Improving STEM Education

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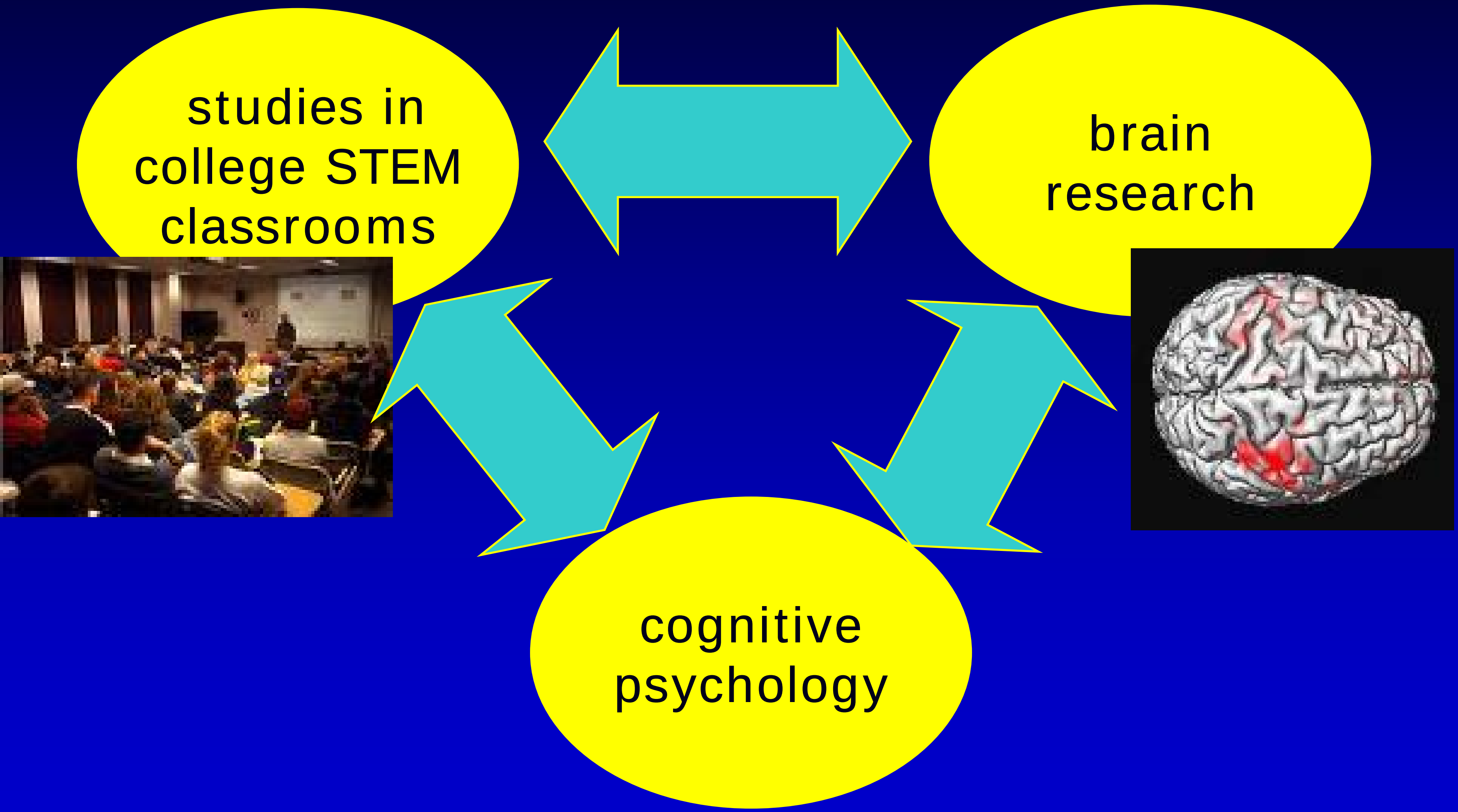
1. The enormous potential for improvement (recent research)

2. (brief) Improving STEM education in major universities for all students. A critical missing step.

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



Cognitive psychology research

What makes up expertise *(thinking like scientist)* and how developed.

