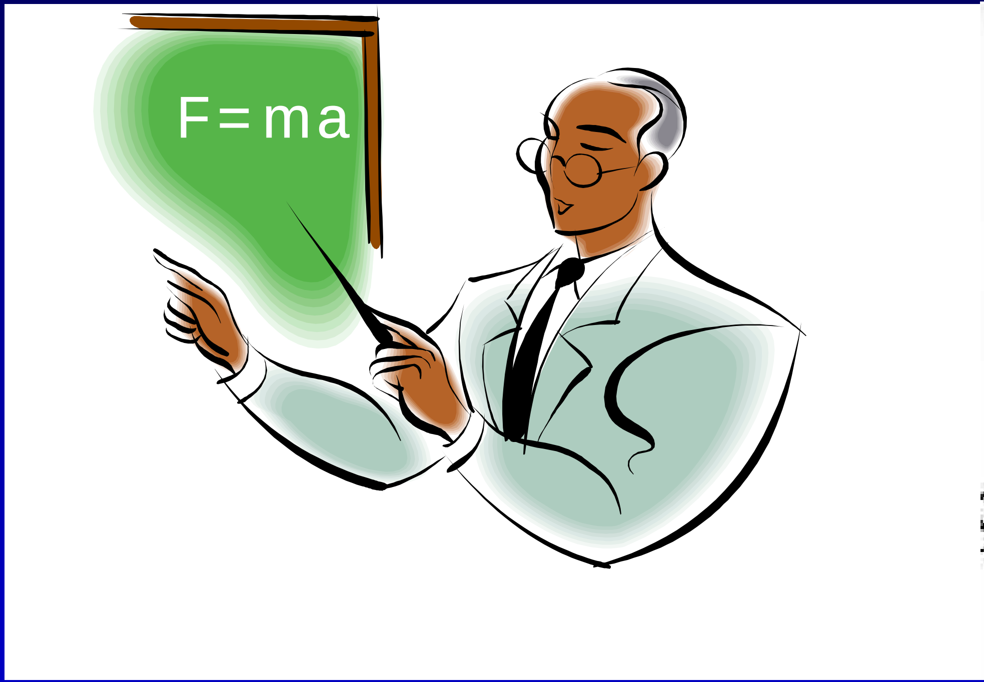
Asking right questions so students challenged but can figure out. Systematic progression.

Let students make mistakes, then discover and fix.

Require reflection: how solved, explain, generalize, etc.

*Lepper and Woolverton pg 135 in Improving Academic Perfomance recent research--Brain development much like muscle

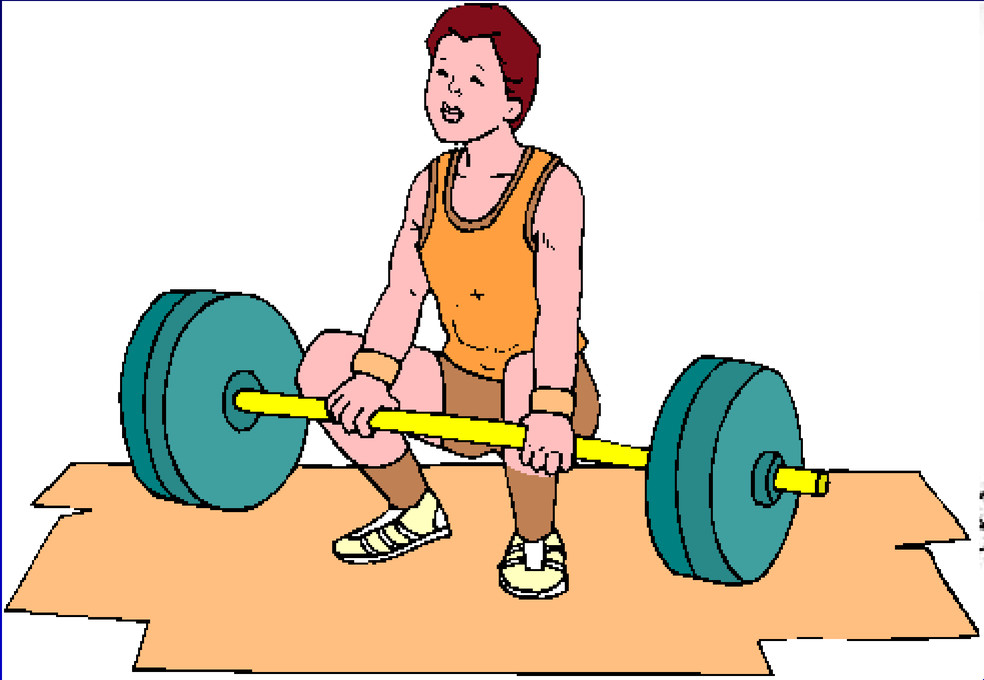
Requires strenuous extended use to develop
(classroom, cog. pysch., & brain imaging)



