Expertise in science, and how it is learned and taught

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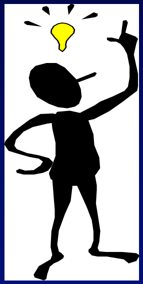
1. Intro– nature & learning of expertise
2. Expertise in your discipline
3. Teaching expertise in sci. & eng.
   examples and data

Graduate students in my lab--
success in classes, clueless about doing physics?



2-4 years later ⇒ expert physicists!

??????

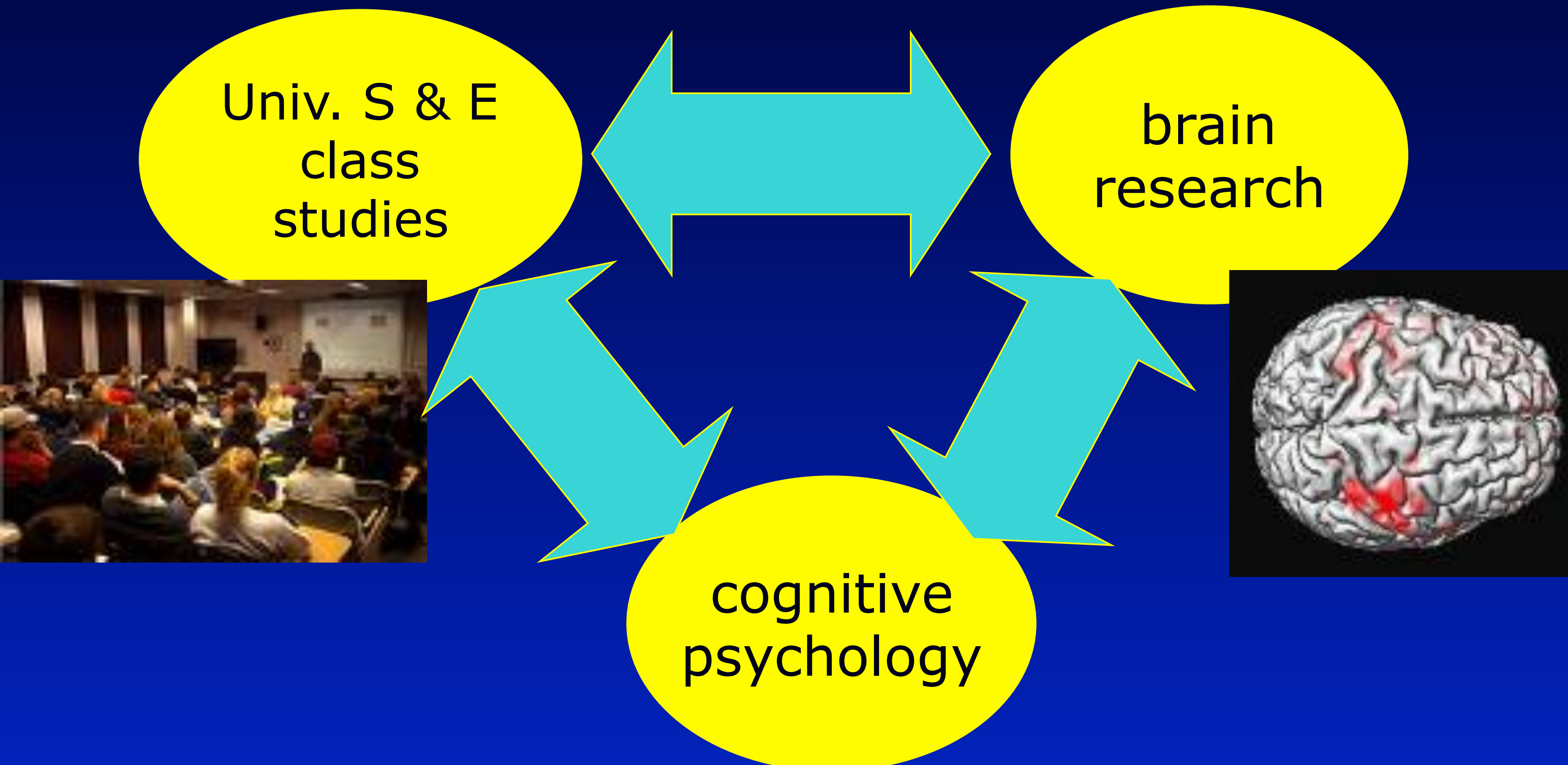
Research on how people learn, particularly physics

