Science Education for the 21st Century

Using the tools of science to teach science

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 effectiveness of traditional science teaching and how to improve?

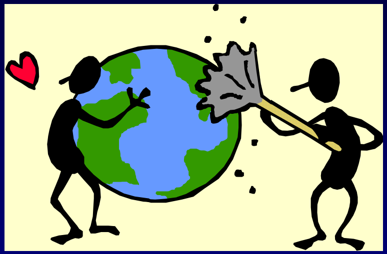
III) Some technology that can help
(if used correctly!)

IV) What am I doing at UBC (brief)

Changing purpose of science education

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

- *Scientifically-literate populace--wise decisions*

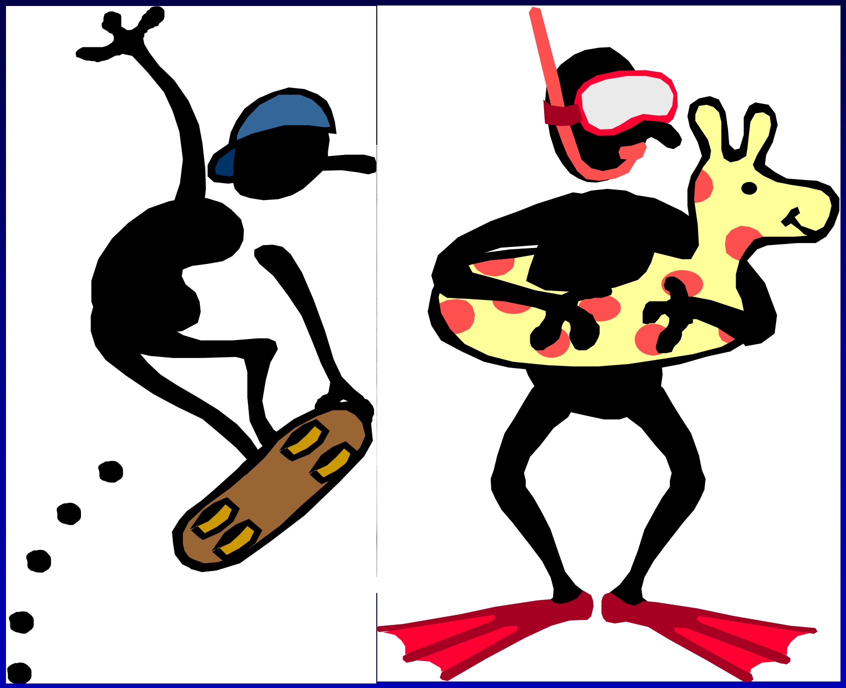


- *Workforce in modern economy.*

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

Effective education

Transform how think--



Think about and use science like a scientist.

Unprecedented educational challenge!

Hypothesis--

Yes, if approach teaching of science like a science--

- Practices based on good data
- Guided by fundamental research
- Disseminate results in scholarly manner, & copy what works
- Utilize modern technology

$\Rightarrow$ improve effectiveness and efficiency

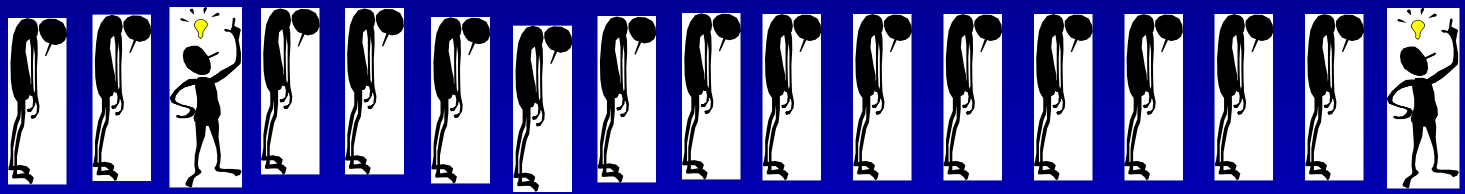
Supporting the hypothesis.....

<u>II)</u> What does research tell us about effectiveness of traditional science teaching?

