Identifying, measuring, and teaching physics expertise

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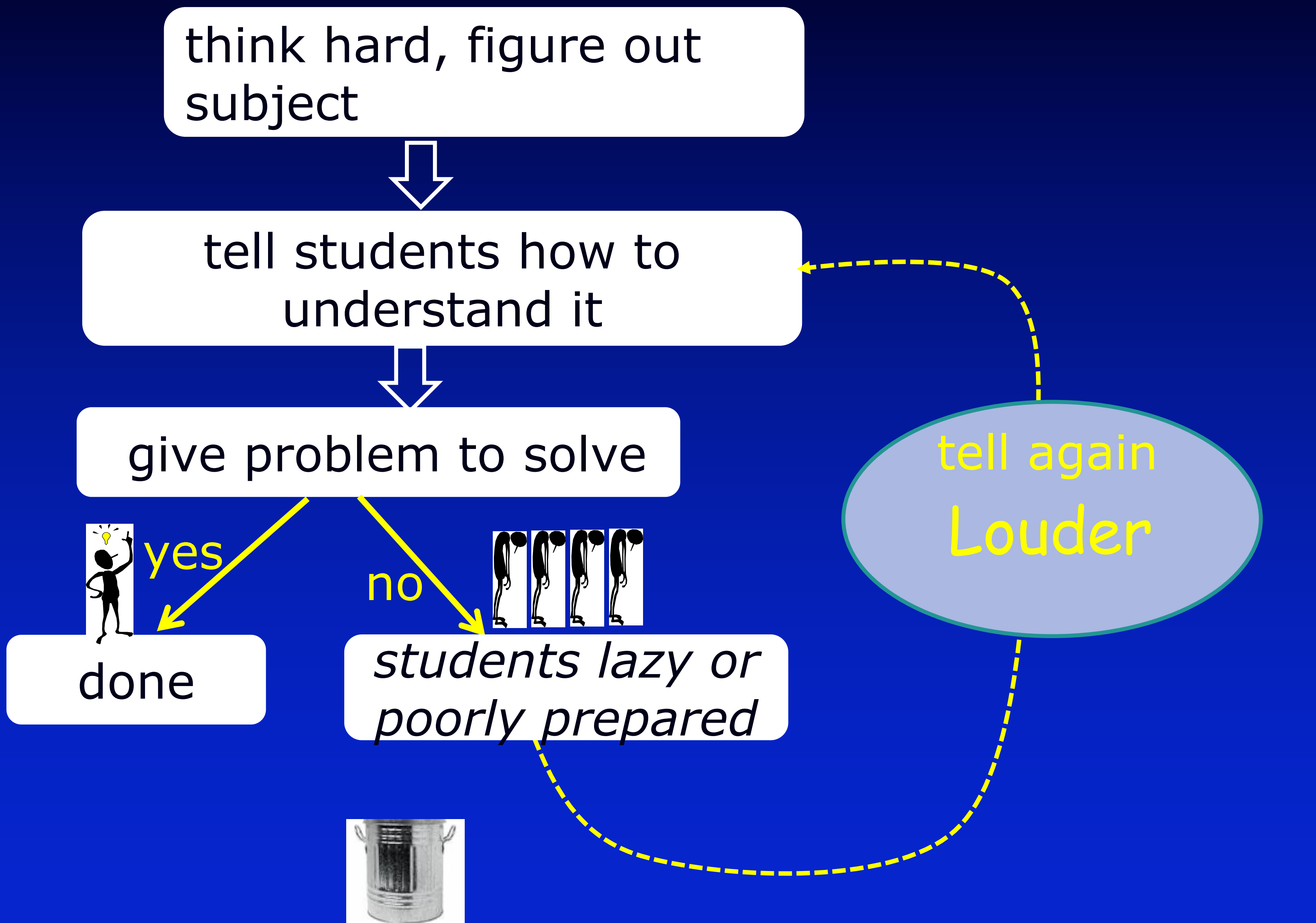
Colorado physics & chem education research group:
W. Adams, K. Perkins, K. Gray, L. Koch, J. Barbera, S. McKagan, N. Finkelstein, S. Pollock, R. Lemaster, S. Reid, C. Malley, M. Dubson... $$ NSF, Hewlett)

