Science Education for the 21st Century

Using the insights of science to teach/learn science

Carl Wieman UBC & CU

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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, Hewlett)

The Vision

Guided by research on learning
All students much better educated.
$\Rightarrow$ many benefits to society.

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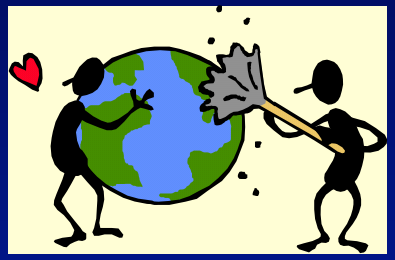
Scientifically literate public



Modern economy

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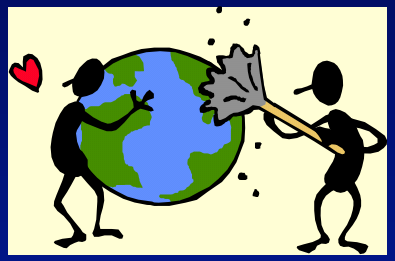

Modern economy

Teaching more effective and more efficient and rewarding for the teacher.

How to achieve?

I. 2 models for teaching.

II. Research on science learning
   a. Components of scientific expertise
   b. Measuring development of expertise
   c. Effective teaching and learning

Science teaching Model 1 (I used for many years)

think hard, figure out subject

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tell students how to understand it

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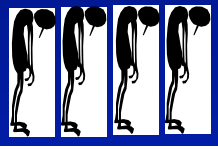

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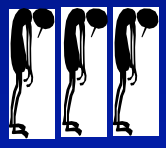

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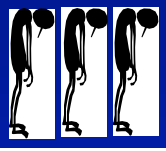

students lazy or poorly prepared

tell again

Louder

Model 1 (*figure out and tell*) Strengths & Weaknesses

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Works well for basic knowledge, prepared brain:

bad, avoid

good, seek

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Easy to test. ⇒ Effective feedback on results.

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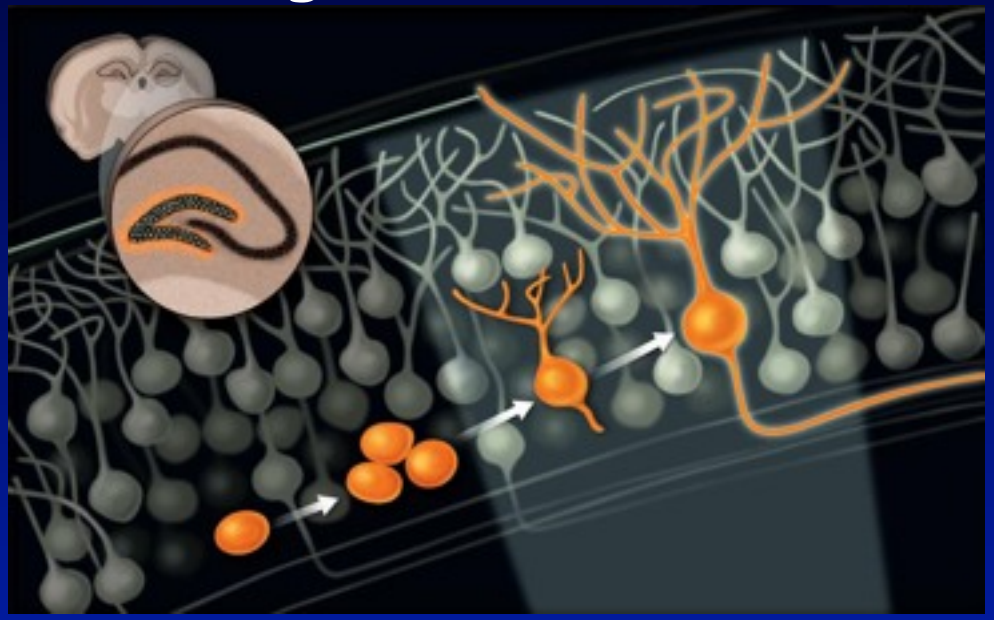
Complex learning-- different.

Significantly changing the brain, not just adding bits of knowledge.



Growing neurons & building proteins ⇒ enhance neuron connections, ...

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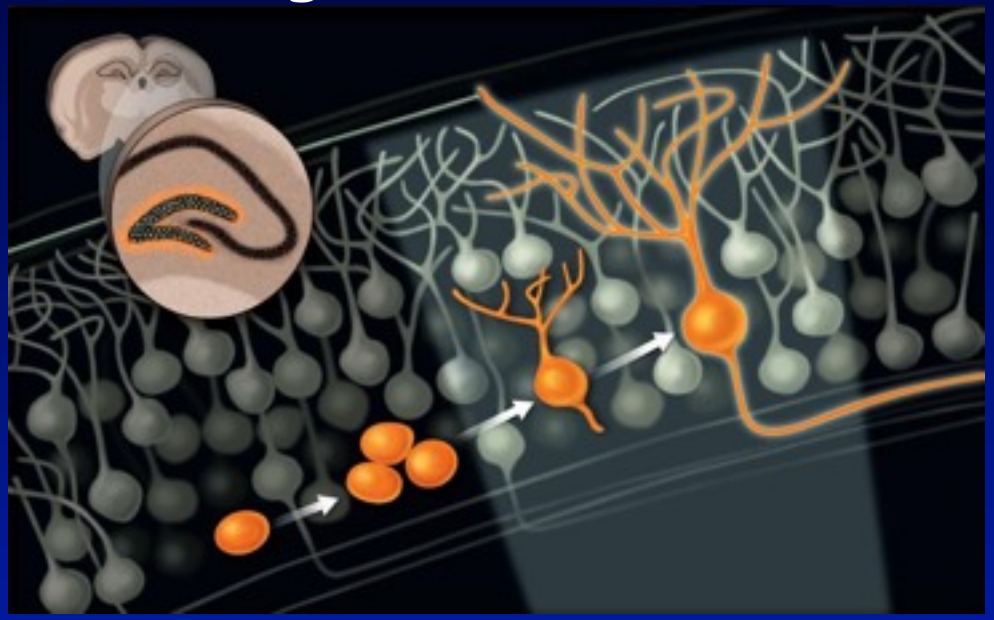

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How to teach and measure this complex learning?

Model 2 --scientific approach to science education

Methods based on careful measurements of desired expert performance.

Guided by research on learning.

Experiment & iterate until achieve desired result.

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⇒**New opportunities for improving teaching.**

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

classroom studies

brain research

cognitive psychology

Model 2-- scientific approach

What has been learned?

1. Identifying components of expertise *(thinking scientifically*), and how expertise is developed.

2. How to measure components of science expertise. *(and what traditional exams have been missing)*

3. Components of effective teaching and learning.

Expert competence research*

historians, scientists, chess players, software engineers,...

