Science Education for the 21st Century

Using the insights 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

0) What is the Science Education Initiative?

I) What does research tell us about expert thinking and effectiveness of different teaching approaches?

II) Implementing principles of learning
(& some technology that can help)

UBC CW Science Education Initiative and U. Col. SEI

from "bloodletting to antibiotics" in science education

Changing educational culture in major research university science departments

necessary first step for science education overall

- Departmental level

⇒**scientific approach to teaching, all undergrad courses = learning goals, measures, tested best practices**

Dissemination and duplication.

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

rest of the talk-- basis for this effort

<u>Need for science education</u>

⇒ technically literate population

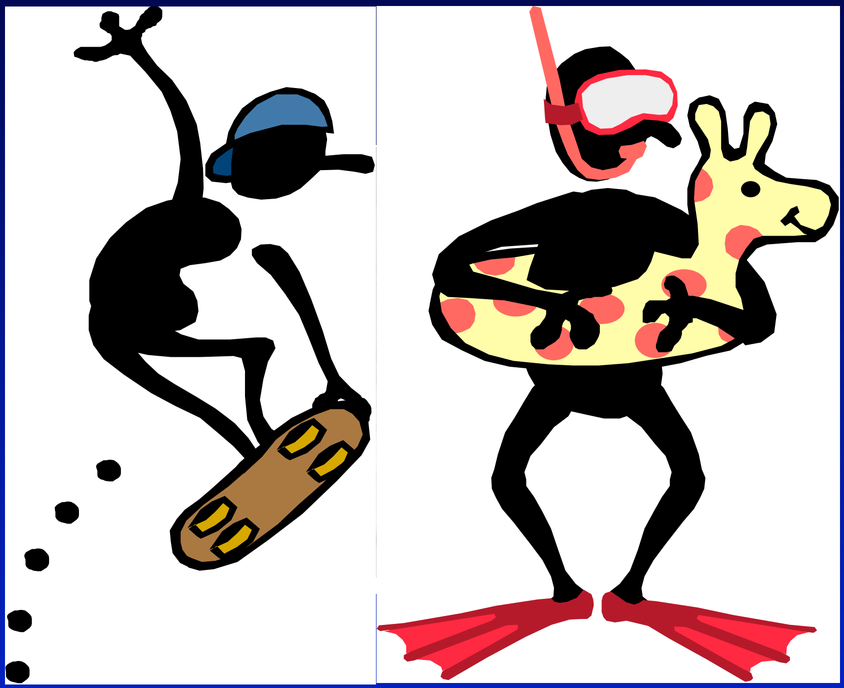
- *global scale problems (technical)*

- *science/technology based modern economy.*

Need science education effective and relevant for large fraction of population!
(not just next generation of scientists)

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--

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

Some Data:

traditional lecture method		research-based teaching
• Retention of information from lecture		
10% after 15 minutes	⇒	**>90 % after 2 days**
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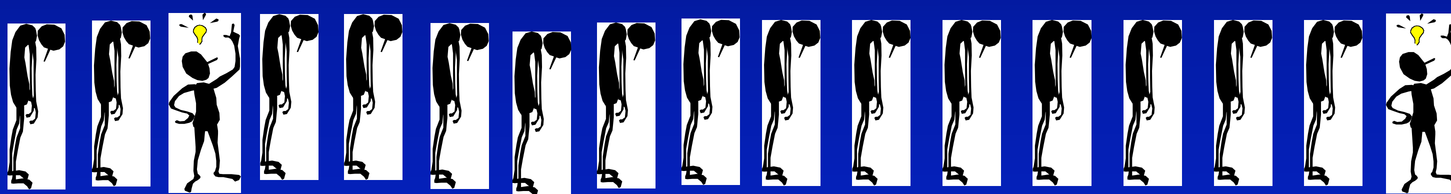
• Beliefs about science-- what it is, how to learn, how to solve problems, interest		
significantly less (5-10%) **like expert**	⇒	**more like expert**

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.



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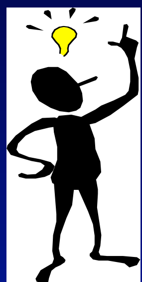
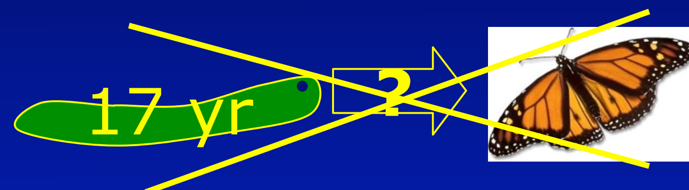
grad students

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



2-4 years later ⇒ expert physicists!