Not stronger or smarter!
Both require strenuous effort

recent research--Brain development much like muscle

Requires strenuous extended use to develop
(classroom, cog. pysch., & brain imaging)



self improvement?

IV. Institutionalizing improved research-based teaching practices. *(From bloodletting to antibiotics)*

Univ. of Brit. Col. CW Science Education Initiative *(CWSEI.ubc.ca)*
& Univ. of Col. Sci. Ed. Init.

- Departmental level, widespread sustained change at major research universities
  ⇒scientific approach to teaching, all undergrad courses
- Departments selected competitively
- Substantial one-time $$$ and guidance

Extensive development of educational materials, assessment tools, data, etc. Available on web.
Visitors program

Implications for instruction

Student beliefs about science and science problem solving important!

- Beliefs ←→ content learning
- Beliefs -- powerful filter → choice of major & retention
- **Teaching practices → students' beliefs**

  typical significant decline (phys and chem)

  (and less interest)

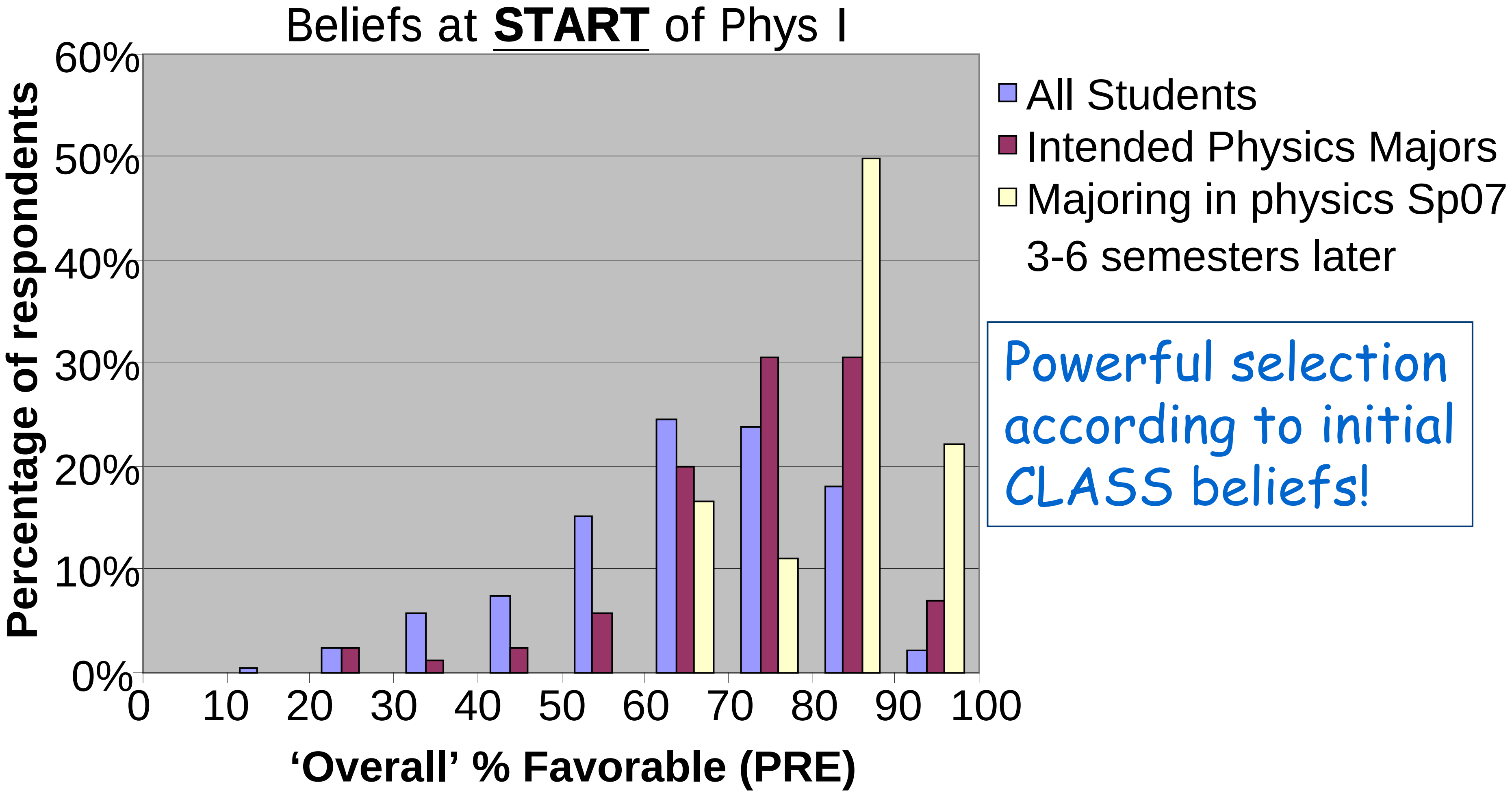
Avoid decline if explicitly address beliefs.