Expert competence =

*Cambridge Handbook on Expertise and Expert Performance

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- factual knowledge

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- Organizational framework ⇒ effective retrieval and application

or ?

patterns, associations, scientific concepts

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

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

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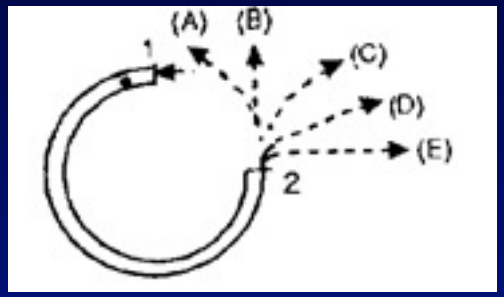
Measuring conceptual mastery

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



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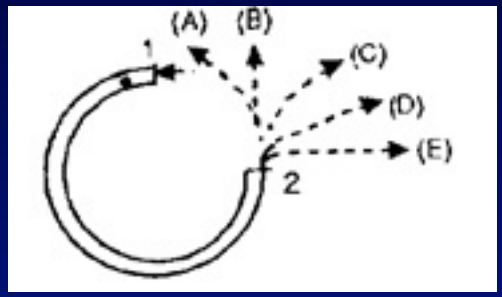
Ask at start and end of semester--
What % learned? (100's of courses)



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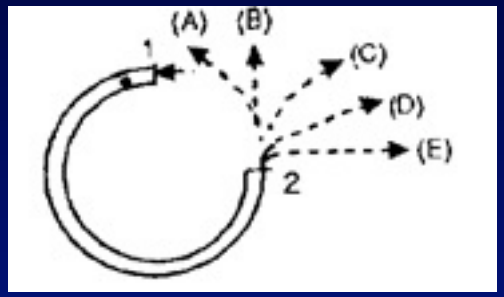

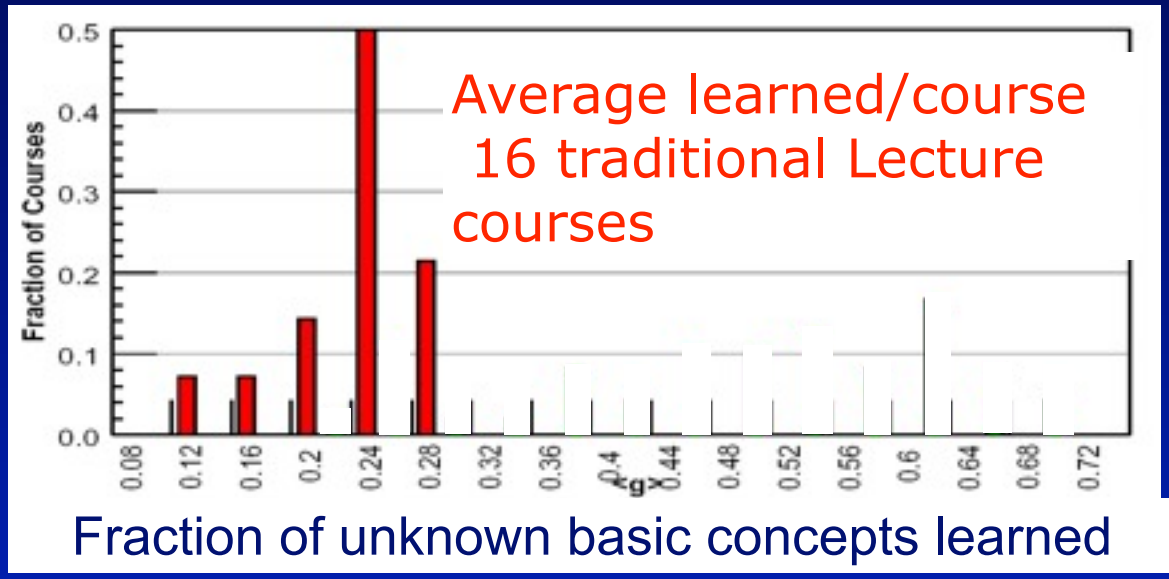

On average learn <30% of concepts did not already know.
Lecturer quality, class size, institution,...doesn't matter!
Similar data for conceptual learning in other courses.

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

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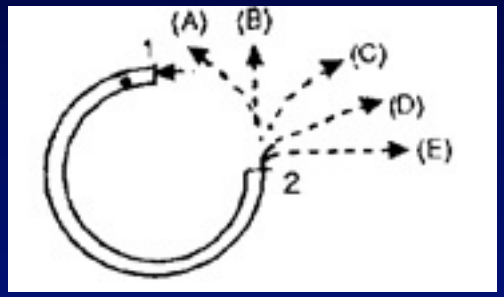

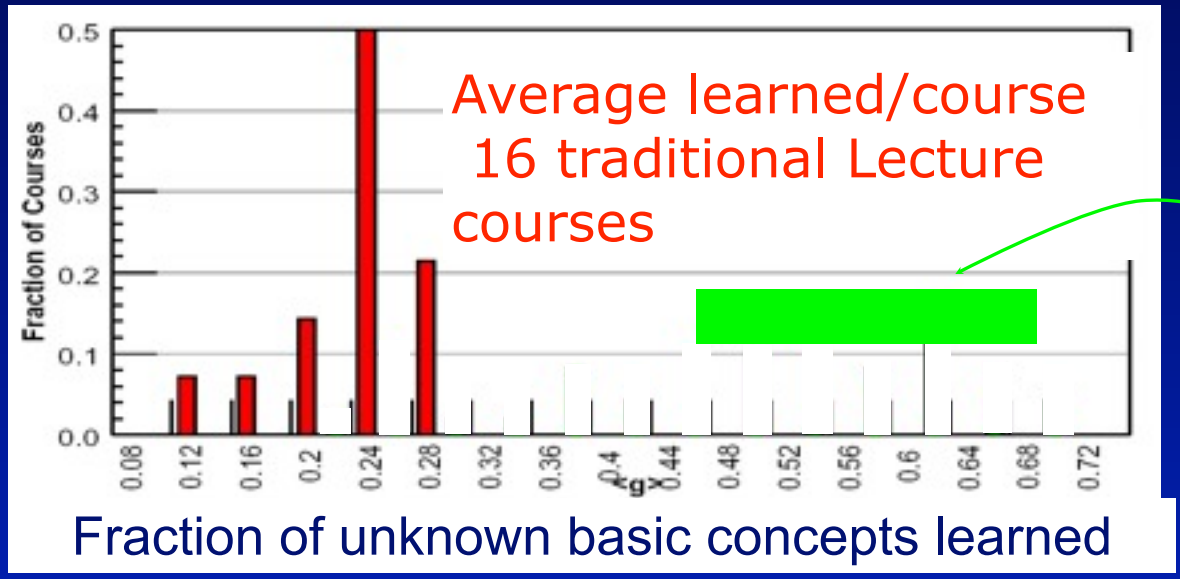

improved methods

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success in courses ≠ thinking like expert

Perceptions about subject

highly relevant to:

- interest/recruitment
- retention in major
- attracting under-represented groups
- public literacy

- Experts in a science have unique perception

Novice **Expert**

*adapted from D. Hammer

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understand why, how to change

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Model 2-- scientific approach

What has been learned?