Developing expertise
(= thinking like physicist)

A. Grad student in lab
Practicing with feedback

B. Students in class--**not**

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



new instructional methods

"active learning", "student-centered",
"inquiry learning", "experiential learning", ...

underlying foundation must be

Disciplinary expertise

"Expertise-centered" classroom

good teaching–transfer of sci & eng expertise
(learning to think like scientist or engineer)

Student not become expert, but maximize progress

I. Expertise research*

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

Expert competence =

- factual knowledge
- **Mental organizational framework** ⇒ retrieval and application

or ?

patterns, relationships, scientific concepts,

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

New ways of thinking-- everyone requires MANY hours of intense practice to develop.
Brain changed

*Cambridge Handbook on Expertise and Expert Performance

II. Learning expertise*--

Requires brain "exercise"

Challenging but doable tasks/questions

Practice all the elements of expertise with feedback and reflection. Motivation critical!

Subject expertise of instructor essential—

- designing practice tasks
  (what is expertise, how to practice)
- feedback/guidance on learner performance
- why worth learning

* "Deliberate Practice", A. Ericsson research
accurate, readable summary in "Talent is over-rated", by Colvin

Some components of S & E expertise

- concepts and mental models + selection criteria
- recognizing relevant & irrelevant information
- what information is needed to solve
- does answer/conclusion make sense- ways to test
- **model** development, testing, and use
- moving between specialized representations (graphs, equations, physical motions, etc.)
- …

Only make sense in context of topics.
Knowledge important but only as integrated part– *how to use/make-decisions with that knowledge.*

Small group activity—

Make a list of components of expertise in your discipline.

Cognitive activities of experts—

How have practice and feedback on these for students?

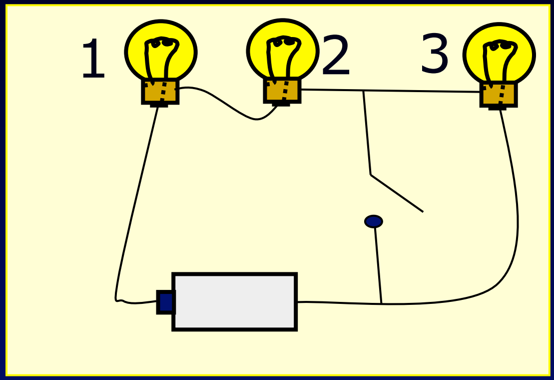
III. How to apply in classroom?
(best opportunity for feedback & student-student learning)

example– large intro physics class

Teaching about electric current & voltage

1. Preclass assignment--Read pages on electric current. Learn basic facts and terminology without wasting class time. Short online quiz to check/reward.

2. Class starts with question:



When switch is closed, bulb 2 will

a. stay same brightness,

b. get brighter

c. get dimmer,

d. go out.

answer & reasoning

3. Individual answer with clicker
(accountability=intense thought, primed for feedback)

4. Discuss with "consensus group", revote.

<u>Listening in</u>! What aspects of student thinking like physicist, what not?

5. Demonstrate/show result

6. Instructor follow up summary– feedback on which models & which reasoning was correct, & **which incorrect and why**. Many student questions.

Students practicing physicist thinking—
deciding on relevant information
selecting and applying conceptual model
testing thinking and modifying as needed

Feedback—other students, informed instructor, demo

Teacher subject expertise required—
Question design, evaluating student thinking, follow up response

"Wouldn't it be a lot quicker and more efficient if I just started class by telling all this to the students?"

