Science Education for the 21st Century

Using the insights of science to teach/learn science

and most 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, Hewlett)

<u>The Vision</u>

Students much better educated.
Thrive in 21st century world $\Longrightarrow$ host of benefits to society.

Teaching more effective, <u>and</u> more fun, efficient, and meaningful for the instructor.

paraphrase J. Kotter

How to achieve?

I. 2 models for science, ... teaching and learning.

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

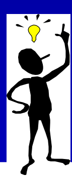
Relevant to:
- becoming better teacher
- becoming better learner

Science education Model 1 (I used for many years)

think hard, figure out subject

tell students how to understand it

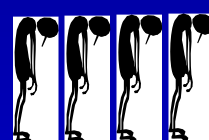
give problem to solve



yes

done

no



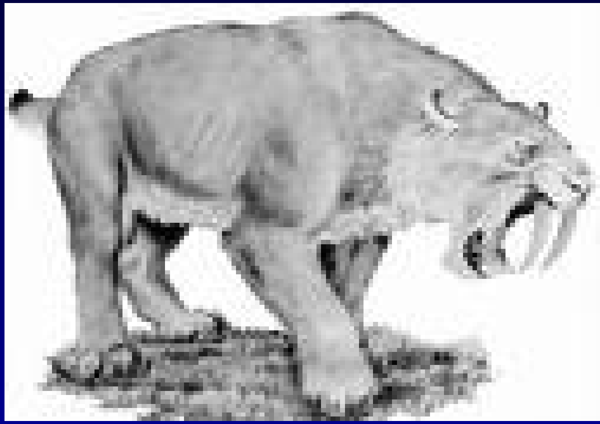
students lazy or poorly prepared

tell again

Louder

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

Works well for basic knowledge, prepared brain:



bad,
avoid

good,
seek

Easy to test. ⇒ Effective feedback on results.

Problem if learning:

- involves complex analysis or judgment
- organize large amount of information
- ability to learn new information and apply

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

Model 1 (*figure out and tell--traditional lecture*)

Not adequate for education today.
Need high level expertise & expert learners.