1. Identifying components of expertise, and how expertise developed.

2. How to measure components of science expertise. *(and what traditional exams have been missing)*

⇒**3. Components of effective teaching and learning.**

Components of effective learning/teaching

apply to all levels, all settings, all subjects

1. Motivation *(essential & often neglected)*

2. Connect with and build on prior thinking

*3. Apply what is known about memory

*4. Explicit authentic practice of expert thinking.
Extended & strenuous
(brain development like muscle development)

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Research provides guidance on all.
Today just those with *.

Principle + example application

Components of effective teaching/learning

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1. Motivation

2. Connect with and build on prior thinking

3. Apply what is known about memory
   a. achieving long term retention
   b. short term limitations

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a. Long term memory retention

(R. Bjork-- accessible summaries of research)

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⇒ encourages cramming for exams.
Maximizes performance on exam,
but terrible long term retention.

b. Limits on working memory--best established, most ignored result from cognitive science

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

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MUCH less than in typical science lecture

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⇒ processing and retention from lecture tiny

(for novice)

repeatedly shown in research

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Also true in technical talks!

“Curse of knowledge” common teaching mistake

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step 1-- teach all the pieces of background knowledge and math procedures.

step 2-- give problem and show how pieces are put together to solve.

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Better Approach:

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step 2-- bring in facts and procedures as parts of solution.

Reduces working memory demands & more motivating.

Builds expert connections and mental framework.

Components of effective teaching/learning

apply to all levels, all settings

1. Motivation

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3. Apply what is known about memory

4. Explicit authentic practice of expert thinking. Extended & strenuous
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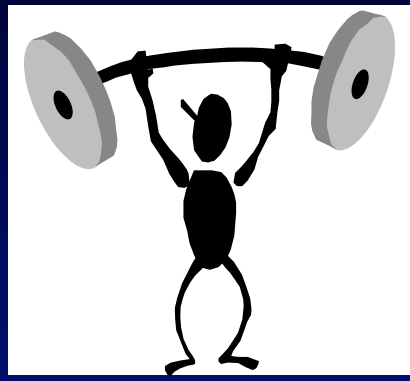
Practicing expert-like **thinking--**



Challenging but doable tasks/questions

Explicit focus on expert-like thinking

- concepts and mental models

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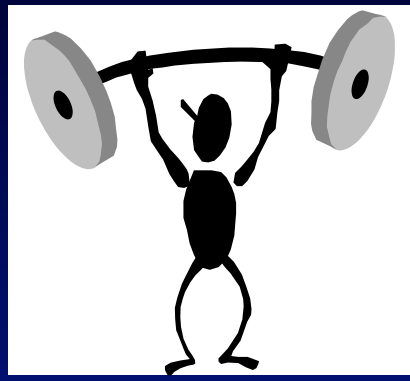

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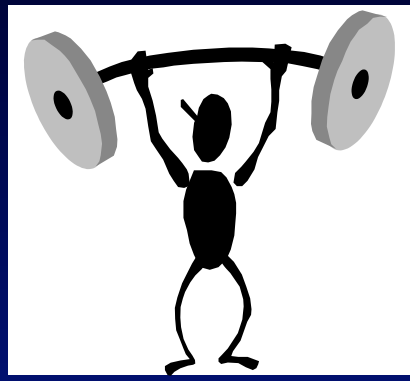

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- self-checking, sense making, & reflection

Teacher provide effective feedback (timely and specific)

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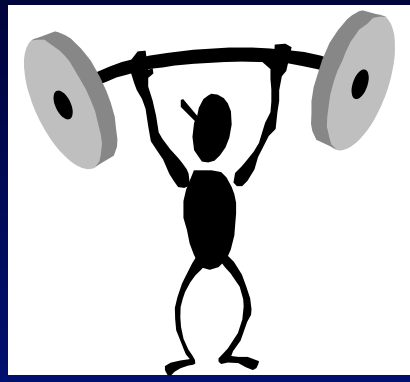

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Research shows time and effort not enough-- need to know <u>what and how</u> to practice.

Components of expertise-- software design

Sonnentag, et al, Chap. 21,
Cambridge Handbook of Expertise

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Two conspicuously missing from most CS teaching:

- Debugging and testing
- Communication and collaboration

How to actually do in class?
Hundreds of students???

use technology to help

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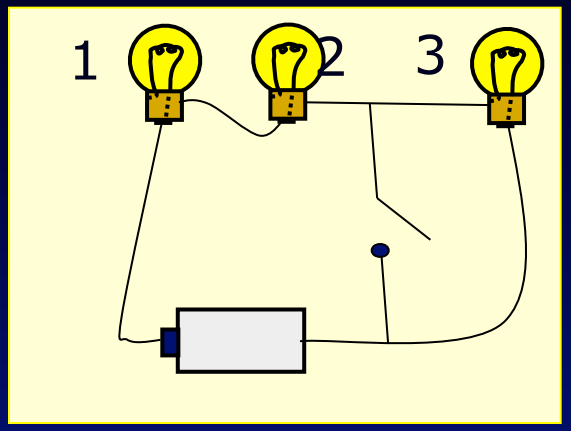
Example from a class--practicing expert thinking with effective guidance/feedback

1. Assignment--Read chapter on electric current. Learn basic facts and terminology. Short quiz to check/reward.

2. Class built around series of questions.



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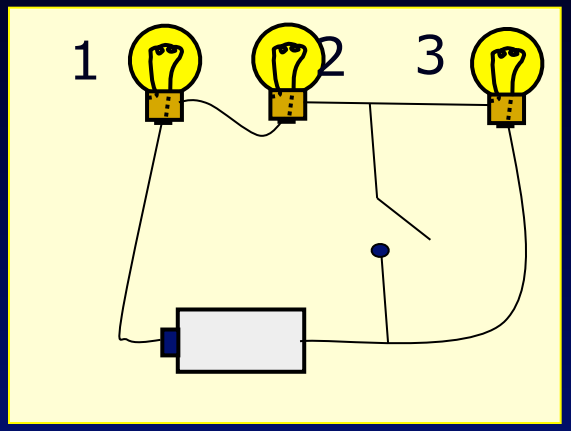
a. stay same brightness,

b. get brighter

c. get dimmer,

d. go out.