Expertise invisible to them, information meaningless, no practice

= no learning of expertise

Compare with typical HW & exam problems, in-class examples

- Provide all information needed, and only that information, to solve the problem
- Say what to neglect
- Not ask for argument why answer reasonable
- Only call for use of one representation
- *Possible* to solve quickly and easily by plugging into equation/procedure

- ~~concepts and mental models + selection criteria~~
- ~~recognizing relevant & irrelevant information~~
- ~~what information is needed to solve~~
- ~~How I know this conclusion correct (or not)~~
- ~~**model** development, testing, and use~~
- ~~moving between specialized representations (graphs, equations, physical motions, etc.)~~

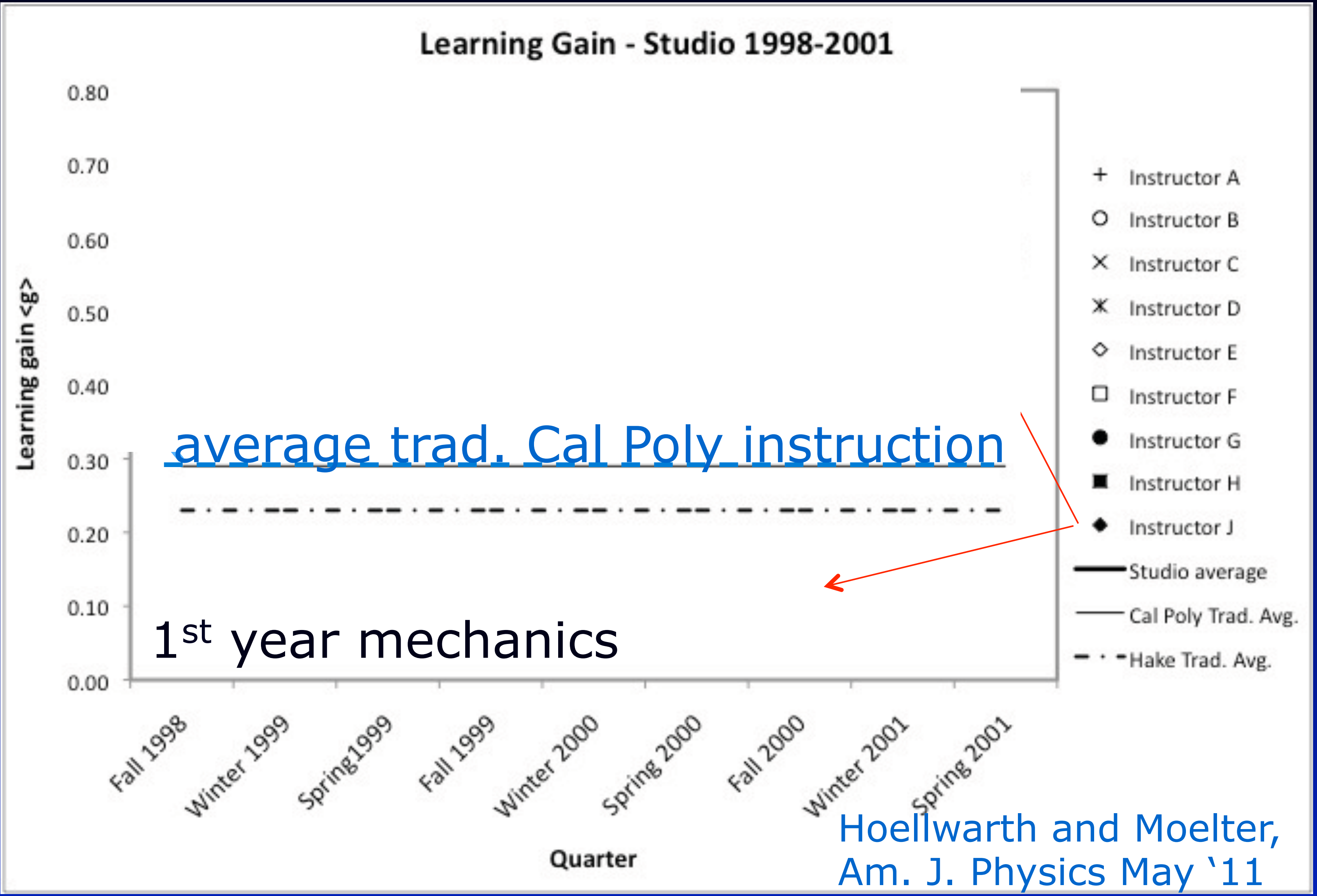
Results from Sci. & Eng. classrooms

"Discipline-Based Education Research: Understanding and Improving Learning in Undergraduate Sci. and Eng." (NAS Press)
NSF supported, Susan Singer led

many hundreds of STEM ed research studies comparing teaching results with standard lecture
Freeman et al. meta-analysis, just out in PNAS