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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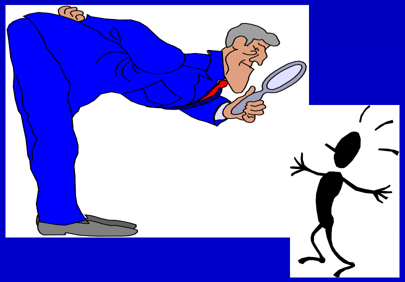
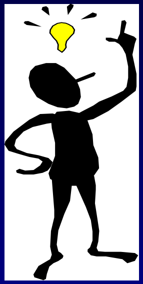


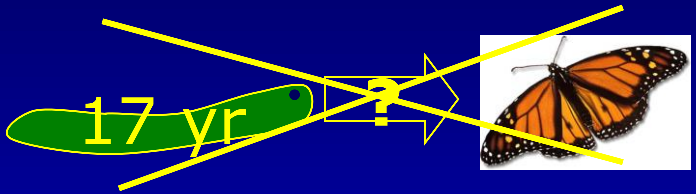
grad students

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



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

??????



Research on how people learn, particularly science.

- above actually makes sense.

$\Rightarrow$ ideas for improving teaching.

Data on effectiveness of traditional science teaching *(& some implications for improving)*.
-lectures, textbook homework problems, exams

1. Retention of information from lecture.

2. Conceptual understanding.

3. Beliefs about physics and problem solving.

⇒ Developing expert competence.

Mostly intro university physics (best data), but other subjects and levels consistent.

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

other more structured studies- similar results

Does this make sense?
Can it possibly be generic?

Cognitive science says yes.

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

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

Maximum

~7 items short term memory,
process 4 ideas at once.

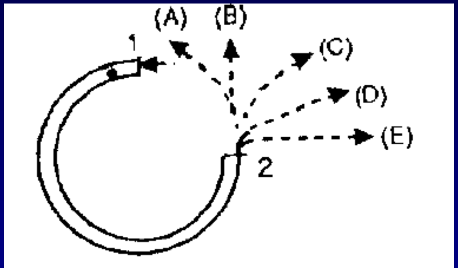
MUCH less than in typical science lecture

copies of slides available

Data 2. Conceptual understanding in traditional course.

- Force Concept Inventory- basic concepts of force and motion 1st semester physics *(100's of courses)*

30 multiple choice questions

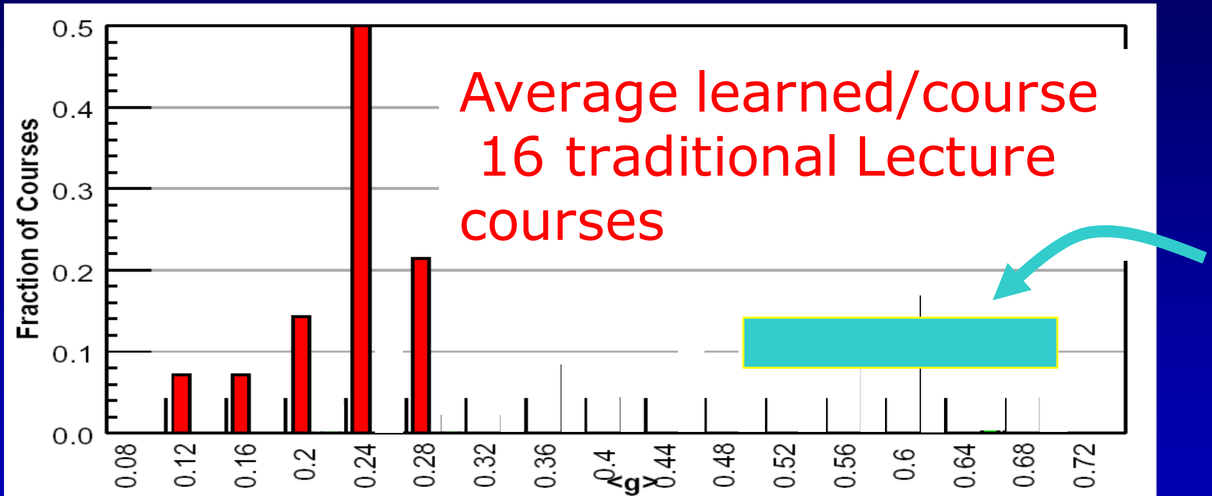


Ask at start and end of course--
Look at % of questions get wrong at beginning, but learned by end.

Data 2. Conceptual understanding in traditional course.

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

Class average, learn <30% of concepts did not already know.



new research driven approaches

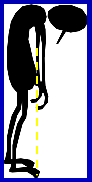
Fraction of unknown basic concepts learned

Lecturer quality, class size, institution,...doesn't matter! Similar data on higher level courses.