Why is this worth learning?
How does it connect to real world?
How connects to things student knows/makes sense?

Who from Calc-based Phys I, majors in physics?

K. Perkins

- Calc-based Phys I (Fa05-Fa06): 1306 students
  - "Intend to major in physics": 85 students
  - Actually majoring in physics 1.5-3 yrs later: 18 students

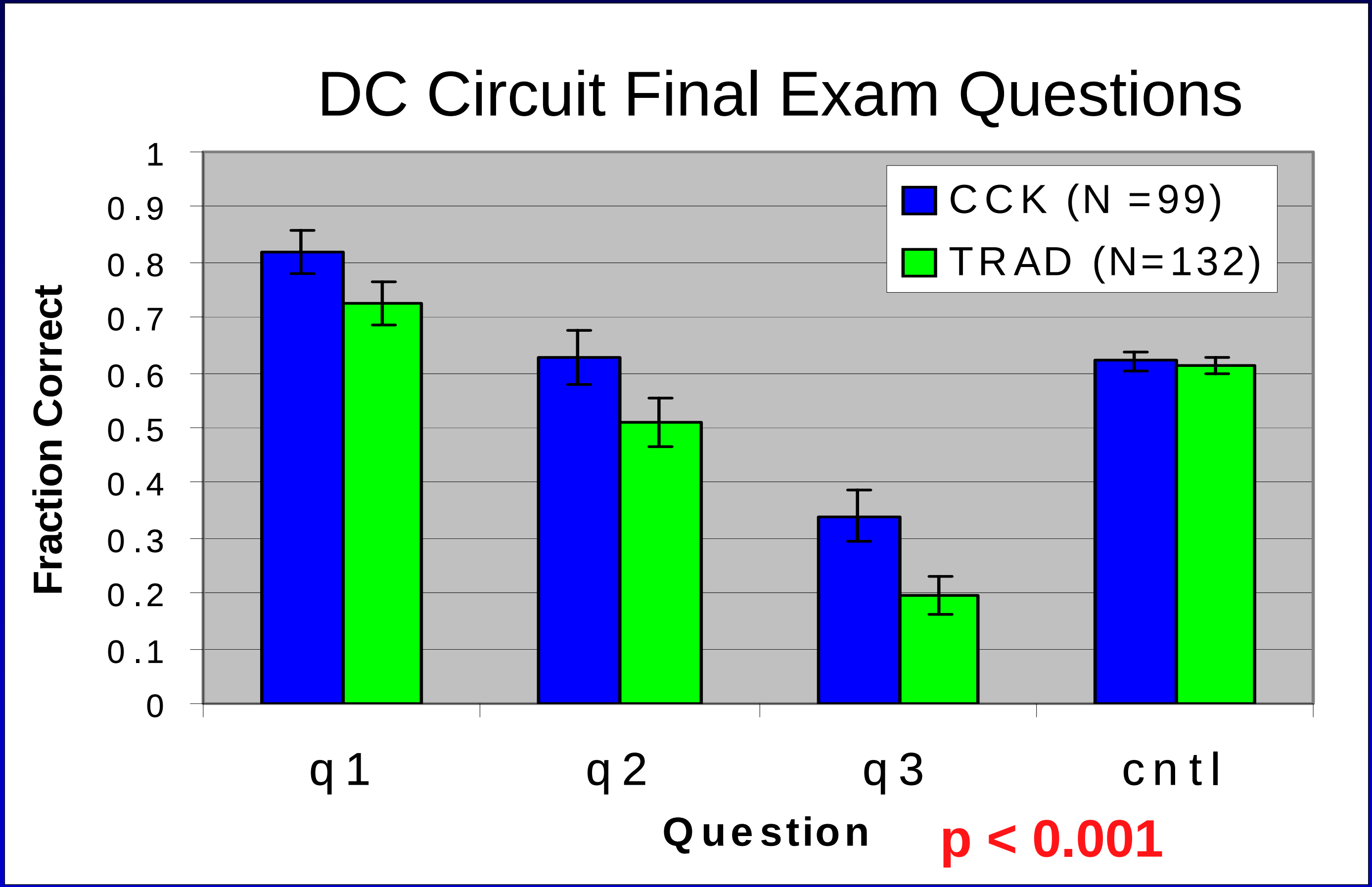


Powerful selection according to initial CLASS beliefs!