Science education Model 1   (I used for many years)



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

Works well for basic knowledge, prepared brain:

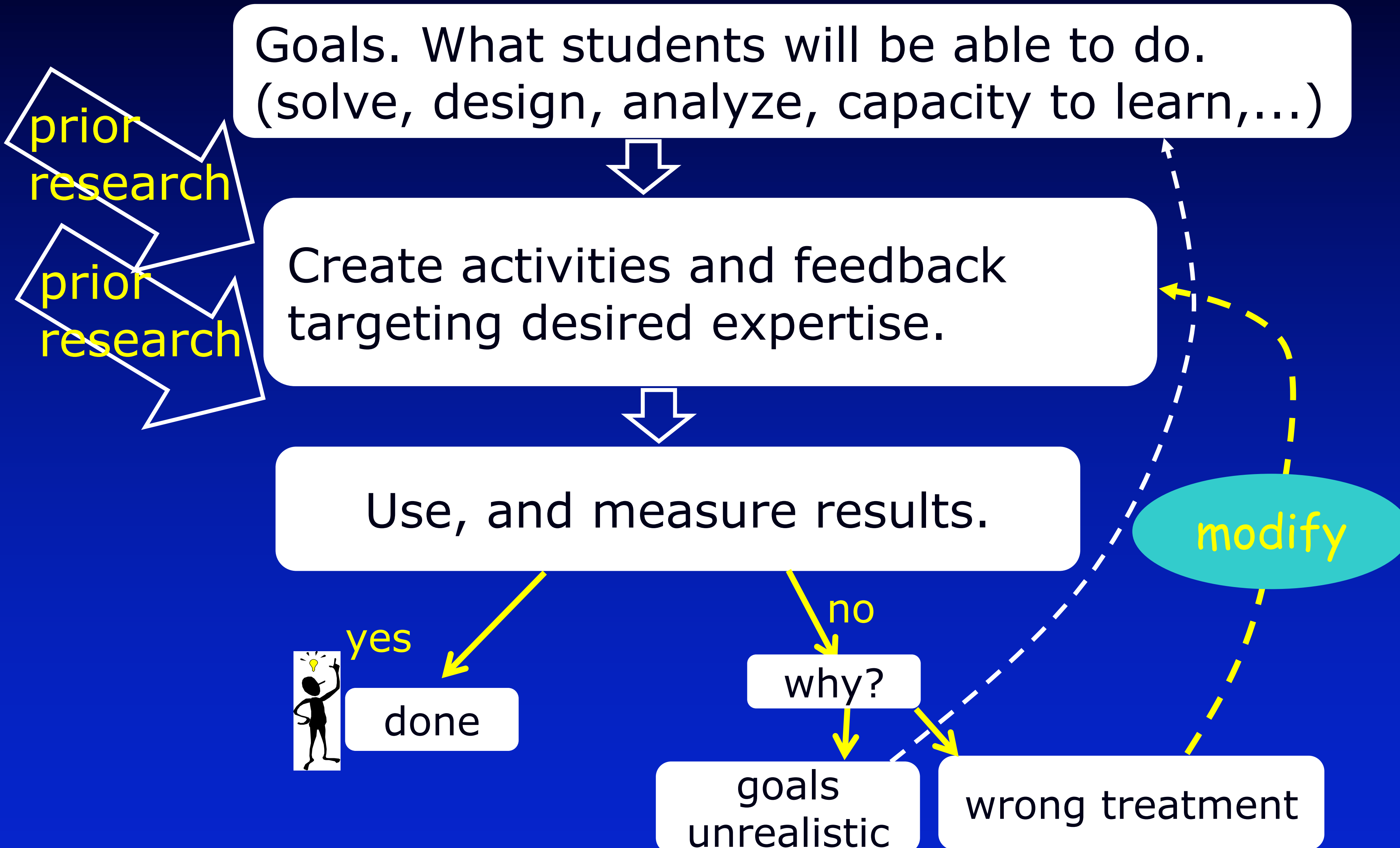
bad, avoid

good, seek

Fails for more complex knowledge, like becoming physicist

More complex learning-- changing brain, not just adding bits of knowledge.