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

Data 3. Beliefs about physics and problem solving

Novice	**Expert**
Content: isolated pieces of information to be memorized.	**Content: coherent structure of concepts.**
Handed down by an authority. Unrelated to world.	**Describes nature, established by experiment.**
Problem solving: pattern matching to memorized recipes.	**Prob. Solving: Systematic concept-based strategies. Widely applicable.**



% shift?

nearly all intro physics courses ⇒ *more* novice

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

*adapted from D. Hammer

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?

Connecting to cog. sci.

Expert competence research

Expert competence =

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

or ?

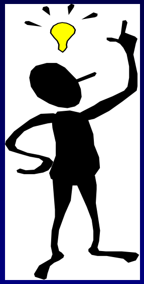
- **Ability to monitor own thinking**

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

- New ways of thinking--require extended focused mental effort to "construct".
- Built on prior thinking.

  (long-term memory development)

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.

Principle ⇒ people learn by creating **own** understanding.
Effective teaching = facilitate creation, by engaging, then monitoring & guiding thinking.
Exactly what is happening continually in research lab!

⇒ guidance for improving classroom instruction

Results when develop/copy research-based pedagogy

- Retention of information from lecture

  10% after 15 minutes $\Rightarrow$ >90 % after 2 days

- Conceptual understanding gain

  25% $\Rightarrow$ 50-70%

- Beliefs about physics and problem solving

  significant drop $\Rightarrow$ small improvement

Research guided pedagogy

Effective teaching = get them thinking, then monitor and guide thinking.

Actively engage students and guide their learning.

- Know where students are starting from.

- Get actively processing ideas, then probe and guide thinking (classroom).

- Build further with extended "effortful practice" focusing on developing expert-thinking and skills. (homework- authentic problems)

(Required to develop long term memory)

Mentally engaging, monitoring, & guiding thinking.

5-200 students at a time?!

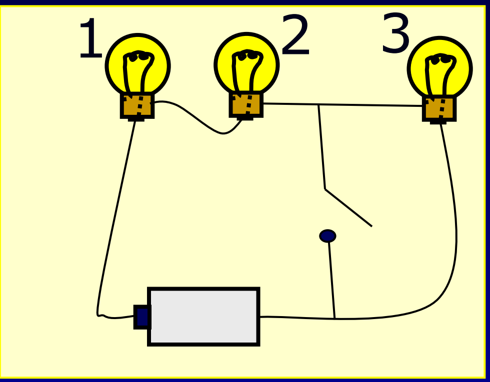
Technology that can help. *(when used properly)*

examples:

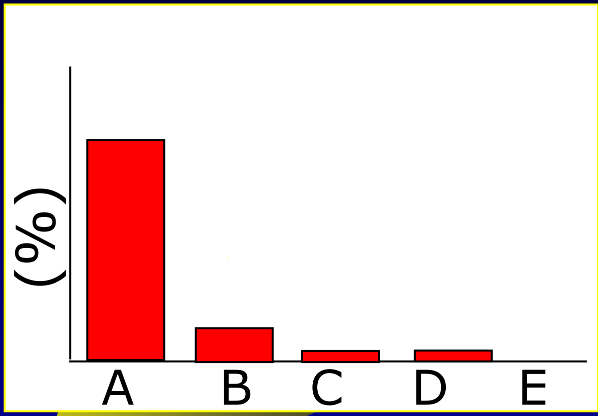
a. concept questions & "peer instruction" enhanced by student personal response systems ("clickers")