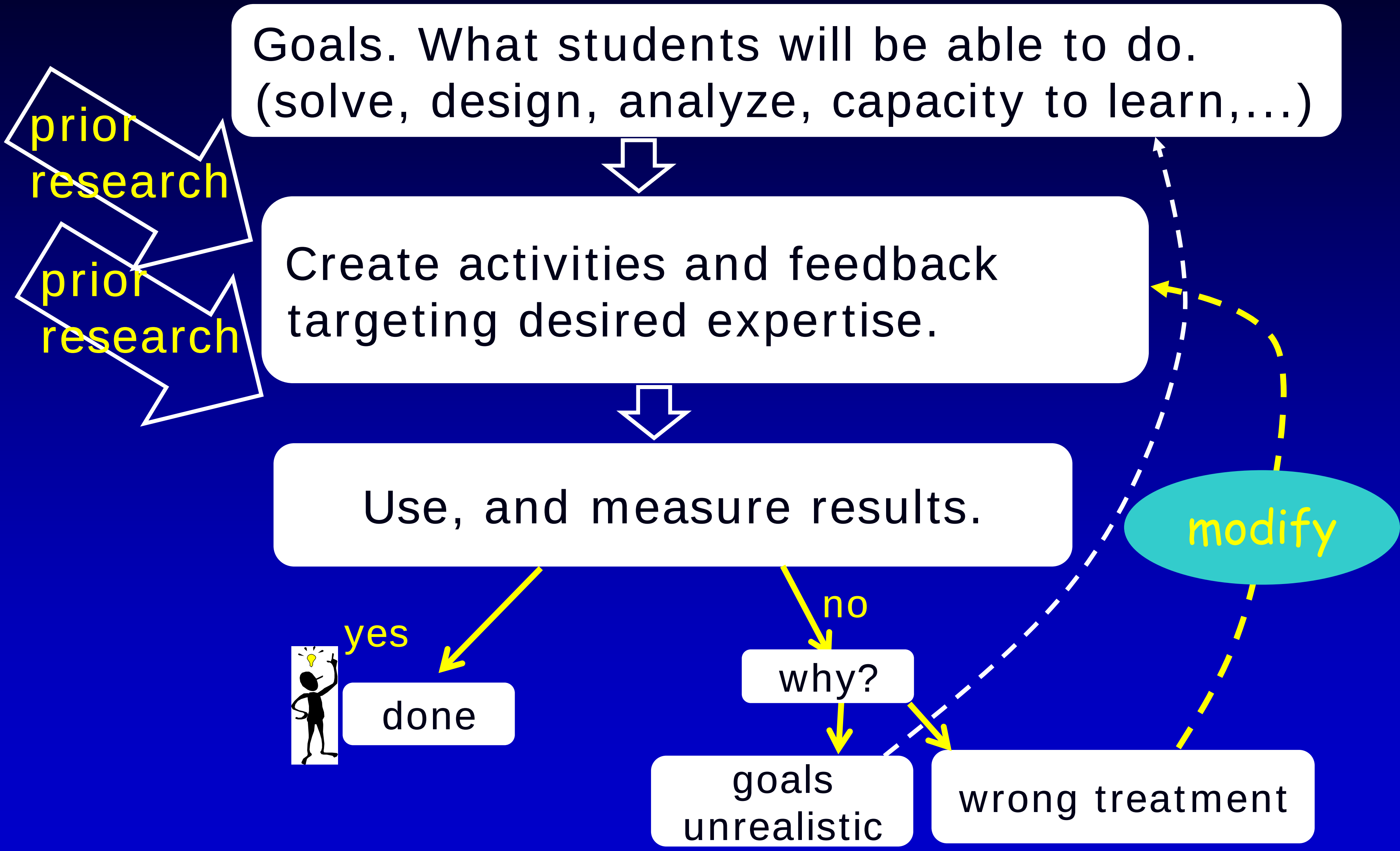
Large fraction of population.