Science Education Model 2- like do science.



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.

Expert competence research*

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

Expert competence =

- factual knowledge
- **Organizational framework** ⇒ effective retrieval and application

or ?

patterns, associations, scientific concepts

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

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

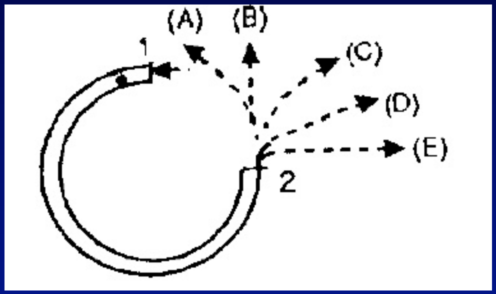
New ways of thinking-- require MANY hours of intense practice with guidance/reflection. Change brain "wiring"

Measuring how well expert thinking is developed.

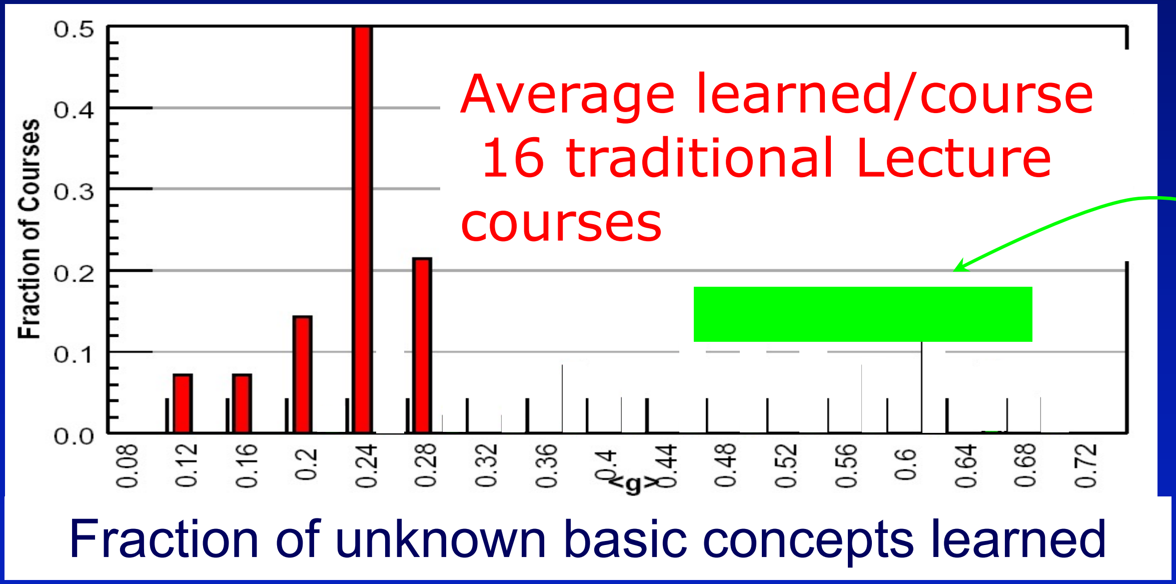
*Cambridge Handbook on Expertise and Expert Performance

Measuring conceptual mastery

• 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)



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).

Physicists also have unique “belief” systems

Novice	**Physicist**
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.

*adapted from D. Hammer

Measuring student beliefs about science

Novice — **Expert**

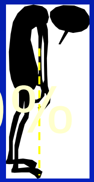
Survey instruments--
MPEX--1st yr physics, CLASS--physics, chem, bio tests

~40 statements, strongly agree to strongly disagree--

Understanding physics basically means being able to recall something you've read or been shown.

I do not expect physics equations to help my understanding of the ideas; they are just for doing calculations.

5-10%



pre & post
% shift?

intro physics ⇒ *more* novice

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

Intro Chemistry and biology just as bad!

*adapted from D. Hammer

Test development process *(~ 6 months post-doc)*

1. Interview faculty-- establish learning goals.
2. Interview students-- understand thinking on topic

$\Rightarrow$ patterns emerge where nonexpert thinking & traditional exams missing.