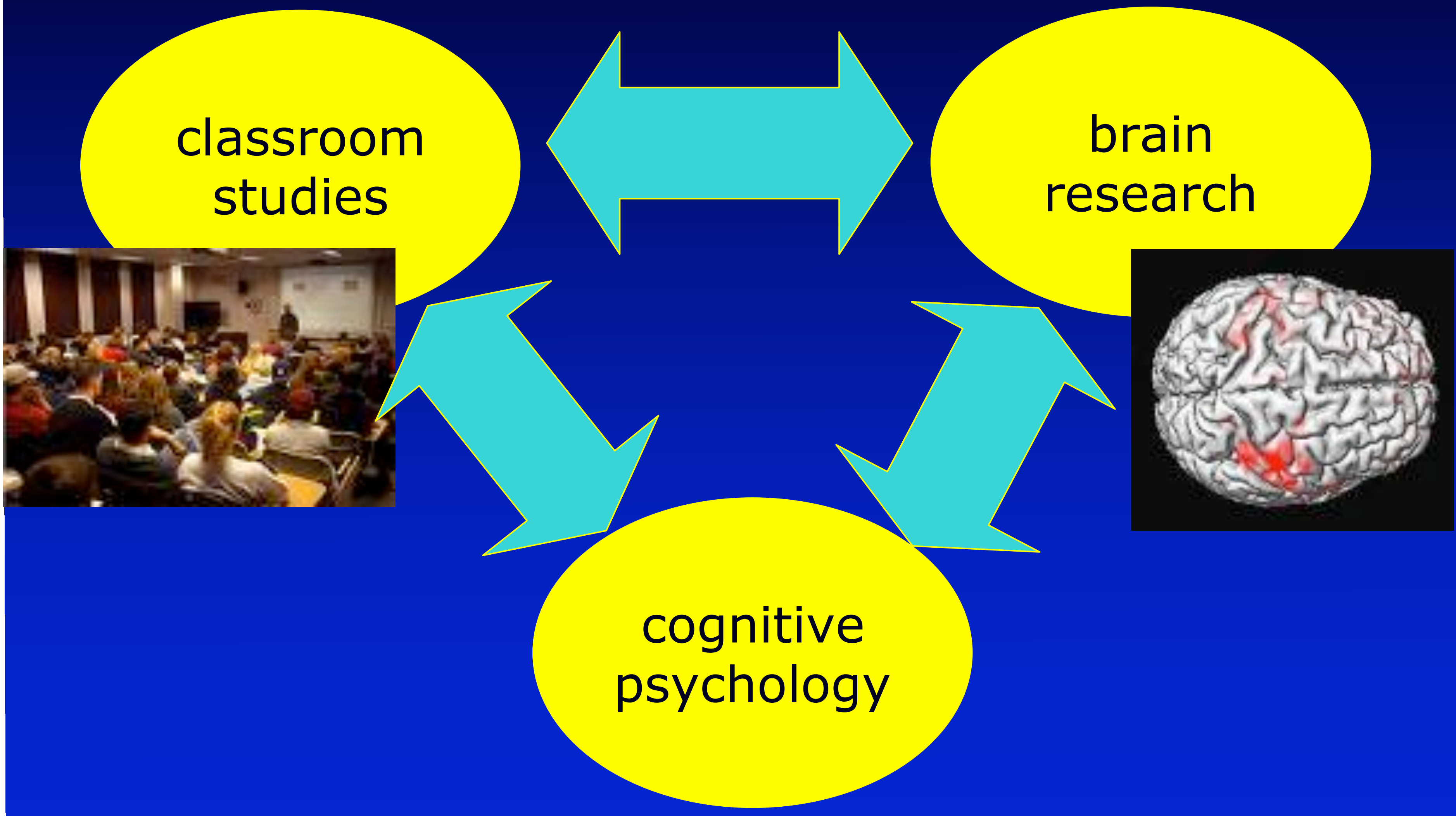
?????? 

Research on how people learn, particularly science.
- above actually makes sense.

⇒ opportunity--how to improve learning.

& makes teaching a lot more rewarding and fun!

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



II. Research on teaching & learning

A. How experts think and learn.
Expert-novice differences.

B. Research on traditional science teaching.
How well teaches expert thinking and why.

C. How to do better (brief)
--principles of learning & their implementation

Expert competence research*

historians, scientists, chess players, doctors,...

Expert competence =

- factual knowledge
- **Organizational framework** ⇒ effective retrieval and use of facts

or ?

patterns, structure, connections-- scientific concepts

- **Ability to monitor own thinking and learning**

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

New ways of thinking-- require MANY hours of intense practice with guidance/reflection. Change brain "wiring"

*Cambridge Handbook on Expertise and Expert Performance

How well are students learning expert-like thinking from traditional science teaching
-lectures, textbook homework problems, exams

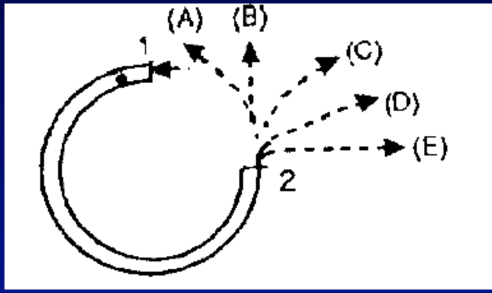
1. Conceptual understanding.

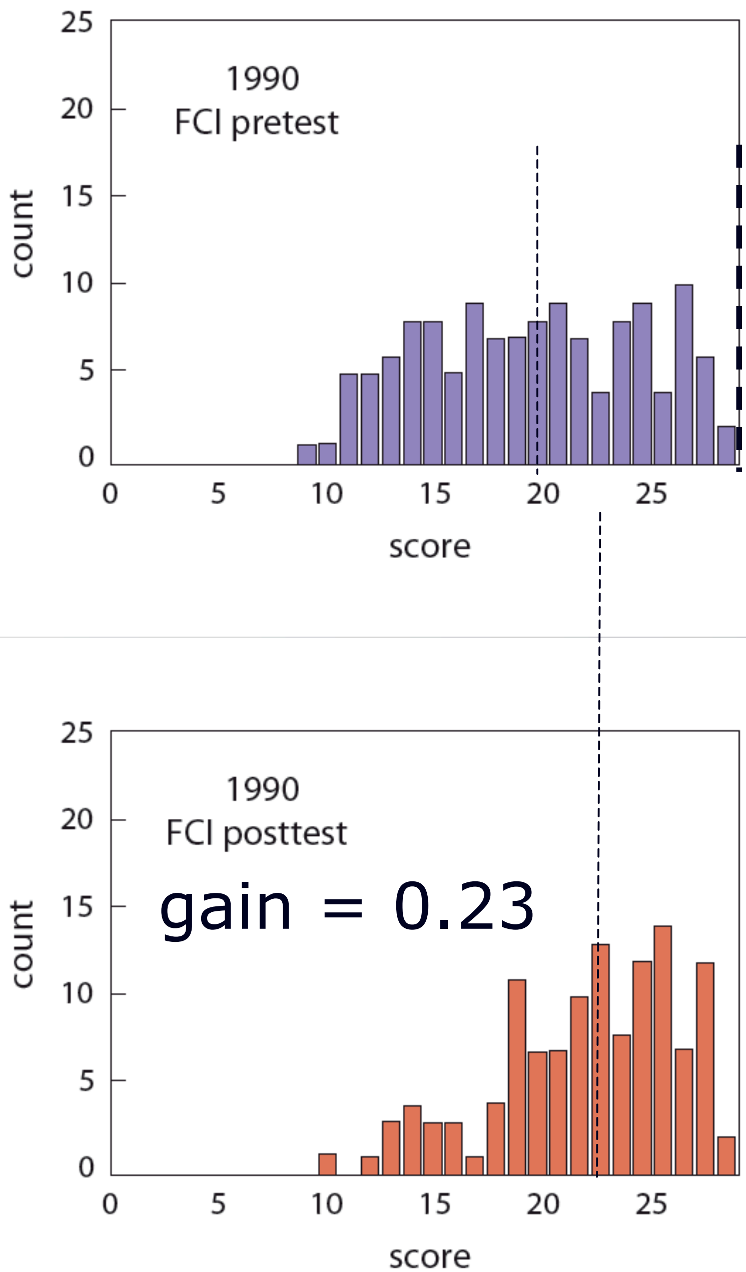
2. Beliefs about physics and chemistry
   what and how to learn