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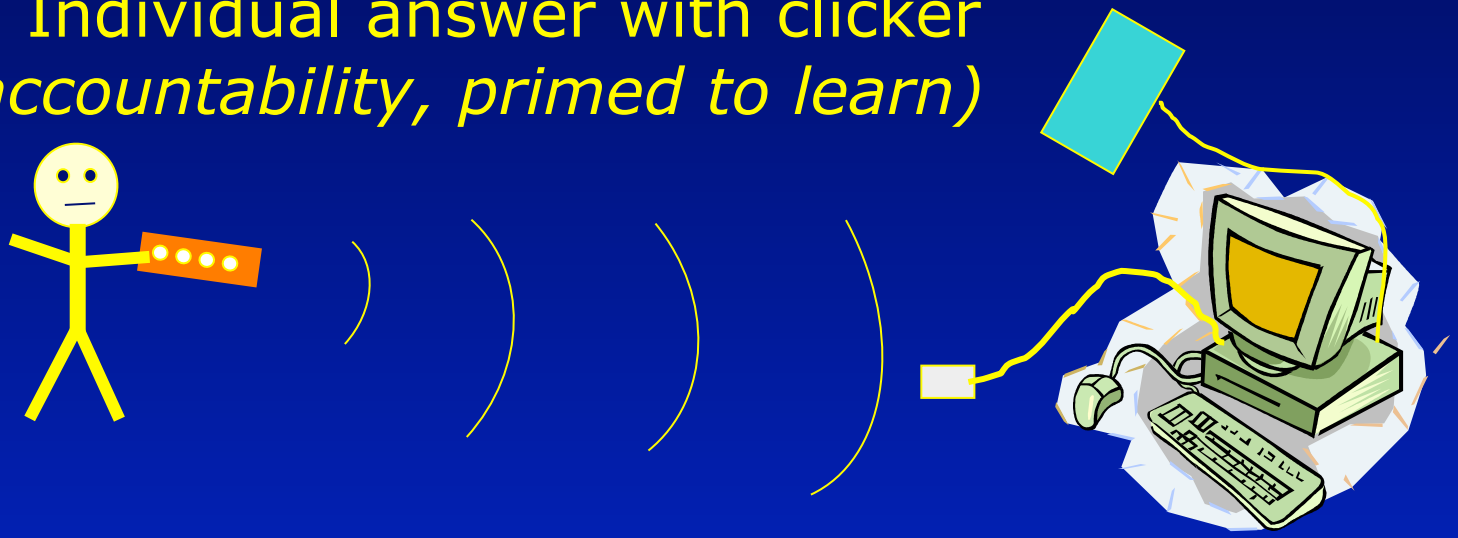
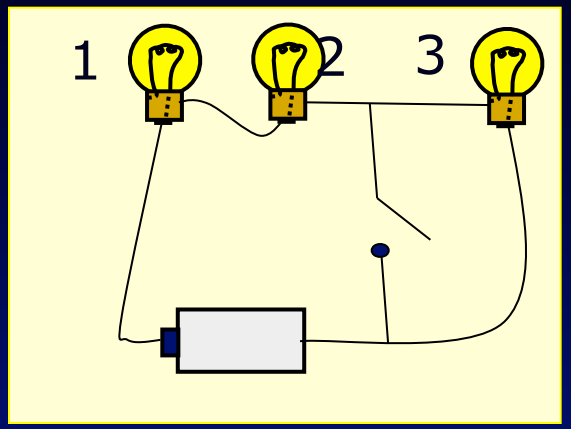
3. Individual answer with clicker *(accountability, primed to learn)*





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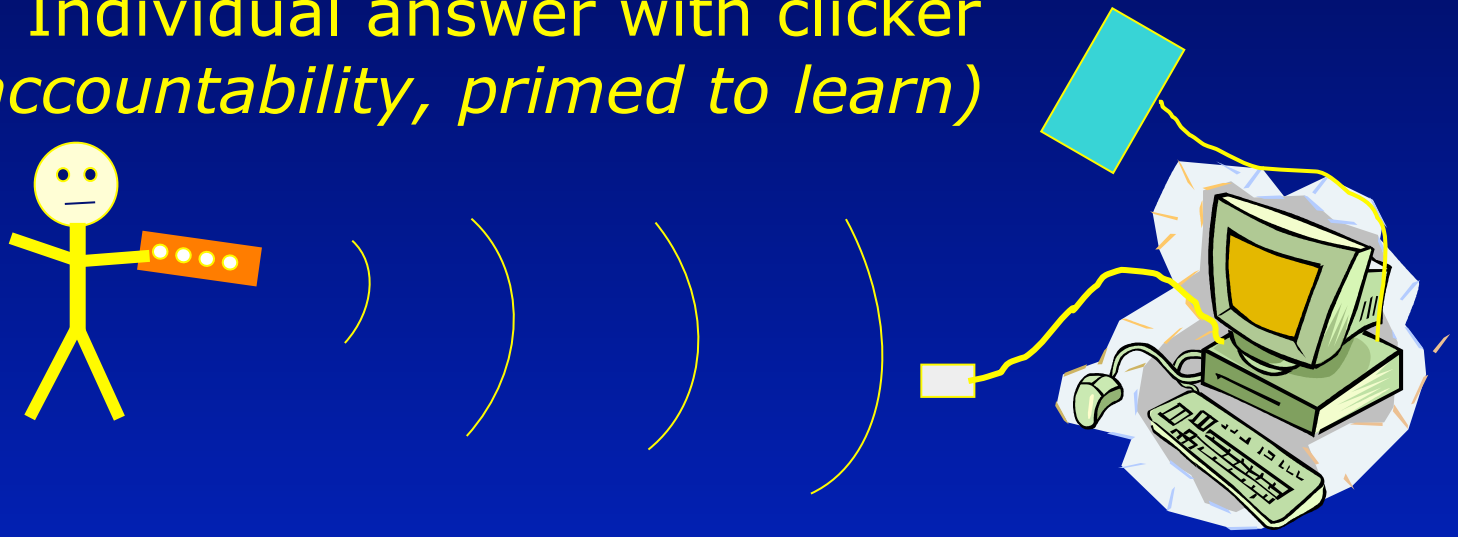

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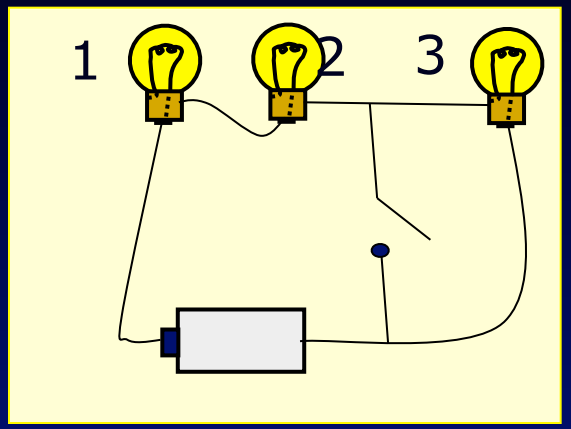

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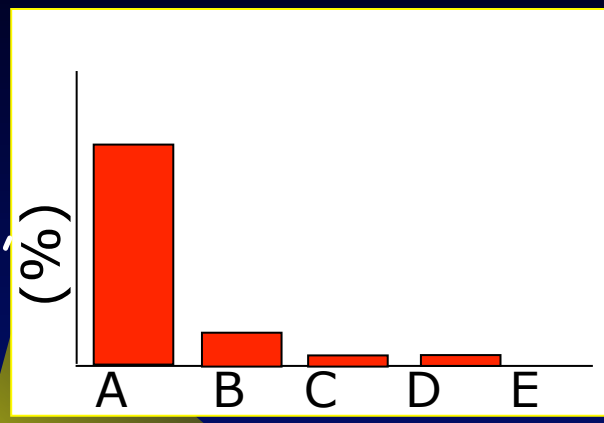