- Way knowledge in subject is organized and applied = "Conceptual mastery"
- Way experts approach learning and problem solving

Create tests, validate and refine with interviews and statistical analysis

Validated Concept Inventories following this process

FCI and FMCE (intro mechanics)
BEMA (intro electricity and magnetism)
QMCI Quantum mechanics concept inventory (intro quantum)
3rd year quantum test in development
CUSE (3rd year electricity)

Concept inventory tests under development or in early use in geology, chem, biology, physiology, ...

"Attitudinal" surveys for Physics, Chemistry, Biology, Earth Sciences

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⇒3. Components of effective teaching and learning.

Components of effective teaching/learning

apply to all levels, all settings (including conference talks!)

1. Reduce unnecessary demands on working memory

2. Explicit authentic modeling and practice of expert thinking. Extended & strenuous *(brain like muscle)*

3. Motivation

4. Connect with and build on prior thinking

Limits on working memory--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

$\Rightarrow$ fraction retained tiny

Reducing unnecessary demands on working memory improves learning.

~~jargon~~, use figures, analogies, avoid digressions

Features of effective activities for learning.

1. Reduce unnecessary demands on working memory

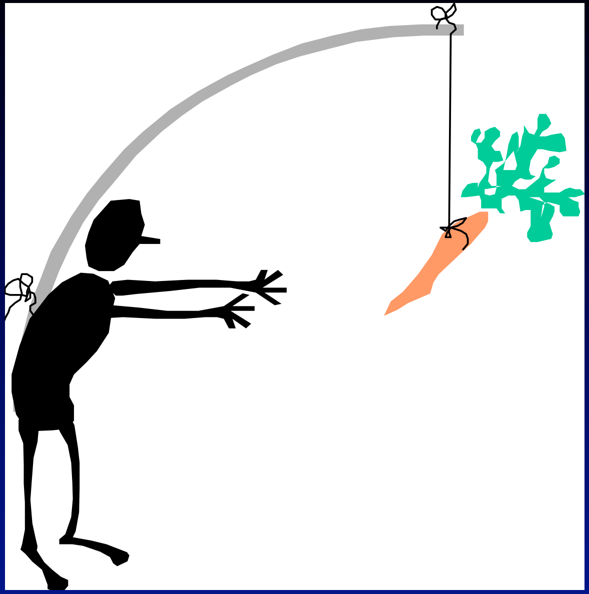
2. Explicit authentic modeling and practice of expert thinking. Extended & strenuous *(brain like muscle)*

3. Motivation

4. Connect with and build on prior thinking

3. Motivation-- essential

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



a. Relevant/useful/interesting to learner (**meaningful context-- connect to what they know and value)**
Problems where value of solution obvious.

b. Sense that can master subject and how to master

c. Sense of personal control/choice

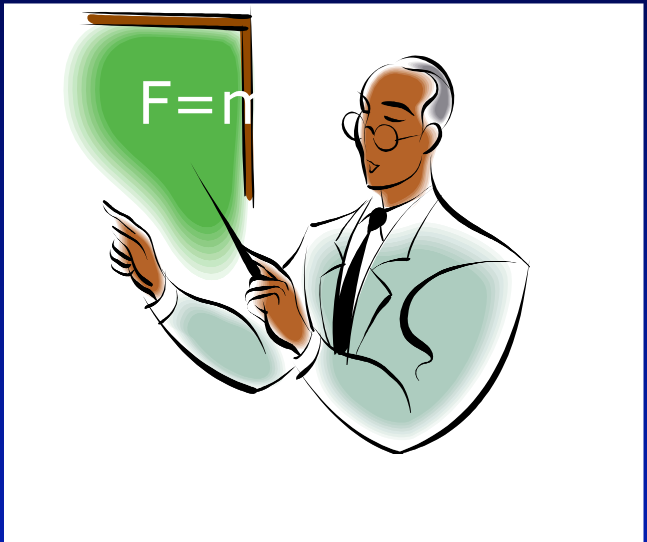
Effective activities for learning.