Scientifically literate public

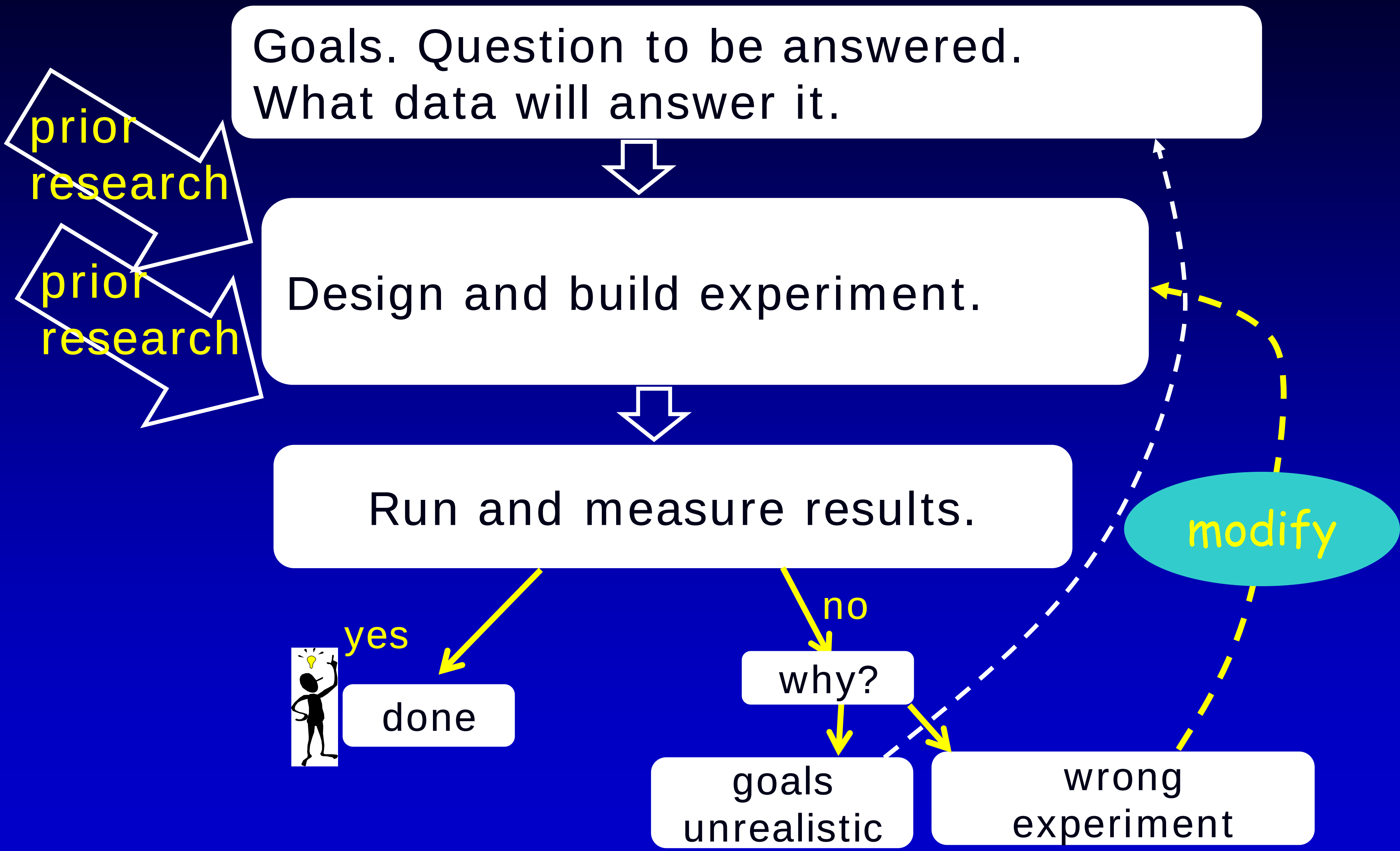
Modern economy

How to achieve and measure more complex learning?

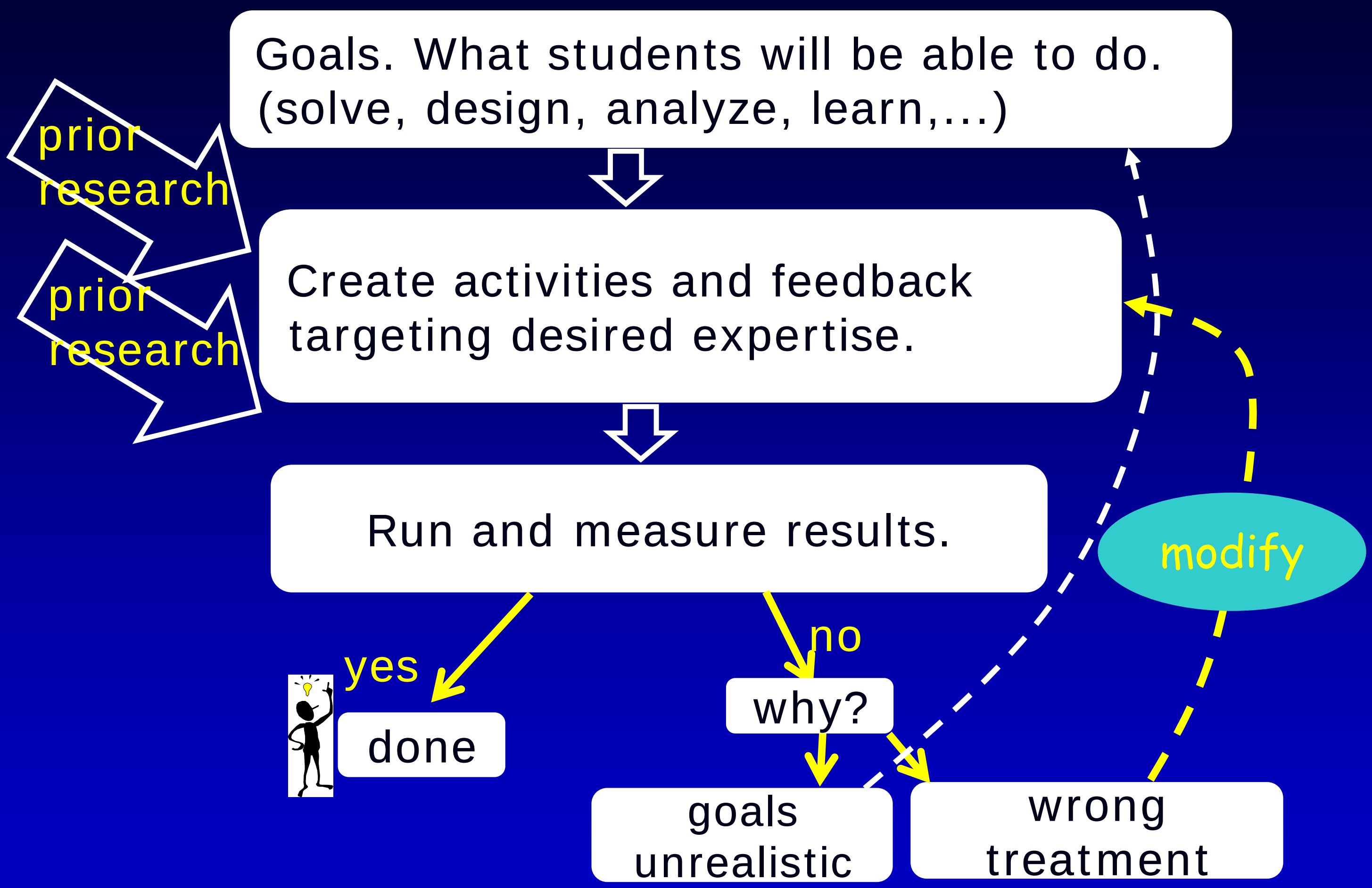
Science Education Model 2.