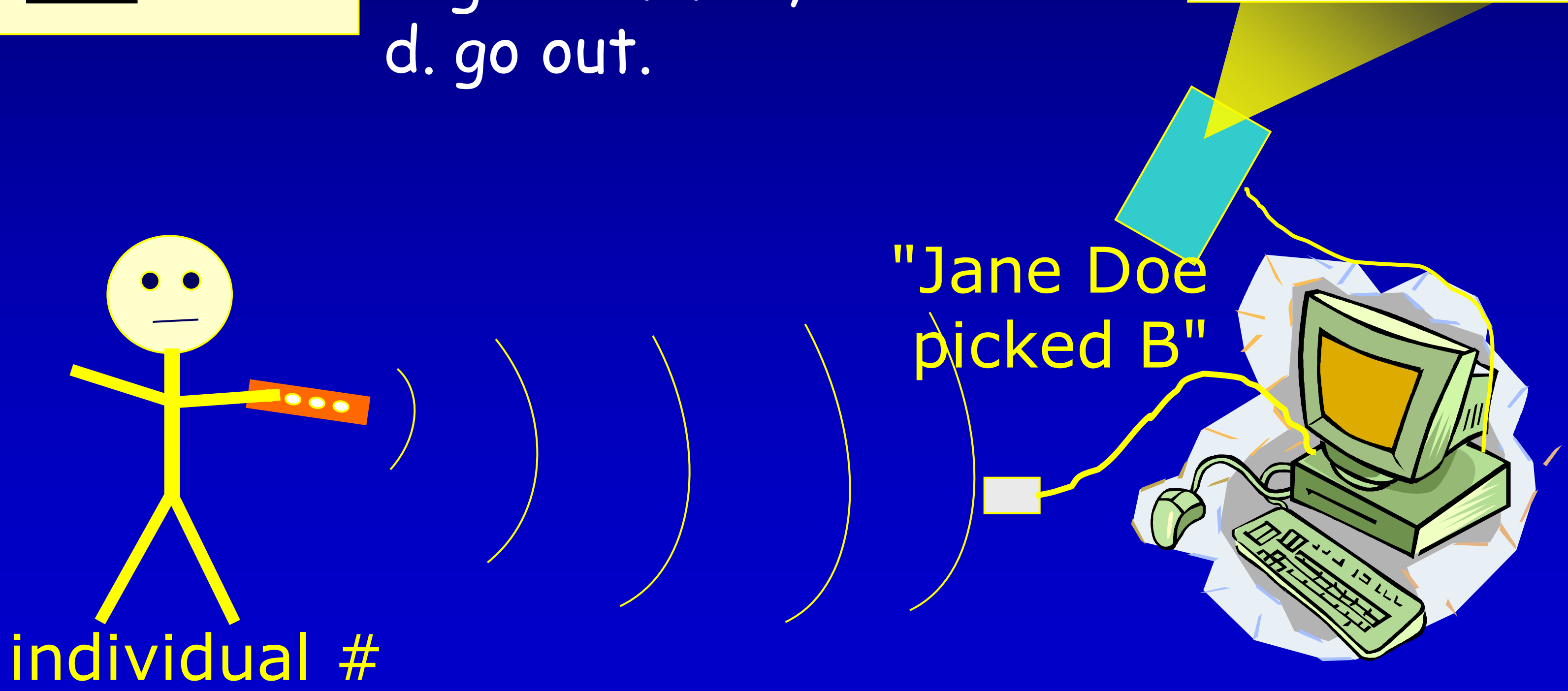
b. interactive simulations

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--
Only provides:
accountability + peer anonymity+ fast response

Used/perceived to enhance student mental engagement and feedback ⇒ transformative

Use guided by research on learning
•challenging conceptual questions
•student-student discussion ("peer instruction") & responses
•follow up discussion

b. Interactive simulations

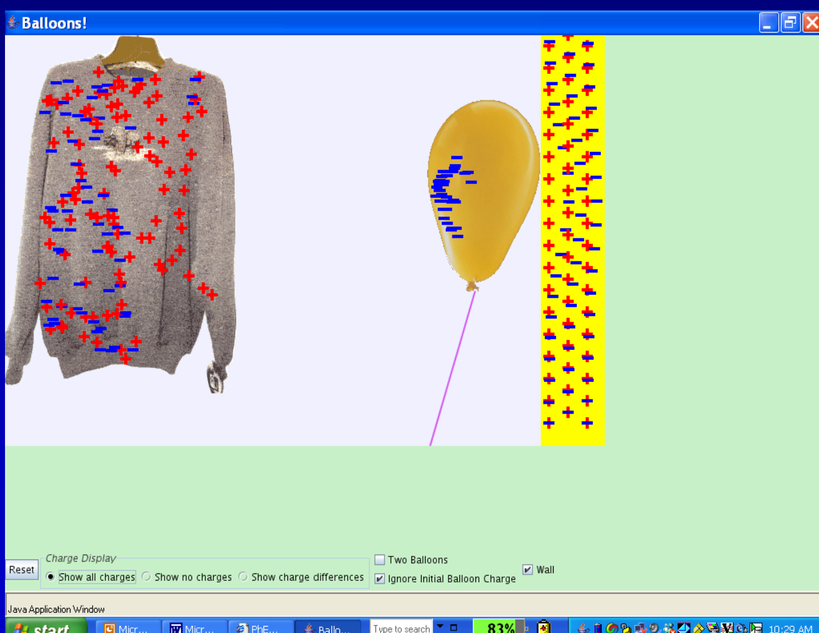
phet.colorado.edu

Physics Education Technology Project (PhET)