Data 1. 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)





typical FCI scores
(Mazur- Harvard)

gain = 0.23

1990 traditional

gain= fraction of way to perfect score

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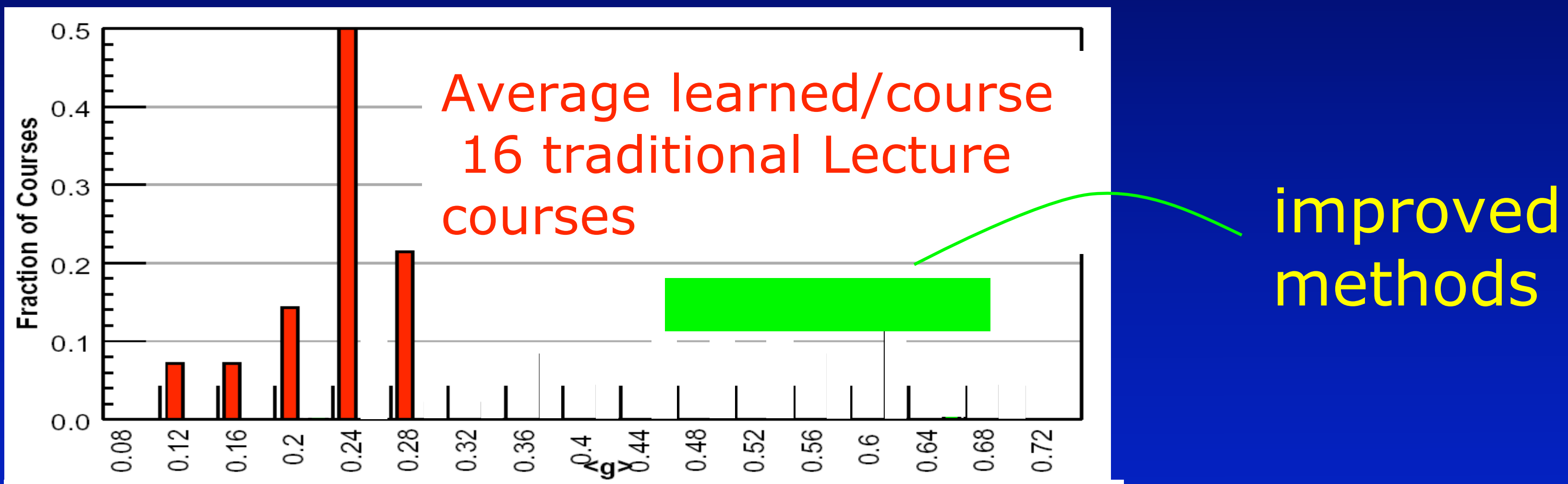


Fraction of unknown basic concepts learned

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 2. 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.

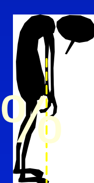
Expert

Content: coherent structure of concepts.

Describes nature, established by experiment.

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

~10%



% shift?

intro physics ⇒ *more* novice

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

Chemistry just as bad!

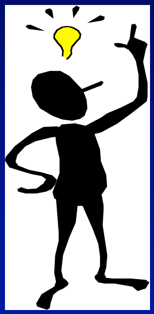
*adapted from D. Hammer

Why results so bad?

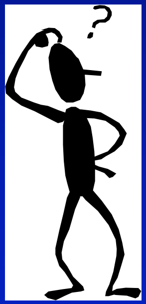
1) Treat learning as information transfer, not brain development.
2) Differences in perception. 3) Working memory limits.

2. Different Perceptions

Expert-- Relevance & conceptual structure obvious.



Novice-- invisible.
Sees only facts and formulas to memorize.



3. Aggravated by limits on working memory.

<u>Limits on working memory</u>--best established, most ignored result from cognitive science

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

Working memory capacity
VERY LIMITED!
(remember & process
<7 distinct new items)

MUCH less than in typical science lecture

PPT slides will be available

⇒ processing and retention from lecture tiny
(for novice)

many examples:

I. <u>Redish</u>- students interviewed as came out of lecture.
"What was the lecture about?"

only vaguest generalities

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

17 yrs of success in classes.
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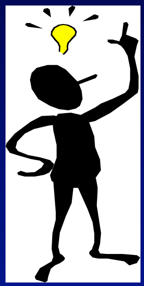

2-4 years later ⇒ expert physicists!