1. Reduce unnecessary demands on working memory

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

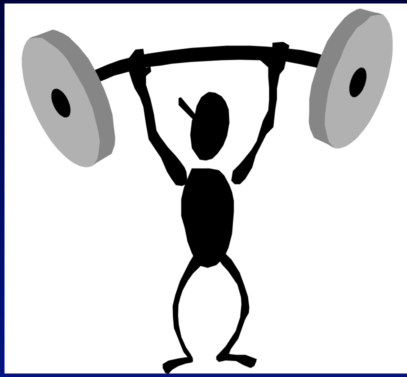
3. Motivation

4. Connect with and build on prior thinking



listing to lectures
not the required “strenuous mental effort”

Practicing expert-like thinking--



Challenging but doable tasks/questions

Explicit focus on expert-like thinking

- concepts and mental models
- recognizing relevant & irrelevant information
- self-checking, sense making, & reflection

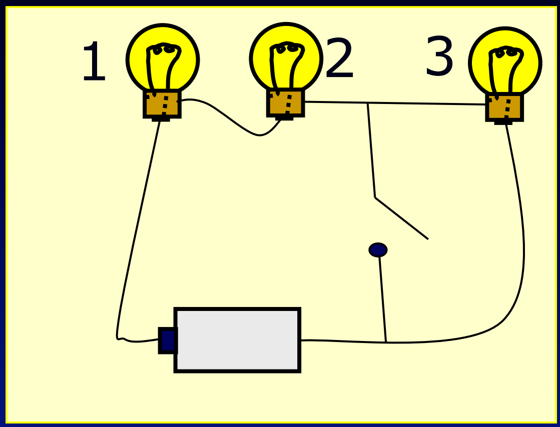
Provide effective feedback (timely and specific)

"cognitive coach"

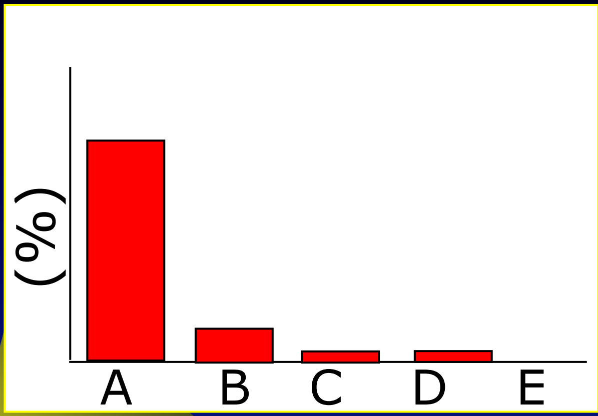
Example from a class--practicing expert thinking with effective guidance/feedback

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

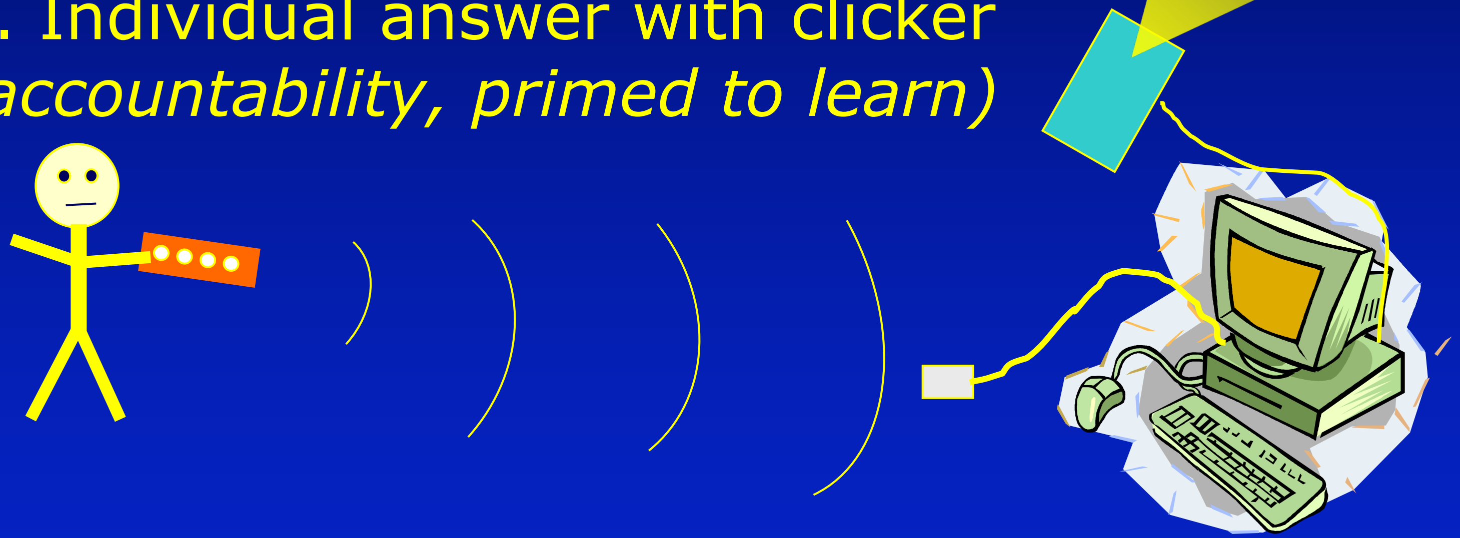
2. Class built around series of questions.