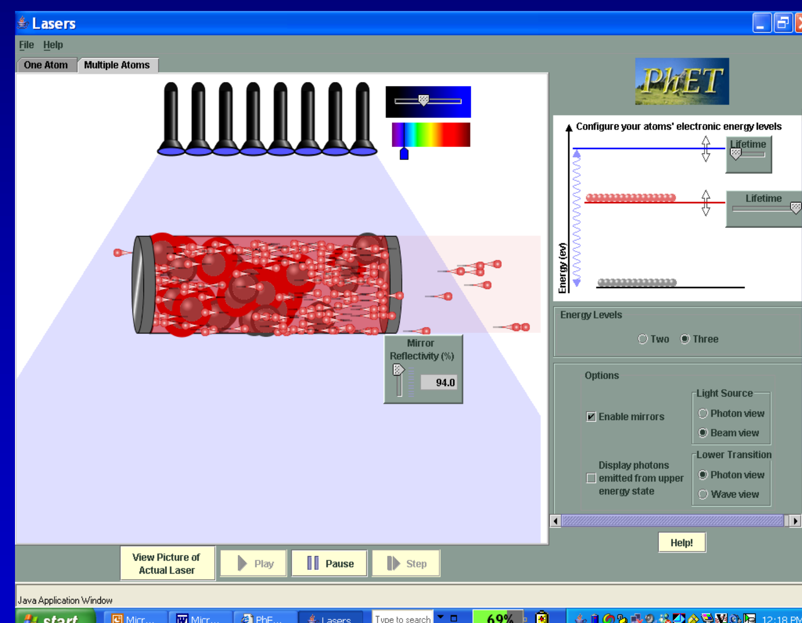
>65 simulations

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
moving man
circuit construction kit

new feature- very easy to translate into Swedish

data on effectiveness- many different settings and types of use

Simulation testing $\Rightarrow$ educational research microcosm.
Consistently observe:

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

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

Actively trying to figure out + with feedback
$\Rightarrow$ mastery.

build into simulations and test that work

IV. What am I doing at UBC?

Widespread improvement in science education

- University Departments -- widespread sustained change $\Rightarrow$scientific approach to teaching, all undergrad courses

- Focused $$$ and guidance

All materials, assessment tools, references etc available on web

CWSEI.ubc.ca

Summary:

Need new, more effective approach to science ed.

Solution: Approach teaching as we do science

- Practices based on good data
- Utilize research on how people learn
- Disseminate results & copy what works
- Utilize modern technology

and teaching is more fun!

Good Refs.:

CWSEI.UBC.CA

NAS Press "How people learn"

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

Handelsman, et al. "Scientific Teaching"

Wieman, Change Magazine- Oct. 07 (~ this talk)

Wieman and Perkins, Physics Today (Nov. 2005)