??????

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

Practicing "expert thinking" continually happening in research lab!
(extended strenuous engagement + guiding feedback)

How to improve teaching? Straightforward.

III. Essentials for learning
(principles from research) *most of what matters*

1. Build on/connect with prior thinking

2. Explicit modeling and practice of expert thinking.
   extended & strenuous *(brain like muscle)*
   a. engagement
   b. effective feedback (timely and specific)

3. Motivation

4. Reduce unnecessary demands on working memory

5. Spaced, repeated retrieval and application, & build connections $\Rightarrow$ retention

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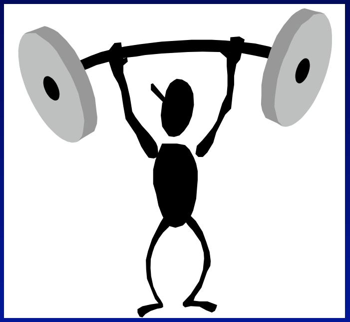
Practicing expert-like thinking--engaging, monitoring, & guiding



Challenging but doable tasks/questions.

Explicit focus on expert-like thinking

- concepts
- recognizing relevant & irrelevant information when & how to apply methods
- self-checking, sense making & reflection

with feedback ("cognitive coaching")

Practicing expert-like thinking, monitoring, & guiding.

5-300 students at a time?!

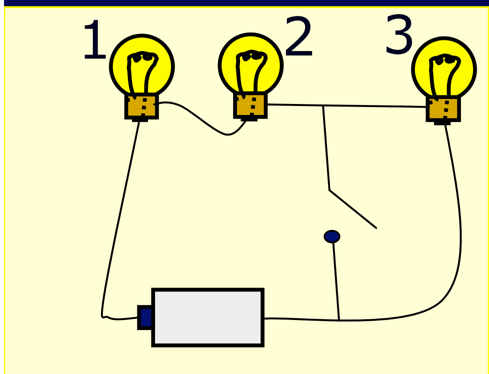
Technology that can help. *(when used properly)*

examples:

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

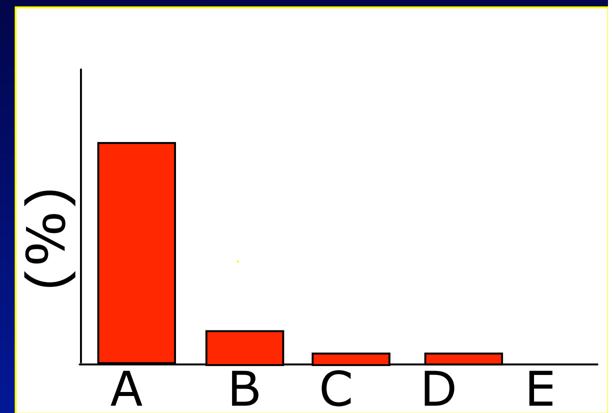
b. interactive simulations (Science Magazine last week)

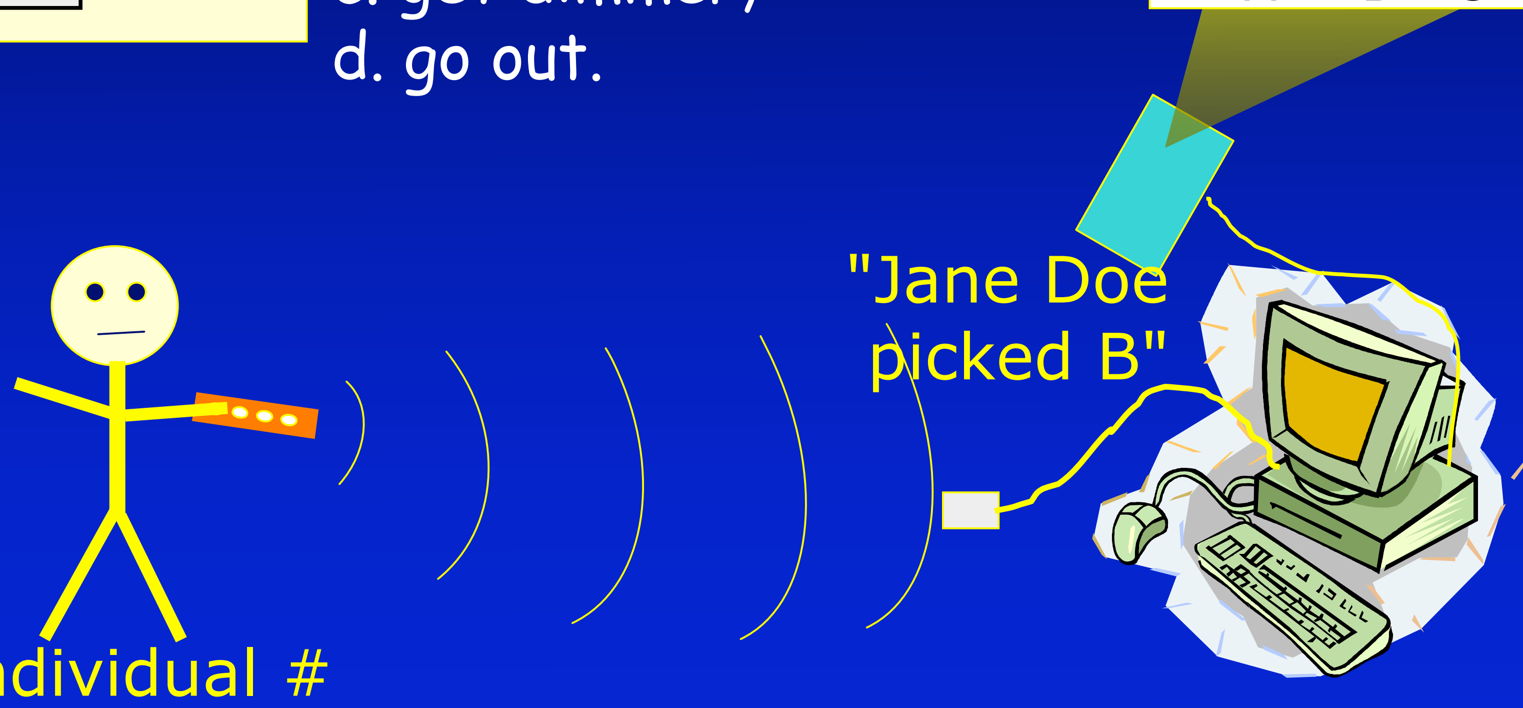
a. concept questions & “Clickers”--



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 (more & deeper questions, students and faculty swear by)