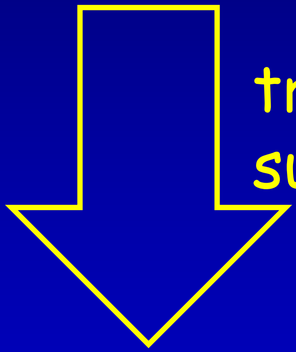
old view, current teaching

knowledge

soaks in, variable

new view brain plastic

~ same



transform via suitable "exercise"

Effective STEM teaching for all students--transforming brains

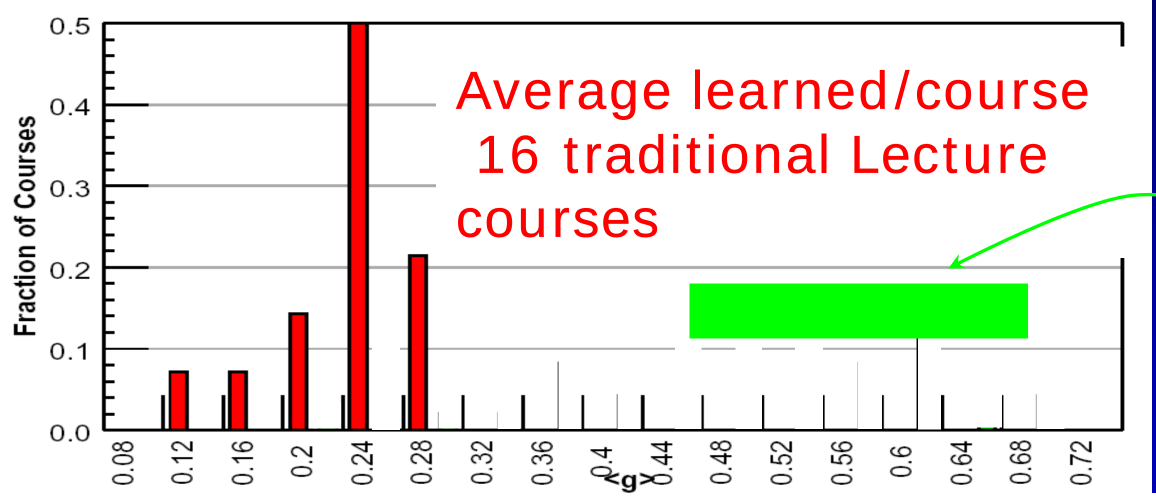
1. delineate all components of STEM thinking
2. create suitable tasks to explicitly practice
3. provide feedback/guidance & motivation to ensure many hours of intense effective practice.

$\Rightarrow$ Resulting improvement over traditional STEM teaching (demonstration examples)

Examples of results. 1. Conceptual mastery

Basic concepts of force and motion 1st semester physics.
Applying in simple real world contexts. (FCI test)

Test students at start and end of course--
What % learned? (100's of courses)



Fraction of unknown basic concepts learned

improved
methods
2-3 x higher

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

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

Examples of results **2. Perceptions of science**

how scientific knowledge is established, learned, used

Measure

Novice → **Expert**

Novices: isolated pieces of information to be memorized, unrelated to world outside of classroom.

Instruments to measure student perceptions before and after college sciences classes.
~ all intro physics courses-- shift to novice, chemistry & biology results similar*

Modify courses to fix $\Rightarrow$ positive results

* see class.colorado.edu & PERC 2009 proceedings for references

Many demonstrations that research-based approach to STEM learning can achieve large (2-3) improvements.

How much more is possible?