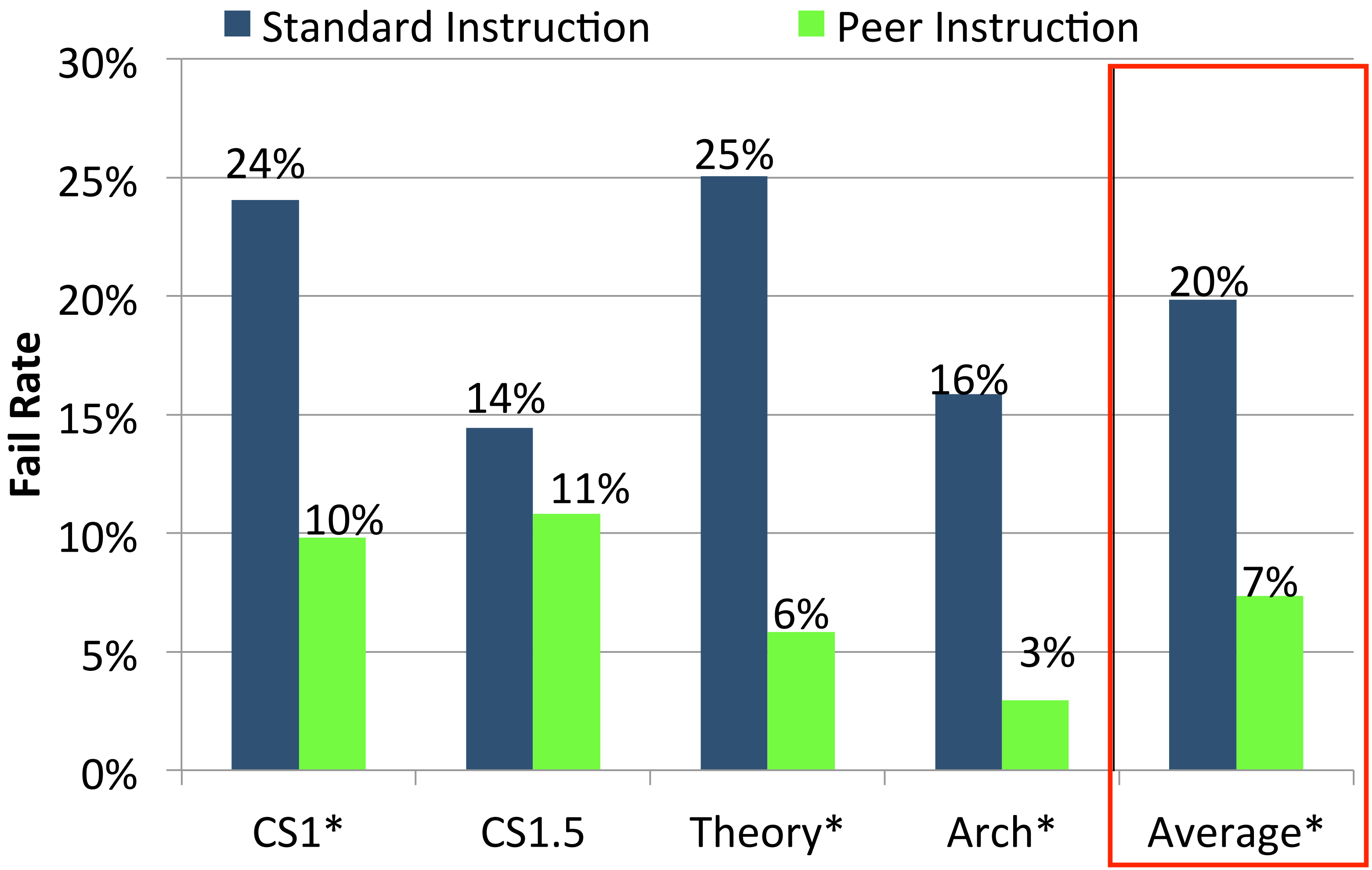
Example 1. Conceptual learning—
apply concepts like physicists?