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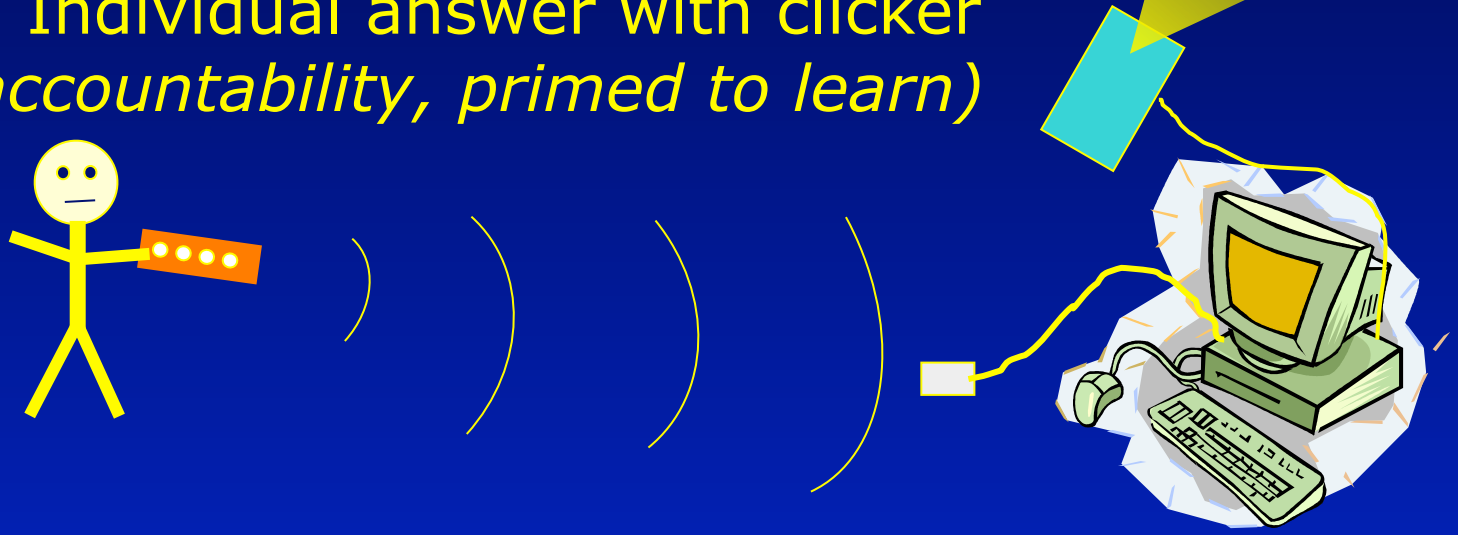

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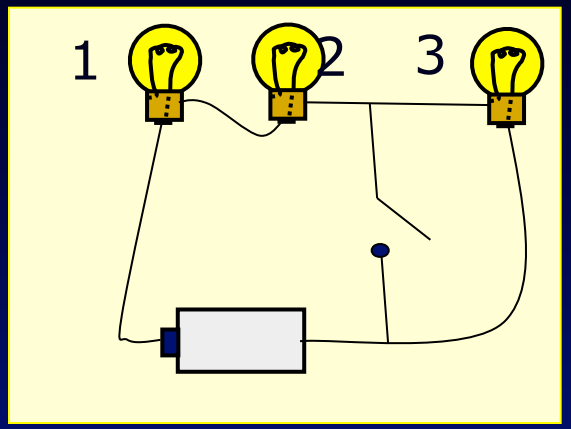

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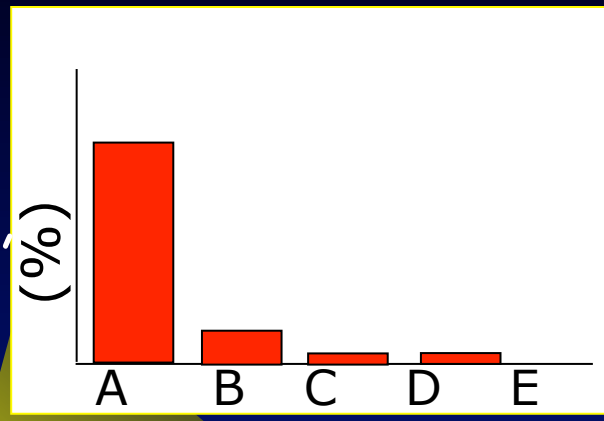

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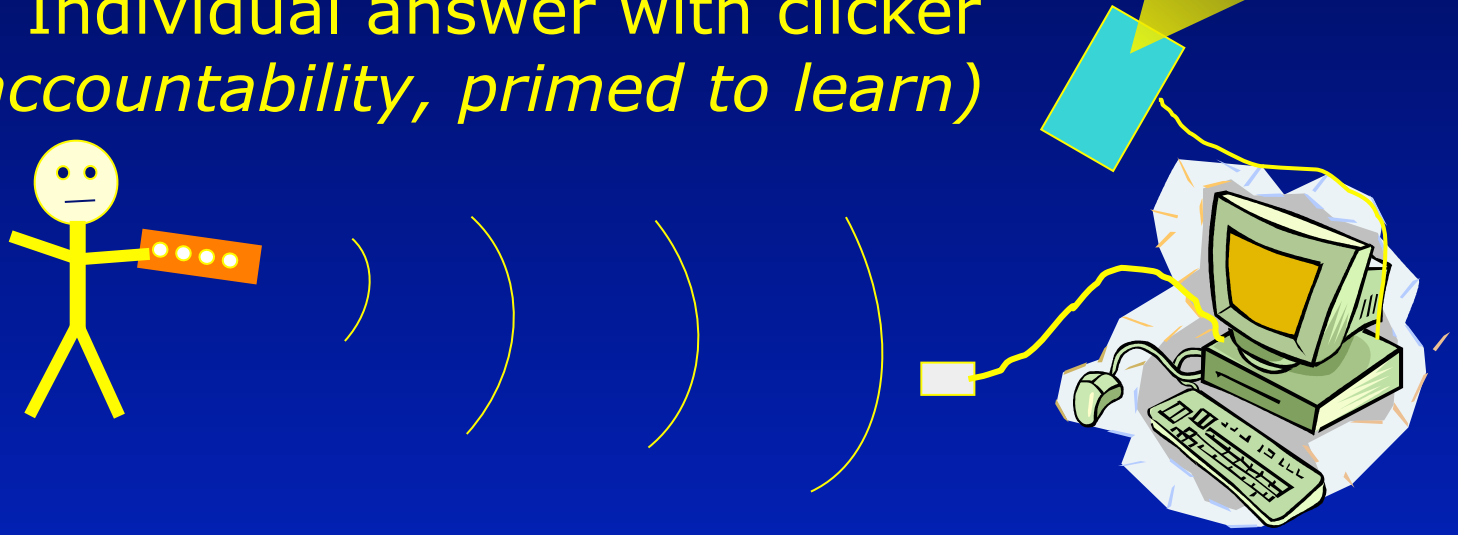

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Do "experiment."-- simulation.