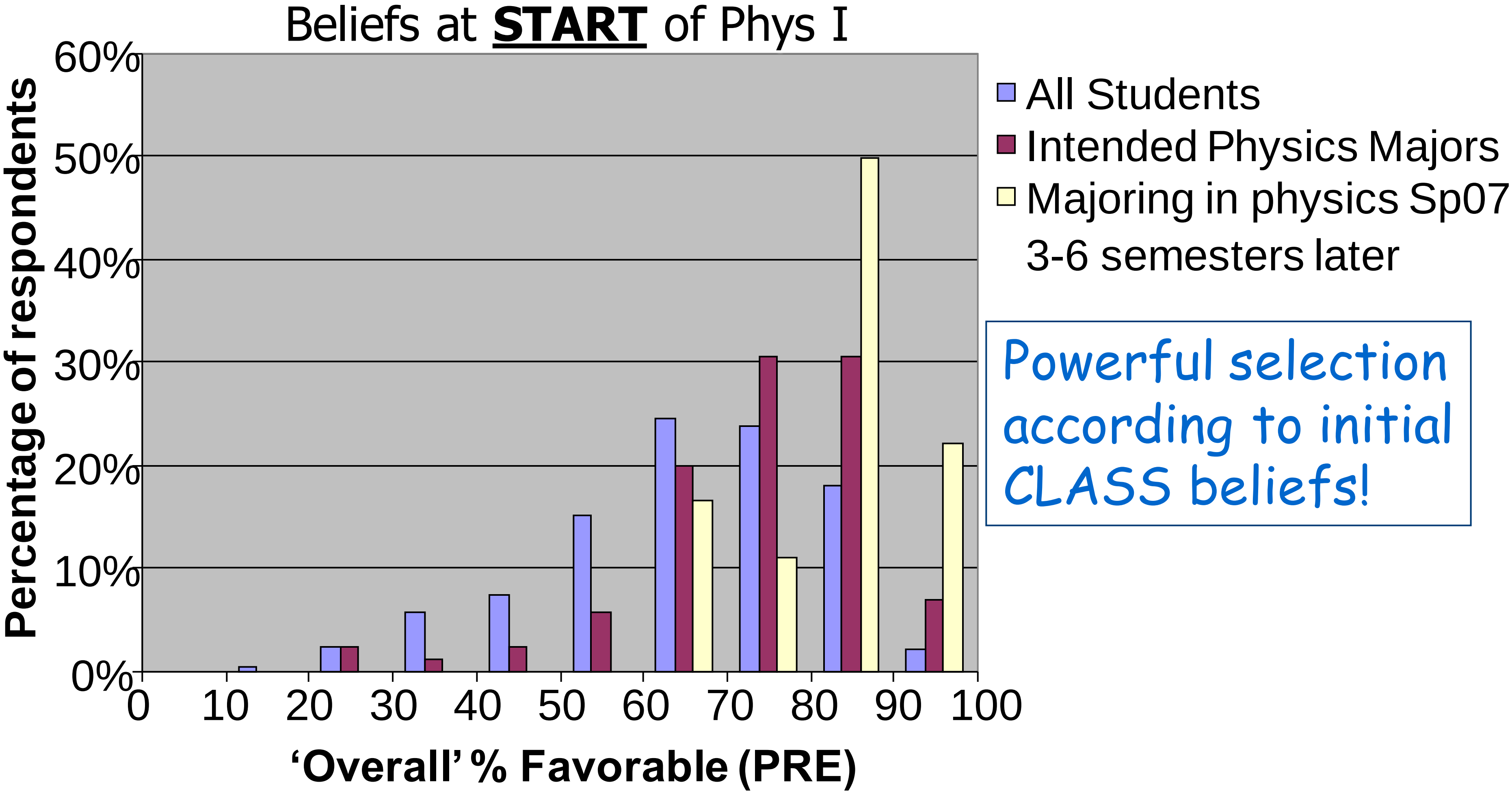
CLASS belief survey: CLASS.colorado.edu

phet simulations: phet.colorado.edu

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!

IV. What am I doing at UBC?

Widespread improvement in science education (start at university undergraduate)

Carl Wieman Science Education Initiative *(CWSEI.ubc.ca)*

- Departmental level, widespread sustained change

⇒scientific approach to teaching, all undergrad courses

- 5 departments, selected competitively
- Focused $$$ and guidance

All materials, assessment tools, etc available on web

Visitors program

effective clicker use-

- challenging concept questions
- peer instruction
- follow up discussion
- minimal but nonzero grade impact