California Poly Univ. study
1st year mechanics concepts. Standard test, pre and post course– learning gained.
Same instructors, different teaching methods



9 instructors, 8 terms, 40 students/section.
Same prescribed set of in-class learning tasks.

Example 2. Univ. Cal. San Diego, Computer Science Failure & drop rates– *Beth Simon et al., 2012*



a little new stuff

Intro physics course design- totally explicit "deliberate/effortful practice"*
Practice, feedback, motivation– no shortcuts
students poorly prepared in every respect

Results:
Learning gains (effect size= change/standard dev.)
male students **2.5 (unprecedented)**
female students **3.5 !!**

student evaluations– average
(like every university, only data collected)
→Adam's departmental teaching rating– average

Teaching Practices Inventory score- recored highest

*Wendy Adams & C. Wieman– submitted for publication

Stanford intro physics for eng. & sci. students
(~ 600 students, **very** dedicated teacher)

Data on common difficulties (50%+ students on final)
(Yanwen Sun)

Easy to categorize components of missing expertise

- Knowledge organization
  (force vs. torque vs. energy)
- Choosing which concept applies (*were always told)*
- Simple ideas, but told, not practiced

no practice = poor performance—easy to fix

Students

no practice = poor performance—easy to fix

Teacher-- missing teaching expertise

practice **but** no feedback = poor performance

practice + feedback ➡ expertise

Good teaching methods = practice & feedback to students

and feedback to teacher

Conclusion– Development of expertise.
Requires practice with feedback.
Intrinsically hard work, exercising brain.

Design principle for effective science and engineering teaching

Good References:

S. Ambrose et. al. “How Learning works”
Colvin, “Talent is over-rated”
cwsei.ubc.ca-- resources, references, effective clicker use booklet and videos
Teaching Practices Inventory (10 min, % effective practices) (under “tools”)

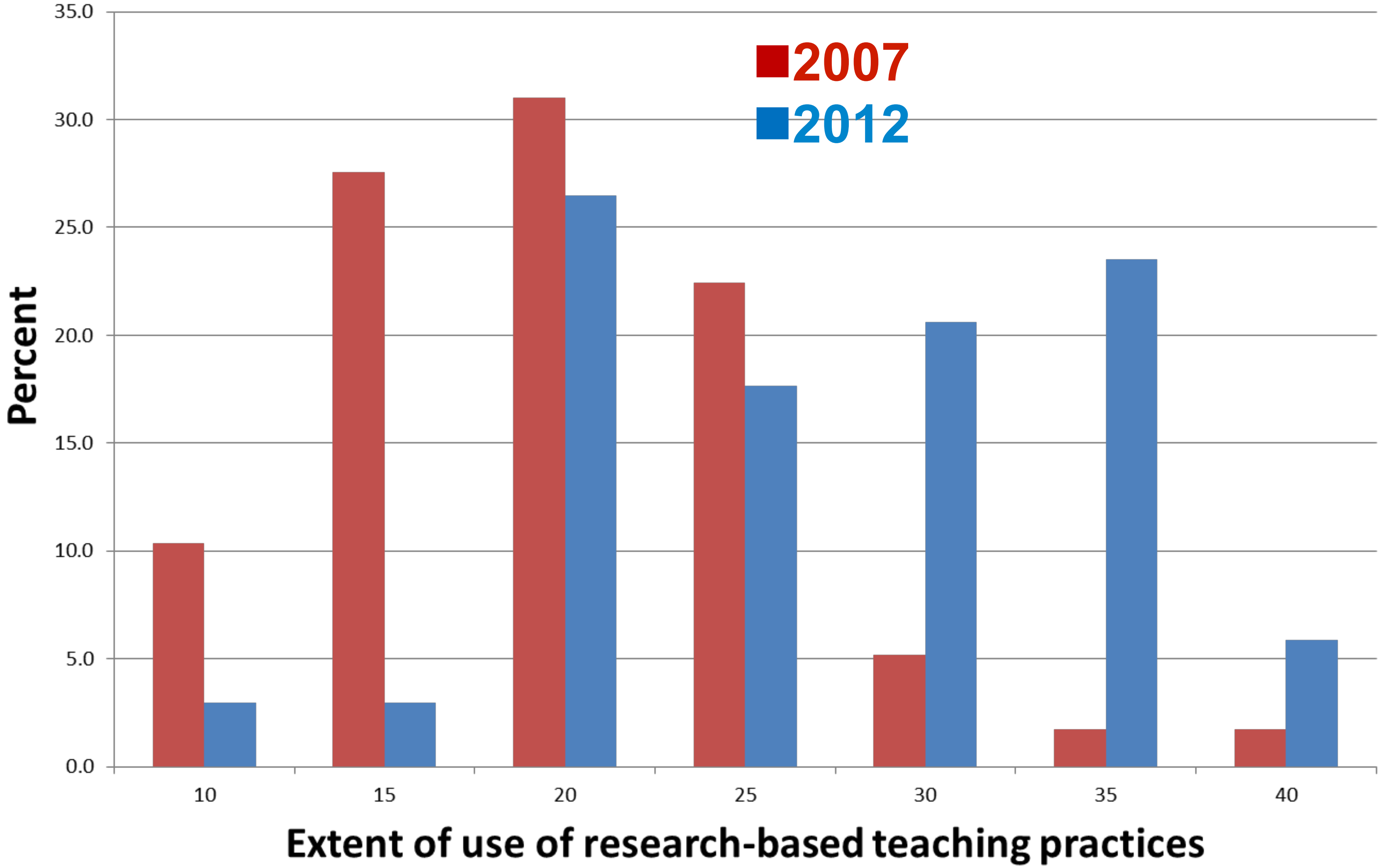
NAS Press, “Discipline-Based Education Research: Understanding and Improving Learning in Und. Sci & Eng.