•challenging questions-- concepts
•student-student discussion ("peer instruction") & responses (learning and feedback)
•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

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

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

⇒ **homework**- authentic problems, useful feedback

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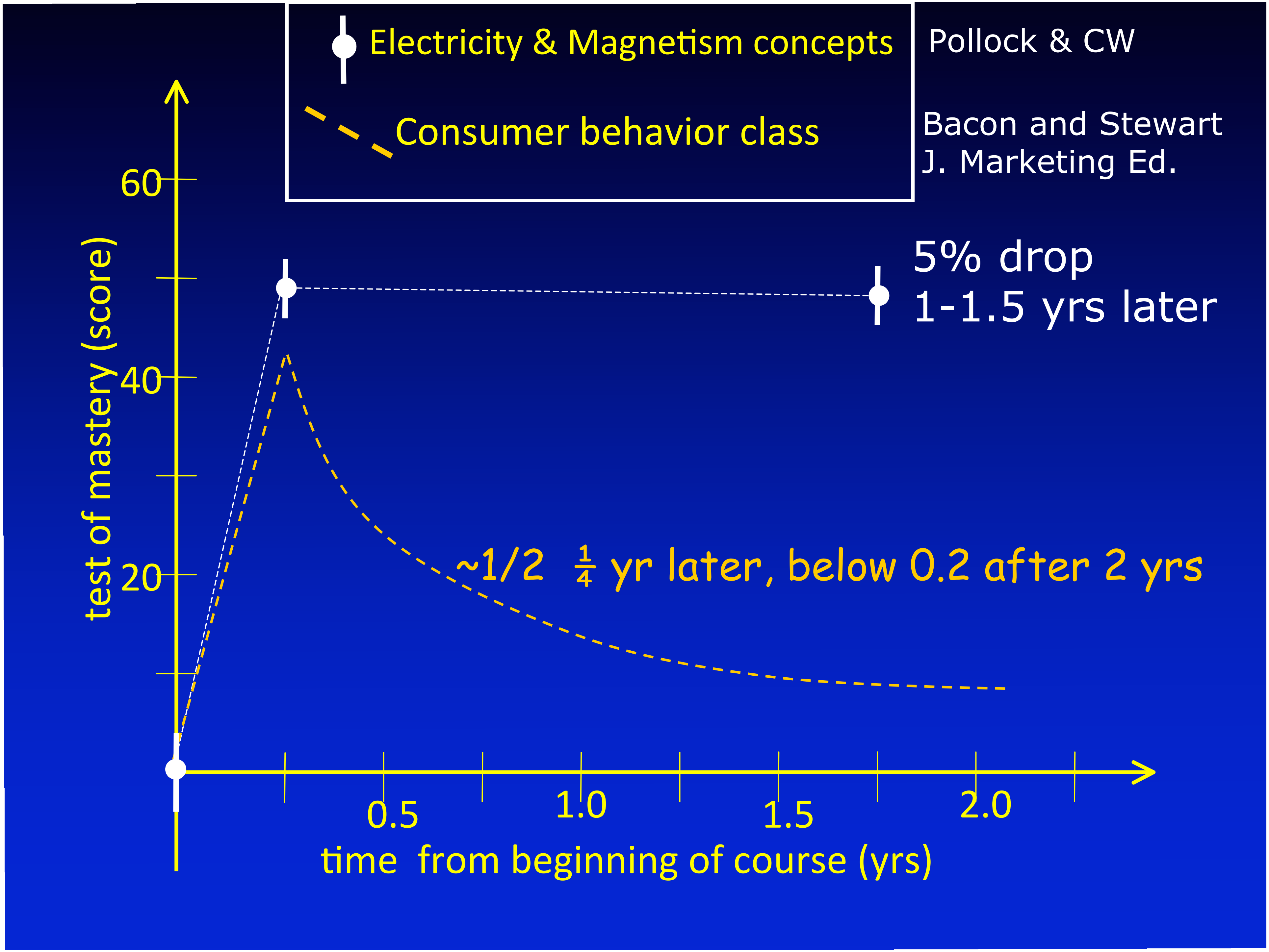

Electricity & Magnetism concepts
Consumer behavior class
Pollock & CW
Bacon and Stewart
J. Marketing Ed.
5% drop
1-1.5 yrs later
~1/2 ¼ yr later, below 0.2 after 2 yrs
test of mastery (score)
60
40
20
0.5
1.0
1.5
2.0
time from beginning of course (yrs)

Summary:

Need new, more effective approach to science ed.