Is model for *doing* science



Model 2 --scientific approach to science education



⇒New insights on traditional science teaching, how to improve.

Major advances past 1-2 decades
Consistent picture $\Rightarrow$ Achieving learning

university classroom studies

brain research

cognitive psychology

Some Data (science from classrooms):

Model 1 (telling)
traditional lecture method ⇒ 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**

improves for future nonscientists and scientists

Model 2-- scientific approach

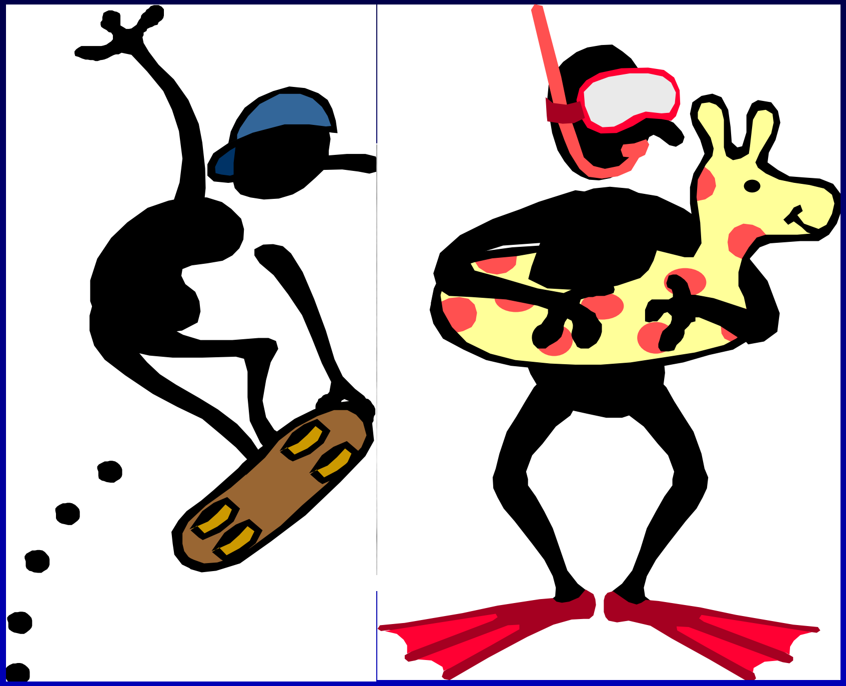
What has been learned?