extras below

Example 2. Worksheet activities.
Do in class in small groups, turn in. (15-20 minute+)
Problem solutions shown in old lectures often easy to turn into good worksheet activities.

Instructor moves from group to group, sampling and providing brief feedback. At regular intervals, or when sees common difficulty, pulls class together to provide general feedback, ensure all on same page.

EOAS teaching practices



Limits on short-term working memory--best established, most ignored result from cog. science

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

Working memory capacity
VERY LIMITED!
(remember & process 5-7 distinct new items)

MUCH less than in typical lecture

slides to be provided

What is the role of the teacher?

"Cognitive coach"

- Designs tasks that practice the specific components, of "expert thinking", appropriate level
- Motivate learner to put in LOTS of effort
- Evaluates performance, provides timely specific feedback. Recognize and address particular difficulties (inappropriate mental models, ...)
- repeat, repeat, ...-- always appropriate challenge

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.
⇒ 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

How are students practicing thinking like a scientist?

- forming, testing, applying conceptual mental models (deciding what is relevant and irrelevant)
- testing their reasoning & conclusions
- critiquing scientific arguments

+ feedback to refine thinking
(fellow students, clicker results, experimental test of prediction, instructor targeted followup)

Works educationally *because* instructor's science expertise is used in both task design and feedback. Provides "deliberate practice" for students.

True of all research-based instruction.

Principles from research for effective learning task all levels, all settings

1. Motivation *(lots of research)*

basic psychology, diversity

2. Connect with prior thinking, proper level of challenge. *(group work expands range)*

3. Apply what is known about memory
   a. short term limitations– don't overload
   b. achieving long term retention

*4. Explicit authentic practice of expert thinking. Extended & strenuous. Timely & specific feedback.

5. Checking that it worked.

Applying all the important principles of effective teaching/learning

1. Motivation

2. Connect with and build on prior thinking & knowledge

3. Apply what is known about limitations of short-term memory

4. Explicit strenuous practice of expert thinking.
   Timely & specific feedback.

Targeted pre-class reading with brief online quiz.
Set of in-class small group tasks: clicker questions, worksheets. Instructor follow up, but no pre-prepared lecture.