Standard Laboratory

(Alg-based Physics, single 2 hours lab):

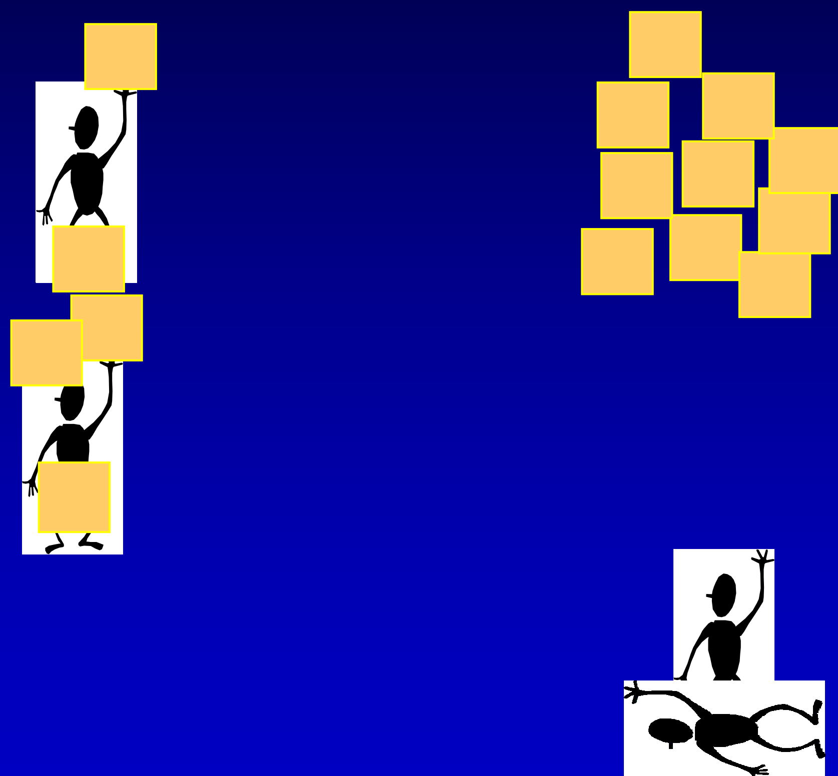
Simulation vs. Real Equipment



N D. Finkelstein, et al, "When learning about the real world is better done virtually: a study of substituting computer simulations for laboratory equipment," *PhysRev: ST PER 010103 (Sept 2005)*

Implication for instruction--Reducing unnecessary cognitive load improves learning.