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.

Developing expertise-- transforming brain



Think about and use science like a scientist.

What does that mean?
How is it accomplished?

Expert competence research*

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

Expert competence =

- factual knowledge
- **Organizational framework** $\Rightarrow$ effective retrieval and application

or ?

patterns, associations, scientific concepts

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

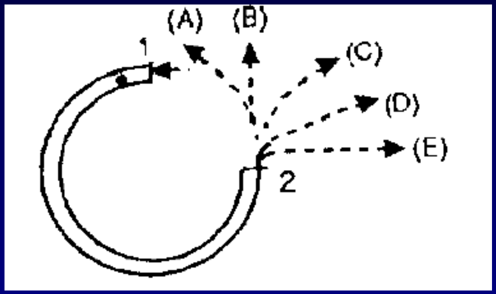
("Do I understand this? How can I check?")

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

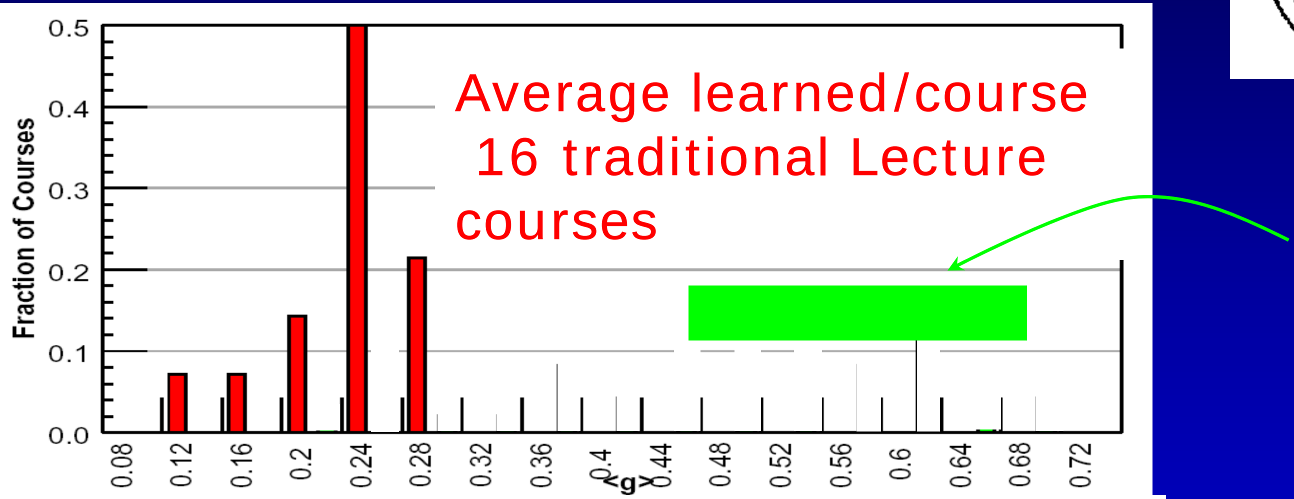
*Cambridge Handbook on Expertise and Expert Performance

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)



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).

- Experts in science also have unique “belief” systems

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.