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

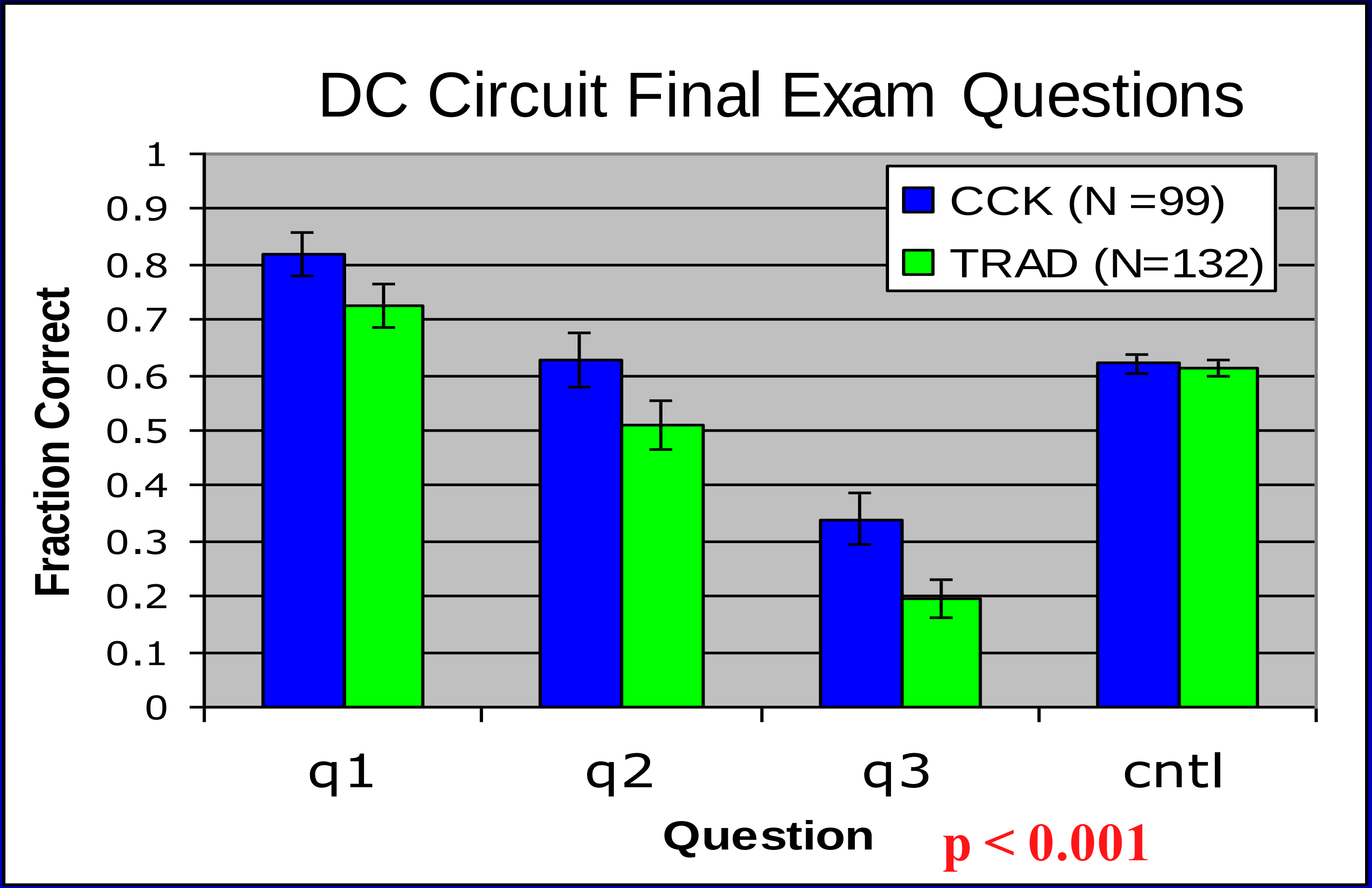
Student-student discussion (*consensus groups*) & enhanced student-instructor communication

⇒ rapid + targeted = effective feedback.

Standard Laboratory

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

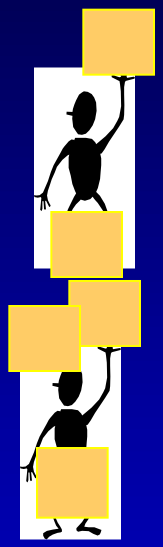
Simulation vs. Real Equipment

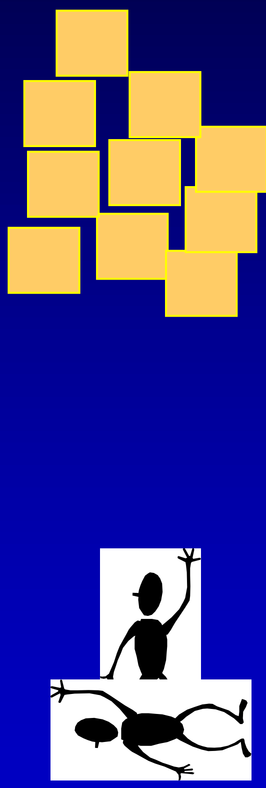


N D. Finkelstein, et al, "When learning about the real world is better done virtually: a study of substituting computer simulations for laboratory equipment," *PhysRev: ST PER 010103 (Sept 2005)*