Tremendous opportunity for improvement
⇒ Approach teaching like we do science
CWSEI spreading this approach

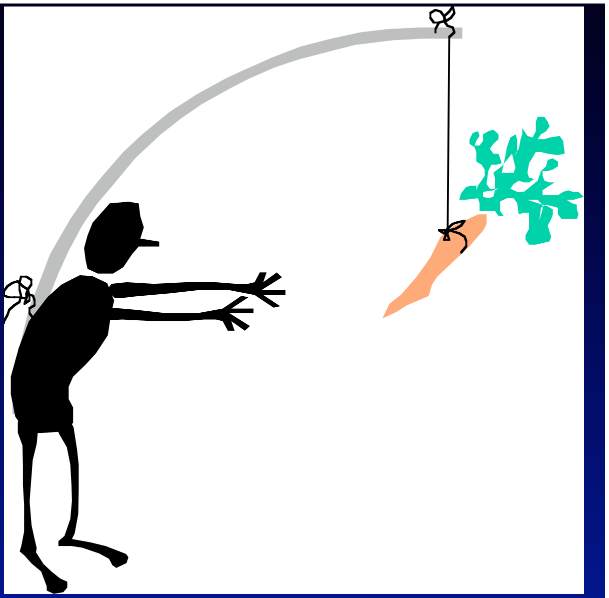
Good Refs.:

NAS Press "How people learn"
Redish, "Teaching Physics" (Phys. Ed. Res.)
Handelsman, et al. "Scientific Teaching"
Wieman, Change Magazine-Oct. 07
at *www.carnegiefoundation.org/change/*

CLASS belief survey: CLASS.colorado.edu
phet simulations: phet.colorado.edu
Sci. Ed. Initiative cwsei.ubc.ca

Motivation-- a few findings

(complex subject-- dependent on previous experiences, ...)



a. Relevance/usefulness to learner very important (meaningful context)

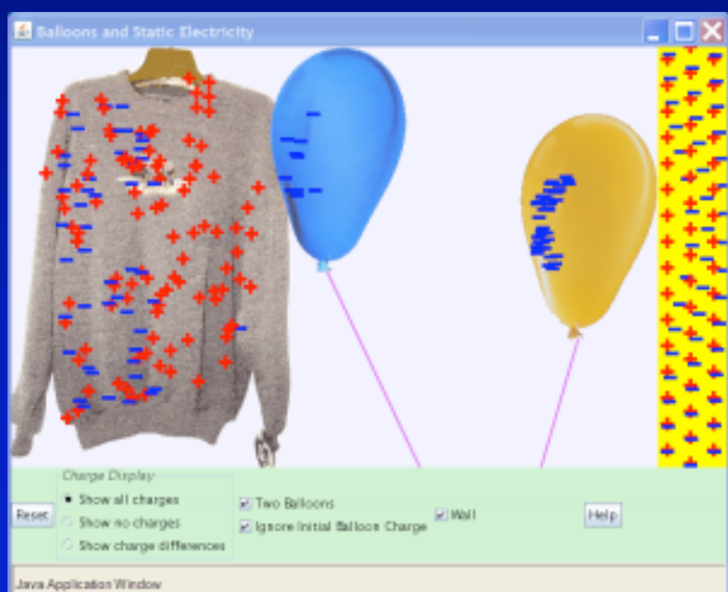
b. Sense that can master subject and how to master

c. Sense of personal control/choice

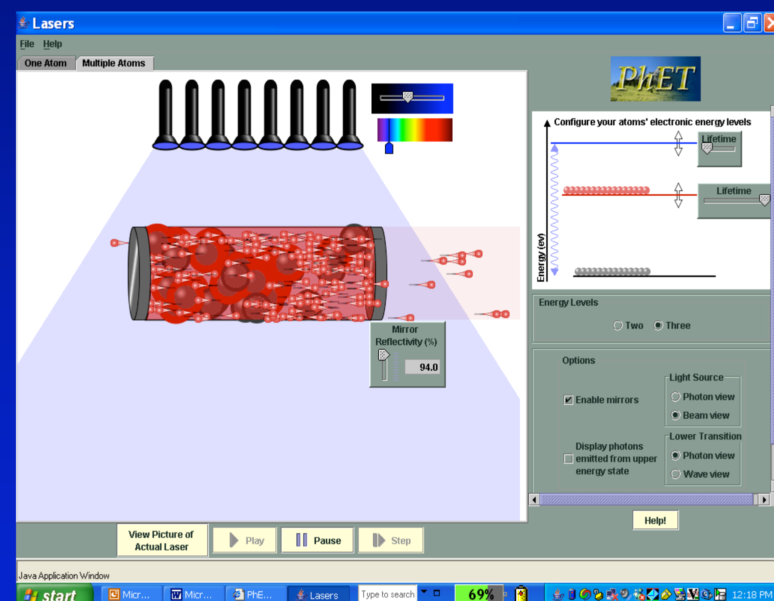
- extra unused slides below

<u>Highly Interactive educational simulations</u>--
phet.colorado.edu ~80 simulations physics & chem
FREE, Run through regular browser

Build-in & test that develop expert-like thinking and learning *(& fun)*



balloons and sweater



laser

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.

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.
⇒ 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.

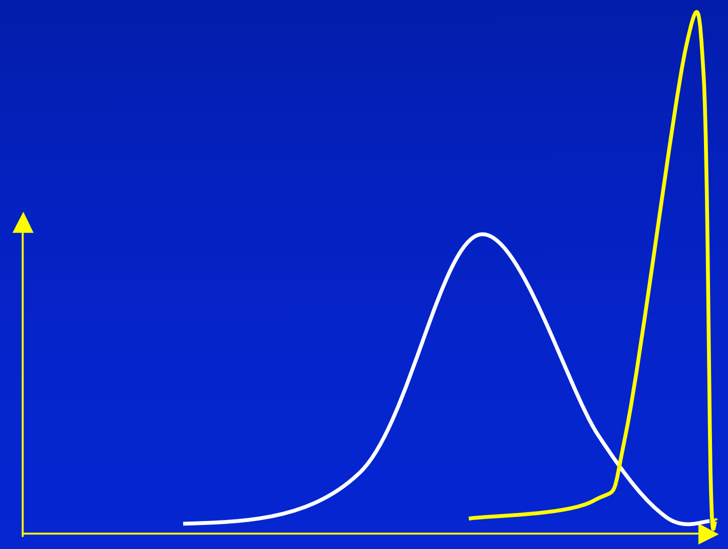
*Lepper and Woolverton pg 135 in Improving Academic Perfomance