*adapted from D. Hammer

Measuring student beliefs about science

Novice **Expert**

Survey instruments--

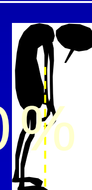
MPEX--1st yr physics, CLASS--physics, chem, bio tests

~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

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 teaching/learning

apply to all levels, all settings

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

make PPT slides available

⇒ processing and retention from lecture tiny (for novice)

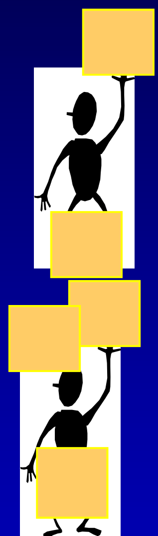
many examples from research:

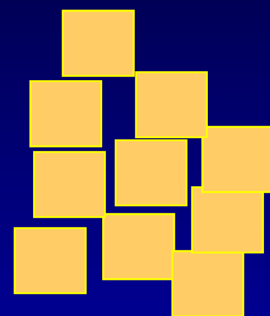
Wieman and Perkins - test 15 minutes after told nonobvious fact in lecture.
10% remember

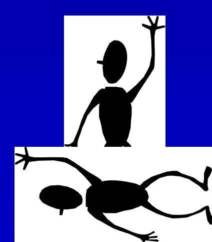
Also true in technical talks!

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

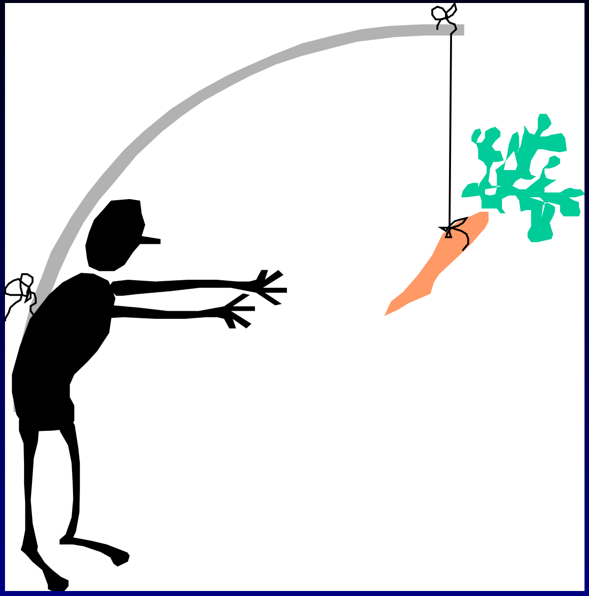
2. Explicit authentic modeling and practice of expert thinking. Extended & strenuous *(brain like muscle)*

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.

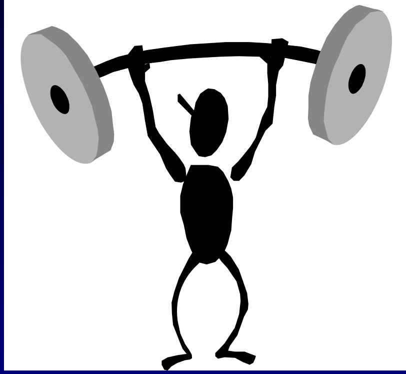
1. Reduce unnecessary demands on working memory

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

3. Motivation

4. Connect with and build on prior thinking

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"

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

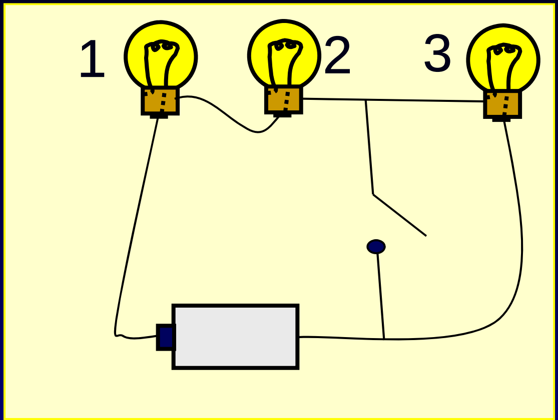
a) good examples from Mazur and others

b) use technology to help
printing press, ...