Follow up instructor discussion--
review correct and incorrect thinking, extend ideas.
Respond to student questions & suggestions.
(additional student learning)

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review correct and incorrect thinking, extend ideas.
Respond to student questions & suggestions.
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Example 2. 10 minute in-class activity.
" Divide into groups of 3 and create algorithm (or code) that will accomplish this task...
Write down on piece of paper to share and discuss.
Include how to test that it is correct."

How practicing expert thinking--

Challenging but doable question
(difficult concept, prior thinking)

Explicit focus on expert-like thinking

- actively developing concepts and mental models

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Getting timely and specific feedback

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- actively developing concepts and mental models
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- self-checking, sense making, & reflection

Getting timely and specific feedback
(peers, clicker histogram, instructor)

Highly engaged-- "exercising" brain in optimum way

good start, but not enough time in class!

further practice-- well designed homework

good start, but not enough time in class!

further practice-- well designed homework
Require expert thinking & feedback,

$\Rightarrow$ true expertise

Some Data (from science classrooms):

Model 1 (telling) traditional lecture method	scientific teaching

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improve for future nonscientists and scientists

Summary:
Scientific model for science education

Much more effective. (and more fun)

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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
cwsei.ubc.ca-- resources, Guide to effective use of clickers

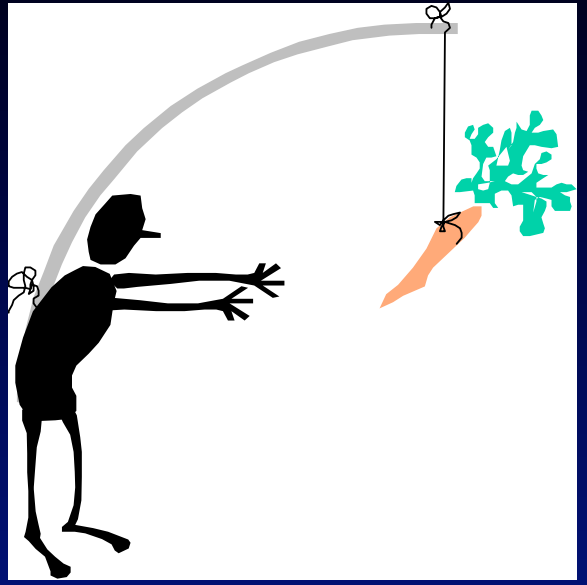
- extra unused slides below

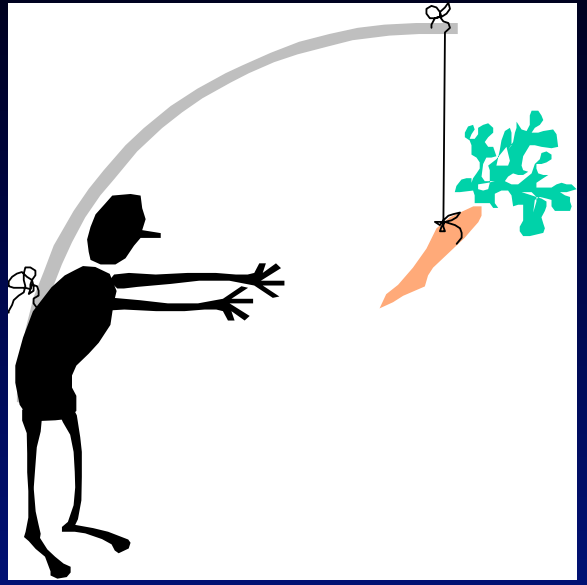
How to get into every classroom?

Motivation-- essential

(complex- depends on previous experiences, ...)

Enhancing motivation to learn





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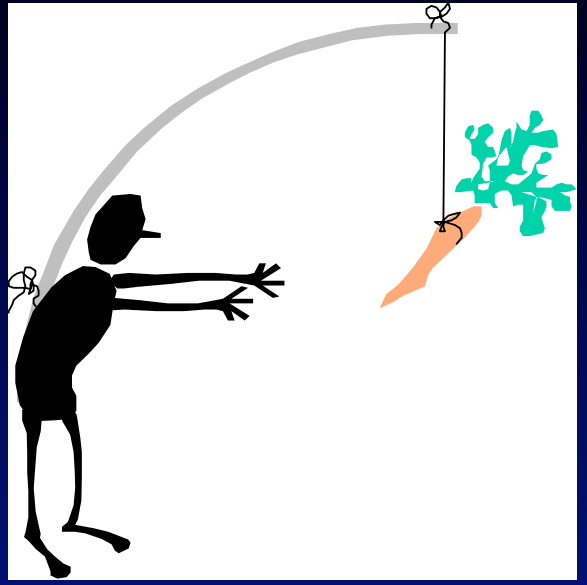

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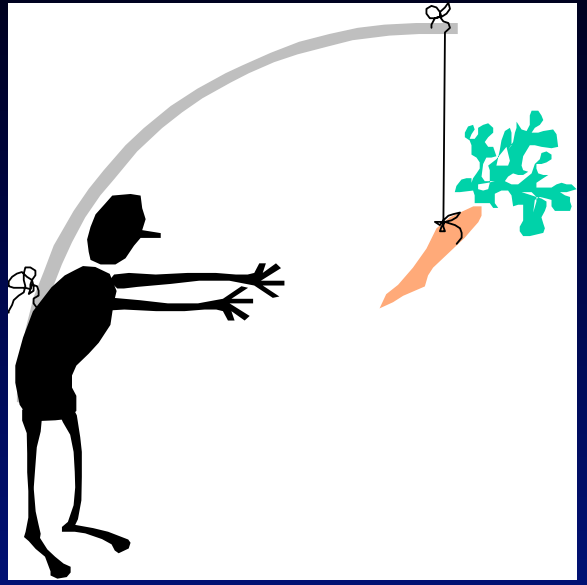

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b. Sense that can master subject and how to master

c. Sense of personal control/choice

UBC CW Science Education Initiative and U. Col. SEI

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

Science teaching Model 2.

Goals. What students will be able to do. (solve, design, analyze, capacity to learn,...)

Create activities and feedback targeting desired expertise.

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wrong treatment

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modify

Is model for ***doing*** science

Goals. Question to be answered.
What data will answer it.

prior research

prior research

Design and build experiment.