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



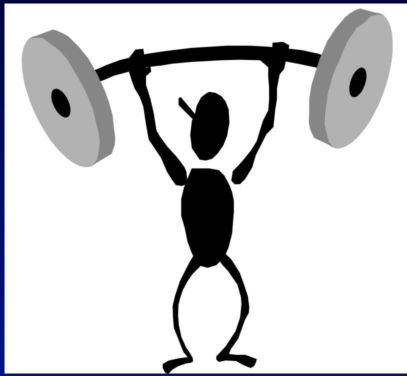
3. Individual answer with clicker
(accountability, primed to learn)



4. Discuss with "consensus group", revote. (prof listen in!)

5. Show responses. Elicit student reasoning.
Do "experiment."-- simulation.

Practicing expert-like thinking--



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Only a start! Follow up with homework problems to do much more of the same!

Some Data:

Model 1 (telling) traditional lecture method	Model 2 scientific teaching

- Retention of information from lecture

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

- Fraction of concepts mastered in course

15-25% ⇒ **50-70% with retention**

- Beliefs about science-- what it is, how to learn,

significantly less
(5-10%) **like scientist** ⇒ **more like scientist**

Summary:
Scientific approach to physics education.
Understand and teach physics expertise.

Good Refs.:
NAS Press "How people learn"
Redish, "Teaching Physics" (Phys. Ed. Res.)
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

clickers*--

Not automatically helpful--

give accountability, anonymity, fast response

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

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

- 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

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?

UBC CW Science Education Initiative and U. Col. SEI

from "bloodletting to antibiotics" in science education

Changing educational culture in <u>major research university science departments</u>
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.

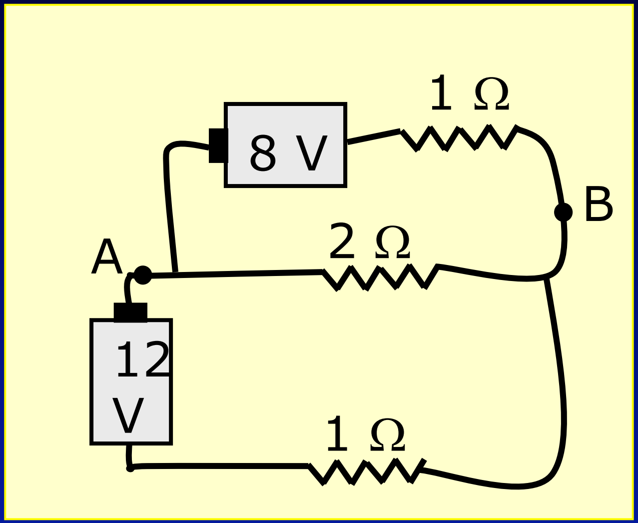
All materials, assessment tools, etc to be available on web