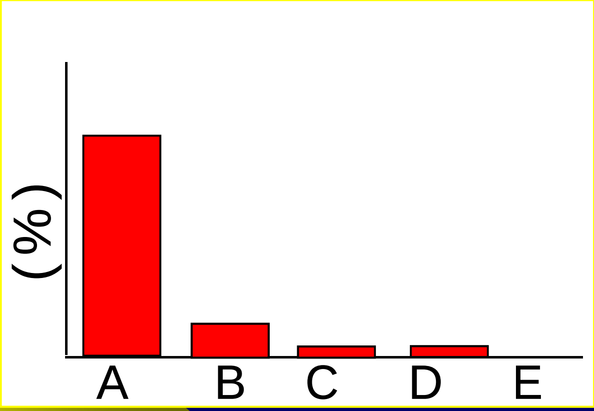
Example from a class--practicing expert thinking with effective guidance/feedback

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

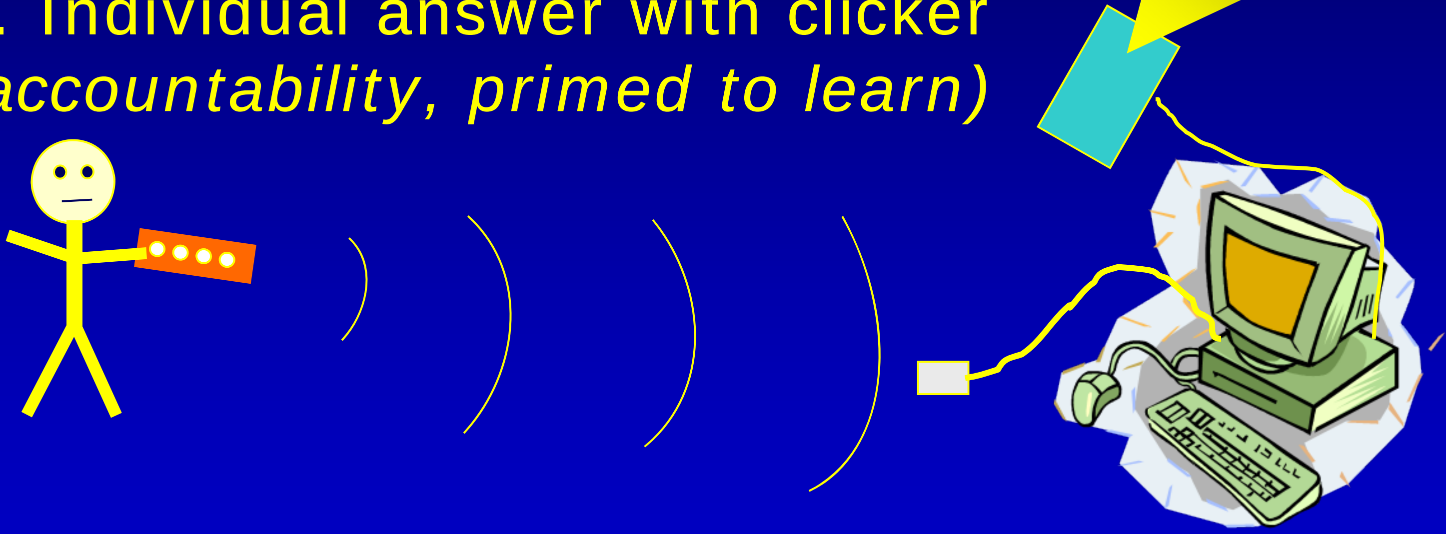
2. Class built around series of questions.



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.

show cck sim

Follow up instructor discussion--
review correct and incorrect thinking, extend ideas.
Respond to student questions & suggestions.
*(covers extensive **new** material)*

How practicing expert thinking--

Challenging but doable question (difficult concept)

Explicit focus on expert-like thinking

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

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

Highly engaged-- further questions/predictions with sim, testing understanding = “Expert learning” good start, but not enough time in class!

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

$\Rightarrow$ long term retention

Some Data:

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Summary:

Scientific model for science education

Much more effective. (and more fun)

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*

clickers*--

Not automatically helpful--

give accountability, anonymity, fast response

Used/perceived as expensive attendance and testing device$\Rightarrow$ little benefit, student resentment.

Used/perceived to enhance engagement, communication, and learning $\Rightarrow$ 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