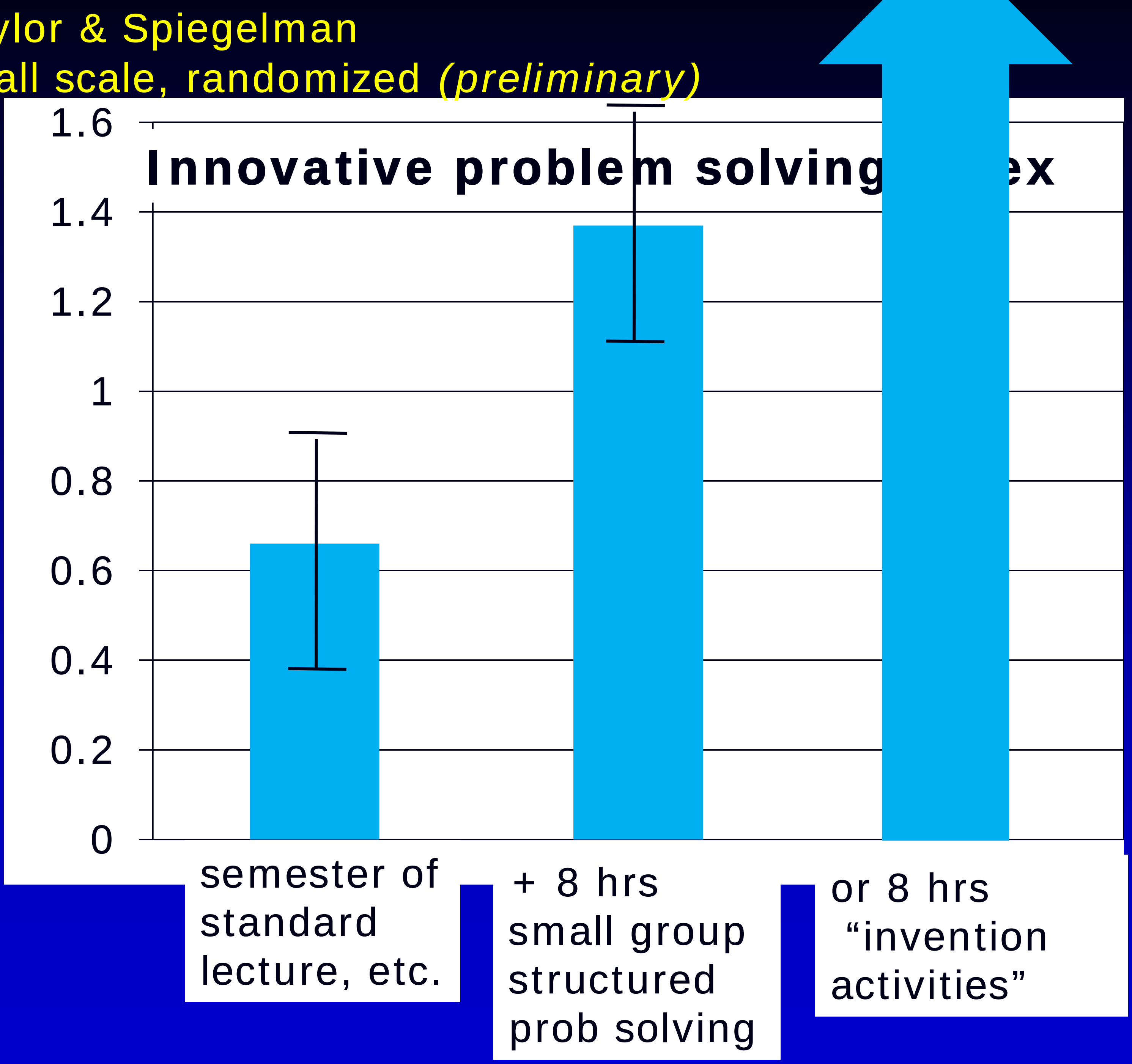
Probably a lot.

Very recent example (preliminary just being written up)--
teaching innovative scientific problem solving