Data 2. Conceptual understanding in traditional course

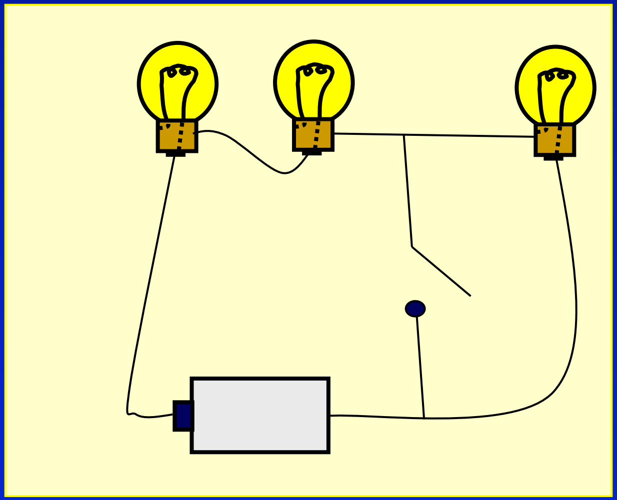
electricity

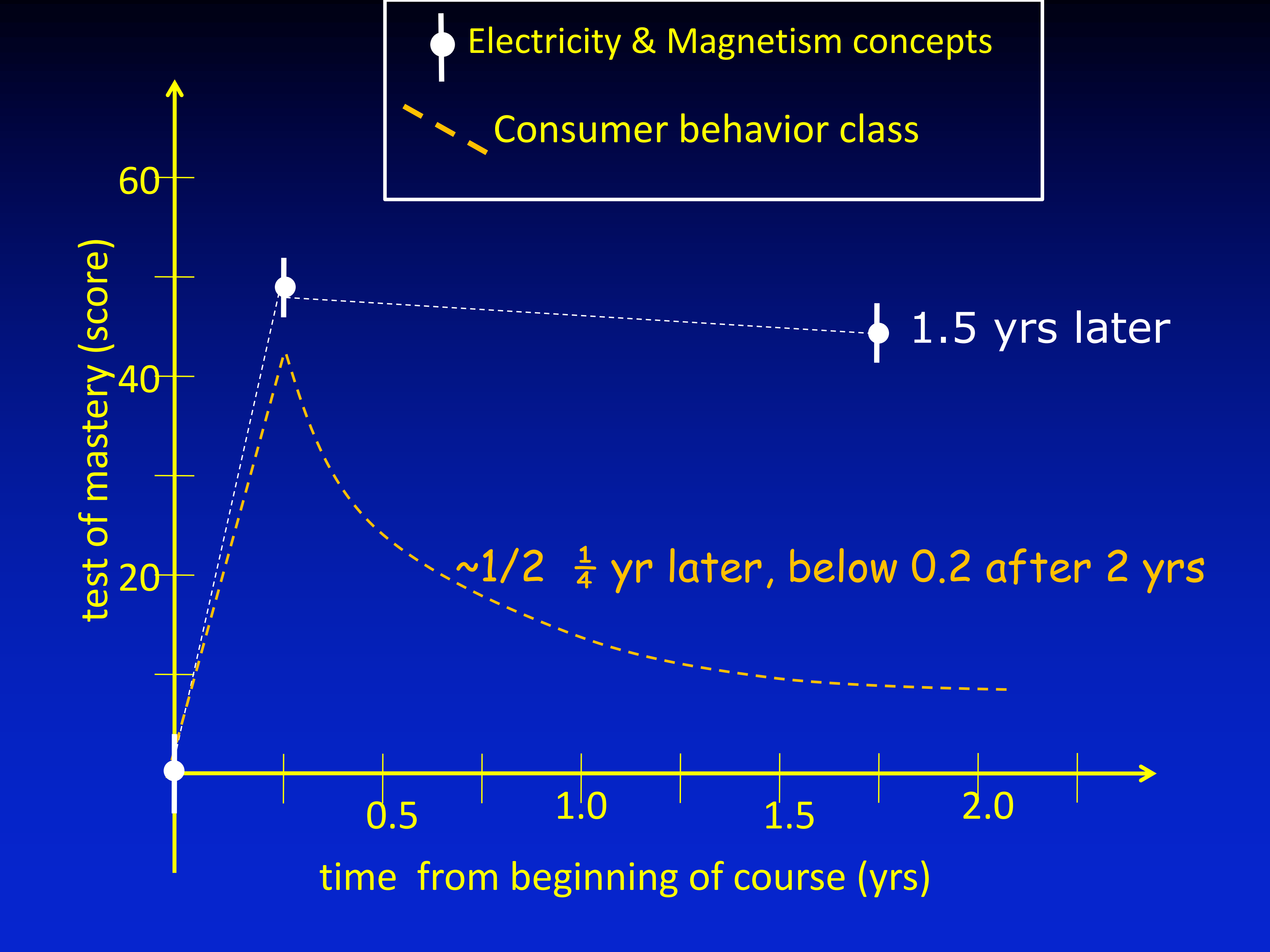
Eric Mazur (Harvard Univ.)