Run and measure results.

modify

yes

done

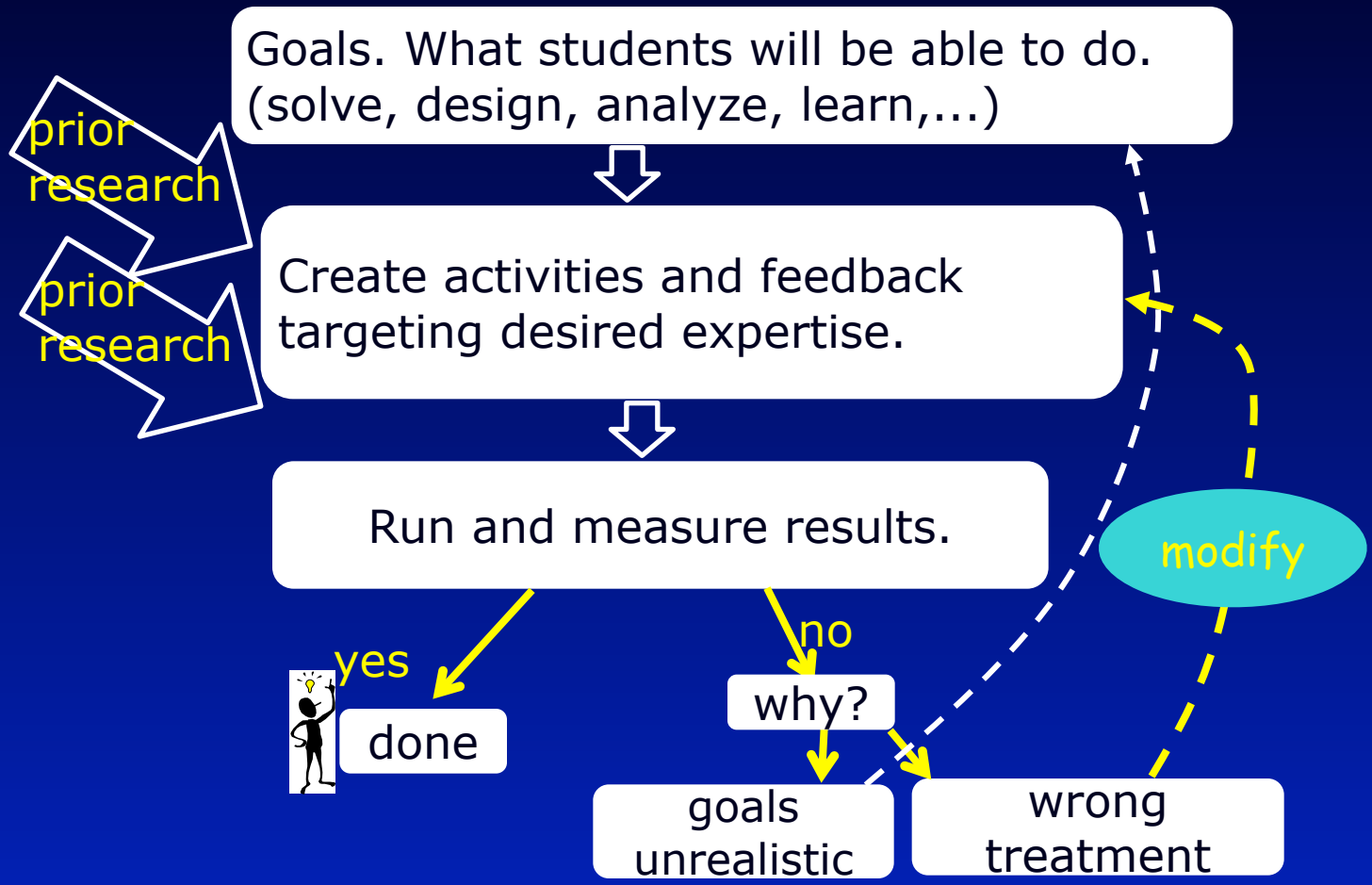
no

why?

goals unrealistic

wrong experiment

Model 2 --scientific approach to science education



⇒New opportunities for improving teaching.

Measuring student perceptions about science

Novice → **Expert**

Survey instruments--

MPEX--1st yr physics, CLASS--physics, chem, bio tests

*adapted from D. Hammer

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~40 statements, strongly agree to strongly disagree--

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Intro Chemistry and biology just as bad!

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

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

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how to cover as much material?
transfer information gathering outside of class

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

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- Departments selected competitively
- Substantial one-time $$$ and guidance

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

Characteristics of expert tutors*

(Which can be duplicated in classroom?)

*Lepper and Woolverton pg 135 in Improving Academic Perfomance

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

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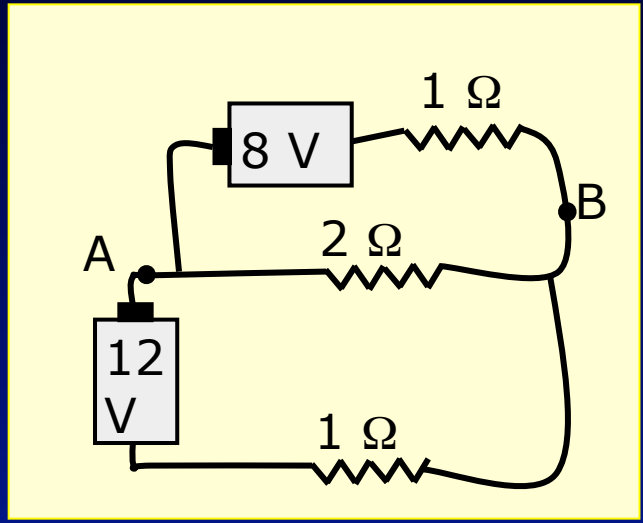
Why is this worth learning?
How does it connect to real world?
How connects to things student knows/makes sense?

Data 2. Conceptual understanding in traditional course

electricity

Eric Mazur (Harvard Univ.)

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



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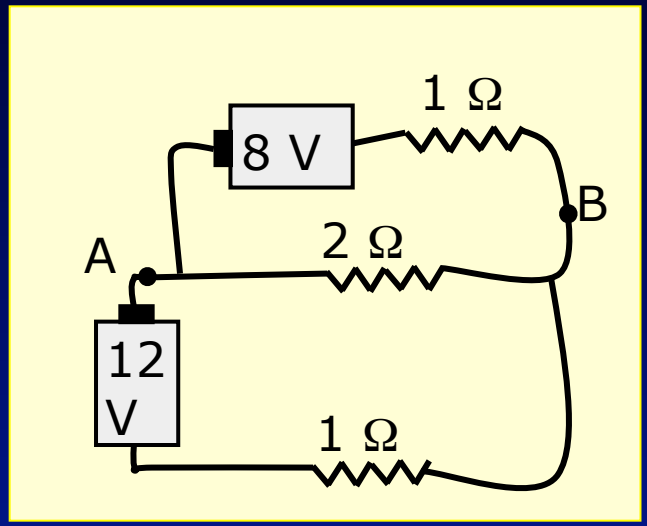