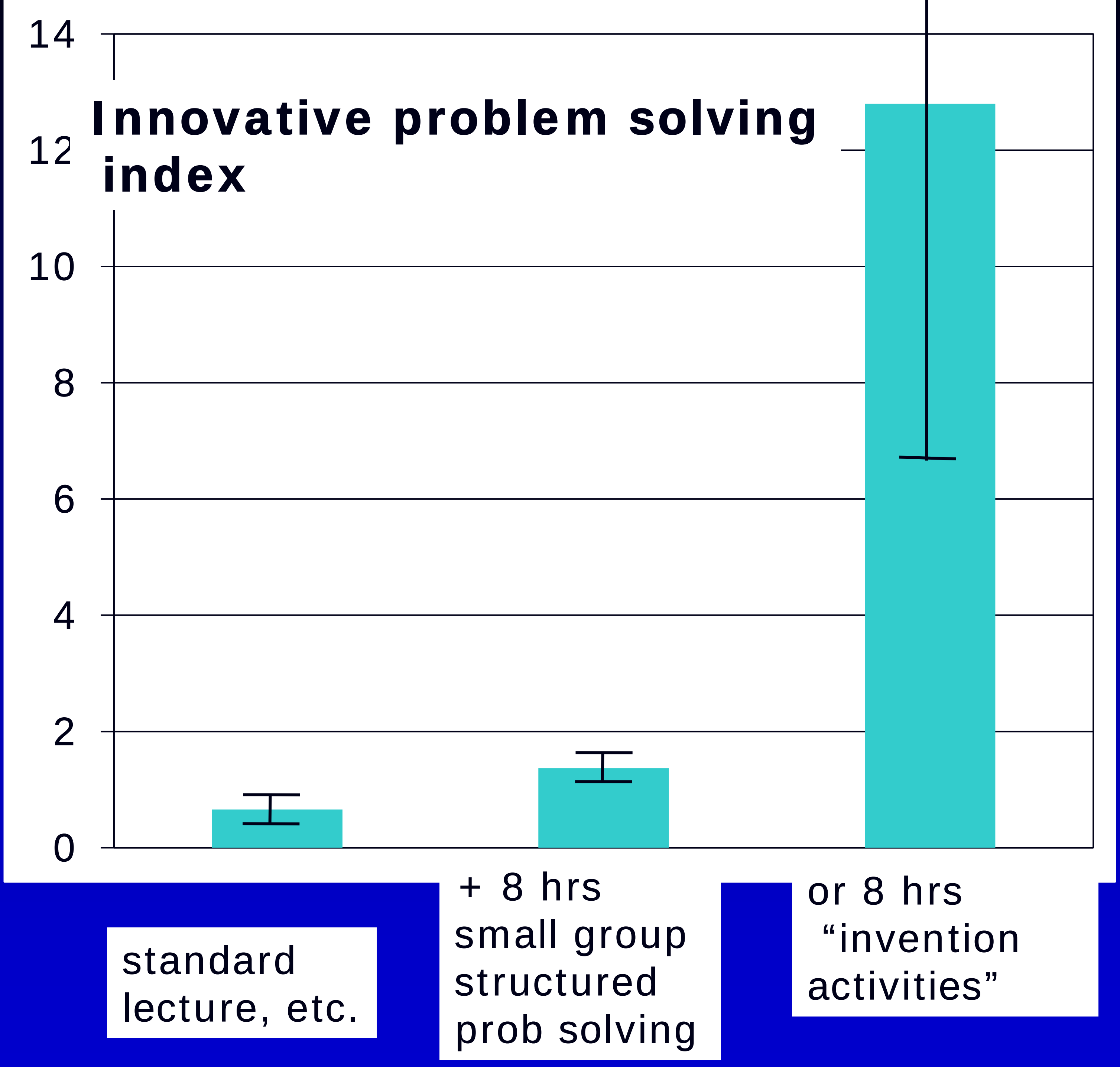
advance in cog. psychology *(D. Schwartz)*
$\Rightarrow$use in large 1st year biology course
(Taylor, Spiegelman & CW)

Taylor & Spiegelman

small scale, randomized *(preliminary)*



Taylor & Spiegelman small scale, randomized. *preliminary*



Dramatic improvements demonstrated in STEM learning.
(without costing more, if good use of technology)

2. How to get into every classroom?

Critical step in the process.
Changing STEM teaching for all students in large research universities.
Set the standards.

Largely ignored in efforts to improve STEM education.

One reason why lots of money and concern focused on k-12 STEM education has achieved little.

Higher ed defines “teaching and learning of STEM”.
$\Rightarrow$ teaching future teachers and parents deficient models of both.

Improving STEM teaching at universities-- ancient culture.

Is widespread change possible?