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



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

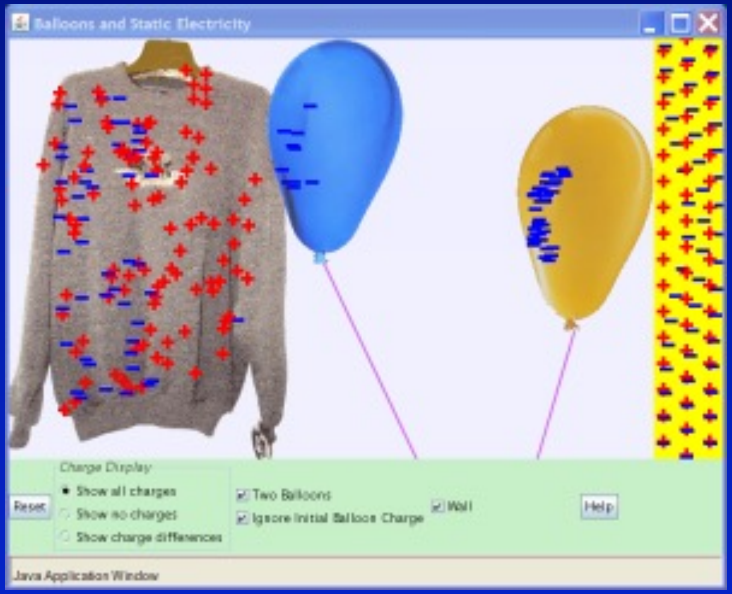




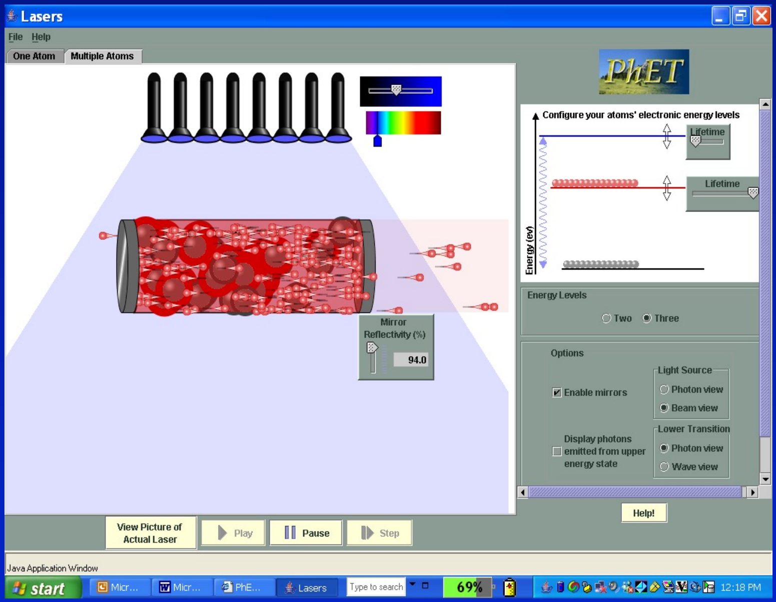
Electricity & Magnetism concepts
Consumer behavior class
60
40
20
test of mastery (score)
1.5 yrs later
~1/2 ¼ yr later, below 0.2 after 2 yrs
0.5
1.0
1.5
2.0
time from beginning of course (yrs)

Highly Interactive educational simulations--
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

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