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

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)

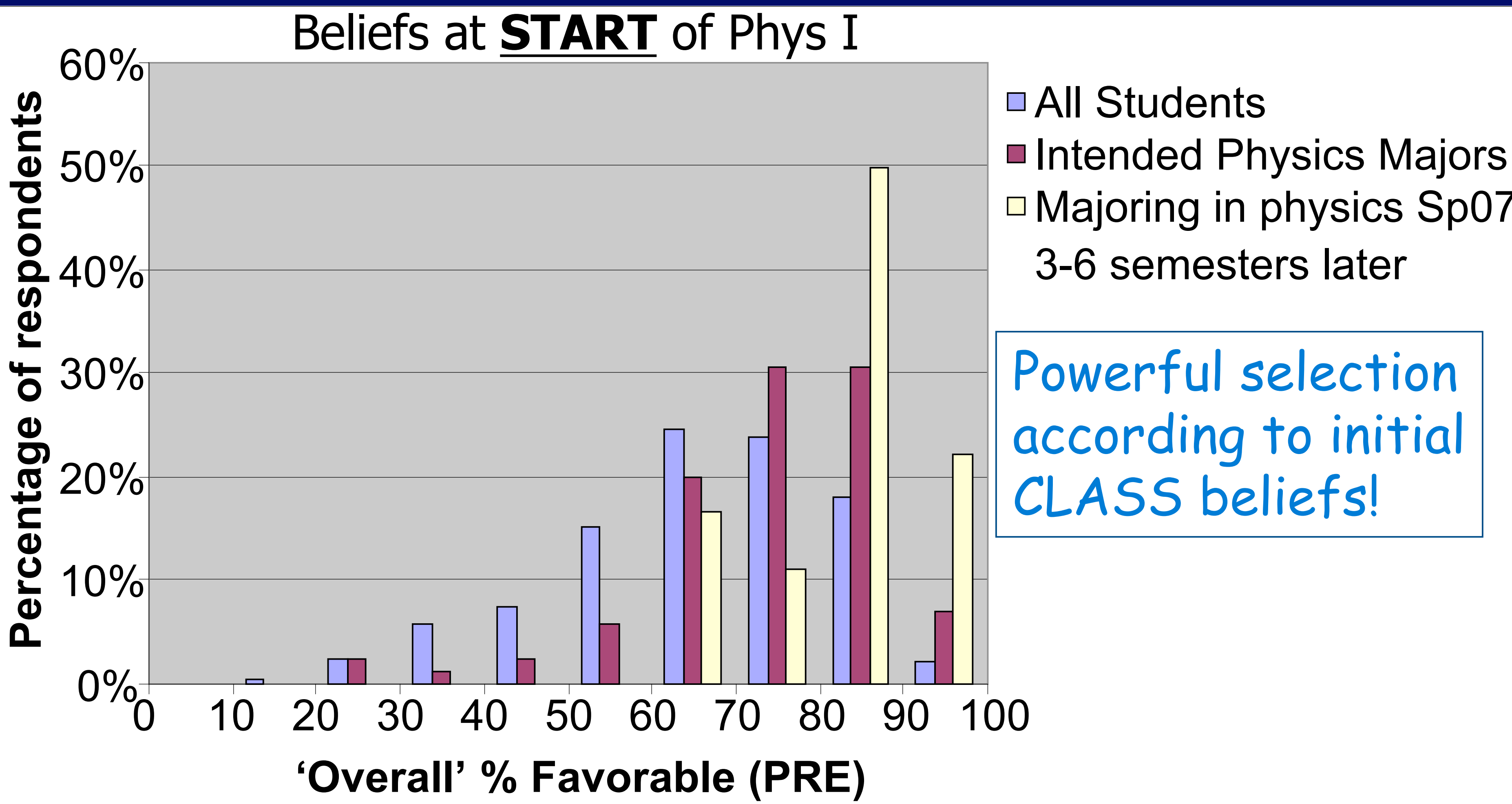
Avoid decline if explicitly address beliefs.