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

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



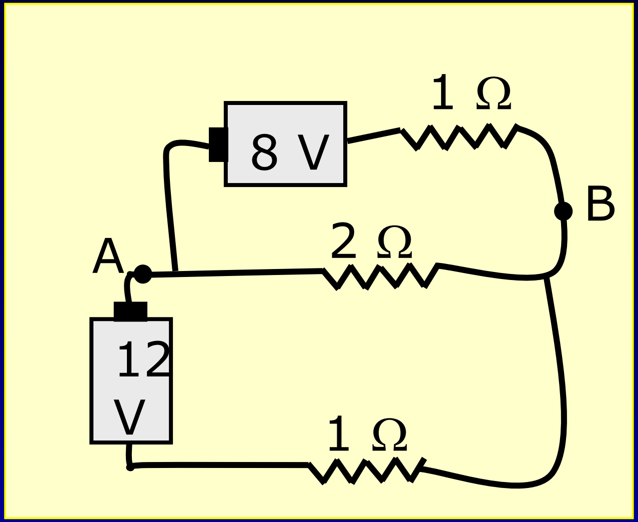


Data 2. Conceptual understanding in traditional course

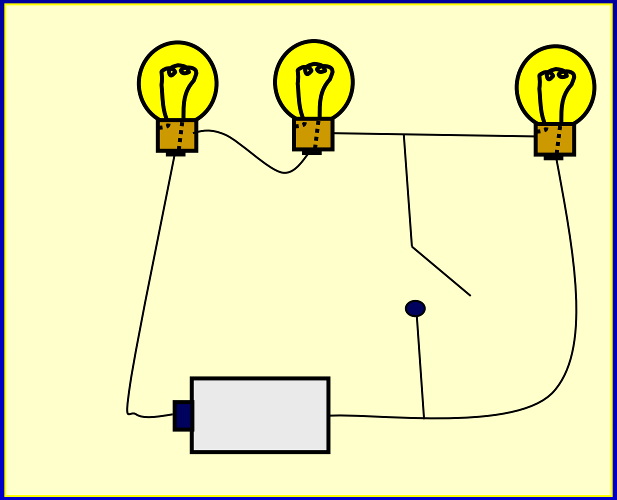
electricity

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.

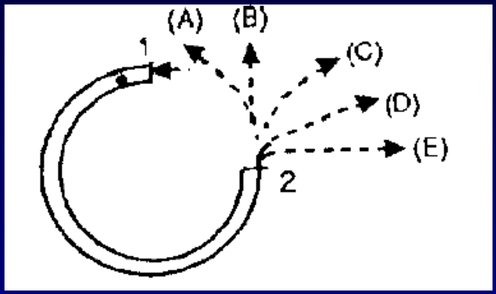
Challenges in changing science department cultures--

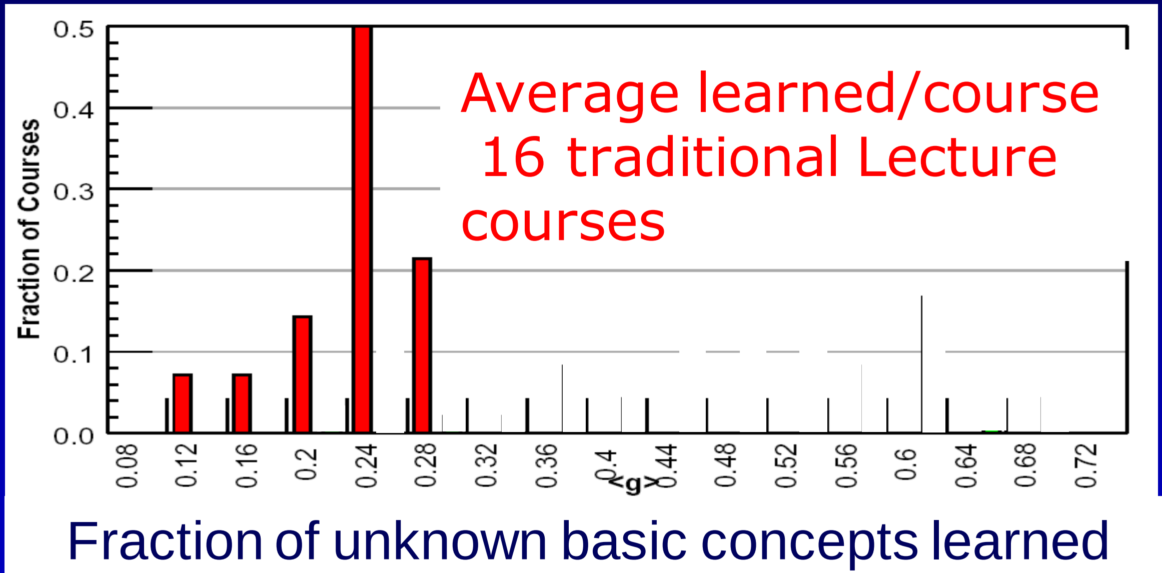
- no coupling between support/incentives and student learning.
- very few authentic assessments of student learning
- investment required for development of assessment tools, pedagogically effective materials, supporting technology, training
- no $$$ *(not considered important)*

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)





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