~~jargon~~ use figures, connect topics, ...



V. Institutional change -- what is the CWSEI?

Widespread improvement in science education
Requirement--change educational culture in major research university science departments

Carl Wieman Science Education Initiative

- Departmental level, widespread sustained change
$\Rightarrow$scientific approach to teaching, all undergrad courses
- 5 departments, selected competitively
- Focused $$$ and guidance
- Partner with Univ. Colorado SEI

All materials, assessment tools, etc available on web
Visitors program

effective clicker use-

Class designed around series of questions and follow-up--
Students actively engaged in figuring out.

Student-student discussion (*consensus groups*)
& enhanced student-instructor communication

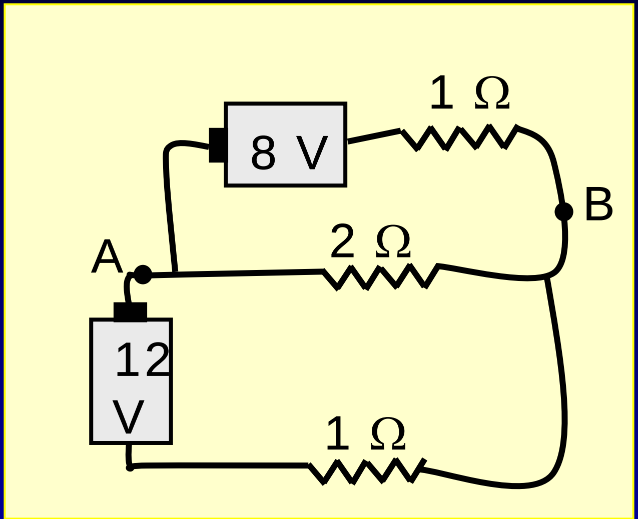
$\Rightarrow$ **rapid + targeted = effective feedback.**

Data 2. Conceptual understanding in traditional course

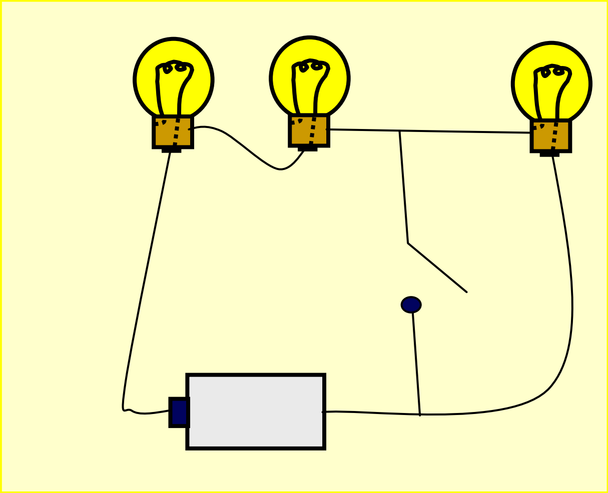
electricity

Eric Mazur (Harvard Univ.)

End of course.
70% can calculate currents and voltages in this circuit.



only 40% correctly predict change in brightness of bulbs when switch closed!



V. Issues in structural change (my assertions)

Necessary requirement--become part of culture in major research university science departments

set the science education norms

$\Rightarrow$ produce the college teachers,

who teach the k-12 teachers.