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

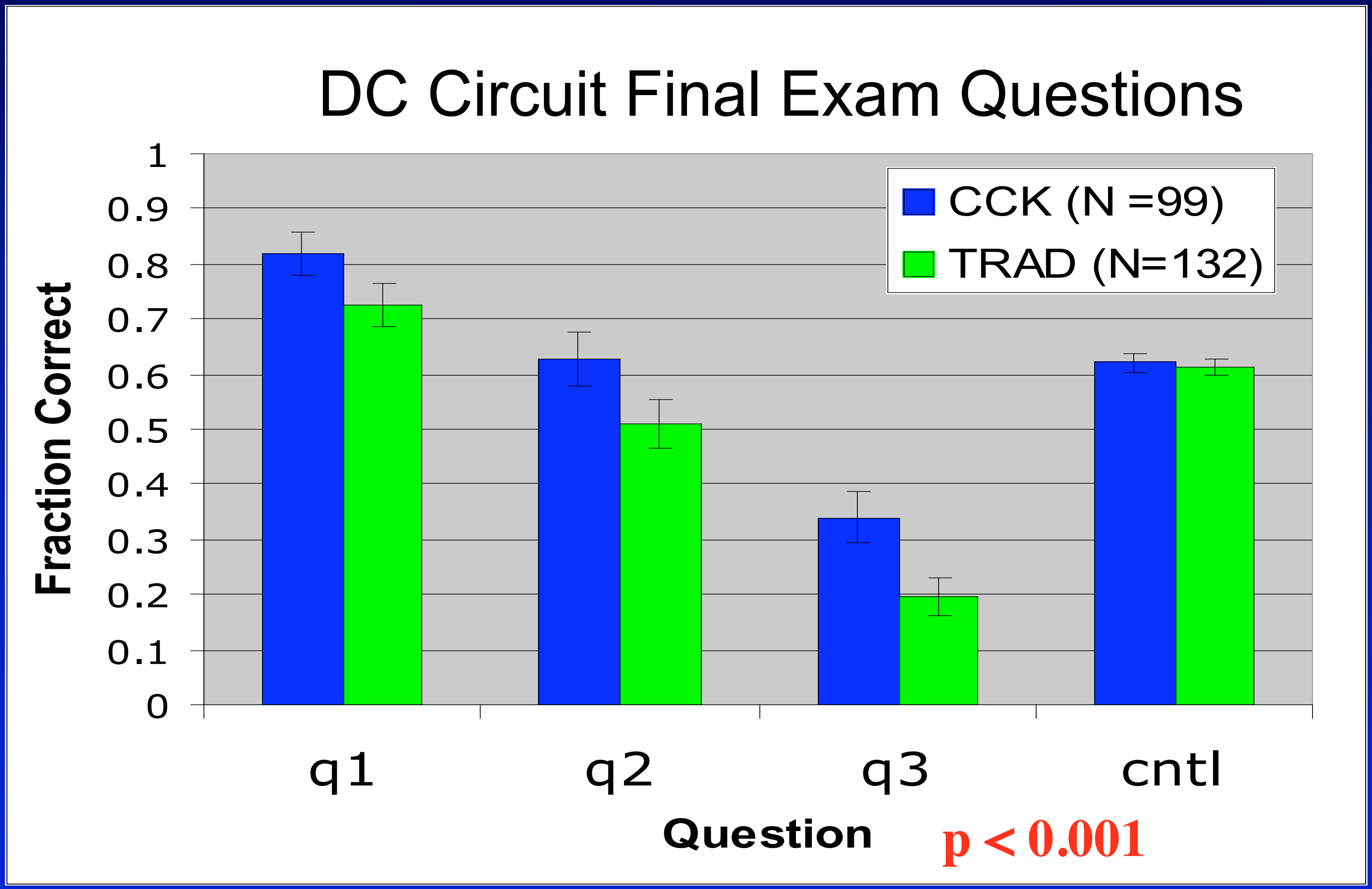


Powerful selection according to initial CLASS beliefs!

Standard Laboratory

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

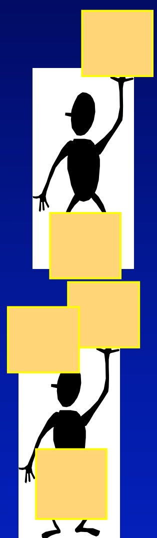
Simulation vs. Real Equipment

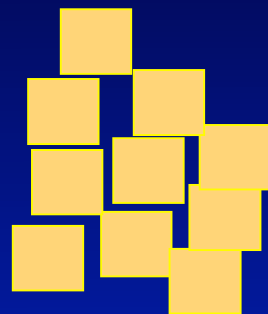


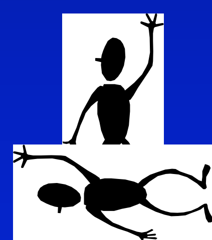
N D. Finkelstein, et al, "When learning about the real world is better done virtually: a study of substituting computer simulations for laboratory equipment," *PhysRev: ST PER 010103 (Sept 2005)*

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

~~jargon~~ use figures, connect topics, …



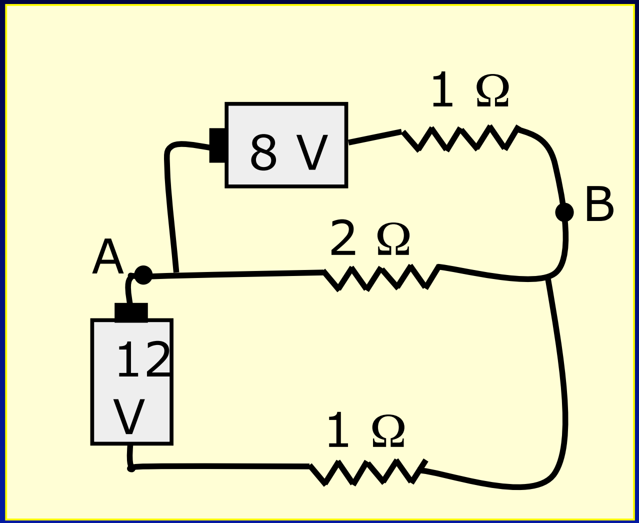




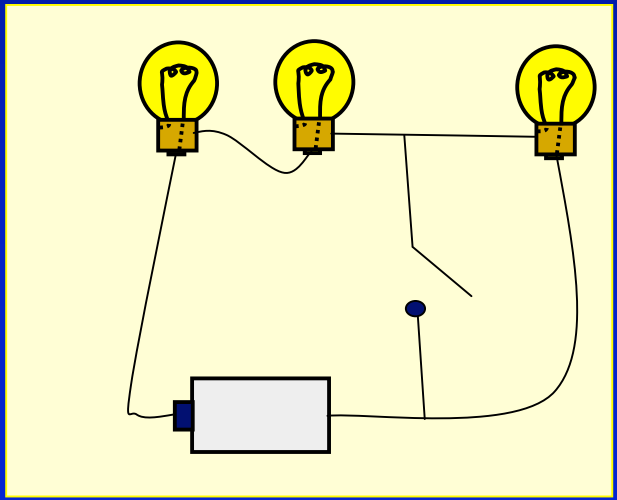
electricity

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

⇒ 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)*