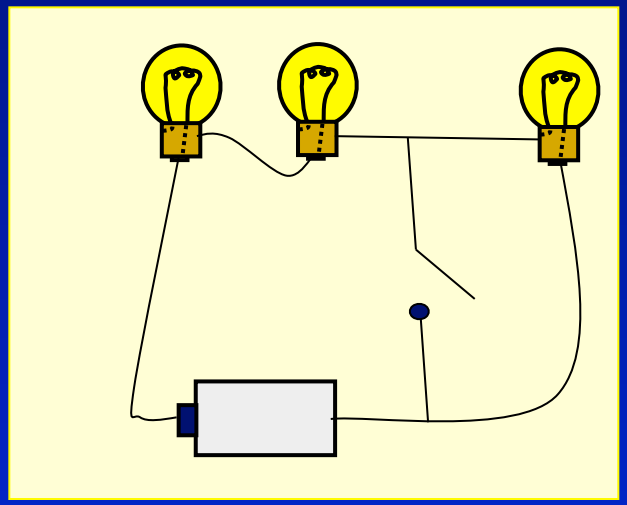

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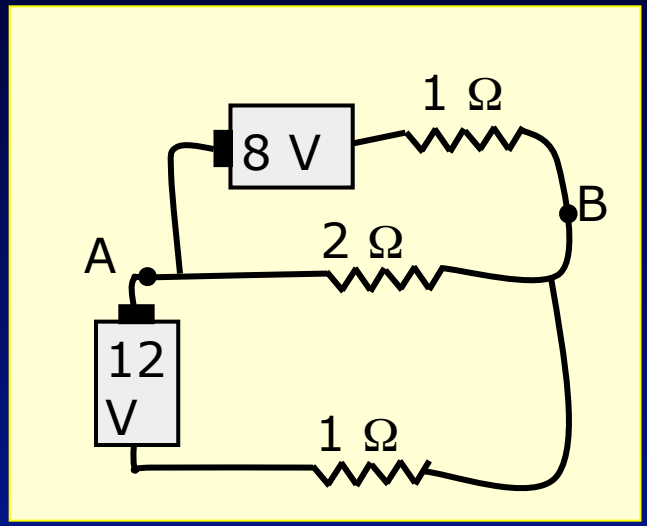
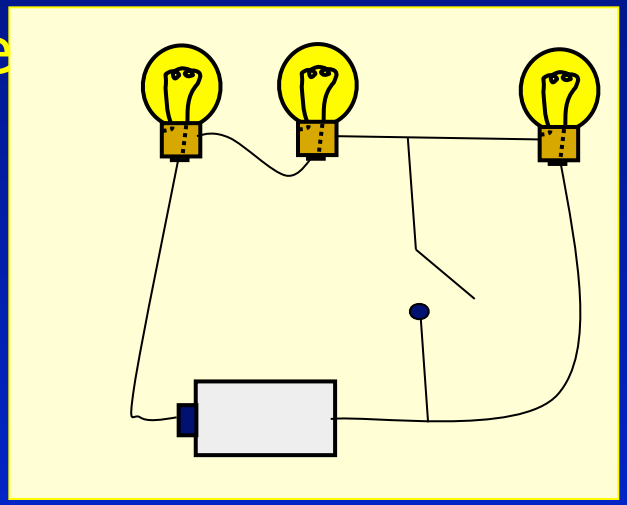


only 40% correctly predict change in brightness of bulbs when switch closed!



Developing expertise-- transforming brain

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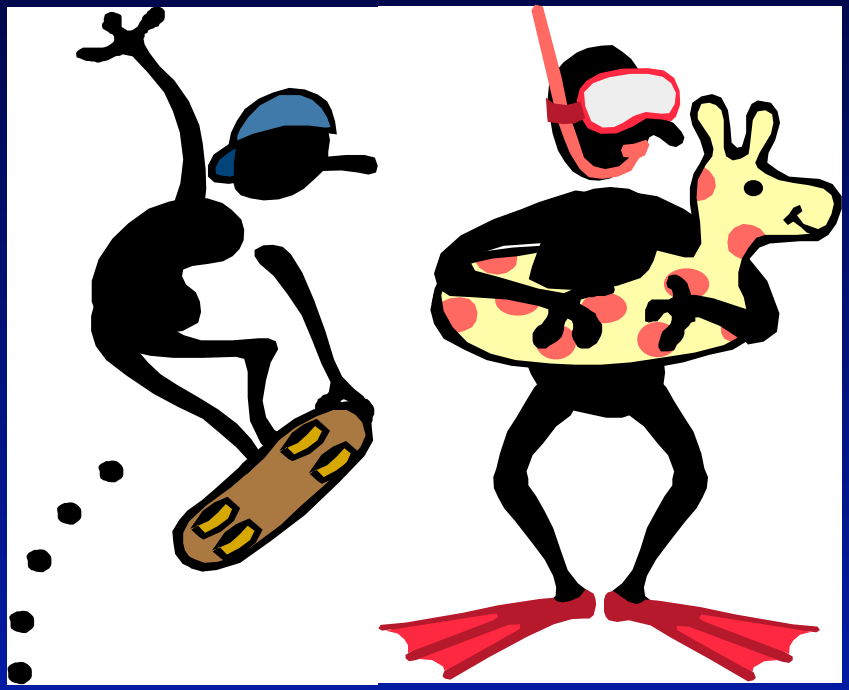

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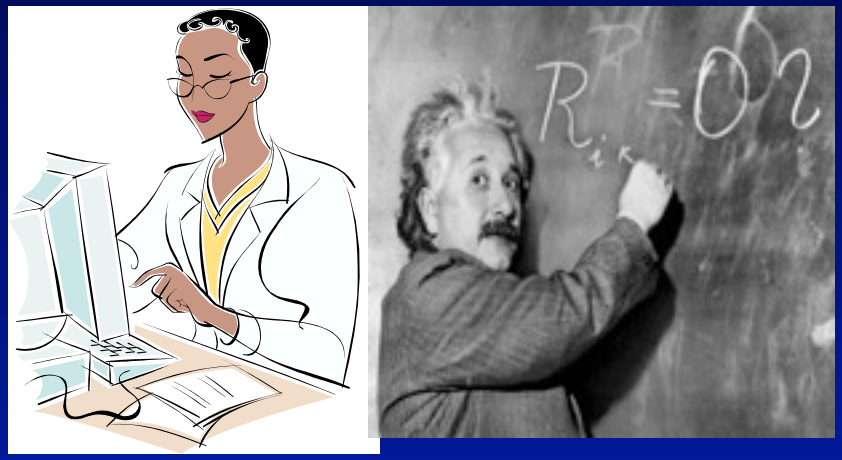

Think about and use science like a scientist.

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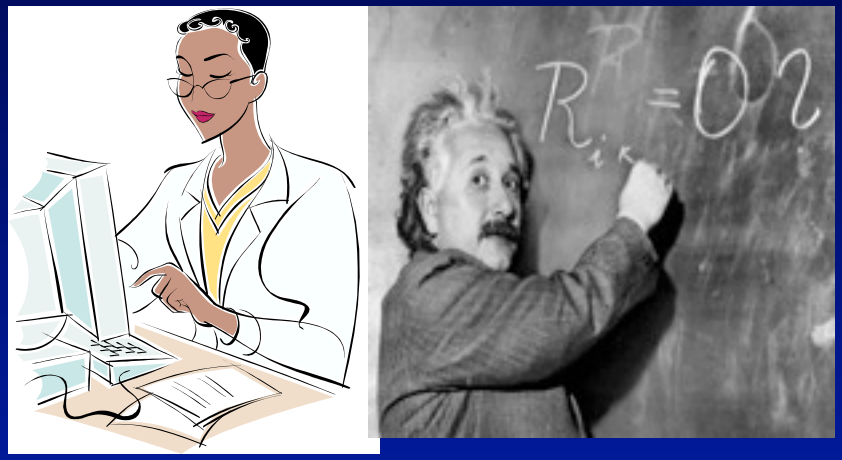

Think about and use science like a scientist.

What does that mean?
How is it accomplished?