Science Education Initiatives (CU & UBC)

Experiment-- existence proof. Changing science teaching at large public research universities.
(Science editorial Sept 4)

Detailed model for cultural change

- Departmental-wide focus
- One time funds (3-5% annual budget for 5 yrs)

Goal: evidence based practices & assessment.
All undergraduate courses in dept, ~ all faculty.
Teaching more effective, rewarding, and efficient

Results: After 3 years, 4 large science departments
> 60% of faculty significantly changed teaching
> 80% student credit hours.
Existence proof ✓
Sustainability?
All STEM departments & widespread replication?

Summary

- Opportunity exists for great improvement in science education

- Research shows how people learn & how to teach science much better

- Implemented in real classrooms, gives expected improvements without additional costs, but these remain isolated experiments

- First step to making widespread is adoption at major research universities.
Existence proof successful.

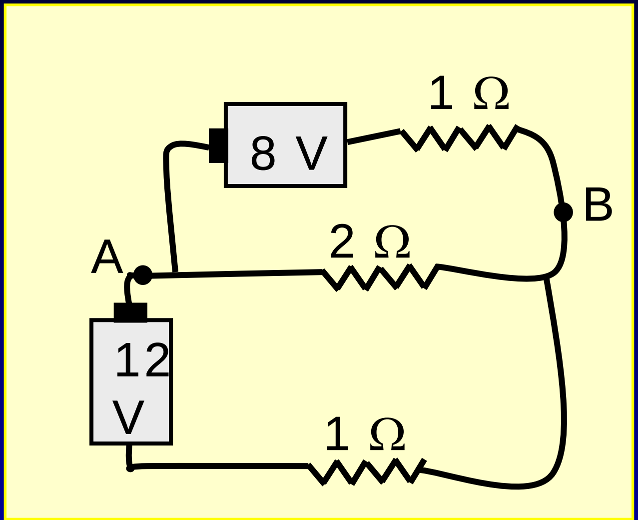
extras below

Data 2. Conceptual understanding in traditional course

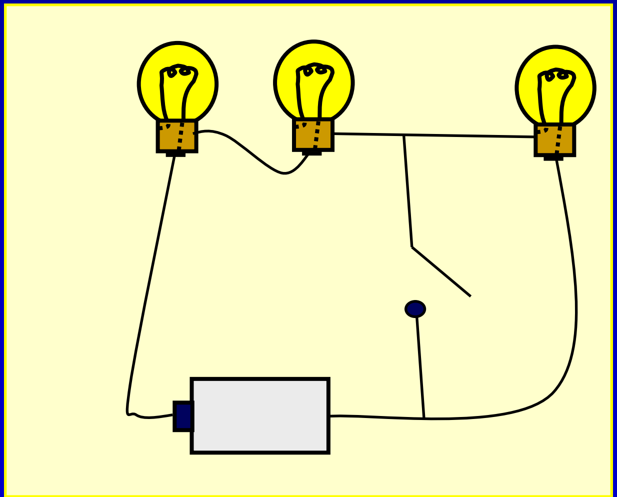
electricity

Eric Mazur (Harvard Univ.)

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



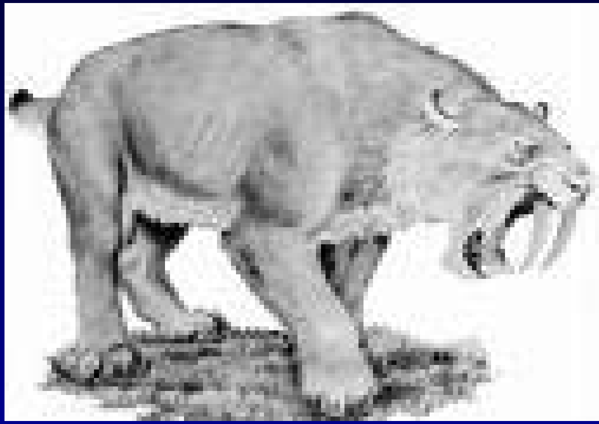
only 40% correctly predict change in brightness of bulbs when switch closed!



solving problems, but not
by scientist-like thinking!