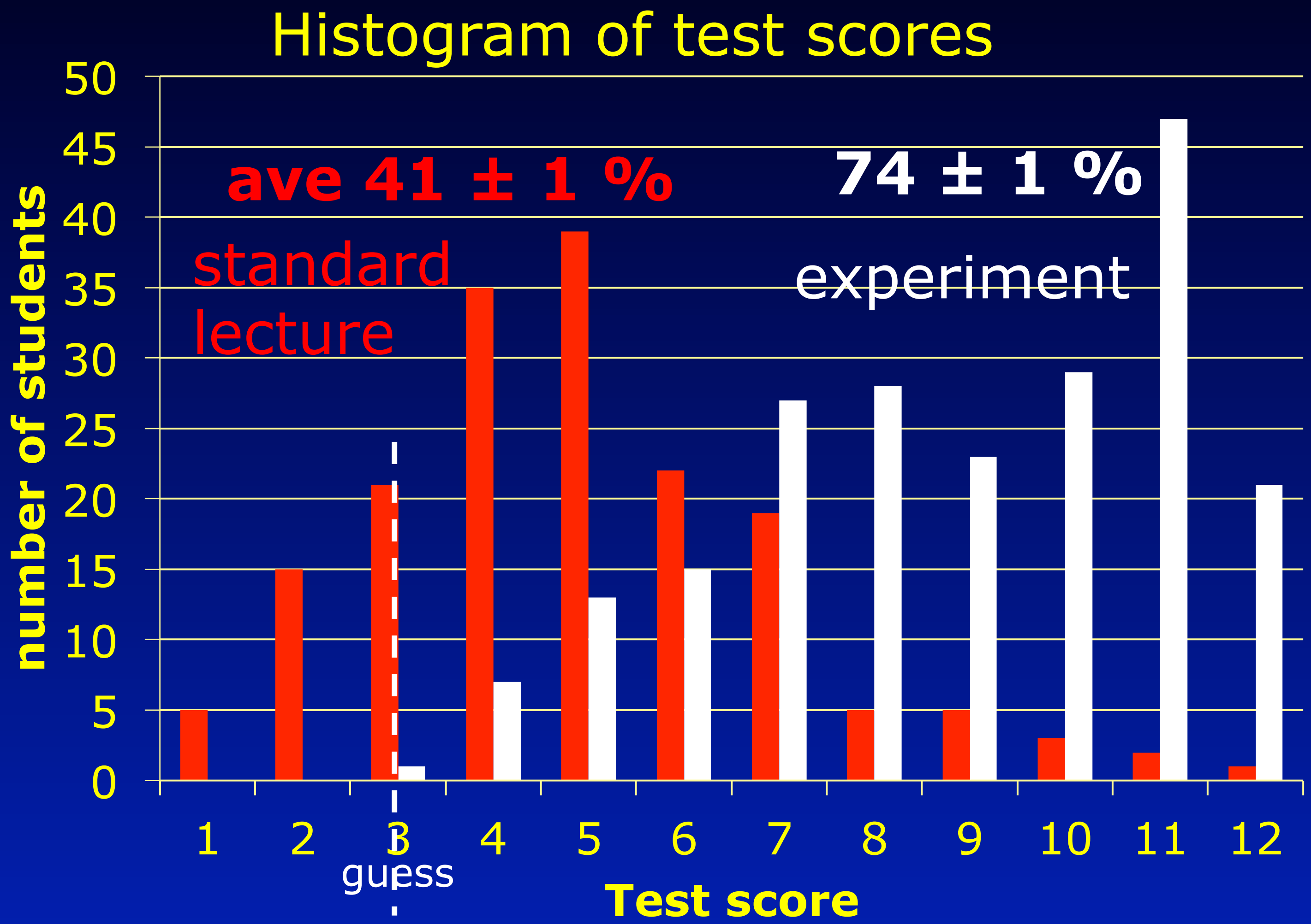
Learning **in the in classroom***

Comparing the learning in two identical sections of 1st year college physics. 270 students each.

Control--standard lecture class– highly experienced Prof with good student ratings.
Experiment–- inexperienced teacher (postdoc) trained to use principles of effective teaching.

- Same learning objectives
- Same class time (3 hours, 1 week)
- Same exam (jointly prepared)- start of next class

**Deslauriers, Schewlew, Wieman, Sci. Mag. May 13, '11*



Clear improvement for <u>entire</u> student population.
Engagement 85% vs 45%.