Challenges in changing science department cultures--

- no coupling between support/incentives and student learning.
- very few authentic assessments of student learning
- investment required for development of assessment tools, pedagogically effective materials, supporting technology, training
- no $$$ *(not considered important)*

b. Interactive simulations

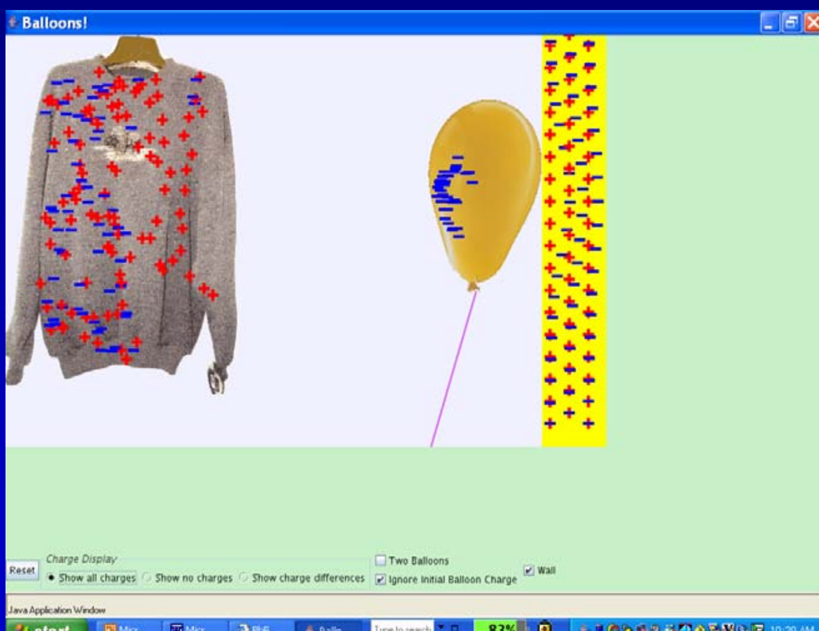
phet.colorado.edu

Physics Education Technology Project (PhET)

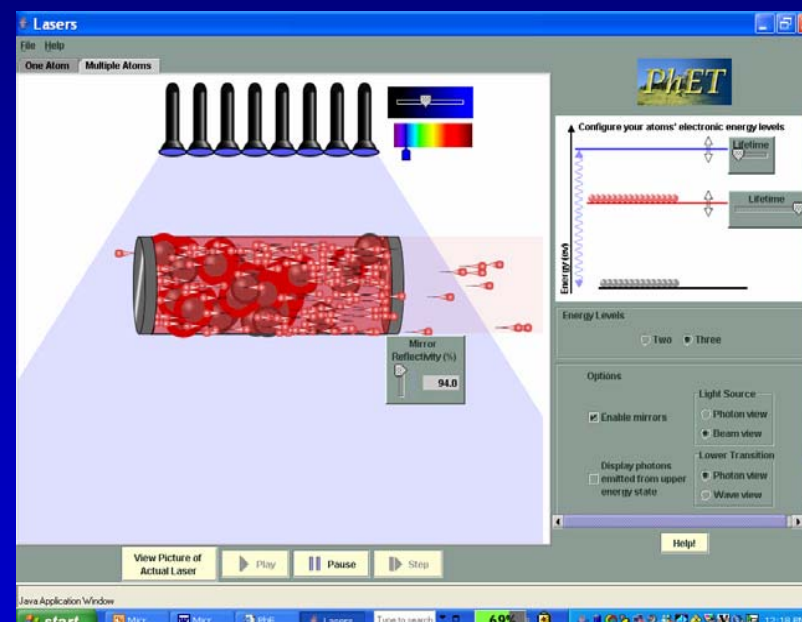
>60 simulations

Wide range of physics (& chem) topics. Activities database.

Run in regular web-browser, online or download site.



balloon and sweater



laser

supported by: Hewlett Found., NSF, Univ. of Col., and A. Nobel examples:

balloon and sweater

circuit construction kit

data on effectiveness- many different settings and types of use

Simulation testing ⇒ educational research microcosm. Consistently observe:

- Students think/perceive differently from experts
  (not just uninformed--brains ***different***)

- Understanding created/discovered.
  (Attention necessary, not sufficient)

Actively figuring out + with timely feedback and encouragement ⇒ mastery.