Science teaching model 1 (*tell*) Strengths & Weaknesses

Works well for basic knowledge, prepared brain:



bad, avoid

good, seek

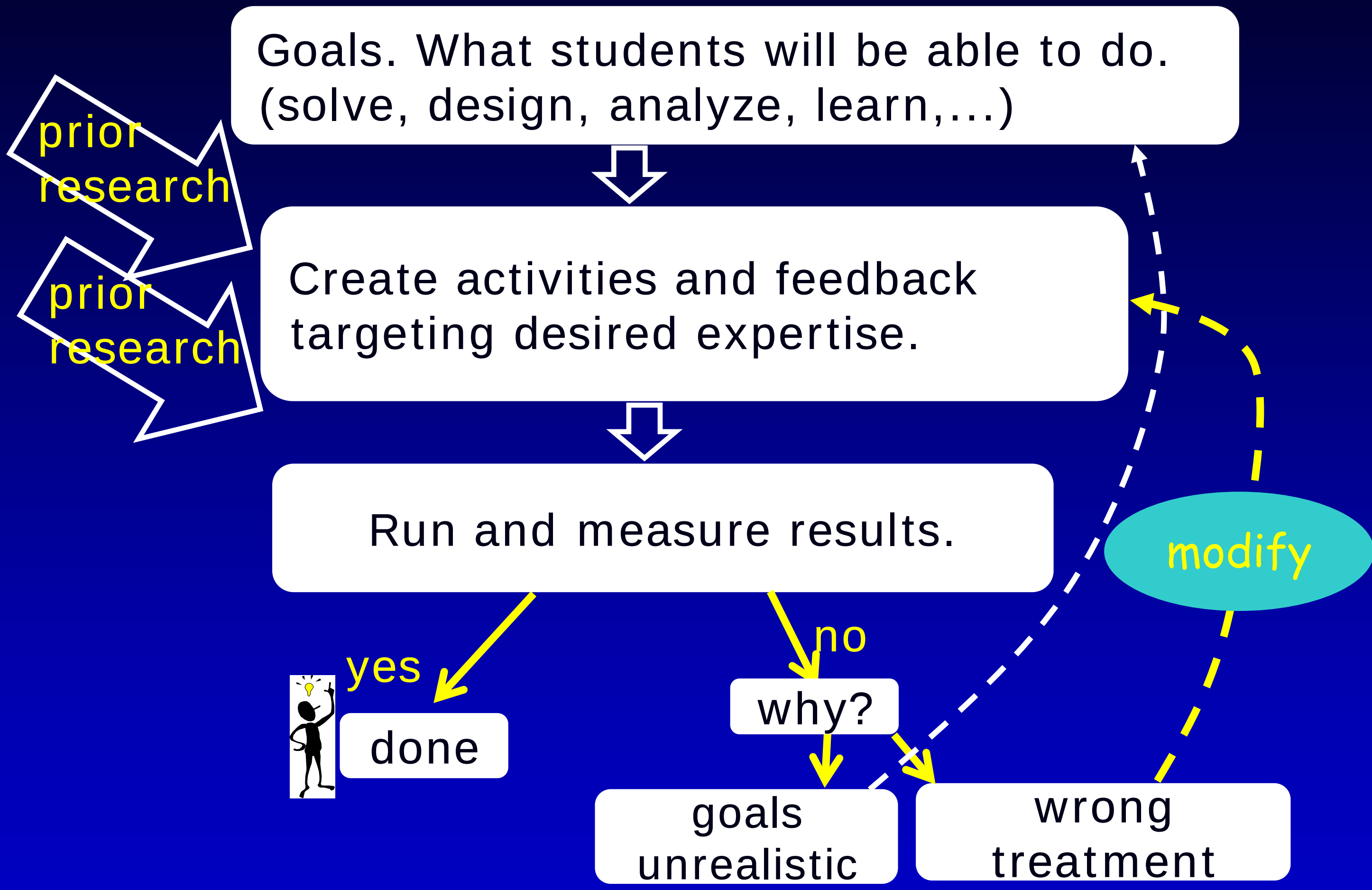
Easy to test.

Has problems if the desired learning:

- involves complex analysis or judgment
- organize large amount of information
- ability to learn new information and apply (i.e. all scientific thinking)

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

Model 2 --scientific approach to science education



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

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 (thousands) hours of intense practice with guidance. Change brain "wiring"

*Cambridge Handbook on Expertise and Expert Performance

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*